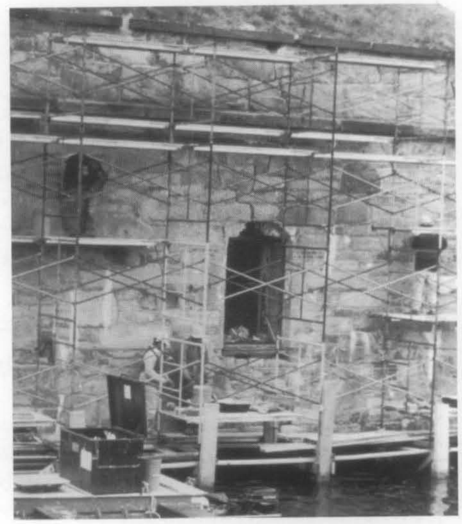
39 PRESERVATION BRIEFS



Holding the Line: Controlling Unwanted Moisture in Historic Buildings

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Uncontrolled moisture is the most prevalent cause of deterioration in older and historic buildings. It leads to erosion, corrosion, rot, and ultimately the destruction of materials, finishes, and eventually structural components. Ever-present in our environment, moisture can be *controlled* to provide the differing *levels* of moisture necessary for human comfort as well as the longevity of historic building materials, furnishings, and museum collections. The challenge to building owners and preservation professionals alike is to understand the patterns of moisture movement in order to better manage it — not to eliminate it. There is never a single answer to a moisture problem. Diagnosis and treatment will always differ depending on where the building is located, climatic and soil conditions, ground water effects, and local traditions in building construction.

Remedial Actions within an Historic Preservation Context

In this Brief, advice about controlling the sources of unwanted moisture is provided within a preservation context based on philosophical principles contained in the *Secretary of the Interior's Standards for the Treatment of Historic Properties.* Following the Standards means significant materials and features that contribute to the historic character of the building should be preserved, not damaged during remedial treatment (see fig.1). It also means that physical treatments should be reversible, whenever possible. The majority of treatments for moisture management in this Brief stress preservation maintenance for materials, effective drainage of troublesome ground moisture, and improved interior ventilation.

The Brief encourages a systematic approach for evaluating moisture problems which, in some cases, can be undertaken by a building owner. Because the source of moisture can be elusive, it may be necessary to consult with historic preservation professionals prior to starting work that would affect historic materials. Architects, engineers, conservators, preservation contractors, and staff of State Historic Preservation Offices (SHPOs) can provide such advice.

Regardless of who does the work, however, these are the principles that should guide treatment decisions:

- Avoid remedial treatments without prior careful diagnosis.
- Undertake treatments that protect the historical significance of the resource.
- Address issues of ground-related moisture and rain run-off thoroughly.
- Manage existing moisture conditions before introducing humidified/dehumidified mechanical systems.
- Implement a program of ongoing monitoring and maintenance once moisture is controlled or managed.
- Be aware of significant landscape and archeological resources in areas to be excavated.

Finally, mitigating the effects of catastrophic moisture, such as floods, requires a different approach and will not be addressed fully in this Brief.

Fig. 1. Moisture problems, if not properly corrected, will increase damage to historic buildings. This waterproof coating trapped moisture from the leaking roof, causing portions of the masonry parapet to fail. Photo: NPS Files.

How and Where to Look for Damaging Moisture

Finding, treating, and managing the sources of damaging moisture requires a systematic approach that takes time, patience, and a thorough examination of all aspects of the problem—including a series of variable conditions (See this page). Moisture problems may be a direct result of one of these factors or may be attributable to a combination of interdependent variables.

> **Factors Contributing to Moisture Problems**
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> A variety of simultaneously existing conditions contribute to moisture problems in old buildings. For recurring moisture problems, it may be necessary for the owner or preservation professional to address many, if not all, of the following variables:
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> - Types of building materials and construction systems
> - Type and condition of roof and site drainage systems and their rates of discharge
> - Type of soil, moisture content, and surface / subsurface water flow adjacent to building
> - Building usage and moisture generated by occupancy
> - Condition and absorption rates of materials
> - Type, operation, and condition of heating, ventilating, cooling, humidification/ dehumidification, and plumbing systems
> - Daily and seasonal changes in sun, prevailing winds, rain, temperature, and relative humidity (inside and outside), as well as seasonal or tidal variations in groundwater levels
> - Unusual site conditions or irregularities of construction
> - Conditions in affected wall cavities, temperature and relative humidity, and dewpoints
> - Amount of air infiltration present in a building
> - Adjacent landscape and planting materials

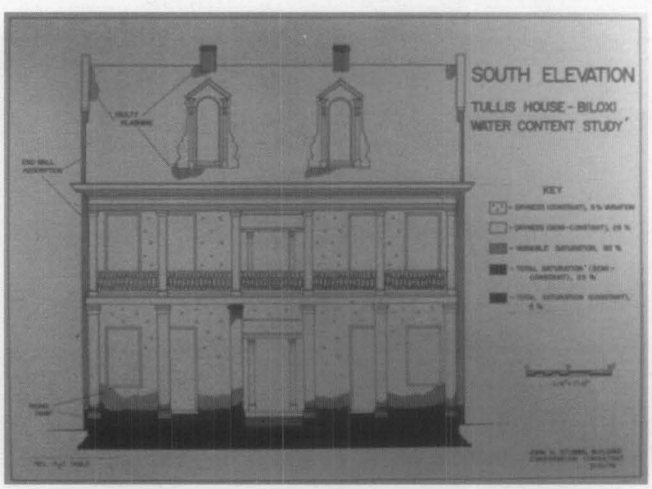


Fig. 2. Historic buildings plagued by dampness problems will benefit from systematic documentation to set a baseline against which moisture changes can be measured. Exterior areas with higher moisture levels may have algae growth or discoloration stains. Drawing: John H. Stubbs.

Diagnosing and treating the cause of moisture problems requires looking at both the localized decay, as well as understanding the performance of the entire building and site. Moisture is notorious for traveling far from the source, and moisture movement within concealed areas of the building construction make accurate diagnosis of the source and path difficult. Obvious deficiencies, such as broken pipes, clogged gutters, or cracked walls that contribute to moisture damage, should always be corrected promptly.

For more complicated problems, it may take several months or up to four seasons of monitoring and evaluation to complete a full diagnosis. Rushing to a solution without adequate documentation can often result in the unnecessary removal of historic materials—and worse—the creation of long-term problems associated with an increase, rather than a decrease, in the unwanted moisture.

Looking for Signs

Identifying the type of moisture damage and discovering its source or sources usually involves the human senses of sight, smell, hearing, touch, and taste combined with intuition. Some of the more common signs of visible as well as hidden moisture damage (see fig. 2, 3) include:

- Presence of standing water, mold, fungus, or mildew
- Wet stains, eroding surfaces, or efflorescence (salt deposits) on interior and exterior surfaces
- Flaking paint and plaster, peeling wallpaper, or moisture blisters on finished surfaces
- Dank, musty smells in areas of high humidity or poorly ventilated spaces
- Rust and corrosion stains on metal elements, such as anchorage systems and protruding roof nails in the attic
- Cupped, warped, cracked, or rotted wood
- Spalled, cracked masonry or eroded mortar joints
- Faulty roofs and gutters including missing roofing slates, tiles, or shingles and poor condition of flashing or gutters
- Condensation on window and wall surfaces
- Ice dams in gutters, on roofs, or moisture in attics

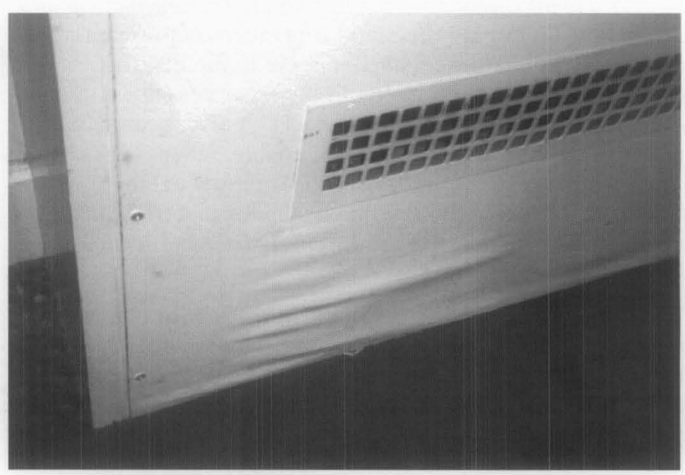


Fig. 3. The deterioration of this wooden cover was a sign that water was leaking from the fan coil unit behind. Photo: author.

Uncovering and Analyzing Moisture Problems

Moisture comes from a variety of external sources. Most problems begin as a result of the weather in the form of rain or snow, from high ambient relative humidity, or from high water tables. But some of the most troublesome moisture damage in older buildings may be from internal sources, such as leaking plumbing pipes, components of heating, cooling, and climate control systems, as well as sources related to use or occupancy of the building. In some cases, moisture damage may be the result of poorly designed original details, such as projecting outriggers in rustic structures that are vulnerable to rotting, and may require special treatment.

The five most common sources of unwanted moisture include:

- Above grade exterior moisture entering the building
- Below grade ground moisture entering the building
- Leaking plumbing pipes and mechanical equipment
- Interior moisture from household use and climate control systems
- Water used in maintenance and construction materials.

Above grade exterior moisture generally results from weather related moisture entering through deteriorating materials as a result of deferred maintenance, structural settlement cracks, or damage from high winds or storms (see fig. 4). Such sources as faulty roofs, cracks in walls, and open joints around window and door openings can be corrected through either repair or limited replacement. Due to their age, historic buildings are notoriously "drafty," allowing rain, wind, and damp air to enter through missing mortar joints; around cracks in windows, doors, and wood siding; and into uninsulated attics. In some cases, excessively absorbent materials, such as soft sandstone, become saturated from rain or gutter overflows, and can allow moisture to dampen interior surfaces. Vines or other vegetative materials allowed to grow directly on building materials without trellis or other framework can cause damage from roots eroding mortar joints and foundations as well as dampness being held against surfaces. In most cases, keeping vegetation off buildings, repairing damaged materials, replacing flashings, rehanging gutters, repairing downspouts, repointing mortar, caulking perimeter joints around windows and doors, and repainting surfaces can alleviate most sources of unwanted exterior moisture from entering a building above grade.

Below grade ground moisture is a major source of unwanted moisture for historic and older buildings. *Proper handling of surface rain run-off is one of the most important measures of controlling unwanted ground moisture.* Rain water is often referred to as "bulk moisture" in areas that receive significant annual rainfalls or infrequent, but heavy, precipitation. For example, a heavy rain of 2" per hour can produce 200 gallons of water from downspout discharge alone for a house during a one hour period. When soil is saturated at the base of the building, the moisture will wet footings and crawl spaces or find its way through cracks in foundation walls and enter into basements (see fig. 5). Moisture in saturated basement or foundation walls—also exacerbated by high water tables—will generally rise up within a wall and eventually cause deterioration of the masonry and adjacent wooden structural elements.

Builders traditionally left a working area, known as a builder's trench, around the exterior of a foundation wall. These trenches have been known to increase moisture problems if the infill soil is less than fully compacted or includes rubble backfill, which, in some cases, may act as a reservoir holding damp materials against masonry walls. Broken subsurface pipes or downspout drainage can leak into the builder's trench and dampen walls some distance from the source. Any subsurface penetration of the foundation wall for sewer, water, or other piping also can act as a direct conduit of ground moisture unless these holes are well sealed. A frequently unsuspected, but serious, modern source of ground moisture is a landscape irrigation system set too close to the building. Incorrect placement of sprinkler heads can add a tremendous amount of moisture at the foundation level and on wall surfaces.

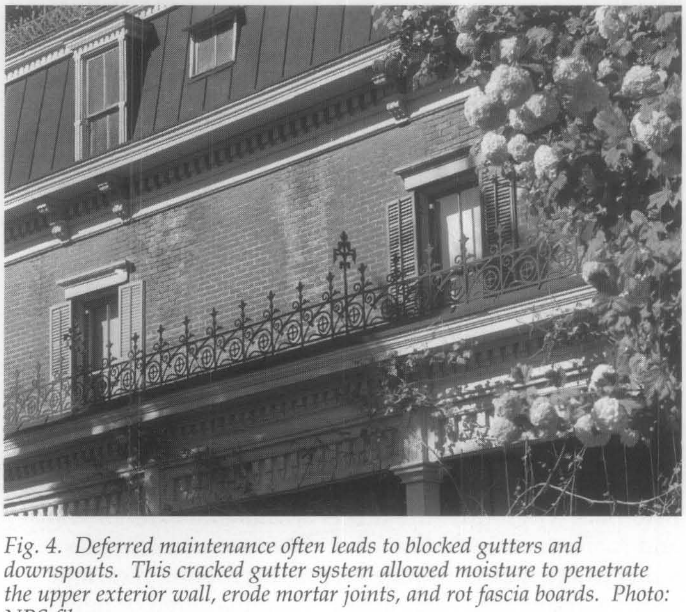


Fig. 4. Deferred maintenance often leads to blocked gutters and downspouts. This cracked gutter system allowed moisture to penetrate the upper exterior wall, erode mortar joints, and rot fascia boards. Photo: NPS files.

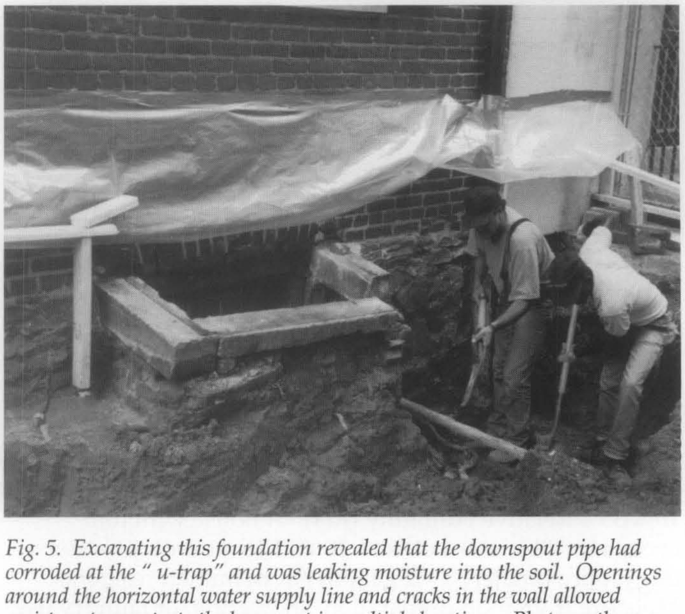


Fig. 5. Excavating this foundation revealed that the downspout pipe had corroded at the " u-trap" and was leaking moisture into the soil. Openings around the horizontal water supply line and cracks in the wall allowed moisture to penetrate the basement in multiple locations. Photo: author.

The ground, and subsequently the building, will stay much drier by 1) re-directing rain water away from the foundation through sloping grades, 2) capturing and disposing downspout water well away from the building, 3) developing a controlled ground gutter or effective drainage for buildings historically without gutters and downspouts, and 4) reducing splash-back of moisture onto foundation walls. The excavation of foundations and the use of dampproof coatings and footing drains should only be used after the measures of reducing ground moisture listed above have been implemented.

Leaking plumbing pipes and mechanical equipment can cause immediate or long-term damage to historic building interiors. Routine maintenance, repair, or, if necessary, replacement of older plumbing and mechanical equipment are common solutions. Older water and sewer pipes are subject to corrosion over time. Slow leaks at plumbing joints hidden within walls and ceilings can ultimately rot floor boards, stain ceiling plaster, and lead to decay of structural members. Frozen pipes that crack can damage interior finishes (see fig. 6). In addition to leaking plumbing pipes, old radiators in some historic buildings have been replaced with water-supplied fan coil units which tend to leak. These heating and cooling units, as well as central air equipment, have overflow and condensation pans that require cyclical maintenance to avoid mold and mildew growth and corrosion blockage of drainage channels. Uninsulated forced-air sheet metal ductwork and cold water pipes in walls and ceilings often allow condensation to form on the cold metal, which then drips and causes bubbling plaster and peeling paint. Careful design and vigilant maintenance, as well as repair and insulating pipes or ductwork, will generally rid the building of these common sources of moisture.

Fig. 6. Uninsulated plumbing pipes close to the exterior wall froze and cracked, wetting this ornamental plaster ceiling before the water supply line could be shut off. As a result, limited portions of the ceiling needed reattaching. Photo: author.

Interior moisture from building use and modern humidified heating and cooling systems can create serious problems. In northern U.S. climates, heated buildings will have winter-time relative humidity levels ranging from 10%-35% Relative Humidity (RH). A house with four occupants generates between 10 and 16 pounds of water a day (approximately 1 – 2 gallons) from human residents. Moisture from food preparation, showering, or laundry use will produce condensation on windows in winter climates. When one area or floor of a building is air-conditioned and another area is not, there is the chance for condensation to occur between the two areas. Most periodic condensation does not create a long-term problem.

Humidified climate control systems are generally a major problem in museums housed within historic buildings. They produce between 35%-55% RH on average which, as a vapor, will seek to dissipate and equalize with adjacent spaces (see fig. 7). Moisture can form on single-glazed windows in winter with exterior temperatures below 30 F and interior temperatures at 70 F with as little as 35% RH. Frequent condensation on interior window surfaces is an indication that moisture is migrating into exterior walls, which can cause long-term damage to historic materials. Materials and wall systems around climate controlled areas may need to be made of moisture resistant finishes in order to handle the additional moisture in the air. Moist interior conditions in hot and humid climates will generate mold and fungal growth. Unvented mechanical equipment, such as gas stoves, driers, and kerosene heaters, generate large quantities of moisture. It is important to provide adequate ventilation and find a balance between interior temperature, relative humidity, and airflow to avoid interior moisture that can damage historic buildings.

Fig. 7. Condensation dripping from the large overhead courtyard skylight was damaging the masonry in this museum. A new skylight with thermal glazing was installed, replacing the deteriorated single-glazed unit. A new climate control system monitors interior temperature and humidity. Photo: © Isabella Stewart Gardner Museum, Boston.

Moisture from maintenance and construction materials can cause damage to adjacent historic materials. Careless use of liquids to wash floors can lead to water seepage through cracks and dislodge adhesives or cup and curl materials. High-pressure power washing of exterior walls and roofing materials can force water into construction joints where it can dislodge mortar, lift roofing tiles, and saturate frame walls and masonry. Replastered or newly plastered interior walls or the construction of new additions attached to historic buildings may hold moisture for months; new plaster, mortar, or concrete should be fully cured before they are painted or finished. The use of materials in projects that have been damaged by moisture prior to installation or have too high a moisture content may cause concealed damage (see fig. 8).

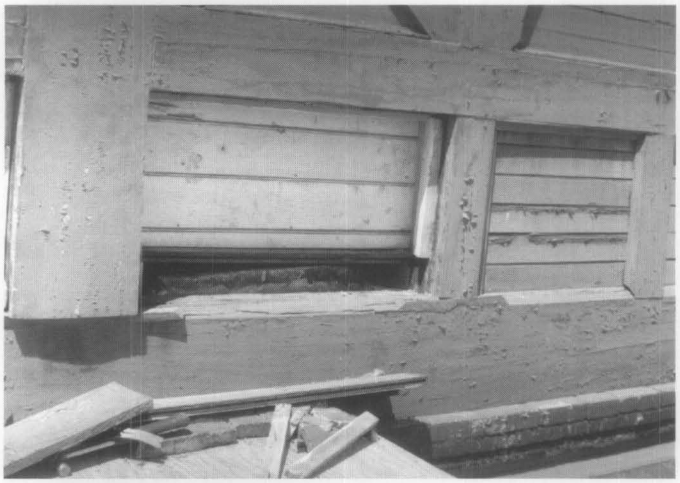


Fig. 8. Damaging moisture conditions can occur during construction. Peeling paint on this newly rehabilitated frame wall was attributed to wall insulation that had become wet during the project and was not discovered. Photo: NPS Files.

Transport or Movement of Moisture

Knowing the five most common sources of moisture that cause damage to building materials is the first step in diagnosing moisture problems. But it is also important to understand the basic mechanisms that affect moisture movement in buildings. Moisture transport, or movement, occurs in two states: liquid and vapor. It is directly related to pressure differentials. For example, water in a gaseous or vapor state, as warm moist air, will move from its high pressure area to a lower pressure area where the air is cooler and drier. Liquid water will move as a result of differences in hydrostatic pressure or wind pressure. *It is the pressure differentials that drive the rate of moisture migration in either state.* Because the building materials themselves resist this moisture movement, the rate of movement will depend on two factors: the permeability of the materials when affected by vapor and the absorption rates of materials in contact with liquid.

The mechanics, or physics, of moisture movement is complex, but if the driving force is difference in pressure, then an approach to reducing moisture movement and its damage is to reduce the difference in pressure, not to increase it. That is why the treatments discussed in this Brief will look at *managing moisture by draining bulk moisture and ventilating vapor moisture* before setting up new barriers with impermeable coatings or over-pressurized new climate control systems that threaten aging building materials and archaic construction systems.

Three forms of moisture transport are particularly important to understand in regards to historic buildings — *infiltration, capillary action, and vapor diffusion* —remembering, at the same time, that the subject is infinitely complex and, thus, one of continuing scientific study (see fig. 9). Buildings were traditionally designed to deal with the movement of air. For example, cupolas and roof lanterns allowed hot air to rise and provided a natural draft to pull air through buildings. Cavity walls in both frame and masonry buildings were constructed to allow moisture to dissipate in the air space between external and internal walls. Radiators were placed in front of windows to keep cold surfaces warm, thereby reducing condensation on these surfaces. Many of these features, however, have been altered over time in an effort to modernize appearances, improve energy efficiency, or accommodate changes in use. The change in use will also affect moisture movement, particularly in commercial and industrial buildings with modern mechanical systems. Therefore, the way a building handles air and moisture today may be different from that intended by the original builder or architect, and poorly conceived changes may be partially responsible for chronic moisture conditions.

Moisture moves into and through materials as both a visible liquid (capillary action) and as a gaseous vapor (infiltration and vapor diffusion). Moisture from leaks, saturation, rising damp, and condensation can lead to the deterioration of materials and cause an unhealthy environment. Moisture in its solid form, ice, can also cause damage from frozen, cracked water pipes, or split gutter seams or spalled masonry from freeze-thaw action. Moisture from melting ice dams, leaks, and condensation often can travel great distances down walls and along construction surfaces, pipes, or conduits. The amount of moisture and how it deteriorates materials is dependent upon complex forces and variables that must be considered for each situation.

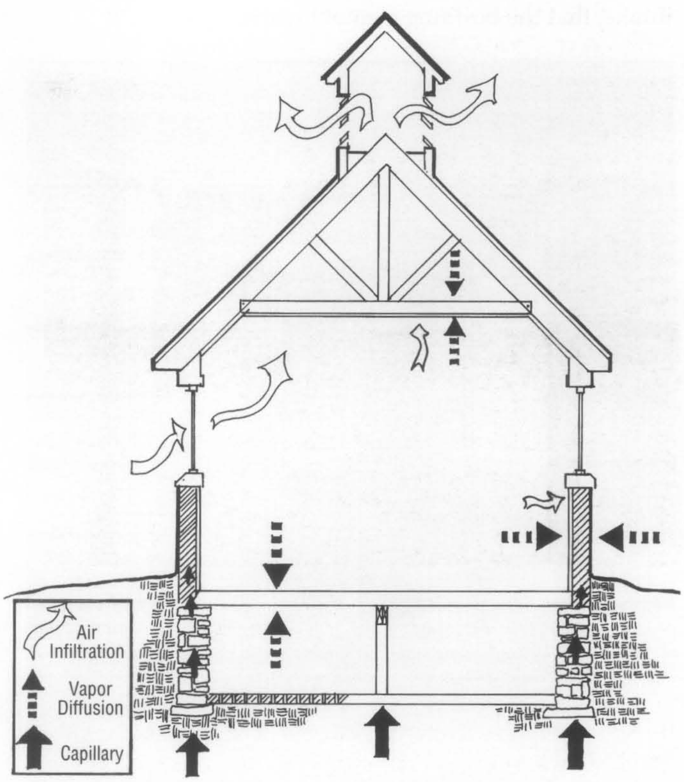


Fig. 9. The dynamic forces that move air and moisture through a building are important to understand particularlly when selecting a treatment to correct a moisture problem. Air infiltration, capillary action, and vapor diffusion all affect the wetting and drying of materials. Drawing; NPS Files.

Determining the way moisture is handled by the building is further complicated because each building and site is unique. Water damage from blocked gutters and downspouts can saturate materials on the outside, and high levels of interior moisture can saturate interior materials. Difficult cases may call for technical evaluation by consultants specializing in moisture monitoring and diagnostic evaluation. In other words, it may take a team to effectively evaluate a situation and determine a proper approach to controlling moisture damage in old buildings.

Infiltration is created by wind, temperature gradients (hot air rising), ventilation fan action, and the stack or chimney effect that draws air up into tall vertical spaces. Infiltration as a dynamic force does not actually move liquid water, but is the vehicle by which dampness, as a component of air, finds its way into building materials. Older buildings have a natural air exchange, generally from 1 to 4 changes per hour, which, in turn, may help control moisture by diluting moisture within a building. The tighter the building construction, however, the lower will be the infiltration rate and the natural circulation of air. In the process of infiltration, however, moisture that has entered the building and saturated materials can be drawn in and out of materials, thereby adding to the dampness in the air (see fig. 10). Inadequate air circulation where there is excessive moisture (i.e., in a damp basement), accelerates the deterioration of historic materials. To reduce the unwanted moisture that accompanies infiltration, it is best to incorporate maintenance and repair treatments to close joints and weatherstrip windows, while providing controlled air exchanges elsewhere. The worst approach is to seal the building so completely, while limiting fresh air intake, that the building cannot breathe.

Fig. 10. Infiltration of damp air can occur around loose-fitting or deteriorated window sash and through cracks or open joints in building exteriors. Photo: Ann Brooks Prueher.

Capillary action occurs when moisture in saturated porous building materials, such as masonry, wicks up or travels vertically as it evaporates to the surface. In capillary attraction, liquid in the material is attracted to the solid surface of the pore structure causing it to rise vertically; thus, it is often called "rising damp," particularly when found in conjunction with ground moisture. It should not, however, be confused with moisture that laterally penetrates a foundation wall through cracks and settles in the basement. Not easily controlled, most rising damp comes from high water tables or a constant source under the footing. In cases of damp masonry walls with capillary action, there is usually a whitish stain or horizontal tide mark of efflorescence that seasonally fluctuates about 1- 3 feet above grade where the excess moisture evaporates from the wall (see fig. 11). This tide mark is full of salt crystals, that have been drawn from the ground and building materials along with the water, making the masonry even more sensitive to additional moisture absorption from the surrounding air. Capillary migration of moisture may occur in any material with a pore structure where there is a constant or recurring source of moisture.

Fig. 11. Capillary rise of moisture in masonry is often accompanied with a horizontal tide-mark line several feet above the grade, as seen here. Removing or redirecting as much ground moisture as possible usually helps reduce moisture within a wall. Photo: NPS Files.

The best approach for dealing with capillary rise in building materials is to reduce the amount of water in contact with historic materials. If that is not possible due to chronically high water tables, it may be necessary to introduce a horizontal damp-proof barrier, such as slate course or a lead or plastic sheet, to stop the vertical rise of moisture. Moisture should not be sealed into the wall with a waterproof coating, such as cement parging or vinyl wall coverings, applied to the inside of damp walls. This will only increase the pressure differential as a vertical barrier and force the capillary action, and its destruction of materials, higher up the wall.

Vapor diffusion is the natural movement of pressurized moisture vapor through porous materials. It is most readily apparent as humidified interior air moves out through walls to a cooler exterior. In a hot and humid climate, the reverse will happen as moist hot air moves into cooler, dryer, air-conditioned, interiors. The movement of the moisture vapor is not a serious problem until the dewpoint temperature is reached and the vapor changes into liquid moisture known as *condensation*. This can occur within a wall or on interior surfaces. Vapor diffusion will be more of a problem for a frame structure with several layers of infill materials within the frame cavity than a dense masonry structure. Condensation as a result of vapor migration usually takes place on a surface or film, such as paint, where there is a change in permeability.

The installation of climate control systems in historic buildings (mostly museums) that have *not* been properly designed or regulated and that force pressurized damp air to diffuse into perimeter walls is an ongoing concern. These newer systems take constant monitoring and back-up warning systems to avoid moisture damage.

Long-term and undetected condensation or high moisture content can cause serious structural damage as well as an unhealthy environment, heavy with mold and mildew spores. Reducing the interior/exterior pressure differential and the difference between interior and exterior temperature and relative humidity helps control unwanted vapor diffusion. This can sometimes be achieved by reducing interior relative humidity. In some instances, using vapor barriers, such as heavy plastic sheeting laid over damp crawl spaces, can have remarkable success in stopping vapor diffusion from damp ground into buildings. Yet, knowledgeable experts in the field differ regarding the appropriateness of vapor barriers and when and where to use them, as well as the best way to handle natural diffusion in insulated walls.

Adding insulation to historic buildings, particularly in walls of wooden frame structures, has been a standard modern weatherization treatment, but it can have a disastrous effect on historic buildings. The process of installing the insulation destroys historic siding or plaster, and it is very difficult to establish a tight vapor barrier. While insulation has the benefit of increasing the efficiency of heating and cooling by containing temperature controlled air, it does not eliminate surfaces on which damaging moisture can condense. For insulated residential frame structures, the most obvious sign of a moisture

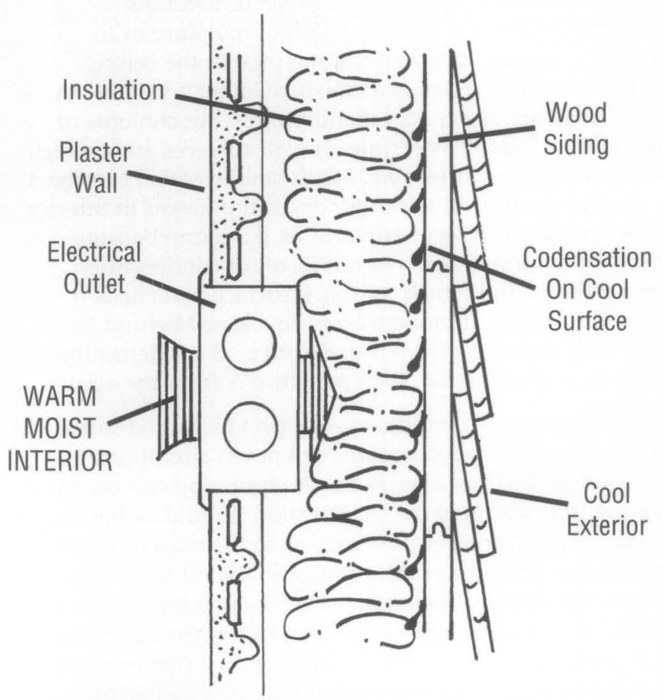


Fig. 12. Vapor diffusion can result in damp air migrating into absorbent materials and condensing on colder surfaces, thereby wetting insulation, damaging electrical conduits, and causing deterioration of the wooden framing. Drawing: NPS Files.

diffusion problem is peeling paint on wooden siding, even after careful surface preparation and repainting. Vapor impermeable barriers such as plastic sheeting, or more accurately, *vapor retarders,* in cold and moderate climates generally help slow vapor diffusion where it is not wanted.

In regions where *humidified* climate control systems are installed into insulated frame buildings, it is important to stop *interstitial*, or in-wall, dewpoint condensation. This is very difficult because humidified air can penetrate breaches in the vapor barrier, particularly around electrical outlets (see fig. 12). Improperly or incompletely installed retrofit vapor barriers will cause extensive damage to the building, just in the installation process, and will allow trapped condensation to wet the insulation and sheathing boards, corrode metal elements such as wiring cables and metal anchors, and blister paint finishes. Providing a tight wall vapor barrier, as well as a ventilated cavity behind wooden clapboards or siding appears to help insulated frame walls, if the interior relative humidity can be adjusted or monitored to avoid condensation. Correct placement of vapor retarders within building construction will vary by region, building construction, and type of climate control system.

Surveying and Diagnosing Moisture Damage: Key Questions to Ask

It is important for the building to be surveyed first and the evidence and location of suspected moisture damage systematically recorded before undertaking any major work to correct the problem. This will give a baseline from which relative changes in condition can be noted.

When materials become wet, there are specific physical changes that can be detected and noted in a record book or on survey sheets. Every time there is a heavy rain, snow storm, water in the basement, or mechanical systems failure, the owner or consultant should note and record the way moisture is moving, its appearance, and what variables might contribute to the cause. *Standing outside to observe a building in the rain may answer many questions and help trace the movement of water into the building.* Evidence of deteriorating materials that cover more serious moisture damage should also be noted, even if it is not immediately clear what is causing the damage. (For example, water stains on the ceiling may be from leaking pipes, blocked fan coil drainage pans above, or from moisture which has penetrated around a poorly sloped window sill above.) Don't jump to conclusions, but use a systematic approach to help establish an educated theory — or hypothesis — of what is causing the moisture problem or what areas need further investigation.

Surveying moisture damage must be systematic so that relative changes can be noted. Tools for investigating can be as simple as a notebook, sketch plans, binoculars, camera, aluminum foil, smoke pencil, and flashlight. The systematic approach involves looking at buildings from the top down and from the outside to the inside. Photographs, floor plans, site plan, and exterior elevations — even roughly sketched — should be used to indicate all evidence of damp or damaged materials, with notations for musty or poorly ventilated areas. Information might be needed on the absorption and permeability characteristics of the building materials and soils. Exterior drainage patterns should be noted and these base plans referred to on a regular basis in different seasons and in differing types of weather (see fig. 13).

Glossary:

Air flow/ infiltration: The movement that carries moist air into and through materials. Air flow depends on the difference between indoor and outdoor pressures, wind speed and direction as well as the permeability of materials.

Bulk water: The large quantity of moisture from roof and ground run-off that can enter into a building either above grade or below grade.

Capillary action: The force that moves moisture through the pore structure of materials. Generally referred to as rising damp, moisture at or below the foundation level will rise vertically in a wall to a height at which the rate of evaporation balances the rate at which it can be drawn up by capillary forces.

Condensation: The physical process by which water vapor is transformed into a liquid when the relative humidity of the air reaches 100% and the excess water vapor forms, generally as droplets, on the colder adjacent surface.

Convection: Heat transfer through the atmosphere by a difference in force or air pressure is one type of air transport. Sometimes referred to as the "stack effect," hotter less dense air will rise, colder dense air will fall creating movement of air within a building.

Dewpoint: The temperature at which water vapor condenses when the air is cooled at a constant pressure and constant moisture content.

Diffusion: The movement of water vapor through a material. Diffusion depends on vapor pressure, temperature, relative humidity, and the permeability of a material.

Evaporation: The transformation of liquid into a vapor, generally as a result of rise of temperature, is the opposite of condensation. Moisture in damp soil, such as in a crawl space, can evaporate into the air, raise the relative humidity in that space, and enter the building as a vapor.

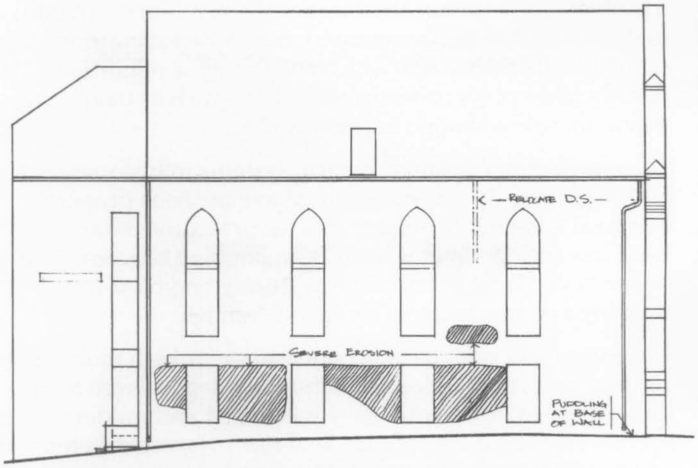
Ground moisture: The saturated moisture in the ground as a result of surface run-off and naturally occuring water tables. Ground moisture can penetrate through cracks and holes in foundation walls or can migrate up from moisture under the foundation base.

Monitoring instrumentation: These devices are generally used for long term diagnostic analysis of a problem, or to measure the preformance of a treatment, or to measure changes of conditions or environment. In-wall probes or sensors are often attached to data-loggers which can be down-loaded into computers.

Permeability: A characteristic of porosity of a material generally listed as the rate of diffusion of a pressurized gas through a material. The pore structure of some materials allows them to absorb or adsorb more moisture than other materials. Limestones are generally more permeable than granites.

Relative humidity (RH): Dampness in the air is measured as the percent of water vapor in the air at a specific temperature relative to the amount of water vapor that can be held in a vapor form at that specific temperature.

Survey instrumentation: technical instrumentation that is used on-site to provide quick readings of specific physical conditions. Generally these are hand-held survey instruments, such as moisture, temperature and relative humidity readers, dewpoint sensors, and fiber optic boroscopes.



DATE: June 2, 1992	TEMP: 70°	OTHER: Thunderstorm
WEATHER: Fair	TIME: 10:00AM	previous day

Fig. 13. Using sketch plans and elevation drawings to record the moisture damage along with the date, time, and weather conditions will show how moisture is affecting buildings over time. Drawing: Courtesy, Quinn Evans Architects.

It is best to start with one method of periodic documentation and to use this same method each time. Because moisture is affected by gravity, many surveys start with the roof and guttering systems and work down through the exterior walls. Any obvious areas of water penetration, damaged surfaces, or staining should be noted. Any recurring damp or stain patterns, both exterior and interior, should also be noted with a commentary on the temperature, weather, and any other facts that may be relevant (driving rains, saturated soil, high interior humidity, recent washing of the building, presence of a lawn watering system, etc.).

The interior should be recorded as well, beginning with the attic and working down to the basement and crawl space. It may be necessary to remove damaged materials selectively in order to trace the path of moisture or to pinpoint a source, such as a leaking pipe in the ceiling. The use of a basic resistance moisture meter, available in many hardware stores, can identify moisture contents of materials and show, over time, if wall surfaces are drying or becoming damper (see fig. 14). A smoke pencil can chart air infiltration around windows or draft patterns in interior spaces. For a quick test to determine if a damp basement is caused by saturated walls or is a result of condensation, tape a piece of foil onto a masonry surface and check it after a day or two; if moisture has developed behind the foil, then it is coming from the masonry. If condensation is on the surface of the foil, then moisture is from the air.

Comparing current conditions with previous conditions, historic drawings, photographs, or known alterations may also assist in the final diagnosis. A chronological record, showing improvement or deterioration, should be backed up with photographs or notations as to the changing size, condition, or features of the deterioration and how these changes have been affected by variables of temperature and rainfall. If a condition can be related in time to a particular event, such as efflorescence developing on a chimney after the building is no longer heated, it may be possible to isolate a cause, develop a hypothesis, and then test the hypothesis (by adding some temporary heat), before applying a remedial treatment.

Fig. 14. Using instruments in this damp-check kit can help determine the relative change in wet conditions over time. This involves readings of air temperature, computing dewpoint temperatures, and tracking the moisture content of materials to indicate if they are drying properly. Photo: Dell Corporation.

If the owner or consultant has access to moisture survey and monitoring equipment such as resistance moisture meters, dewpoint indicators, salt detectors, infrared thermography systems, psychrometer, fiber-optic boroscopes, and miniaturized video cameras, additional quantified data can be incorporated into the survey (see fig. 15). If it is necessary to track the wetting and drying of walls over a period of time, deep probes set into walls and in the soil with connector cables to computerized data loggers or the use of long-term recording of hygrothermographs may require a trained specialist. Miniaturized fiber-optic video cameras can record the condition of subsurface drain lines without excavation (see fig. 16). It should be noted, however, that *instrumentation, while extremely useful, cannot take the place of careful personal observation and analysis.* Relying on instrumentation alone rarely will give the owner the information needed to fully diagnose a moisture problem.

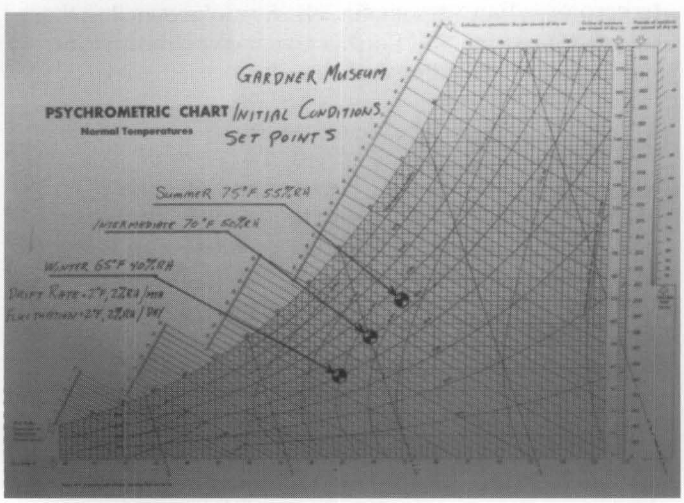


Fig. 15. Psychrometric charts quantify the amount of relative humidity a building can tolerate before dewpoint condensation occurs. This is important when the range of temperature and humidity are critical to both collections management and historic building preservation. Chart: Landmark Facilities Group.

Fig. 16. Contractors specializing in building diagnostics often have video cameras or fiber optic equipment that allow the viewing of inaccessible areas. This is particularly helpful in chimney flues or subsurface drains, as shown here. In the past, these areas would need to be excavated for visual inspection. Photo: author.

To avoid jumping to a quick—potentially erroneous—conclusion, a series of questions should be asked first. This will help establish a theory or hypothesis that can be tested to increase the chances that a remedial treatment will control or manage existing moisture.

How is water draining around building and site? What is the effectiveness of gutters and downspouts? Are the slopes or grading around foundations adequate? What are the locations of subsurface features such as wells, cisterns, or drainage fields? Are there subsurface drainage pipes (or drainage boots) attached to the downspouts and are they in good working condition? Does the soil retain moisture or allow it to drain freely? Where is the water table? Are there window wells holding rain water? What is the flow rate of area drains around the site (can be tested with a hose for several minutes)? Is the storm piping out to the street sufficient for heavy rains, or does water chronically back up on the site? Has adjacent new construction affected site drainage or water table levels?

How does water/moisture appear to be entering the building? Have all five primary sources of moisture been evaluated? What is the condition of construction materials and are there any obvious areas of deterioration? Did this building have a builder's trench around the foundation that could be holding water against the exterior walls? Are the interior bearing walls as well as the exterior walls showing evidence of rising damp? Is there evidence of hydrostatic pressure under the basement floor such as water percolating up through cracks? Has there been moisture damage from an ice dam in the last several months? Is damage localized, on one side of the building only, or over a large area?

What are the principal moisture dynamics? Is the moisture condition from liquid or vapor sources? Is the attic moisture a result of vapor diffusion as damp air comes up through the cavity walls from the crawl space or is it from a leaking roof? Is the exterior wall moisture from rising damp with a tide mark or are there uneven spots of dampness from foundation splash back, or other ground moisture conditions? Is there adequate air exchange in the building, particularly in damp areas, such as the basement? Has the height of the water table been established by inserting a long pipe into the ground in order to record the water levels?

How is the interior climate handling moisture? Are there areas in the building that do not appear to be ventilating well and where mold is growing? Are there historic features that once helped the building control air and moisture that can be reactivated, such as operable skylights or windows? Could dewpoint condensation be occurring behind surfaces, since there is often condensation on the windows? Does the building feel unusually damp or smell in an unusual way that suggest the need for further study? Is there evidence of termites, carpenter ants, or other pests attracted to moist conditions? Is a dehumidifier keeping the air dry or is it, in fact, creating a cycle where it is actually drawing moisture through the foundation wall?

Does the moisture problem appear to be intermittent, chronic, or tied to specific events? Are damp conditions occuring within two hours of a heavy rain or is there a delayed reaction? Does rust on most nail heads in the attic indicate a condensation problem? What are the wet patterns that appear on a building wall during and after a rain storm? Is it localized or in large areas? Can these rain patterns be tied to gutter over-flows, faulty flashing, or saturation of absorbent materials? Is a repaired area holding up well over time or is there evidence that moisture is returning? Do moisture meter readings of wall cavities indicate they are wet, suggesting leaks or condensation in the wall?

Once a hypothesis of the source or sources of the moisture has been developed from observation and recording of data, it is often useful to prove or disprove this hypothesis with interim treatments, and, if necessary, the additional use of instrumentation to verify conditions. For damp basements, test solutions can help determine the cause. For example, surface moisture in low spots should be redirected away from the foundation wall with regrading to determine if basement dampness improves. If there is still a problem, determine if subsurface downspout collection pipes or cast iron boots are not functioning properly. The above grade downspouts can be disconnected and attached to long, flexible extender pipes and redirected away from the foundation (see fig. 17). If, after a heavy rain or a simulation using a hose, there is no improvement, look for additional ground moisture sources such as high water tables, hidden cisterns, or leaking water service lines as a cause of moisture in the basement. New data will lead to a new hypothesis that should be tested and verified. *The process of elimination can be frustrating, but is required if a systematic method of diagnosis is to be successful.*

Selecting an Appropriate Level of Treatment

The treatments in chart format at the back of this publication are divided into levels based on the degree of moisture problems. Level I covers preservation maintenance; Level II focuses on repair using historically compatible materials and essentially mitigating damaging moisture conditions; and Level III discusses replacement and alteration of materials that permit continued use in a chronically moist environment. It is important to begin with Level I and work through to a manageable treatment as part of the control of moisture problems. Buildings in serious decay will require treatments in Level II, and difficult or unusual site conditions may require more aggressive treatments in Level III. Caution should always be exercised when selecting a treatment. The treatments listed are a guide and not intended to be recommendations for specific projects as the key is always proper diagnosis.

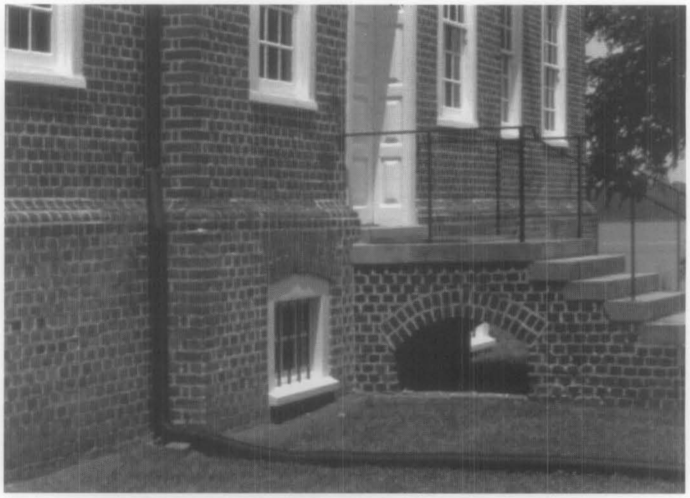


Fig. 17. In testing a theory for the cause of basement wetness, the owner used long black extender pipes to direct roof run-off away from the foundation. This test established that the owner did not need expensive waterproofing of the foundation, but a better drainage system. Photo: Baird M. Smith.

Start with the repair of any obvious deficiencies using sound preservation maintenance. If moisture cannot be managed by maintenance alone, it is important to reduce it by mitigating problems *before* deteriorated historic materials are replaced (see fig. 18). Treatments should not remove materials that can be preserved; should not involve extensive excavation unless there is a documented need; and should not include coating buildings with waterproof sealers that can exacerbate an existing problem. Some alteration to historic materials, structural systems, mechanical systems, windows, or finishes may be needed when excessive site moisture cannot be controlled by drainage systems, or in areas prone to floods. These changes, however, should, be sensitive to preserving those materials, features, and finishes that convey the historic character of the building and site.

Ongoing Care

Once the building has been repaired and the larger moisture issues addressed, it is important to keep a record of additional evidence of moisture problems and *to protect the historic or old building through proper cyclical maintenance* (see fig. 19) In some cases, particularly in museum environments, it is critical to monitor areas vulnerable to moisture damage. In a number of historic buildings, in-wall moisture monitors are used to ensure that the moisture purposely generated to keep relative humidity at ranges appropriate to a museum collection does not migrate into walls and cause deterioration. The potential problem with all systems is the failure of controls, valves, and panels over time. Back-up systems, warning devices, properly trained staff and an emergency plan will help control damage if there is a system failure.

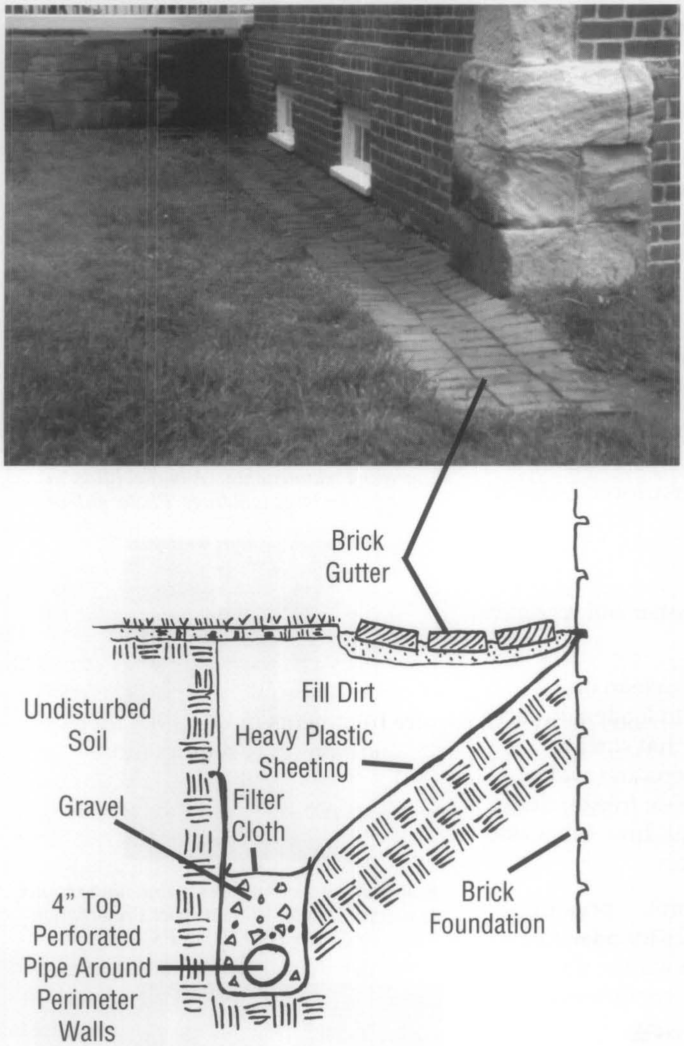


Fig. 18. This detail drawing shows a sub-surface perimeter drain in conjunction with a historic brick ground gutter system to help control roof run-off moisture from entering the historic foundation. Detail: Courtesy, Gunston Hall Plantation. Photo: Elizabeth Sasser.

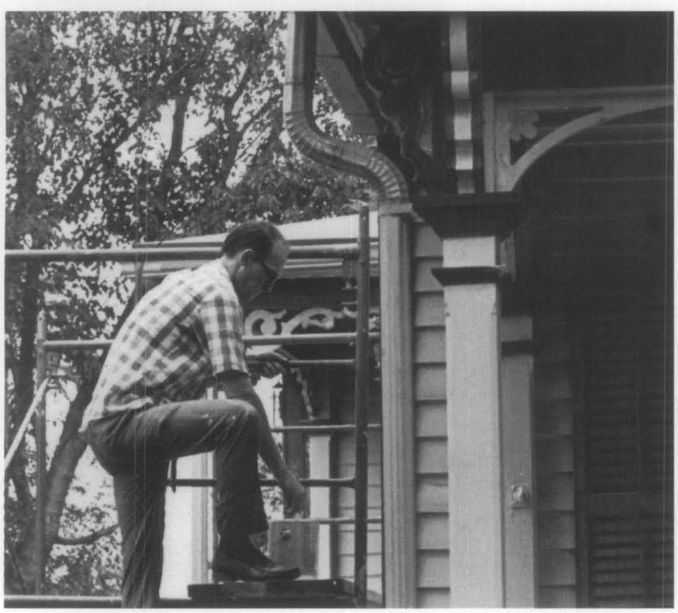


Fig. 19. Maintaining gutters and downspouts in good operable condition, repairing exteriors to keep water out, redirecting damaging moisture away from foundations and controlling interior moisture and condensation are all important when holding the line on moisture deterioration. Photo: Nebraska State Historical Society.

Ongoing maintenance and vigilance to situations that could potentially cause moisture damage must become a routine part of the everyday life of a building. The owner or staff responsible for the upkeep of the building should inspect the property weekly and note any leaks, mustiness, or blocked drains. Again, observing the building during a rain will test whether ground and gutter drainage are working well.

For some buildings a back-up power system may be necessary to keep sump pumps working during storms when electrical power may be lost. For mechanical equipment rooms, condensation pans, basement floors, and laundry areas where early detection of water is important, there are alarms that sound when their sensors come into contact with moisture.

Conclusion

Moisture in old and historic buildings, though difficult to evaluate, can be systematically studied and the appropriate protective measures taken. Much of the documentation and evaluation is based on common sense combined with an understanding of historic building materials, construction technology, and the basics of moisture and air movement. Variables can be evaluated step by step and situations creating direct or secondary moisture damage can generally be corrected. The majority of moisture problems can be mitigated with maintenance, repair, control of ground and roof moisture, and improved ventilation. For more complex situations, however, a thorough diagnosis and an understanding of how the building handles moisture at present, can lead to a treatment that solves the problem without damaging the historic resource.

It is usually advantageous to eliminate one potential source of moisture at a time. Simultaneous treatments may set up a new dynamic in the building with its own set of moisture problems. Implementing changes sequentially will allow the owner or preservation professional to track the success of each treatment.

Moisture problems can be intimidating to a building owner who has diligently tried to control them. Keeping a record of evidence of moisture damage, results of diagnostic tests, and remedial treatments, is beneficial to a building's long-term care. The more complete a survey and evaluation, the greater the success in controlling unwanted moisture now and in the future.

Holding the line on unwanted moisture in buildings will be successful if 1) there is constant concern for signs of problems and 2) there is ongoing physical care provided by those who understand the building, site, mechanical systems, and the previous efforts to deal with moisture. For properties with major or difficult-to-diagnose problems, a team approach is often most effective. The owner working with properly trained staff, contractors and consultants can monitor, select, and implement treatments within a preservation context in order to manage moisture and to protect the historic resource.

MOISTURE: LEVEL I PRESERVATION MAINTENANCE

Exterior: Apply cyclical maintenance procedures to eliminate rain and moisture infiltration.

Roofing/ guttering: Make weather-tight and operational; inspect and clean gutters as necessary depending on number of nearby trees, but at least twice a year; inspect roofing at least once a year, preferably spring; replace missing or damaged roofing shingles, slates, or tiles; repair flashing; repair or replace cracked downspouts.

Walls: Repair damaged surface materials; repoint masonry with appropriately formulated mortar; prime and repaint wooden, metal, or masonry elements or surfaces; remove efflorescence from masonry with non-metallic bristle brushes.

Window and door openings: Eliminate cracks or open joints; caulk or repoint around openings or steps; repair or reset weatherstripping; check flashing; repaint, as necessary.

A. Inspecting the overall building on at least an annual basis will identify areas needing maintenance. A bucket lift is helpful for large buildings. Photo: author.

Ground: Apply regular maintenance procedures to eliminate standing water and vegetative threats to building/site.

Grade: Eliminate low spots around building foundations; clean out existing downspout boots twice a year or add extension to leaders to carry moisture away from foundation; do a hose test to verify that surface drains are functioning; reduce moisture used to clean steps and walks; eliminate the use of chlorides to melt ice which can increase freeze/thaw spalling of masonry; check operation of irrigation systems, hose bib leaks, and clearance of air conditioning condensate drain outlets.

B. Repair exterior surfaces, paint, and recaulk as needed. Photo: Williamsport Preservation Training Center (WPTC), NPS.

Crawl space: Check crawl space for animal infestation, termites, ponding moisture, or high moisture content; check foundation grilles for adequate ventilation; seasonally close grilles when appropriate — in winter, if not needed, or in summer if hot humid air is diffusing into air conditioned space.

Foliage: Keep foliage and vines off buildings; trim overhanging trees to keep debris from gutters and limbs from rubbing against building; remove moisture retaining elements, such as firewood, from foundations.

C. Cleaning out gutters and downspouts should be done at least twice a year. Photo: WPTC, NPS.

Basements and foundations: Increase ventilation and maintain surfaces to avoid moisture.

Equipment: Check dehumidifiers, sump pump, vent fans, and water detection or alarm systems for proper maintenance as required; check battery back-up twice a year.

Piping/ductwork: Check for condensation on pipes and insulate/seal joints, if necessary.

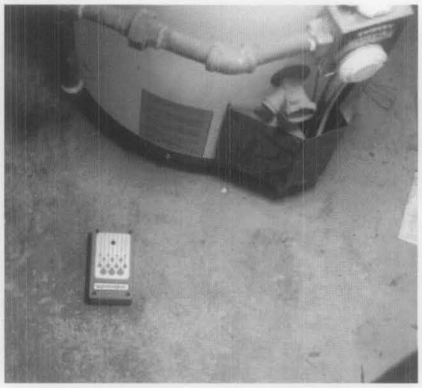
Interior: Maintain equipment to reduce leaks and interior moisture.

Plumbing pipes: Add insulation to plumbing or radiator pipes located in areas subject to freezing, such as along outside walls, in attics, or in unheated basements.

Mechanical equipment: Check condensation pans and drain lines to keep clear; insulate and seal joints in exposed metal ductwork to avoid drawing in moist air.

Cleaning: Routinely dust and clean surfaces to reduce the amount of water or moist chemicals used to clean building; caulk around tile floor and wall connections; and maintain floor grouts in good condition.

Ventilation: Reduce household-produced moisture, if a problem, by increasing ventilation; vent clothes driers to the outside; install and always use exhaust fans in restrooms, bathrooms, showers, and kitchens, when in use.



D. Protect the building from damage by maintaining equipment and using alarms, like this floor water sensor. Photo: Dell Corporation.

MOISTURE: LEVEL II REPAIR AND CORRECTIVE ACTION

Exterior: Repair features that have been damaged. Replace an extensively deteriorated feature with a new feature that matches in design, color, texture, and where possible, materials.

Roofing: Repair roofing, parapets and overhangs that have allowed moisture to enter; add ice and water shield membrane to lower 3-4 feet or roofing in cold climates to limit damage from ice dams; increase attic ventilation, if heat and humidity build-up is a problem. Make gutters slope @ 1/8" to the foot. Use professional handbooks to size gutters and reposition, if necessary and appropriate to historic architecture. Add ventilated chimney caps to unused chimneys that collect rain water.

Walls: Repair spalled masonry, terra cotta, etc. by selectively installing new masonry units to match; replace rotted clapboards too close to grade and adjust grade or clapboards to achieve adequate clearance; protect or cover open window wells.

Ground: Correct serious ground water problems; capture and dispose of downspout water away from foundation; and control vapor diffusion of crawlspace moisture.

Grade: Re-establish positive sloping of grade; try to obtain 6" of fall in the first 10' surrounding building foundation; for buildings without gutter systems, regrade and install a positive subsurface collection system with gravel, or waterproof sheeting and perimeter drains; adjust pitch or slope of eave line grade drains or French drains to reduce splash back onto foundation walls; add subsurface drainage boots or extension pipes to take existing downspout water away from building foundation to the greatest extent feasible.

Crawl space: Add polyethylene vapor barrier (heavy construction grade or Mylar) to exposed dirt in crawlspace if monitoring indicates it is needed and there is no rising damp; add ventilation grilles for additional cross ventilation, if determined advisable.

Foundations and Basements: Correct existing high moisture levels, if other means of controlling ground moisture are inadequate.

Mechanical devices: Add interior perimeter drains and sump pump; add dehumidifiers for seasonal control of humidity in confined, unventilated space (but don't create a problem with pulling dampness out of walls); add ventilator fans to improve air flow, but don't use both the dehumidifier and ventilator fan at the same time.

Walls: Remove commentates coatings, if holding rising damp in walls; coat walls with vapor permeable lime based rendering plaster, if damp walls need a sacrificial coating to protect mortar from erosion; add termite shields, if evidence of termites and dampness cannot be controlled.

Framing: Reinforce existing floor framing weakened by moisture by adding lolly column support and reinforcing joist ends with sistered or parallel supports. Add a vapor impermeable shield, preferably non-ferrous metal, under wood joists coming into contact with moist masonry.

Interior: Eliminate areas where moisture is leaking or causing a problem.

Plumbing: Replace older pipes and fixtures subject to leaking or overflowing; insulate water pipes subject to condensation.

Ventilation: Add exhaust fans and whole house fans to increase air flow through buildings, if areas are damp or need more ventilation to control mold and mildew.

Climate: Adjust temperature and relative humidity to manage interior humidity; Correct areas of improperly balanced pressure for HVAC systems that may be causing a moisture problem.

A. Mitigate poor drainage with gravel, filter cloth, or the use of subsurface drainage mats under finished paving. Photo: Larry D. Dermody.

B. Repair roofs and add ice and water shields at eaves and under valleys in cold climates. Photo: Larry D. Dermody.

C. Develop new drainage systems for roof run-off that remove moisture from the base of the building. Photo: WPTC, NPS.

D. Install ventilating fans when additional air circulation will improve damp conditions in buildings or reduce cooling loads. Photo: Ernest A. Conrad, P. E.

MOISTURE: LEVEL III REPLACEMENT / ALTERATIONS — —

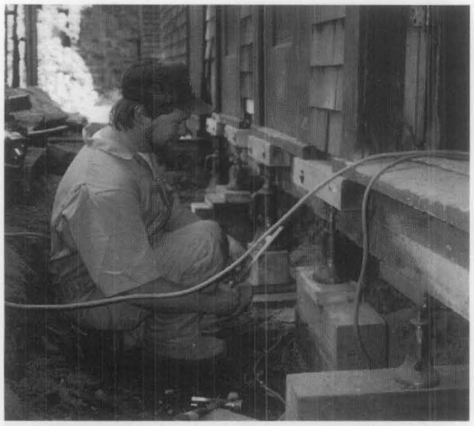
A. This lead sheet was installed at the base of the replacement column to stop rising damp. Photo: Bryan Blundell.

Exterior: Undertake exterior rehabilitation work that follows professional repair practices —i.e., replace a deteriorated feature with a new feature to match the existing in design, color, texture, and when possible, materials. In some limited situations, non-historic materials may be necessary in unusually wet areas.

Roofs: Add ventilator fans to exhaust roofs but avoid large projecting features whose designs might negatively affect the appearance of the historic roof. When replacing roofs, correct conditions that have caused moisture problems, but keep the overall appearance of the roof; for example, ventilate under wooden shingles, or detail standing seams to avoid buckling and cracking. Be attentive to provide extra protection for internal or built-in gutters by using the best quality materials, flashing, and vapor impermeable connection details.

Walls: If insulation and vapor barriers are added to frame walls, consider maintaining a ventilation channel behind the exterior cladding to avoid peeling and blistering paint occurrences.

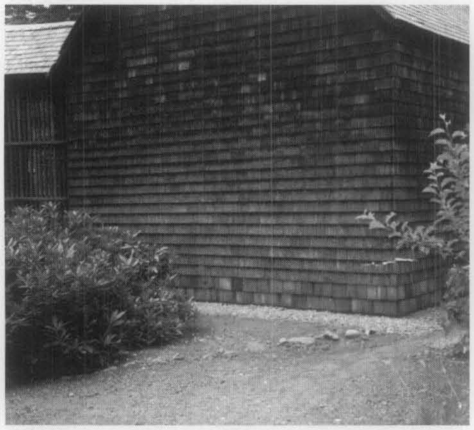
Windows: Consider removable exterior storm windows, but allow operation of windows for periodic ventilation of cavity between exterior storm and historic sash. For stained glass windows using protective glazing, use only ventilated storms to avoid condensation as well as heat build-up.



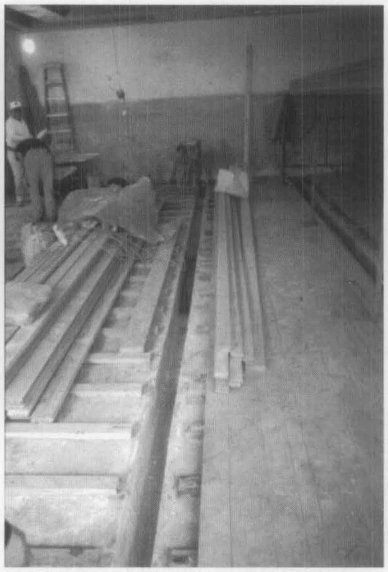
B. Wood sills set on grade were replaced with concrete pier foundation and new wooden sill plates. Changes were not visible on the exterior (see C). Photo: WPTC, NPS.

Ground: Control excessive ground moisture. This may require extensive excavations, new drainage systems, and the use of substitute materials. These may include concrete or new sustainable recycled materials for wood in damp areas when they do not impact the historic appearance of the building.

Grade: Excavate and install water collection systems to assist with positive run-off of low lying or difficult areas of moisture drainage; use drainage mats under finished grade to improve run-off control; consider the use of column plinth blocks or bases that are ventilated or constructed of non-absorbent substitute materials in chronically damp areas. Replace improperly sloped walks; repair non-functioning catch basins and site drains; repair settled areas around steps and other features at grade.



C. The new ground gutter gravel base helps drainage around the concrete foundation (see B above) which is not visible behind the replaced wooden wall shingles. Photo: WPTC, NPS.



D. In a flood plain, rotted joists were replaced with a concrete slab and sleepers designed to drain water. Spaced flooring allowed drainage and room for damp wood to swell without buckling. Harper's Ferry Center, NPS.

E. Mechanical systems on the lower level were placed on platforms above the flood line. Harper's Ferry Center, NPS.

— — FOR CHRONICALLY DAMP CONDITIONS

Foundations: Improve performance of foundation walls with damp-proof treatments to stop infiltration or damp course layers to stop rising damp. Some substitute materials may need to be selectively integrated into new features.

Walls: excavate, repoint masonry walls, add footing drains, and waterproof exterior subsurface walls; replace wood sill plates and deteriorated structural foundations with new materials, such as pressure treated wood, to withstand chronic moisture conditions; materials may change, but overall appearance should remain similar. Add dampcourse layer to stop rising damp; avoid chemical injections as these are rarely totally effective, are not reversible, and are often visually intrusive.

Interior: Control the amount of moisture and condensation on the interiors of historic buildings. Most designs for new HVAC systems will be undertaken by mechanical engineers, but systems should be selected that are appropriate to the resource and intended use.

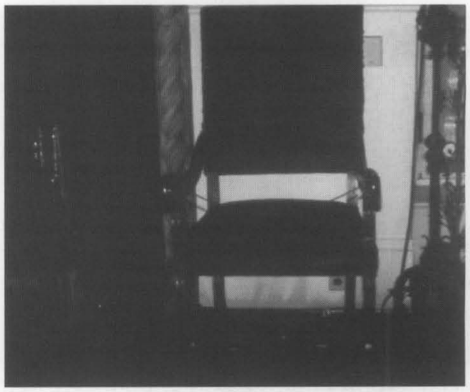
Windows, skylights: Add double and triple glazing, where necessary to control condensation. Avoid new metal sashes or use thermal breaks where prone to heavy condensation.

Mechanical systems: Design new systems to reduce stress on building exterior. This might require insulating and tightening up the building exterior, but provisions must be made for adequate air flow. A new zoned system, with appropriate transition insulation, may be effective in areas with differing climatic needs.

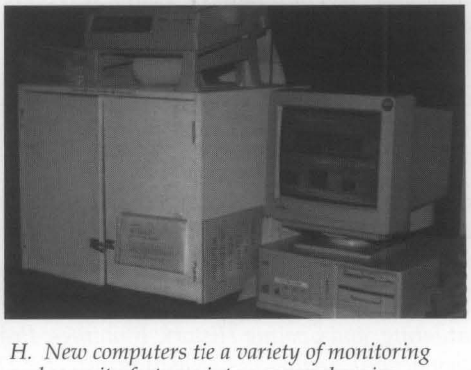
Control devices/Interior spaces: If new climate control systems are added design back-up controls and monitoring systems to protect from interior moisture damage.

Walls: If partition walls sit on floors that periodically flood, consider spacers or isolation membranes behind baseboards to stop moisture from wicking up through absorbent materials.

F. Triple glazed windows replaced the originals to control condensation. Photo: © Isabella Stewart Gardner Museum, Boston.

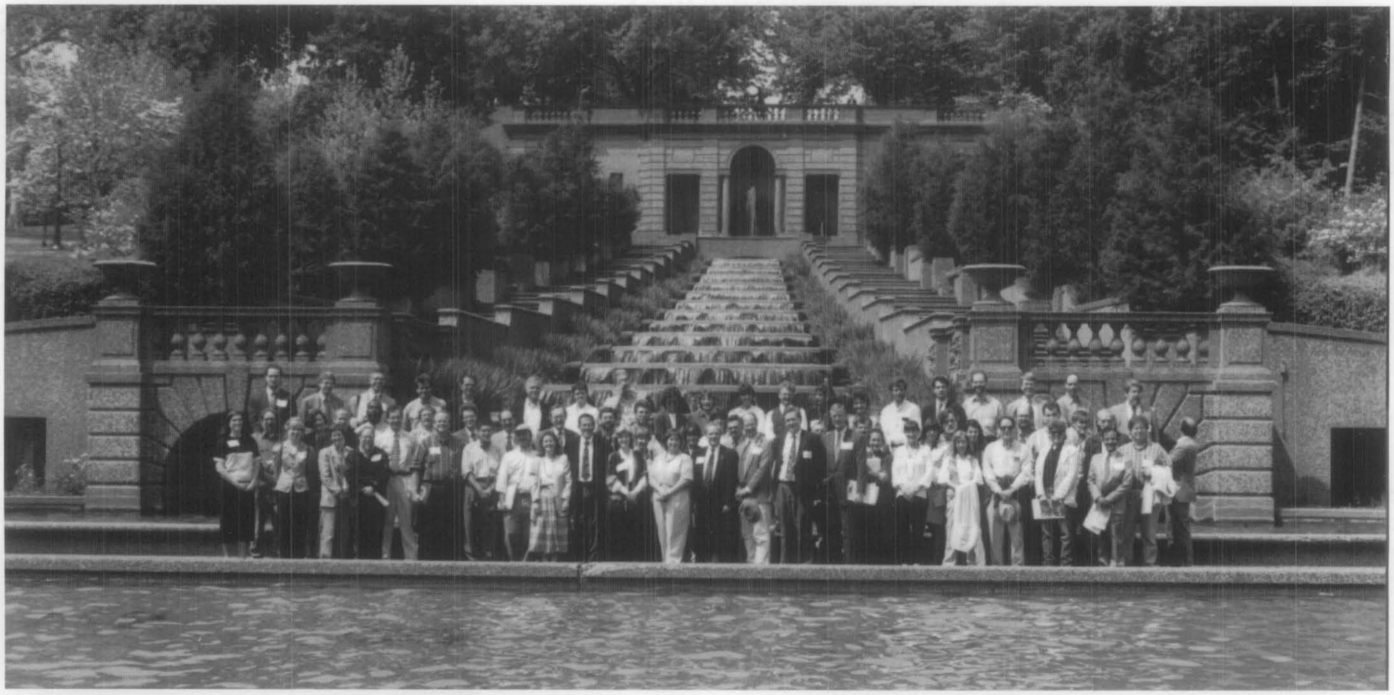


G. New sensors which monitor temperature and relative humidity are located throughout this museum and tied to a computer that controls the climate control system. Photo: © Isabella Stewart Gardner Museum, Boston.



H. New computers tie a variety of monitoring and security features into a comprehensive system which provides warning and backup alerts when any of the system components are not functioning properly. Photo: © Isabella Stewart Gardner Museum, Boston.

I. Critically damp foundation walls were protected with a layer of bentonite clay to reduce moisture penetration. This work was in combination with new downspouts that were connected to drainage boots that deposited captures roof run-off away from the foundation. Photo: Courtesy, Larry D. Dermody and the National Trust for Historic Preservation.



Back Cover: The Diagnosing Moisture in Historic Building Symposium held in Washington, DC, May, 1996, brought together practitioners in the field of historic preservation to discuss the issues contained in this Preservation Brief. Attendees are standing in front of the cascading fountains at Meridian Hill Park, a National Historic Landmark. Photo: Eric Avner.

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This publication has been prepared pursuant to the National Historic Preservation Act, as amended, which directs the Secretary of the Interior to develop and make available information concerning historic properties. Comments about this publication should be directed to de Teel Patterson Tiller, Acting Manager, Heritage Preservation Services Program, National Park Service, P.O. Box 37127, Washington, DC 20013-7127.

Cover Photo: Masonry repointing in a wet environment.
Photo: Williamsport Preservation Training Center, NPS.

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41 PRESERVATION BRIEFS

The Seismic Retrofit of Historic Buildings: Keeping Preservation in the Forefront

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Cultural Resources
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Violent, swift, and unpredictable, earthquakes result from sudden movements of the geological plates that form the earth's crust, generally along cracks or fractures known as "faults." If a building has not been designed and constructed to absorb these swaying ground motions, then major structural damage, or outright collapse, can result, with grave risk to human life. Historic buildings are especially vulnerable in this regard. As a result, more and more communities are beginning to adopt stringent requirements for seismic retrofit of existing buildings. And despite popular misconceptions, the risks of earthquakes are not limited to the West Coast, as the Seismic Zone Map on page 14 illustrates.

Although historic and other older buildings can be retrofitted to survive earthquakes, many retrofit practices damage or destroy the very features that make such buildings significant. Life-safety issues are foremost and, fortunately, there are various approaches which can save historic buildings both from the devastation caused by earthquakes and from the damage inflicted by well-intentioned but insensitive retrofit procedures. Building owners, managers, consultants, and communities need to be actively involved in preparing documents and readying irreplaceable historic resources from these damages (see illus.1).

This Preservation Brief provides essential information on how earthquakes affect historic buildings, how a historic preservation ethic can guide responsible decisions, and how various methods of seismic retrofit can protect human lives *and* historic structures. Because many of the terms used in this Brief are technical, a glossary is provided on page 7. The Brief focuses on unreinforced masonry buildings because these are the most vulnerable of our older resources, but the guidance is appropriate for all historic buildings. Damage to non-structural elements such as furnishings and collections is beyond the scope of this Brief, but consideration should be given to securing and protecting these cultural resources as well.

Planning the retrofit of historic buildings *before* an earthquake strikes is a process that requires teamwork on the part of engineers, architects, code officials, and agency administrators. Accordingly, this Brief also presents guidance on assembling a professional team and ensuring its successful interaction. Project personnel working together can ensure that the architectural, engineering, financial, cultural, and social values of historic buildings are preserved, while rendering them safe for continued use.

1. Earthquake damage to historic buildings can be repaired in a manner sensitive to their historic character as seen in this ca. 1928 five story apartment building. The owners used a combination of federal rehabilitation tax credits, community development block grants, and post earthquake grants to fund a portion of the rehabilitation and seismic upgrade costs. Photos: Historic Resources Group, Los Angeles.

Balancing Seismic Retrofit and Preservation

Reinforcing a historic building to meet new construction requirements, as prescribed by many building codes, can destroy much of a historic building's appearance and integrity. This is because the most expedient ways to reinforce a building according to such codes are to impose structural members and to fill irregularities or large openings, regardless of the placement of architectural detail. The results can be quite intrusive (see illus. 2). However, structural reinforcement can be introduced sensitively. In such cases, its design, placement, patterning, and detailing respect the historic character of the building, even when the reinforcement itself is visible.

Three important preservation principles should be kept in mind when undertaking seismic retrofit projects:

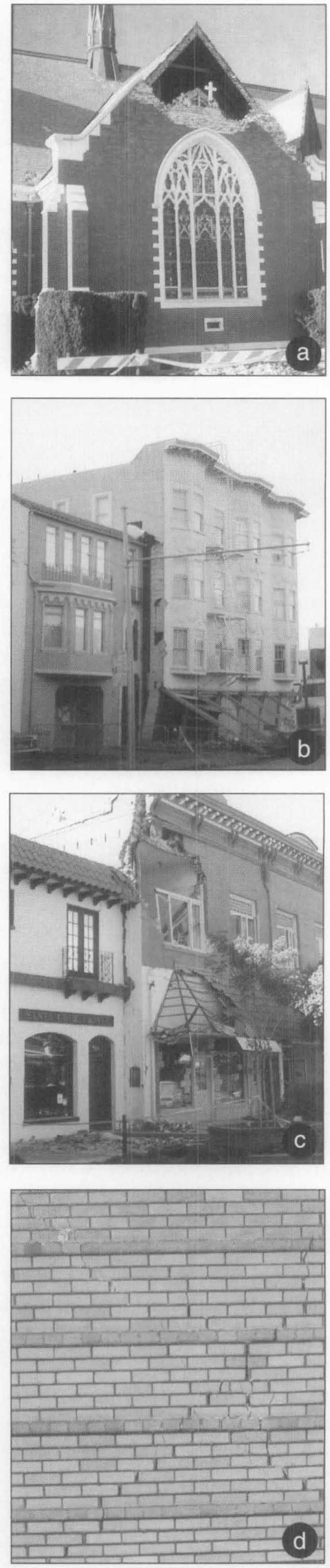
- *Historic materials should be preserved and retained to the greatest extent possible and not replaced wholesale in the process of seismic strengthening;*
- *New seismic retrofit systems, whether hidden or exposed, should respect the character and integrity of the historic building and be visually compatible with it in design; and,*
- *Seismic work should be "reversible" to the greatest extent possible to allow removal for future use of improved systems and traditional repair of remaining historic materials.*

It is strongly advised that all owners of historically significant buildings contemplating seismic retrofit become familiar with The Secretary of the Interior's *Standards for the Treatment of Historic Properties,* which are published by the National Park Service and cited in the bibliography of this publication. These standards identify approaches for working with historic buildings, including preservation, rehabilitation, and restoration. Code-required work to make buildings functional and safe is an integral component of each approach identified in the *Standards.* While some seismic upgrading work is more permanent than reversible, care must be taken to preserve historic materials to the greatest extent possible and for new work to have a minimal visual impact on the historic appearance of the building.

2. Standard approaches to seismic retrofit, as seen with the diagonally braced frame crossing in front of the historic windows, are visually intrusive. Solutions, such as using hidden moment frames around the perimeter of the window, will meet the goals of historic preservation and seismic retrofit. Photo: Steade Craigo.

Earthquake Damage to Historic Buildings: Assessing Principal Risk Factors

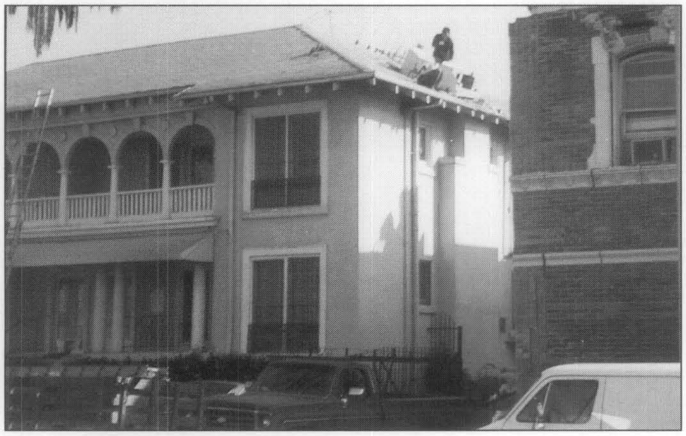
Typical earthquake damage to most older and historic buildings results from poor ductility—or flexibility—of the building and, specifically, poor structural connections between walls, floors, and foundations combined with the very heavy weight and mass of historic materials that are moved by seismic forces and must be resisted. In buildings that have not been seismically upgraded, particularly unreinforced masonry buildings, parapets, chimneys, and gable ends may dislodge and fall to the ground during a moderate to severe earthquake (see illus. 3). Walls, floors, roofs, skylights, porches, and stairs which rely on tied connections may simply fail. Interior structural supports may partially or totally collapse. Unreinforced masonry walls between openings often exhibit shear (or diagonal) cracking. Upper stories may collapse onto under-reinforced lower floors with large perimeter openings or atriums. Unbraced infill material between structural or rigid frame supports may dislodge. Adjacent buildings with separate foundations may move differently in an earthquake creating damage between them. Poorly anchored wood frame buildings tend to slide off their foundations. Ruptured gas and water lines often cause fire and water damage. Many of these vulnerabilities can be mitigated by understanding how the forces unleashed in an earthquake affect the building, then planning and implementing appropriate remedial treatments.



3. Forces from moderate to serious earthquakes caused a) the untied gable to fail, b) the first floor to collapse c) cracks from the pounding effect of adjacent buildings, and d) and diagonal cracks in exterior masonry between windows to form. Photos: David Look.

Six principal factors influence how and why historic buildings are damaged in an earthquake: (1) depth of the earthquake and subsequent strength of earthquake waves reaching the surface; (2) duration of the earthquake, including after-shock tremors; (3) proximity of the building to the earthquake epicenter, although distance is not necessarily a direct relationship; (4) geological and soil conditions; (5) building construction details, including materials, structural systems, and plan configuration; and (6) existing building condition, including maintenance level.

The first three factors—the depth, duration, and proximity to the fault—are beyond human control. Recent earthquakes have shown the fourth factor, geological soil conditions, to be as important as any of the other factors because loose, soft soils tend to amplify ground motion, thereby increasing damage. Further, there is the tendency of soft, unstable soils to "liquefy" as the ground vibrates, causing the building foundations to sink unevenly. This fourth factor, geological and soil conditions, is difficult to address in a retrofit situation, although it can be planned for in new construction. The last two factors—the building's construction type and its existing physical condition—are the two factors over which building owners and managers have control and can ultimately affect how the historic property performs in an earthquake (see illus. 4).



4. The compact size and good condition of the masonry building on the left withstood the earthquake except for the loss of the unsupported chimney at the roof line. The brick building on the right appears to have sustained more damage. Photo: Steade Craigo.

Although historic buildings present problems, the way they were constructed often has intrinsic benefits that should not be overlooked. Diagonal subflooring under tongue-and-groove nailed flooring can provide a diaphragm, or horizontal membrane, that ties the building together. Interior masonry walls employing wire lath with plaster also add strength that binds materials together. The typical construction of older buildings with partition walls that extend from floor to ceiling (instead of just to the underside of a dropped ceiling) also provides additional support and load transfer during an earthquake that keeps shifting floors from collapsing. Moreover, buildings constructed of unreinforced masonry with a wall thickness to height ratio that does not exceed code requirements can often survive shaking without serious damage. The stability of unreinforced masonry walls should not be underestimated; while the masonry may crack, it often does not shift out of plumb enough to collapse.

Type of Building and Construction

A historic building's construction and materials determine its behavior during an earthquake. Some buildings, such as wooden frame structures, are quite ductile and, thus, able to absorb substantial movements. Others, such as unreinforced brick or adobe buildings comprised of heavy individual load-bearing units, are more susceptible to damage from shaking. If an earthquake is strong, or continues for a long time, building elements that are poorly attached or unreinforced may collapse. Most historic buildings still standing in earthquake zones have survived some shaking, but may be structurally weakened.

Buildings of more rigid construction techniques may also have seismic deficiencies. Masonry infill-wall buildings are generally built of steel or concrete structural frames with unreinforced masonry sections or panels set within the frame. While the structural frames may survive an earthquake, the masonry infill can crack and, in some cases, dislodge. The reaction of concrete buildings and concrete frame structures is largely dependent upon the extent and configuration of iron or steel reinforcement. Early buildings constructed of concrete are often inadequately reinforced, inadequately tied, or both, and are thus susceptible to damage during earthquakes.

Recognition of the configuration of the historic structure and inherent areas of weakness are essential to addressing appropriate alternatives for seismic retrofit. For example, the plan and elevation may be as important as building materials and structural systems in determining a historic building's survival in an earthquake. Small round, square, or rectangular buildings generally survive an earthquake because their geometry allows for equal resistance of lateral forces in all directions. The more complex and irregular the plan, however, the more likely the building will be damaged during an earthquake because of its uneven strength and stiffness in different directions. Structures having an "L," "T," "H," "U," or "E" shape have unequal resistance, with the stress concentrated at corners and intersections. This is of particular concern if the buildings have flexible structural systems and/or an irregular layout of shear walls which may cause portions of the building to pull apart.

Similarly, the more complex and irregular a building elevation, the more susceptible it is to damage, especially in tall structures. Large or multiple openings around the building on the ground level, such as storefronts or garage openings, or floors with columns and walls running in only one direction are commonly known as "soft stories" and are prone to structural damage.

Building Condition

Much of the damage that occurs during an earthquake is directly related to the building's existing condition and maintenance history. Well maintained buildings, even without added reinforcement, survive better than buildings weakened by lack of maintenance. The capacity of the structural system to resist earthquakes may be severely reduced if previous alterations or earthquakes have weakened structural connections or if materials have deteriorated from moisture, termite, or other damage. Furthermore, in unreinforced historic masonry buildings, deteriorated mortar joints can weaken entire walls. Cyclical maintenance, which reduces moisture penetration and erosion of materials, is therefore essential. Because damage can be cumulative, it is important to analyze the structural capacity of the building.

Over time, structural members can become loose and pose a major liability. Unreinforced historic masonry buildings typically have a friction-fit connection between horizontal and vertical structural members, and the shaking caused by an earthquake pulls them apart. With insufficient bearing surface for beams, joists, and rafters against the load bearing walls or support columns, they fail. The resulting structural inadequacy may cause a partial or complete building collapse, depending on the severity of the earthquake and the internal wall configuration. Tying the building together by making a positive anchored or braced connection between walls, columns, and framing members, is key to the seismic retrofit of historic buildings.

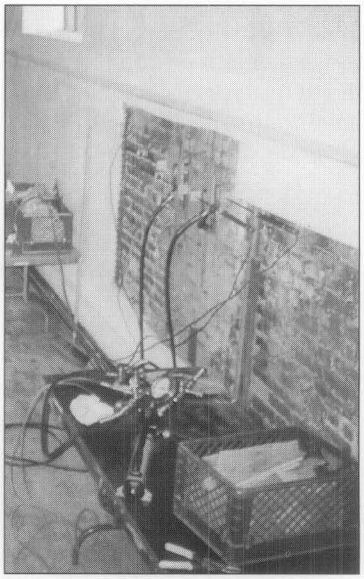
Putting a Team Together

The two goals of the seismic retrofit in historic buildings are life safety and the protection of older and historic buildings during and after an earthquake. Because rehabilitation should be sensitive to historic materials and the building's historic character, it is important to put together a team experienced in both seismic requirements and historic preservation. Team members should be selected for their experience with similar projects, and may include architects, engineers, code specialists, contractors, and preservation consultants. Because the typical seismic codes are written for new construction, it is important that both the architect and structural engineer be knowledgeable about historic buildings and about meeting building code equivalencies and using alternative solutions. Local and state building officials can identify regulatory requirements, alternative approaches to meeting these requirements, and if the jurisdiction uses a historic preservation or building conservation code. Even on small projects that cannot support a full professional team, consultants should be familiar with historic preservation goals. The State Historic Preservation Office and the local historic preservation office or commission may be able to identify consultants who have been successful in preserving historic buildings during seismic retrofit work. Once the team has been assembled, their tasks include:

Compiling documentation. The team should review all available documentation on the historic building, including any previous documentation assembled to nominate the structure to the National Register of Historic Places, and any previous Historic Structures Reports. Original plans and specifications as well as those showing alterations through time often detail structural connections. Early real estate or insurance plans, such as the *Sanborn Maps*, note changes over time. Historic photographs of the building under construction or before and after previous earthquakes are invaluable. Base maps for geological or seismic studies and utility maps showing the location of water, gas, and electric lines should be also identified. The municipal or state office of emergency preparedness can provide data on earthquake hazard plans for the community.

Evaluating significant features and spaces. The team must also identify areas of a historic building and its site that exhibit design integrity or historical significance which must be preserved. It is critical, and a great challenge, to protect these major features, such as domes, atriums, and vaulted spaces or highly decorative elements, such as mosaics, murals, and frescoes. In some cases, secondary areas of the building can provide spaces for additional reinforcement behind these major features, thus saving them from damage during seismic retrofit work. Both primary and secondary spaces, features, and finishes should, thus, be identified.

Assessing the condition of the building and the risk hazards. The team then assesses the general physical condition of the building's interior and exterior, and identifies areas vulnerable to seismic damage. This often requires a structural engineer or testing firm to determine the strength and durability of materials and connections (see illus. 5). A sliding scale of potential damage is established, based on the probability of hazard by locale and building use. This helps the owner distinguish between areas in which repairable damage, such as cracking, may occur and those in which life-threatening problems may arise. These findings help guide cost-benefit decisions, especially when budgets are limited.



5. A careful program of in-place testing is essential to evaluate the existing seismic capacity of a building. This masonry push-test uses hydraulic jacks to estimate the shear capacity of the wall. Test locations should be in areas that do not destroy significant features and repairs should be carried out carefully. Photo: Architectural Resources Group, San Francisco.

Evaluating local and state codes and requirements. Few codes consider historic buildings, but the California State Historical Code and the Uniform Code for Building Conservation provide excellent models for jurisdictions to adopt. Code officials should always be asked where alternative approaches can be taken to provide life safety if the specified requirements of a code would destroy significant historic materials and features. Some jurisdictions require the removal of parapets, chimneys, or projecting decoration from unreinforced masonry buildings which is not a preservation approach. Professionals on the team should be prepared with alternatives that allow for mitigating potential damage to such features while retaining them through reattachment or strengthening.

Developing a retrofit plan. The final task of the project team is to develop a retrofit plan. The plan may require multiple treatments, each more comprehensive than the last. Treating life-safety issues as well as providing a safe route of exit should be evaluated for all buildings. Developing more comprehensive plans, often combined with future rehabilitation, is reasonable. Long-term restoration solutions phased in over time as funding is available should also be considered. In every case, owners and their planning teams should consider options that keep preservation goals in mind.

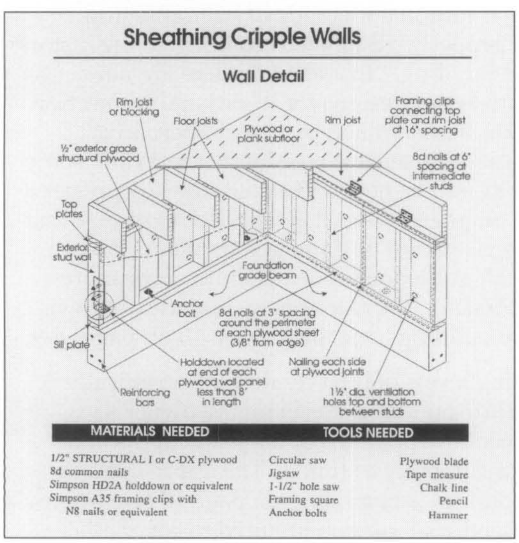
There are significant advantages of completing a seismic survey and analysis even if resources for implementing a retrofit are not yet available. Once the retrofit plan is finished, the project team will have a document by which to assess future damage and proceed with emergency repairs. If construction is phased, its impact to the whole building should be understood. Some partially completed retrofit measures have left buildings more rigid in one area than in others, thereby contributing to more extensive damage during an ensuing earthquake.

Planning for Seismic Retrofit: How Much and Where?

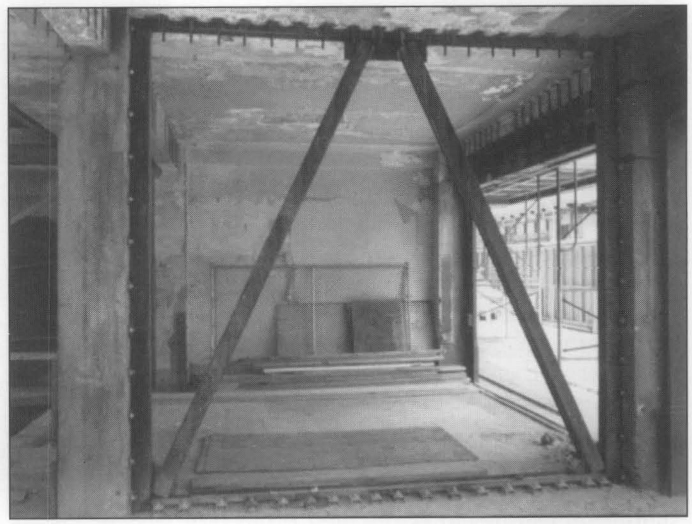
The integrity and significance of the historic building, paired with the cost and benefit of seismic upgrading, need to be weighed by the owner and the consulting team. Buildings in less active seismic areas may need little or no further bracing or tying. Buildings in more active seismic zones, however, may need more extensive intervention. Options for the level of seismic retrofit generally fall into four classifications, depending on the expected seismic activity and the desired level of performance. Realistically, for historic buildings, only the first three categories apply.

1) *Basic Life Safety.* This addresses the most serious life-safety concerns by correcting those deficiencies that could lead to serious human injury or total building collapse. Upgrades may include bracing and tying the most vulnerable elements of the building, such as parapets, chimneys, and projecting ornamentation or reinforcing routes of exit. (see illus. 6). It is expected that if an earthquake were to occur, the building would not collapse but would be seriously damaged requiring major repairs.

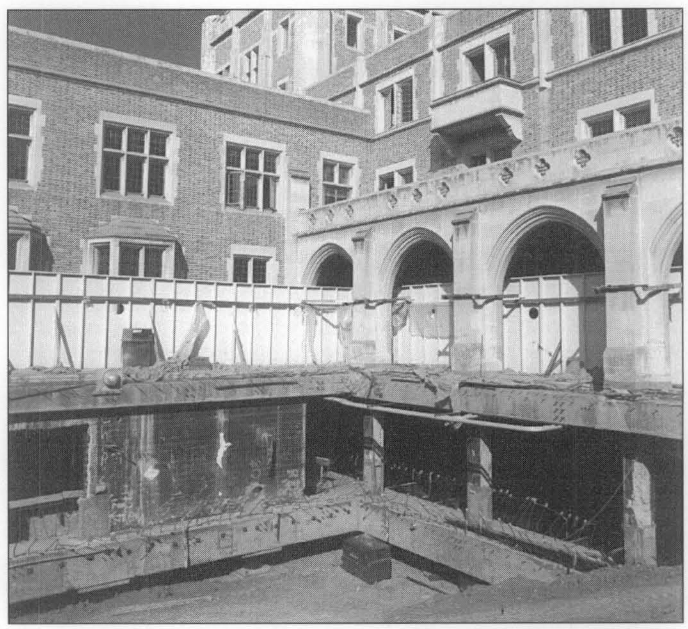
2) *Enhanced Life Safety.* In this approach, the building is upgraded using a flexible approach to the building codes for moderate earthquakes. Inherent deficiencies found in older buildings, such as poor floor to wall framing connections and unbraced masonry walls would be corrected (see illus. 7). After a design level earthquake, some structural damage is anticipated, such as masonry cracking, and the building would be temporarily unusable.



6. Often simple approaches, such as nailing plywood stiffeners between crawlspace studs and onto floor joist above and bolting sill plates to foundations can make a dramatic difference in protecting a building from seismic damage. Illustration: Reproduced with permission from Home Earthquake Preparedness Guide. EQE Incorporated, San Francisco, CA.



7. More extensive seismic issues can be addressed through structural reinforcement, the most common methods using anchor ties and braces. Shown here is an interior diagonal frame, to be covered, which will dampen and transfer seismic loads in a designed path from foundation to roof. Photo: David Look.

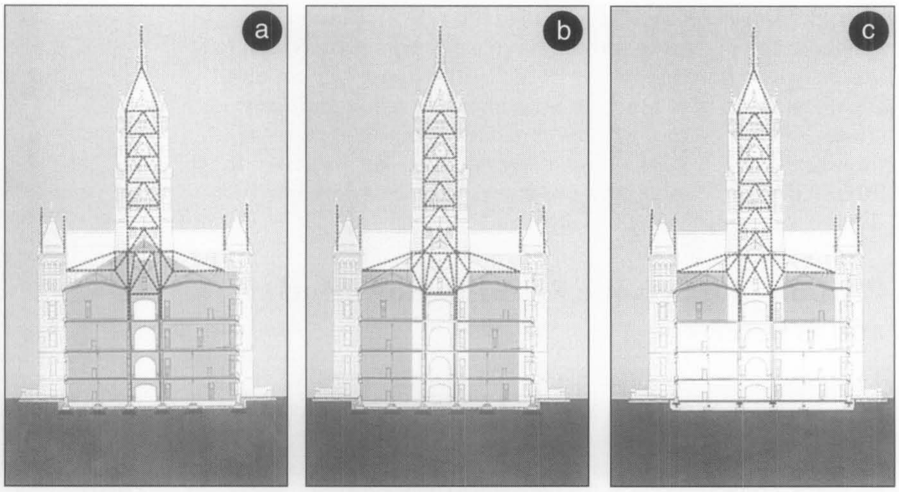


8. Full seismic restructuring to ensure that buildings survive a major earthquake with a minimum of damage may involve extensive reinforcement. Upon completion, the changes to this ca. 1932 Gothic Revival building to add base isolation at the foundation were not visually apparent. Photo: © Jonathan Farrer, courtesy University of California at Los Angeles (UCLA), Capital Programs.

3) *Enhanced Damage Control.* Historic buildings are substantially rehabilitated to meet, to the extent possible, the prescribed building code provision (See illus. 8). Some minor repairable damage would be expected after a major earthquake.

4) *Immediate Occupancy.* This approach is intended for designated hospitals and emergency preparedness centers remaining open and operational after a major earthquake. Even most modern buildings do not meet this level of construction, and so for a historic building to meet this requirement, it would have to be almost totally reconstructed of new materials which, philosophically, does not reflect preservation criteria.

Devising the most appropriate approach for a particular historic building will depend on a variety of factors, including the building's use, whether it remains occupied during construction, applicable codes, budgetary constraints, and projected risk of damage. From a design perspective, the vast majority of historic buildings can tolerate a well-planned hidden system of reinforcement. Utilitarian structures, such as warehouses, may be able to receive fairly visible reinforcement systems without undue damage to their historic character. Other more architecturally detailed buildings or those with more finished interior surfaces, however, will benefit from more hidden systems; installation of such systems may even require the temporary removal of significant features to assure their protection. Most buildings, particularly commercial rehabilitations, can incorporate seismic strengthening during other construction work in a way that ensures a high degree of retention of historic materials in place.



9.These studies for a public building compared, in the shaded areas, the amount of historic material that would be affected by (a) the Uniform Building Code requirements, (b) engineering alternatives that protected significant historic materials, and (c) the use of base isolation systems. The cost for implementing the 3 proposals was similar, and while proposal (c) was selected there were many positive aspects to both (b) and (c). Photos: George Siekkinen, with permission from Ehrenkrantz, Eckstut, & Kuhn Architects.

Assessing the Cost of Seismic Retrofit

Cost plays a critical role in selecting the most appropriate retrofit measure. It is always best to undertake retrofit measures before an earthquake occurs, when options are available for strengthening existing members. Once damage is done, the cost will be substantially higher and finding engineers, architects, and contractors available to do the work on a constricted schedule will be more difficult.

Planned seismic retrofit work may add between \$10 and \$100 per square foot to the cost of rehabilitation work depending on the level of intervention, the condition of the building, and whether work will be undertaken while the building is occupied. Costs can exceed several hundred dollars a square foot for combined restoration and seismic upgrade costs in major public buildings, in order to provide a level of structural reinforcement that would require only minor repairs after a major earthquake. But maintenance and incremental improvements to eliminate life-safety risks are within the cost realm of responsible upkeep.

Each property owner has to weigh the costs and benefits of undertaking seismic retrofit in a timely manner. Owners may find that an extended engineering study evaluating a wide range of options is worthwhile. Not only can such a study consider the most sensitive historic preservation solution, but the most cost-effective one as well. In many cases, actual retrofit expenses have been lower than anticipated because a careful analysis of the existing building was made that took the durability and performance of existing historic materials into consideration. Most seismic retrofit is done incrementally or incorporated into other rehabilitation work. In large public buildings, seemingly expensive "high-tech" solution such as installing foundation base isolators can turn out to be justified because significant historic materials do not have to be removed, replaced, or replicated (see illus. 9). The cost for a fully retrofitted building can offset the potential loss of income, relocation, and rebuilding after an earthquake. Without careful study, these solutions often are not evaluated.

Some municipalities and states provide low-interest loans, tax relief, municipal bonds, or funding grants targeted to seismic retrofit. Federal tax incentives for the rehabilitation of income-producing historic buildings include seismic strengthening as an allowable expense. Information on these incentives is available from the State Historic Preservation Office. It is also in the best interest of business communities to support the retrofit of buildings in seismically active areas to reduce the loss of sales and property taxes, should an earthquake occur.

Seismic Strengthening Approaches

Seismic strength within buildings is achieved through the reinforcement of structural elements. Such reinforcement can include anchored ties, reinforced mortar joints, braced frames, bond beams, moment-resisting frames, shear walls, and horizontal diaphragms. Most historic buildings can use these standard, traditional methods of strengthening successfully, if properly designed to conform to the historic character of the building. In addition, there are new technologies and better designs for traditional connection devices as well as a greater acceptance of alternative approaches to meeting seismic requirements. While some technologies may still be new for retrofit, the key preservation principles on page 2 should be applied, to ensure that historic buildings will not be damaged by them. For an illustrated design guideline for using some of the more traditional methods on the exteriors of historic unreinforced masonry buildings, see illustration 10 on pages 8-9.

There are varying levels of intervention for seismically retrofitting historic buildings based on the owner's program, the recommendations of the team, applicable codes, and the availability of funds. The approaches to strengthening buildings beginning on page 10 are to show a range of treatments and are not intended to cover all methods. Each building should be evaluated by qualified professionals prior to initiating any work.

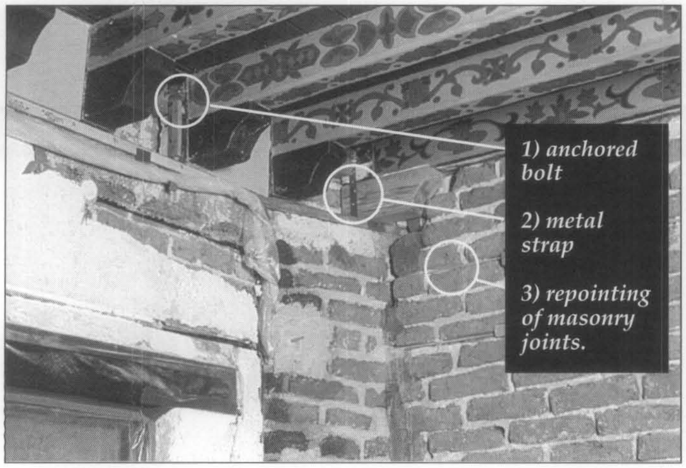
Maintenance/Preparedness

Adequate maintenance ensures that existing historic materials remain in good condition and are not weakened by rot, rust, decay or other moisture problems. Without exception, historic buildings should be well maintained and an evacuation plan developed. Expectation that an earthquake will occur sometime in the future should prepare the owner to have emergency information and supplies on hand.

- Check roofs, gutters, and foundations for moisture problems, and for corrosion of metal ties for parapets and chimneys. Make repairs and keep metal painted and in good condition.
- Inspect and keep termite and wood boring insects away from wooden structural members. Check exit steps and porches to ensure that they are tightly connected and will not collapse during an emergency exit.
- Check masonry for deteriorating mortar, and never defer repairs. Repoint, matching the historic mortar in composition and detailing.
- Contact utility companies for information on flexible connectors for gas and water lines, and earthquake activated gas shut-off valves. Strap oil tanks down and anchor water heaters to wall framing.
- Collect local emergency material for reference and implement simple household or office mitigation measures, such as installing latches to keep cabinets from flying open or braces to attach tall bookcases to walls. Keep drinking water, tarpaulins, and other emergency supplies on hand.

Basic/Traditional Measures

This is not an exhaustive list, but illustrates that most measures to reduce life-safety risks rely on using mechanical fasteners to tie a building together. Incorporating these measures can be done incrementally without waiting for extensive rehabilitation (see illus.11-12). An architectural or engineering survey should identify what is needed. Care should be taken to integrate these changes with the visual appearance of the building.



11. Limited intervention should correct obvious structural deficiencies, such as tying vulnerable elements together and repointing masonry. Seen here is 1) anchored bolt, 2) metal joist strap, and 3) repointing and reinforcing masonry joints. Upon replastering and painting these reinforcements will not be visible. Photo: Historic Preservation Partners for Earthquake Response.

GLOSSARY:

Anchor Ties or bolts: Generally threaded rods or bolt which connect walls to floor and roof framing. Washers, plates, or rosettes anchor the bolt in place.

Base isolation: the ability to isolate the structures from the damaging effects of earthquakes by providing a flexible layer between the foundations and vertical supports.

Diagonal Braces: the use of diagonal, chevron or other type of bracing (X or K) to provide lateral resistance to adjacent walls.

Core drilling: a type of vertical reinforcement of masonry walls that relies on drilling a continuous vertical core that is filled with steel reinforcing rods and grouting to resist in-plane shear and out-of-plane bending.

Cripple wall: A frame wall between a building's first floor and foundation.

Diaphragm: A floor, roof, or continuous membrane that provides for the transfer of earthquake loading to the exterior or interior shear walls of the structure.

Fiber wrap reinforcement: A synthetic compound of filaments that increase the shear capacity of structural members.

Grouted bolts: anchor bolts set, generally on an angle, in a concrete grout mixture, avoid the problem of using an exposed washer. Requires a greater diameter hole than an anchor bolt with washer.

Lateral forces: Generally the horizontal forces transferred to the building from the dynamic effects of wind or seismic forces.

Life-safety: providing a level of assurance that risk of loss of life is kept to minimal levels. For buildings, this includes strengthening to reduce 1)structural collapse, 2) falling debris, 3)blocking exits or emergency routes, and 4) prevention of consequential fire.

Moment-resisting frame: A steel frame designed to provide in-plane resistance to lateral loads particularly by reinforcing the joint connection between column and beams without adding a diagonal brace. Often used as a perimeter frame around storefronts or large door and window openings.

Seismic retrofit: All measures that improve the earthquake performance of a building especially those that affect structural stability and reduce the potential for heavy structural damage or collapse.

Shear stress: A concept in physics where forces act on a body in opposite directions, but not in the same line. Horizontal forces applied to a wall that is insufficient to move with these forces will crack, often in a diagonal or X pattern. Connections at beams and walls will also crack from shear stress.

Shear wall: A wall deliberately designed to transfer the building's loads from the roof and floors to the foundation thereby preventing a building from collapse from wind or earthquake forces.

Unreinforced Masonry (URM): This designation refers to traditional brick, block, and adobe construction that relies on the weight of the masonry and the bonding capacity of mortar to provide structural stability.

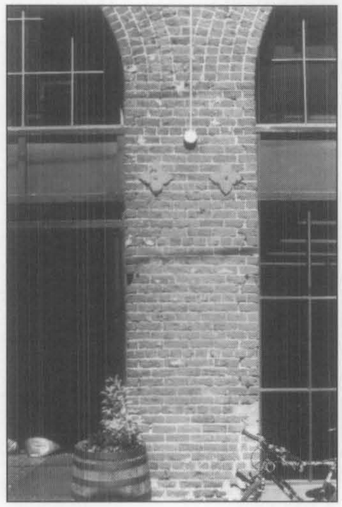
KEEPING PRESERVATI

Anchor Bolts:

Typically $^{1}/_{2}$" bolts with flat metal washers (sometimes called plates or rosettes) are probably the most common retrofit procedure. The tie the exterior wall to the floors and roof causing the building to move as a single unit.

The washers are the most noticeable part of the system. Anchor bolt locations are determined by the structural engineer. Decorative washers, such as cast iron stars, carefully placed, can enhance the building. Poorly placed or carelessly aligned washers are very noticeable.

It is important to control rust by painting ferrous metal washers. New washers can be specified as stainless or galvanized steel. In circumstances where washers are visibly intrusive, the preferable solution would be to recess them below the face material. This is particularly applicable to stucco buildings.



Recommended
- Use decorative washers in areas with high visibility.
- Align washers to create orderly appearance.
- Use stainless or galvanized steel and paint when appropriate, to prevent rust streaks.
- Attempt to conceal the bolts and washers below the exterior finish, when appropriate.

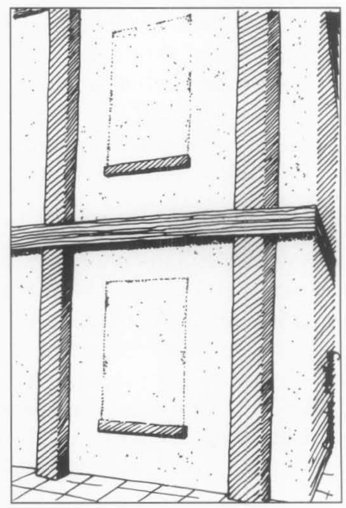
Not Recommended
- The anchor bolts on this building were placed in a haphazard fashion. More care should be taken to align the anchor bolt washers. Also, painting the washers can reduce the unsightly rust streaks that result from weathering.
- Do not place anchor bolts at locations with high relief ornamentation.

Infill Windows:

From an architectural standpoint, infill of openings is not a desirable remedy and should be used only as a last resort. It is often possible to use a braced frames instead of infilling openings, but it may be more expensive.

The purpose of filling the openings is to increase the shear capacity and reduce the stresses on the unreinforced masonry wall. It is not adequate to just infill with the same unreinforced masonry, but generally a reinforced concrete, reinforced block or reinforced brick is specified. If infilling the openings appears to be the only realistic method, the design solution should be sensitive, and if possible, limited to secondary elevations. The opening should be set back and the facing material should be compatible with the surrounding material.

Recommended
- Infill of windows should be avoided in all cases. Where absolutely required, however, the appearance of a window opening should be retained to suggest the original visual rhythm of the facade.



Not Recommended
- Infill techniques such as this are not encouraged. Suggestion of a former window opening should have been emphasized by slightly recessing the former opening.

KEY QUEST

Questions to Ask When Planning Seismic Retrofit:

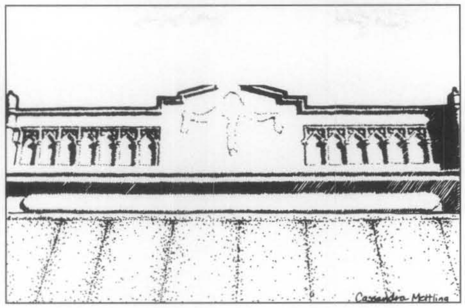
These questions should be asked with the assistance of the team to determine acceptable alternatives. Since there is never a single right answer, the design team and code officials should work together to determine the appropriate level of seismic retrofit with the lowest visual impact on the significant spaces, features, and finishes of both the interior and exterior of historic buildings.

As with the illustrations above, this guide is not intended to proscribe how seismic retrofit should be done, but rather, to illustrate that every physical change to a building will have some consequence. By asking how impacts can be reduced, the owner will have several options from which to choose.

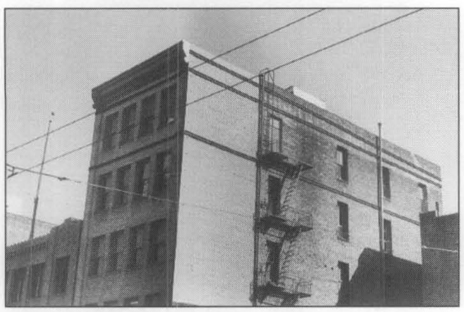
- ✦ Can bracing be installed without damaging decorative details or appearance of parapets, chimneys, or balconies?
- ✦ Are the visible features of the reinforcement, such as anchor washers or exterior buttresses adequately designed to blend with the historic building?
- ✦ Can hidden or grouted bolts be set on an angle to tie floors and walls together, instead of using traditional bolts and exposed washers or rosettes on ornamental exteriors?
- ✦ Are diagonal frames, such as X, K, or struts located to have a minimal impact on the primary facade?
- ✦ Are they set back and painted a receding color if visible through windows or storefronts?
- ✦ Can moment frames or reinforced bracing be added around historic storefronts in order to avoid unsightly exposed reinforcement, such as X braces, within the immediate viewing range of the public?

IN THE FOREFRONT

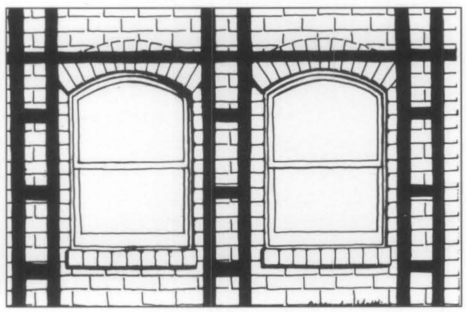
Recommended
• All original building ornamentation enhances the architectural value and should be retained and maintained.



Not Recommended
• If it is determined that ornamentation must be secured or removed, effort should be made to secure it. The parapet of this building shows a "scar" where ornamentation was removed.



Recommended
• Exterior bracing or buttressing should incorporate the building's natural lines. The exterior steel bracing appears to be an original building element because it runs parallel to the cornice line.



Not Recommended
• The exterior bracing on this building dominates its appearance. Care should be taken to design exterior bracing to blend with or enhance the building's natural lines.

Adapted from "Architectural Design Guide for Exterior Treatments of Unreinforced Masonry Buildings During Seismic Retrofit." Used with permission from the San Francisco Chapter, The American Institute of Architects. Drawings © Cassandra Mettling-Davis.

Securing Exterior Ornamentation:

Ornament is one of the character-defining features of a building. Careful forethought and analysis should always precede alteration of a building's ornament.

Generally methods to secure ornamentation by repair and reinforcing connections should be undertaken. Repairs or reinforcement should blend with the appearance of the ornamentation and should be designed to prevent future failures such as cracking due to thermal and seismic stress or unsightly differential weathering.

If ornamental elements must be removed during the repair process, they should be reinstalled or replaced in-kind. The use of substitute materials may be acceptable if no other options exist.

Exterior Buttresses:

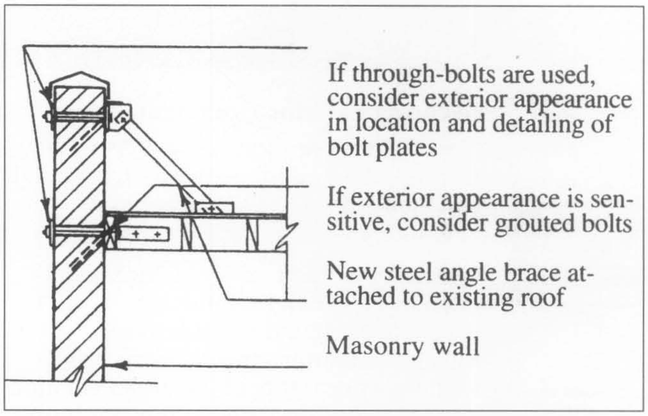
Exterior buttresses, an integral part of Gothic architecture, are not traditionally part of our architecture. In retrofitting an existing building, it is usually better to use an in-wall or interior bracing system rather than a visible exterior system. When used as an exterior bracing system, care must be taken to avoid damage to existing decorative elements. Even if saved, exterior buttresses can obscure decorative elements.

Another problem requiring careful study is the integration of the buttresses with the existing structural system. Their attachment penetrates the building skin making the building more vulnerable to moisture damage. In a few cases where the interior building fabric is highly significant, exterior buttresses may be preferred. Care should be taken to avoid damage or obscuring existing architectural details.

S TO ASK:

- ✦ Can shorter sections of reinforcement be "stitched" into the existing building to avoid removal of large sections of historic materials? This is particularly true for the insertion of roof framing supports.
- ✦ Can shear walls be located in utilitarian interior spaces to reduce the impact on finishes in the primary areas?
- ✦ Are there situations where thinner applied fiber reinforced coating would adequately strengthen walls or supports without the need for heavier reinforced concrete?
- ✦ Can diaphragms be added to non-significant floors in order to protect highly decorated ceilings below, or the reverse if the floor is more ornamental than the ceiling?
- ✦ Are there adequate funds to retain, repair, or reinstall ornamental finishes once structural reinforcements have been installed?
- ✦ Should base isolation, wall damping systems, or core drilling be considered? Are they protecting significant materials by reducing the amount of intervention?
- ✦ Are the seismic treatments being considered "reversible" in a way that allows the most amount of historic materials to be retained and allows future repair and restoration?

10. Keeping preservation in the forefront is a critical aspect of seismic retrofit of historic buildings. These key questions will help keep preservation in mind as decisions are made about how best to improve the structural performance of historic buildings.



12. Bracing parapets, as illustrated here, and supporting chimneys using metal struts or ties, are simple methods to protect these heavy elements from falling. Drawing: Architectural Resources Group.

- Bolt sill plates to foundations and add plywood stiffeners to cripple wall framing around wood frame buildings. Keep reinforcement behind decorative crawlspace lattice or other historic features.
- Reinforce floor and roof framing connections to walls using joist hangers, metal straps, threaded bolts, or other means of mechanical fasteners. Tie columns to beams; reinforce porch and stair connections as well.
- Repair weakened wooden structural systems by adding, pairing, or bracing existing members. Consider adding non-ferrous metal straps in alternating mortar joints if extensive repointing is done in masonry walls.
- Reinforce projecting parapets and tie parapets, chimneys, balconies, and unsecured decorative elements to structural framing. Make the connections as unobtrusive as possible. In some cases, concrete bond beams can be added to reinforce the top of unreinforced masonry or adobe walls.
- Properly install and anchor new diaphragms, such as roof sheathing or subflooring, to the walls of a structure prior to installing finish materials.
- Avoid awkwardly placed exposed metal plates or rosettes when using threaded bolts through masonry walls. When exposed plates will interfere with the decorative elements of the facade, use less visible grouted bolts or plates that can be set underneath exposed finished materials.
- Use sensitively designed metal bracing along building exteriors to tie the unsupported face of long exterior walls to the floor framing. This is often seen along side or party walls in commercial or industrial buildings.

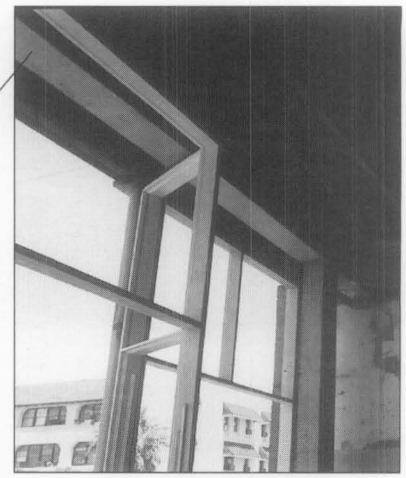
Rehabilitation

When buildings are being rehabilitated, it is generally the most cost effective time to make major upgrades that affect the structural performance of the building (see illus. 13-17). New elements, such as concrete shear walls or fiber reinforcing systems can be added while the structure is exposed for other rehabilitation or code compliance work.

- Inspect and improve all lateral tie connections and diaphragms.

13. Installing diagonal frames, underway in this rehabilitation, are a traditional method of seismic reinforcement. To reduce the impact of the X, K, or diagonal braces, they should be on the inside of the perimeter wall, designed to cross behind solid walls as much as possible, and painted a receding color where visible. Photo: David Look.

steel moment frame

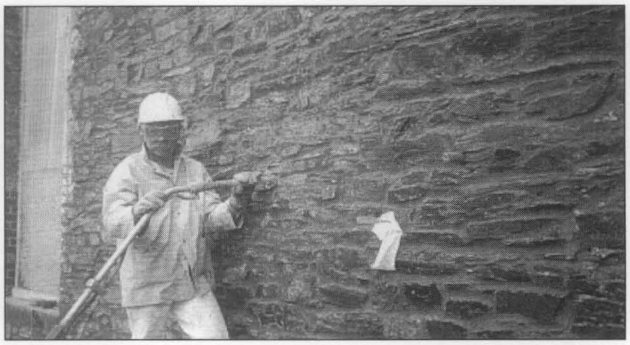


14. The use of a steel moment frame to support the large open storefront during a rehabilitation eliminated the need to place diagonal braces or other intrusive supports in a highly visible area of a historic building. Photo: David Look.

15. The use of fiber composite materials can enhance the shear capacity of existing structural components -beams, columns, and surface elements, such as walls and floors. In this roofing application, the existing roof diaphragm is being strengthened and there is additional benefit to the shear reinforcement of the parapet wall. Photo: The Crosby Group.

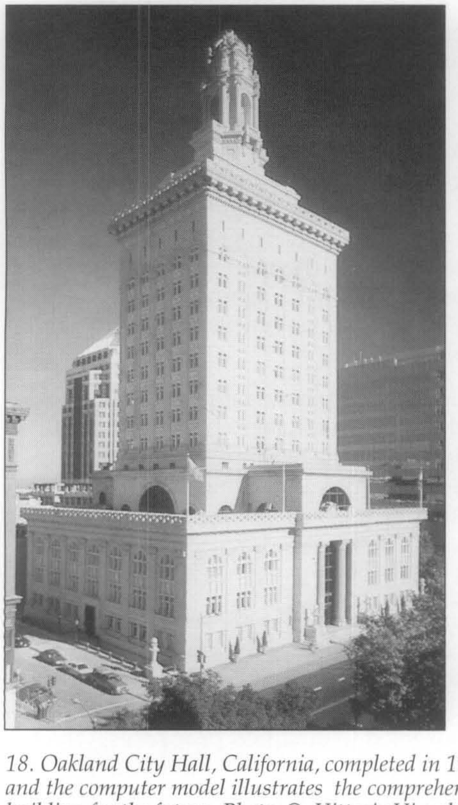
16. During the extensive rehabilitation of this historic building, new concrete, behind the new plaster finishes, strengthened the exterior brick walls and additional roof reinforcement was hidden behind the repaired/ reconstructed coffered ceiling. Photo: © Jonathan Ferrar, courtesy UCLA Capital Programs.

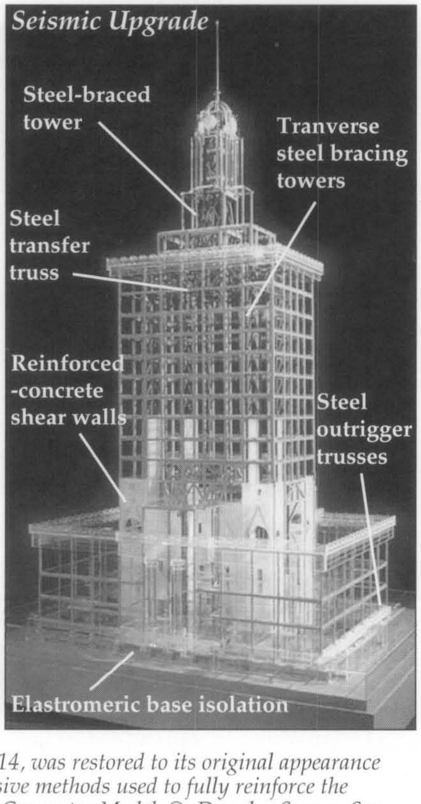
- Reinforce walls and large openings to improve shear strength in locations of doors, windows, and storefront openings. Carefully locate "X" and "K" bracing to avoid visual intrusion, or use moment frames, which are a hidden perimeter bracing in large openings. From a preservation perspective, the use of a more hidden system in finished spaces is generally preferable.
- Strengthen masonry walls or columns with new concrete reinforcement or fiber wrap systems. Avoid the use of heavy spray concrete or projecting reinforced walls that seriously alter the historic relationship of the wall to windows, trim, and other architectural moldings or details.



17. The internal grout injection of rubble walls can improve seismic capacity. Care must be taken in formulating the mortar grout and repairing the area where injection occurs. Photo: Architectural Resources Group, San Francisco.

- Selectively locate new shear walls constructed to assist the continuous transfer of loads from the foundation to the roof. If these walls cannot be set behind historic finishes, they should be located in secondary spaces in conjunction with other types of reinforcement of the primary spaces or features.
- Consider the internal grouting of rubble masonry walls using an injected grout mixture that is compatible in composition with existing mortar. Ensure that exposed areas are repaired and that the mortar matches all visual qualities of the historic mortar joints in tooling, width, color and texture.
- Evaluate odd-shaped buildings and consider the reinforcement of corners and connections instead of infilling openings with new construction. Altering the basic configuration and appearance of primary facades of buildings is damaging to those qualities that make the building architecturally significant.





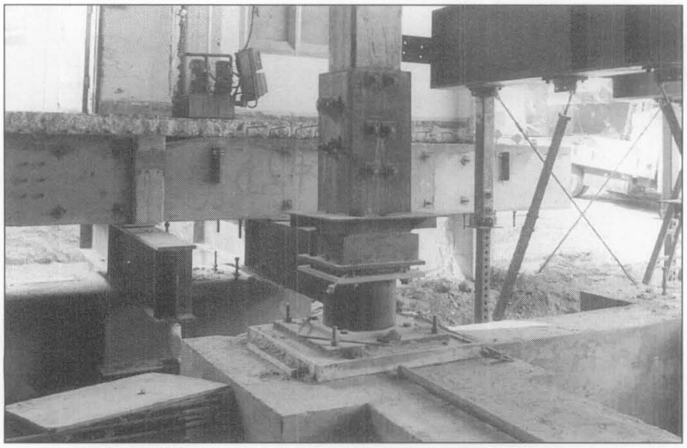
18. Oakland City Hall, California, completed in 1914, was restored to its original appearance and the computer model illustrates the comprehensive methods used to fully reinforce the building for the future. Photo: © Vittoria Visuals; Computer Model: © Douglas Symes, San Francisco. VBN, Architects and Carey & Co, Inc. Architecture.

Specialized Technologies

New technologies, being developed all the time, may have applicability to historic preservation projects. These specialized technologies include: vertical and center core drilling systems for unreinforced masonry buildings, base isolation at the foundations, superstructure damping systems, bonded resin coatings, and reproducing lost elements in lighter materials (see illus. 18-20). However, many new technologies may also be non-reversible treatments resulting in difficulties of repair after an earthquake. The reinforcement of historic materials with special resins, or the use of core drilling to provide a reinforced vertical connection from foundation to roof may not be as repairable after an earthquake as would more traditional means of wall reinforcement. New technologies should be carefully evaluated by the design team for both their benefits as well as their shortcomings.

Using computer modeling of how historic buildings may act in an earthquake suggests options for seismic upgrade using a combination of traditional methods and new technologies. While most projects involving base isolation and other complex damping

19. A system of core drilling, shown here, removes internal cored sections of unreinforced masonry from roof to foundations and fills them with grout and reinforcing rods. This may be an option for some unreinforced masonry buildings with significant interiors and exteriors, although it is a less reversible treatment than traditional diagonal frames or shear walls. Photo: David Look.



20. The new base isolator allows the structural support member at the foundation to move horizontally as it absorbs the earthquake forces. While expensive, base isolation may be justified by reducing the amount of damage to interior finishes and features with traditional methods of seismic retrofit. Photo: Photo: © Jonathan Farrer, courtesy UCLA, Capital Programs.

systems constitute only a small percentage of the projects nationwide that are seismically reinforced, they may be appropriate for buildings with significant interior spaces that should not be disturbed or removed during the retrofit. Each building will needs its own survey and evaluation to determine the most appropriate seismic reinforcement.

Post-Earthquake Issues

Should a historic building suffer damage during an earthquake, it is the owner *who has a plan in place* who will be able to play a critical role in determining its ultimate fate. If the owner has previously assembled a team for the purpose of seismic upgrading, there is a greater chance for the building to be evaluated in a timely fashion and for independent emergency stabilization to occur. In most municipalities, a survey, often by trained volunteers, will be conducted as soon as possible after an earthquake, and buildings will be tagged on the front with a posted notice according to their ability to be entered. Typically red, yellow, and green tags are used to indicate varying levels of damage—*no entry, limited entry, and useable*—to warn citizens of their relative safety. Heavily damaged areas are often secured off-limits and many red tagged, but repairable, buildings have been torn down unnecessarily because owners were unable to evaluate and present a stabilization plan in time (see illus. 21). Owners or members of the preservation community may engage their own engineers with specialized knowledge to challenge a demolition order. Because seismic retrofit is complex and many jurisdictions are involved, the coordination between various regulatory bodies needs to be accomplished *before* an earthquake.

21. Without a plan in place before an earthquake, buildings that could be repaired are often torn down. The loss of significant numbers of buildings within historic districts can further erode the financial and cultural assets of an area. Photo: David Look.

During times of emergencies, many communities, banks, and insurance agencies will not be in a position to evaluate alternative approaches to dealing with damaged historic buildings, and so they often require full compliance with codes for new construction for the major rehabilitation work required. Because seismic after-shocks often create more damage to a weakened building, the inability to act quickly—even to shore up the structure on a temporary basis—can result in the building's demolition. Penetrating rain, uneven settlement, vandalism, and continuing after-shocks can easily undermine a building's remaining structural integrity. Moreover, the longer a building is unoccupied and non-income-producing, the sooner it will be torn down in a negotiated settlement with the insurance company. All of these factors work against saving buildings damaged in earthquakes, and make having an action plan essential.

Having an emergency plan in place, complete with access to plywood, tarpaulins, bracing timbers, and equipment, will allow quick action to save a building following an earthquake. Knowing how the community evaluates buildings and the steps taken to secure an area will give the owner the ability to be a helpful resource to the community in a time of need.

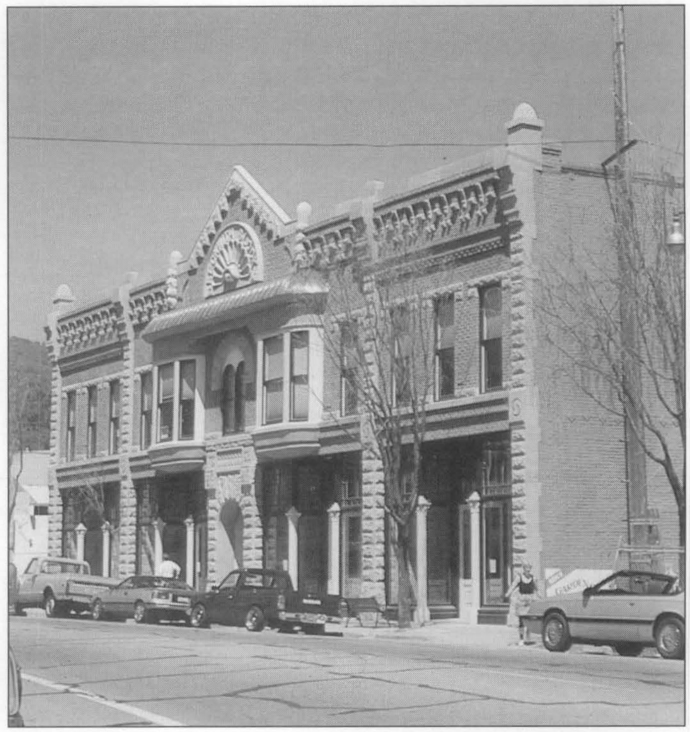
If the federal government is asked to intervene after a natural disaster, technical assistance programs are available. Often after a disaster, grant funds or low-cost loans from federal, state, and congressional special appropriations are targeted to qualified properties, which can help underwrite the high cost of rehabilitation (see information about FEMA on page 15.)

Conclusion

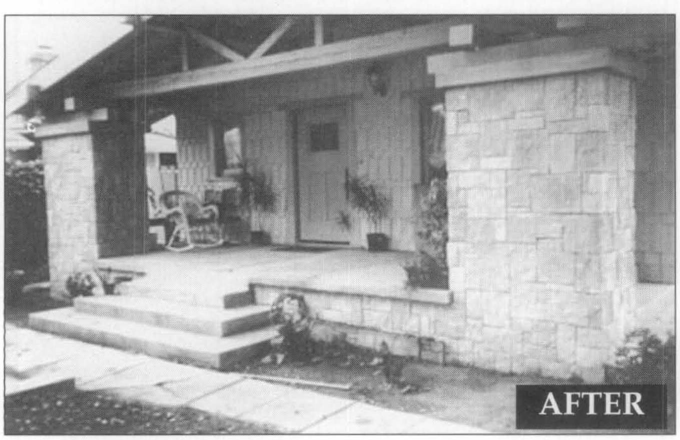
Recent earthquakes have shown that historic buildings retrofitted to withstand earthquakes survive better than those that have not been upgraded. Even simple efforts, such as bracing parapets, tying buildings to foundations, and anchoring brick walls at the highest, or roof level, have been extremely effective. It has also been proven that well maintained buildings have faired better than those in poor condition during and after an earthquake. Thus, maintenance and seismic retrofit are two critical components for the protection of historic buildings in areas of seismic activity. It makes no sense to retrofit a building, then leave the improvements, such as braced parapets or metal bolts with plates, to deteriorate due to lack of maintenance.

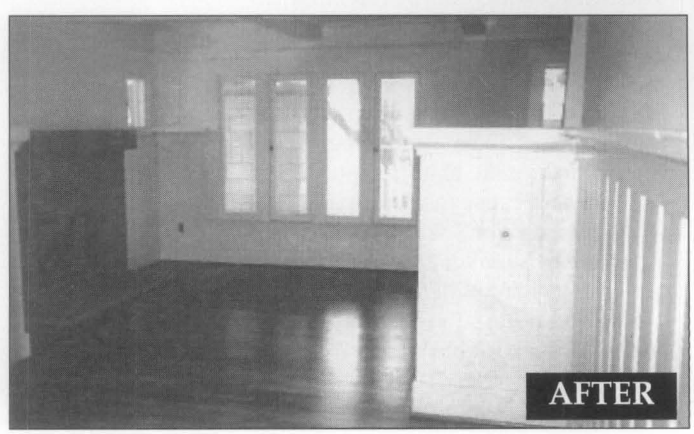
Damage to historic buildings *after* an earthquake can be as great as the initial damage from the earthquake itself. The ability to act quickly to shore up and stabilize a building and to begin its sensitive rehabilitation is imperative. Communities without earthquake hazard reduction plans in place put their historic buildings—as well as the safety and economic well-being of their residents — at risk.

Having the right team in place is important. Seismic strengthening of existing historic buildings and knowledge of community planning for earthquake response makes the professional opinions of the team members that much more important when obtaining permits to do the work. Local code enforcement officials can only implement the provisions of the model or historic preservation codes if the data and calculations work to ensure public safety.



22. When undertaking a substantial rehabilitation to include seismic reinforcement, it is also an opportune time to restore lost or damaged features. The owner of this commercial building, using the Historic Rehabilitation Tax Credits, restored the original bay and parapet gable, and stone detailing that had been removed in an earlier insensitive remodeling. Photo: David Look.





23. Both exteriors and interiors can be severely damaged in an earthquake. This Craftsman Style bungalow was successfully restored and seismically upgraded after the Northridge earthquake in California. Photographs: Historic Preservation Partners in Earthquake Response.

Buildings do not need to be over-retrofitted. A cost-effective balance between protecting the public and the building recognizes that planned for repairable damage can be addressed after an earthquake. Engineers and architects, *who specialize in historic buildings* and who have a working knowledge of alternative options and expected performance for historic structures, are critical to the process.

It is clear that historic and older buildings can be seismically upgraded in a cost-effective manner while retaining or restoring important historic character-defining qualities (see illus. 22, 23). Seismic upgrading measures exist that preserve the historic character and materials of a buildings. However, it takes a multi-disciplined team to plan and to execute sensitive seismic retrofit. It also takes commitment on the part of city, state, and federal leaders to ensure that historic districts are protected from needless demolition after an earthquake so that historic buildings and their communities are preserved for the future.

Seismic Risk Zones

Most local jurisdictions measure seismic risk based on seismic zones established by code, such as the Uniform Building Code with its 4 risk zones [1=low to 4=high]. There are also maps, such as this one, which identify the Effective Peak Acceleration (EPA) which further reflect the light, moderate, and severe shaking risks as a percentage of the acceleration of gravity that can be expected in an area.

In the United States, the greatest activity areas are the western states, Alaska, and some volcanic island areas. However, noted historical earthquakes occurred in Massachusetts (1755), Missouri (1811), South Carolina (1886), and Alaska (1964). The Caribbean Islands and Puerto Rico have been sites of severe earthquakes. The history of earthquakes in the United States has been recorded for over 200 years and new areas of concern include moderate risk areas in southern and mid-western states.

The Richter Magnitude Scale, first published in 1935, records the size of an earthquake at its source, as measured on a seismograph. Magnitudes are expressed in whole numbers and decimals between 1 and 9. An earthquake of a magnitude of 6 or more will cause moderate damage, while one of over 7 will be considered a major earthquake. It is important to remember that an increase of one whole number on the Richter Scale is a tenfold increase in the size of the earthquake.

24. Seismic Map. The shading indicate areas in the United States and Puerto Rico that are affected by the probability of varying shaking intensities. The risk of severe shaking is not limited to the west coast. Map: adapted from Federal Emergency Management Agency, FEMA 74 Guide.

FURTHER READING

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The Federal Emergency Management Agency

The Federal Emergency Management Agency (FEMA) — is an independent agency of the federal government, reporting to the President. Since its founding in 1979, FEMA's mission has been to reduce loss of life and property and protect our nation's critical infrastructure from all types of hazards through a comprehensive, risk-based, emergency management program. FEMA works with the state and local governments and the private sector to stimulate increased participation in emergency preparedness, mitigation, response and recovery programs related to natural disasters. To minimize damage-repair-damage cycles, FEMA carries out and encourages preventive activities referred to as hazard mitigation.

The FEMA Hazard Mitigation Program, established in 1988 with the passage of the Robert T. Stafford Disaster Relief and Emergency Assistance Act, offers a framework for protecting historic structures from natural disasters. In the event of a federally declared disaster, state and local governments as well as eligible non-profit applicants may receive financial and technical assistance to identify and carry out cost-effective hazard mitigation activities.

FEMA encourages hazard mitigation projects, including the restoration of buildings, by providing technical assistance and funding through the Hazard Mitigation Grant Program (HMPG), which can underwrite up to 50% of the cost of the project.

FEMA's public-assistance program provides financial and other assistance to rebuild disaster-damaged facilities that serve a public purpose, such as schools, hospitals, government buildings and public utilities.

In terms of technical assistance, FEMA, under a cooperative agreement with the Building Seismic Safety Council has produced two volumes of comprehensive material dealing with the seismic retrofit of existing buildings (see Further Reading). In addition an ongoing project ATC-43 involves earthquake analysis procedures for Unreinforced Masonry Buildings and Reinforced Concrete Buildings. These documents contain nationally applicable technical criteria intended to ensure that buildings will withstand earthquakes better than before. There is a great deal of information that is applicable to historic buildings, although historic buildings are not necessarily identified as a category. Write for FEMA publications at:

FEMA, PO Box 70274, Washington, DC 20024

For current information about emergency activities, federally declared disaster areas, or how to contact regional offices see the

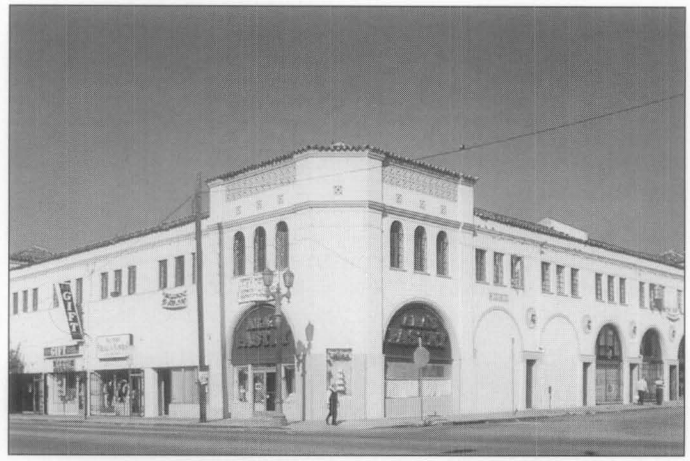
FEMA website: http://www.fema.gov/

For additional information on cultural resource preservation and Historic Rehabilitation Tax Credits see the National Park Service's

NPS website: http://www.cr.nps.gov/

Before

After



25. While it is best to seismically retrofit historic buildings before an earthquake strikes, if earthquake damage is to be repaired, it should be done in a manner respecting the historic character of the building. For this ca. 1925 Mediterranean Revival style building damaged in the Northridge Earthquake in California, financial and planning assistance from the Historic Preservation Partners for Earthquake Response made possible a sensitive rehabilitation. New structural steel and restoration of the historic stucco and decorative tile work and a repaired tile roof reinstated this earthquake damaged building as a major element of the historic district. Photo: Courtesy Historic Preservation Partners for Earthquake Response, M2A Architects.

The Historic Preservation Partners for Earthquake Response was formed after the Northridge Earthquake of 1994 and was comprised of members of the National Park Service, the National Trust for Historic Preservation, The Getty Institute, The California Office of Historic Preservation, the California Preservation Foundation, and the Los Angeles Conservancy. After the earthquake, this organization provided technical assistance and grant funding to various historic buildings. Funding of 10 million dollars from the National Park Service, U.S. Department of the Interior, was made available for the restoration and rehabilitation of cultural resources damaged during this natural disaster. In addition, sub-grants were provided by the National Trust for Historic Preservation and the California Office of Historic Preservation. A number of projects assisted by the Historic Preservation Partners for Earthquake Response are included and used with permission in this *Preservation Brief.*

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Front Cover. Historic buildings damaged by earthquakes can be rehabilitated and seismically retrofitted. The posted tag in the window warns that this building, temporarily, cannot be entered. Photo: David Look.

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October, 1997

National Park Service
U.S. Department of the Interior

Technical Preservation Services
National Center for Cultural Resources

ITS
NUMBER 3

Interpreting The Secretary of the Interior's Standards for Rehabilitation

Subject: New Additions to Mid-size Historic Buildings

Applicable Standards:

2. Retention of Historic Character
9. Compatible New Additions/Alterations
10. Reversibility of New Additions/Alterations

Issue: Sometimes it may be necessary to add extra space to a historic building when it is being rehabilitated to satisfy new use requirements. The best adaptive use is always one that requires the least amount of change to the historic building, which includes being able to fit the new use into the existing structure. But even comparatively large historic buildings may need more space to house certain practical functions that were not part of the historic use, such as mechanical equipment, an elevator shaft, or a stair tower, or just to provide more rentable or occupiable space to make the project economically viable.

The Secretary of the Interior's Standards for Rehabilitation permit new additions to historic buildings if the new addition is compatible with the historic building and its historic character. A new addition will usually meet the Standards if: (1) it is located at the rear, or on another secondary and inconspicuous elevation of the building; (2) its size and scale are limited and appropriate for the historic building; (3) the new addition does not obscure character-defining features of the historic building; and (4) the new addition is designed in such a way that clearly differentiates the new from the old.

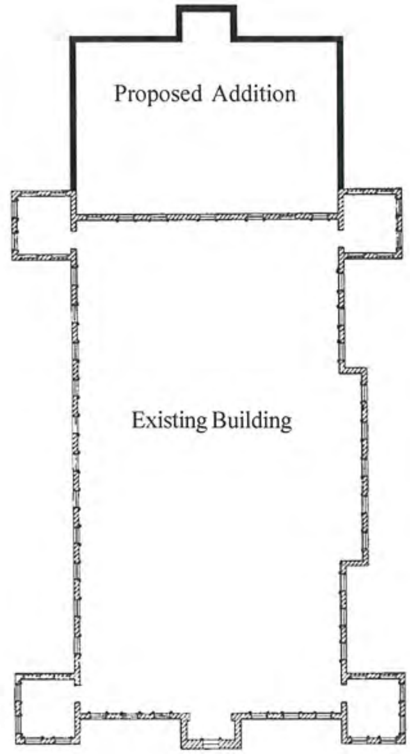
Application 1 (*Compatible addition*): Rehabilitated into apartments, this two and one-half story brick structure was originally constructed in 1887 as an orphanage, but most recently had been used for offices. This building, L-shaped in plan, extends along-a major street for most of a city block, and it is anchored by a three-story double-towered entrance at one end and a smaller simpler tower at the other end. The developer determined that more room was needed to ensure the financial success of the conversion of this building into residential apartments. Accordingly, a new two-story addition was planned at the rear and side of the former orphanage. Constructed of brick, and painted to help blend with the historic building that is also painted, the addition is simply designed, and features flat-arched windows with two-over-two sash that contrast with the rounded arches of the historic windows. This new addition meets the Standards. It is clearly differentiated from the historic building, and it is compatible in materials, design, size, and scale. A row of townhouses in front of the new addition further minimizes its visibility from the street.

The main front entrance of the orphange after its conversion to residential apartments.

The side wing that extends behind the main entrance to the building prior to rehabilitation, and construction of the new addition.

The new addition at the rear of the side wing is unobtrusive, and compatible with the building's historic character. Townhouses (on the right) in front of the addition further limit its visibility.

Application 2 (*Compatible addition*): A historic three-story, 1879 brick school building, long abandoned, was rehabilitated for use as a women's and children's center. The school is a square, Italianate building with decorative towers at each corner, now flat-roofed since the loss many years ago of their Romanesque-arched open bell towers. Although the existing building was not small, it lacked sufficient space to fulfill the center's needs for private and communal living and dining areas for the residents, as well as for administration and staff offices. To provide additional space, two small non-significant additions were removed and a three-story brick addition was constructed at the rear of the school. The new brick is harmonious with the historic brick and the design of the addition is very simple. To further differentiate the addition from the historic building, the windows in the new addition have flat arches and are very plain and unadorned in contrast to the more decorative window openings and stone sills on the original schoolhouse. The new addition is compatible in size, scale, materials and location with the historic building and, thus, meets the Standards.



The rear elevation of the school building before the removal of the two later, non-significant additions.

The simple design of the new addition at the rear of the building is completely compatible with the historic character.

The school, which is prominently situated on a corner, is shown after rehabilitation. The new addition at the back (right) cannot be seen from the corner.

Anne Grimmer, Technical Preservation Services, National Park Service

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ITS
NUMBER 4

Interpreting
The Secretary of the Interior's Standards for Rehabilitation

Subject: Inappropriate Replacement Doors

Applicable Standards:
2. Retention of Historic Character
6. Repair/Replacement of Deteriorated or Missing Features Based on Evidence
9. Compatible New Additions/Alterations

Issue: Selecting appropriate replacement doors as part of a rehabilitation project is important in retaining the character of a historic building regardless of whether it is a residential or a commercial structure. The front door to a house, a store, or an office is an integral feature of the entrance to the building, and it should reflect accurately the building's style, period of architectural significance, and its use. If the historic door is still extant, it should be retained and repaired, or it must be replaced if too deteriorated to repair. Although the replacement may be a compatible new design, it is always preferable that the new door replicate as closely as possible the historic door, while meeting modern code or security requirements that may necessitate a stronger or more fire-resistant door. This includes reproducing the same glass size, pane configuration and profile of true muntins, and the same number, size, and shape of vertical or horizontal panels. A replacement door should also match the historic door in material as well as design, but in some instances, if the situation warrants, an appropriate substitute material may be used.

In accordance with the Secretary of the Interior's Standards and the Guidelines for Rehabilitating Historic Buildings, replacing a missing historic door with one that matches the historic door is preferrable if physical, pictorial, or photographic evidence exists to document its appearance. Absent that, the door may be replaced with a new unit that is compatible with the style and character of the historic building.

Application 1 (*Incompatible treatment, later corrected to meet the Standards*): This two-story, brick building was constructed between 1919-1920 to house the commercial operations of a local dairy. It was rehabilitated as legal offices. While the rehabilitation retained the character-defining glass block windows on the second floor of the primary street elevation the first floor storefront windows and entrance had to be replaced due to extensive deterioration.

Rehabilitated dairy building.

Incompatible "stock" door.

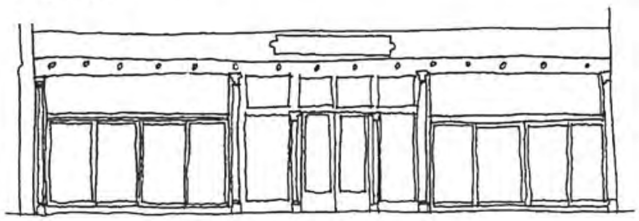
The storefront windows were replaced with simple, contemporary windows with dark-colored frames that were compatible with the historic building. But the "stock" white entrance door with its nine-pane glass and snap-in muntins above two vertical panels was not compatible with the historic building. In order to bring the project into compliance with the Standards, remedial work involved replacing the stock door with a simple glazed wood door that was compatible in both design and color with the historic building.

Appropriate replacement door.

Rehabilitated 1920s commerical building.

Application 2 *(Incompatible treatment, later corrected to meet the Standards)*: Another two-story vernacular masonry commercial building, also dating from the 1920s, that features three, one-bay storefronts on the first floor was rehabilitated for continued use as a restaurant and bar with rental apartments on the second floor. The original, historic storefronts had been replaced in the 1950s with aluminum frame windows and doors. Although, the Standards would also have allowed these later storefronts to be retained in the rehabilitation, the owner chose to install a new wood storefront with a simple, contemporary design, compatible with the building's historic character. However, the replacement wood doors had large stained glass windows and three vertical panels below, and were found to be inconsistent with both the plain character of the 1920s facade and with the replacement storefront. To meet the Standards, the owner replaced the doors with a simpler wood door with full length glass panel like the one shown in the accompanying sketch.

ELEVATION



Suggested design for compatible, contemporary replacement door.

Rehabilitated storefront with incompatible stained glass door.

Application 3 *(Incompatible treatment)*: In a third project, a two and one-half story Foursquare house with Colonial Revival-style details built in the first decade of the 20th century was rehabilitated for continued residential use. Although most of the interior finishes and features, including all lath and plaster, had been removed by a previous owner, the original front door still remained. In the course of the rehabilitation, however, this historic door was replaced with a new door featuring multi-paned glass with two vertical panels below, the same "stock" door, in fact, that was used in the dairy conversion project. This multi-paned door is no more compatible with the character of this early-20th century house, than it was with the 1920s dairy building. To meet the Standards, the owner would have had to have a new door fabricated based on photographs of the original to match the historic door which had been discarded in the rehabilitation. A compatible, contemporary door could also have been installed to meet the Standards.

In general, generic or "stock" doors with multi-paned glass, are not appropriate to use as exterior replacement doors in historic rehabilitation projects.

Rehabilitated Foursquare house with inappropriate "stock" door (left) and no longer extant historic door (right) that was discarded in the rehabilitation.

Anne Grimmer, Technical Preservation Services, National Park Service

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ITS
NUMBER 10

Interpreting
The Secretary of the Interior's Standards for Rehabilitation

Subject: Exterior Stair/Elevator Tower Additions

Applicable Standards:

9. Compatible New Additions/Alterations
10. Reversibility of New Additions/Alterations

Issue: A common problem that must be addressed when rehabilitating a historic structure is providing appropriate access to and from upper floors. Most local building codes require two separate means of egress from commercial buildings. In addition, the Americans with Disabilities Act (ADA), as well as basic real estate marketing, often dictate the need for elevators in buildings that historically did not offer this amenity. In many cases this requirement can be met within the original structure; however, in some situations the addition of a new stair or elevator shaft within the historic building would result in the destruction of significant historic fabric. It is in these situations that the possibility of constructing an exterior addition to house the exit stair or elevator shaft should be explored.

As with all new additions to historic buildings, the Secretary of the Interior's Standards for Rehabilitation require that stair/ elevator tower additions be compatible with the character of the historic building. To achieve this, the addition should be located on a secondary elevation and not be highly visible from public spaces, and its construction should not destroy character-defining historic materials on the building. The addition should also be compatible with the massing, size, scale and architectural features of the historic structure, and designed so that it is clearly apparent that it is a later alteration. Finally, the new addition should be attached in such a way that the future removal would not impair the essential integrity and form of the historic property.

Application 1 *(Incompatible addition)*: A former American Legion Hall, built in 1938 in a simplified Art Deco style, was rehabilitated into commercial office space. The historic building includes a buff brick and stone "head house" with a distinctive stepped gable entrance facing the street, and a later red brick "shed" addition (c.1955) to the rear. The rehabilitation included the construction of an elevator tower adjacent to the front elevation. Although the design of the tower is appropriately simple in design, massing and scale, and is built with compatible materials, its location nearly flush with the building's façade is inappropriate. The addition in this

Prior to rehabilitation. Note the symmetrical head house (1938) and later rear brick shed addition (1955).

After rehabilitation. The addition is located very close to the facade and, as a result, is highly visible, altering the symmetrical balance of the historic facade.

location is a highly visible new element that markedly alters the building's appearance and character by destroying the balance found in the historic facade. A better approach would have been to construct the addition further toward the rear of the building where it would have been less obtrusive, and would have preserved the character of the historic building.

This modern, metal stair tower addition located between an existing projecting tower and articulated corner is compatible with the character of the historic structure. It is also located on the rear elevation of the building, and is not visible from major public vantage points.

Application 2 *(Compatible addition)*: A second example involves a large university building, including a late-19th century stone Gothic Style historic structure with a later brick historic addition abuting it. A new stair to provide an additional means of egress was added to the rear elevation of the original structure, inconspicuously placed near the intersection with the later addition. The new stair is constructed in modern materials and is clearly differentiated from the old. Moreover, its simple, contemporary design is compatible with the historic building. Finally, the addition is not visible when looking at the building's primary elevation. Accordingly, this stair tower addition successfully conforms with the Secretary of the Interior's Standards for Rehabilitation.

Aleca Sullivan, Technical Preservation Services, National Park Service

National Park Service
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Technical Preservation Services

ITS Number 22

Interpreting The Secretary of the Interior's Standards for Rehabilitation

Subject: Adding New Entrances to Historic Buildings

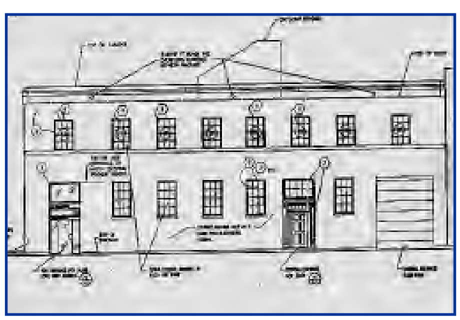
Applicable Standards:

2. Retention of Historic Character
9. Compatible New Additions/Alterations

Issue: The rehabilitation of a historic building may sometimes require the addition of another or a second entrance on a primary facade, or the introduction of an entrance on an elevation that historically did not have one. Another entrance is most commonly needed when the building will have multiple uses after rehabilitation, for example, commercial or office use on the first floor with apartments upstairs, for which a separate entrance may be required for the residents. A new entrance may also be needed on what was originally a secondary elevation but which has assumed greater importance over time or with the new use.

Generally, to meet the Standards, a new entrance should be simple in design; it should not appear historic; it should blend in with the historic facade; and it should be unobtrusive and modestly scaled. Adding a new entryway on a secondary elevation of a building should not give that elevation excessive prominence, nor should it 'reorient' the building or detract from the historic entrance. In other words, the historic front of the building should still read clearly as the primary entrance. Although it is always preferable that a new entrance be added to a rear or side elevation, in some instances a new entrance may be added on a primary elevation in a manner that is compatible with the character of the historic building.

Application 1 *(Compatible treatment)*: This two-story, eight-bay masonry structure was built in 1886 as an ice manufacturing plant. Originally constructed with only one entryway, a garage door had been added later when the building served as a warehouse. As part of the building's conversion into offices, a second pedestrian entrance was added to the street elevation during the rehabilitation to make it easier to get to some of the offices. The size of the new opening is the same as that of the existing historic entrance. But, the new entrance is almost entirely glazed, and consists of a simple butt-mounted glass door with sidelights, and a single-light transom. It is clearly a compatible, contemporary design that does not draw attention to itself. It cannot be confused with the historic entrance, and it does not change the character of the building. Thus, it meets the Standards.



This building was constructed with a single pedestrian entrance in 1886, and a garage door was added later (left). When the building was rehabilitated for office use, an existing window was removed from the end bay and replaced with a new glazed entryway (center and right).

Application 2 (*Compatible treatment*)**:** A larger, free-standing, three-story warehouse building constructed in 1922, with a 1940s addition, was to be rehabilitated into commercial and retail spaces on the first floor with residential apartments on the upper floors. The building featured a loading dock on one side and three utilitarian, non-significant entrances on various elevations. As part of the rehabilitation a new entrance was proposed to be added on a side of the building that never had an entrance. An entrance on this elevation would improve visibility and access to the new shops and businesses, and it would also help increase security for the upstairs apartments since existing entrances could be restricted for residential tenant use. Accordingly, a new glass and steel entryway which reflects the industrial character of the building and its historic metal windows was designed for this side of the building. The new entrance is compatible with the character of the historic building. It is unobtrusive and it does not noticeably impact or change the appearance of this elevation or of the warehouse building as a whole.

This historic warehouse had entrances on three elevations of the building prior to rehabilitation.

A compatible, new entrance was added to the fourth side of the building during rehabilitation.

Anne Grimmer, Technical Preservation Services, National Park Service

National Park Service
U.S. Department of the Interior

Technical Preservation Services
National Center for Cultural Resources

ITS Number 23

Interpreting The Secretary of the Interior's Standards for Rehabilitation

Subject: Selecting New Windows to Replace Non-Historic Windows

Applicable Standards:

2. Retention of Historic Character
6. Repair/Replacement of Deteriorated or Missing Features Based on Evidence

Issue: The windows of a historic building are central to defining its character. Identifying and preserving the functional and decorative components of a window is often crucial to maintaining the character of a property. The style of window is particularly essential to the character of the primary facade. Different shapes, frames, muntin profiles, numbers of panes and their configuration make a window distinctive. Where historic windows exist they should be retained and repaired. When no reparable historic fabric remains and functional replacement windows are in place, a number of options exist. Existing windows may be retained, despite their lack of historic character. If replacement is chosen, the new windows must be based on existing fabric, on historic documentary or pictorial evidence or, they must be compatible with the historic character of the building. As explicitly stated in **Standard 6**, when a historic feature is missing or is too deteriorated to repair, "the new feature shall match the old in design, color, texture and other visual qualities and, where possible, materials."

The second story of the primary facade showing non-historic fixed sash before rehabilitation.

After rehabilitation, the new windows have a three-part configuration that is inappropriate to the historic style of the building.

Application 1 *(Incompatible replacement):* An 1880s Italianate commercial building was rehabilitated for use as an office building. The main elevation of this small building is dominated by the fenestration on the second floor. Prior to rehabilitation, the four large, second -story windows contained incompatible replacement, three-part fixed sash. The owner had the option to retain these windows or replace them with compatible sash. While historic photos did not clearly illustrate the configuration of the original windows, double-hung sash with segmental arched tops or double-hung sash with a small transom would have been historically appropriate. Instead, the owner replaced the windows with three-paned pivot windows, similar to the windows in place before rehabilitation with heavy frames and meeting rails, that were not compatible with the historic character of the building. These replacement windows did not meet the **Secretary of the Interior's Standards**.

Before and after rehabilitation, one-over-one sash helped retain this commercial building's historic character.

Application 2 *(Incompatible treatment, later modified to meet the Standards)*: A 1903 limestone Romanesque revival building was rehabilitated for use as apartments. Extant frames and multi-paned transoms were in place on the primary facade, but all sash had been replaced with one-over-one double-hung sash. Though the windows were not original, the one-over-one configuration was compatible with the building. A secondary facade revealed some remaining two-over-two double-hung sash. Owners had the option to retain the windows or replace them with historically appropriate sash. They installed two-over-two wooden sash on the primary facade based on the secondary elevation window configuration. Since there was no evidence that the front windows had ever been two-over-two, this treatment failed to meet the **Secretary of the Interior's Standards**. In order to meet the Standards, the owner subsequently changed the windows on the primary facade to one-over-one sash. The resulting fenestration is compatible with the historic character of the building.

Application 3 *(Compatible replacement based on physical evidence)*: A 1920, seven-story commercial warehouse located on a corner was rehabilitated for use as a hotel. Both street facades were heavily fenestrated. At the time of rehabilitation, the historic windows had been replaced with three-part, horizontal sliding windows, inappropriate to the building. One original window, a multi-pane steel industrial sash, was still extant. Based on this, the owner was able to reproduce the historic windows using fixed, steel, multi-paned sash, thereby reintroducing these distinctive features and reestablishing the historic character of the building.

Prior to rehabilitation the building had inappropriate modern windows.

Installing multi-pane steel sash helped restore the building's historic appearance.

Application 4 *(Compatible replacement based on historic documentation)*: A large brick apartment complex, built in 1927, was rehabilitated for its original use. The windows in the buildings had been replaced in the 1960s with one-over-one steel sash, out of character with the buildings. Because these windows were in place when the owners purchased the apartment complex they could retain the existing windows, use historic photographs to recreate the original windows, or install windows appropriate to the building. The owners chose to use photographic evidence to replicate the historic, multi-paned configuration of the apartment windows using vinyl-clad wood windows. The decision satisfied Standard 6 which requires that "replacement of missing features shall be substantiated by documentary, physical, or pictorial evidence."

Prior to rehabilitation showing one-over-one sash. Similar sash is concealed by plywood covers on the first and second floors.

Historic pictorial evidence shows the original multi-pane configuration of the windows.

After rehabilitation the new multi-paned sash are appropriate to the historic style and character of the apartment buildings.

Claire Kelly, Technical Preservation Services, National Park Service

National Park Service
U.S. Department of the Interior

Technical Preservation Services
National Center for Cultural Resources

ITS
NUMBER 24

Interpreting The Secretary of the Interior's Standards for Rehabilitation

Subject: Installing New Systems in Historic Corridors

Applicable Standards: 2. Retention of Historic Character

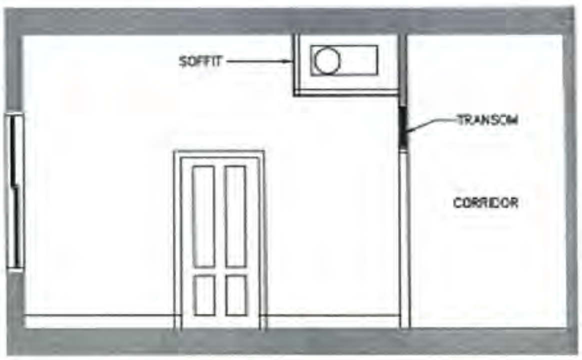
Issue: Updating or introducing new systems in a historic building requires careful planning and some resourcefulness in order to avoid altering important interior spaces. Corridors are considered public areas within a building's interior, and as such, are very important in conveying the qualities that give a particular historic building its individual character. Whether highly ornamented or simply detailed, unsympathetic installations of new mechanical, plumbing, or electrical systems negatively impact the character of these spaces.

Application 1 (*Incompatible treatment*): The tangle of pipes along the corridor of this 1926 bank building, which was rehabilitated into apartments, creates a sharp visual distraction. Given the straightforward detailing of this corridor, installing a new ceiling to hide the overhead pipes would have been the preferred treatment, even if it meant lowering the original height of the ceiling. Where there is insufficient room in the corridor space to drop a new ceiling without significantly altering the volume of the space or interfering with existing features such as door transoms, trim, or other features, other solutions are required.

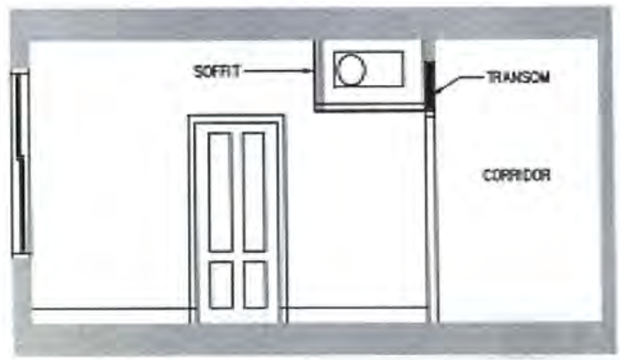
Left: The exposed pipes give the corridor, although quite plain, an unfinished appearance which is not compatible with the historic character of this 1926 bank building.

Right: These ducts should have been installed in a secondary space since lowering the corridor ceiling would have concealed the transoms.

Application 2 (*Incompatible treatment and suggested remedial treatment*): A new dropped ceiling would have not been the appropriate solution for hiding the large ducts in the corridors of this 1886 commercial building. Dropping the ceiling height low enough to conceal the ducts above would have required the ceiling to drop below the door transoms. In this case, if the ducting could not be reduced in size, a possible treatment could entail routing the ductwork parallel to the corridor in less significant interior spaces. The first drawing illustrates a scheme in which the ductwork is encased by a soffit above the existing transom. When the ceiling height does not allow sufficient room above the transom, other compromises might be required, such as the one depicted in the second drawing. In this case, the new mechanical equipment was also installed parallel to the corridor, but the lack of clearance between the top of the door transom and the existing overhead structure requires that the new soffit cover the transom behind the corridor wall. Although obscuring existing historic features is generally not recommended, when such alterations cannot be avoided, it is preferable to limit these treatments to less significant or secondary service areas such as closets, bathrooms, or kitchens inside new offices or apartments to avoid altering more significant public spaces such as corridors.



Routing HVAC and other systems along spaces on either side of corridors is a more sensitive approach that often works well in rehabilitations of historic office buildings.



Although obscured on one side, the transom can be retained on the more visible corridor side.

Application 3 (*Compatible treatment*): Another possible approach is illustrated in the conversion of this 1925 office building into a hotel. The design of this new floating ceiling allows covering new HVAC systems without obscuring or damaging existing features along the corridor walls. Holding the ceiling back away from the walls allows the existing trim and other details to be retained and kept visible.

A partial ceiling can cover new systems in a corridor without obscuring existing historic features.

National Park Service
U.S. Department of the Interior

Technical Preservation Services

ITS NUMBER 39

Interpreting The Secretary of the Interior's Standards for Rehabilitation

Subject: Changes to Historic Site

Applicable Standards:

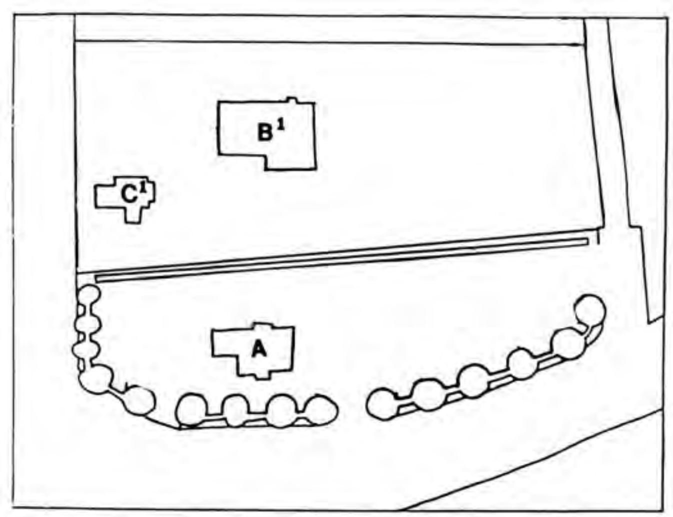
1. Compatible Use
2. Retention of Historic Character

Issue: The site of a historic building is usually an essential feature in defining its historic character. Accordingly, the Secretary of the Interior's Standards for Rehabilitation require that a rehabilitation involve minimal change to the defining characteristics of a building and its site and environment. The Guidelines for Rehabilitating Historic Buildings stress that site changes such as locating new parking lots adjacent to historic buildings and other landscape changes can impair the defining characteristics of a property. The Guidelines also note that moving buildings onto the site of a historic building can create a false historical appearance. Such major changes can result in an overall rehabilitation that fails to meet the Secretary's Standards even when work on the historic building itself is not in question.

Application *(Incompatible treatment)*: A large, finely detailed Neo-Classical mansion, built in 1900 and representing the wealth of prosperous mill owners, was listed individually in the National Register of Historic Places. Although the large lot on which it stood was overgrown prior to the start of the rehabilitation, the character of the house as an imposing suburban residence on a spacious lot had survived.

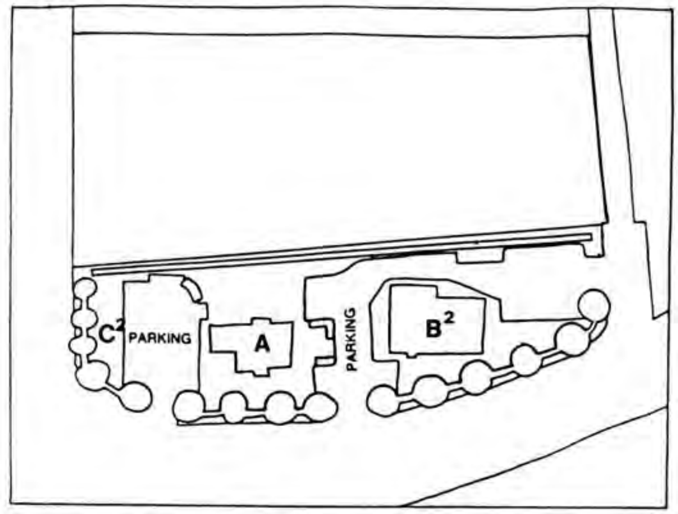
To convert the site into an office condominium complex, the owner moved a house from an adjacent lot with a similar setback and orientation, and set it in the front yard of the National Register-listed property. The moved building was turned to face the 1900 building, and a new parking lot was placed between the two structures. A smaller building from the adjacent property was also moved and sited at the rear of the 1900 building.

Although both of the moved buildings were saved from demolition, their relocation in the manner shown here has greatly altered the historic setting of the listed build-



Top: Although the site was overgrown, the character of this 1900 house as a large suburban residence had survived.

Bottom: Site plan before rehablitation. The 1900 house (A) stood alone on its lot. On the adjoining property stood another large house (B1) and a dependent cottage (C1) ing. The central parking lot, has become a dominant new feature of the site. The historic building now appears as but one element in a new composition bearing little relationship to the historic appearance of the property. As a result, the historic character of the overall property has been greatly diminished, and the project does not meet the Standards.



Site plan after rehabilitation of buildings. The neighboring house was moved and turned around (B2) to face the 1900 building (A) across a new paved parking lot. The cottage associated with the moved house was relocated (C2) behind the 1900 building.

Turned 180 degrees, the moved building (B2) faces the historic one from a distance of 60 feet.

The new parking lot completes the drastic alteration of the setting. The second relocated structure (C2) can be seen through the porte-cochere at left.

Michael J. Auer, Technical Preservation Services, National Park Service

National Park Service
U.S. Department of the Interior

Technical Preservation Services

ITS Number 41

Interpreting The Secretary of the Interior's Standards for Rehabilitation

Subject: Incompatible Alterations to the Setting and Environment of a Historic Property

Applicable Standards:

2. Retention of Historic Character
9. Compatible New Additions/Alterations
10. Reversibility of New Additions

Issue: Setting is essential to a historic property's significance. Drastic changes to the surrounding grading, landscape features, or incompatible new construction on the site, diminish a historic property's ability to convey its historic significance. Therefore, such alterations do not conform to the Secretary of the Interior's Standards for Rehabilitation.

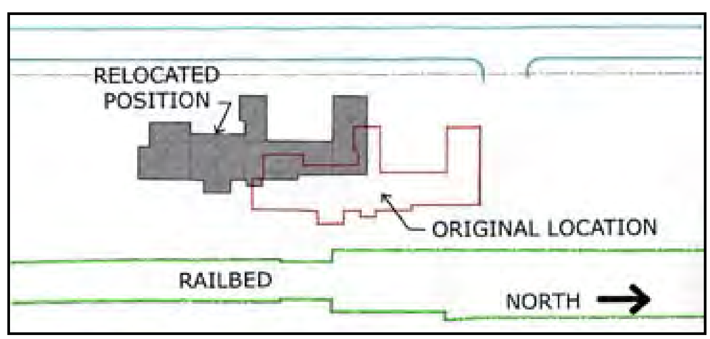
Application *(Incompatible treatment)***:** The rehabilitation of this 1935 Spanish Colonial Revival-style railroad depot involved temporarily removing the structure from the site in order to prepare the site for redevelopment, and then returning the building to the site in a slightly different location. The depot would be relocated about 85 feet south and 21 feet west of its original location, but otherwise it would maintain the same orientation to the street and to the railroad tracks. Relocation of the depot, which required approval from the National Register of Historic Places, did not have a significant impact on the historic setting of the building and appeared to meet the Standards.

However, as more details of the project were provided, it became apparent that the proposed site development would have a negative impact on the historic character of the property. The proposed relocation of the building was not a matter of simply moving the building some distance south and west from its original location. The rehabilitation project also involved excavating the site in order to build an underground parking structure and placing the historic building on top of it. In addition, extensive new landscaping features and new construction several stories taller than the historic depot were also proposed on the site.

Passenger waiting area before rehabilitation.

Primary street elevation before rehabilitaiton.

The extensive reconfiguration of the site significantly altered the historic setting of the depot. Originally, the building sat



Site plan showing the relocation of the depot on the site.

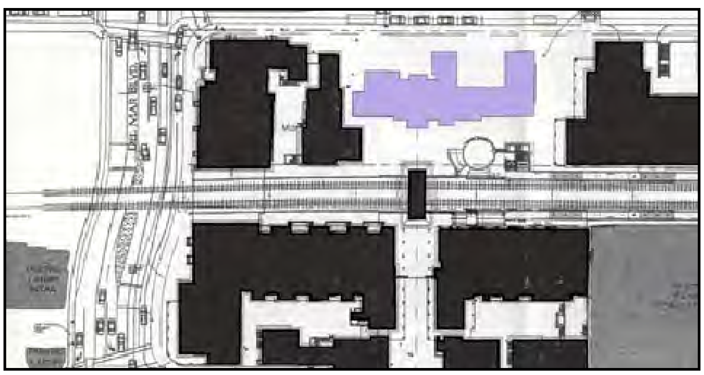
SETTING

Exit leading to train platform before rehabilitation.

Exit with new steps to former train platform after rehabilitation.

on a slab poured at grade. Historically, minimal changes in elevation between the surrounding grade and the interior floor permitted passengers to pass smoothly from the sidewalk through the building and on to the railroad platform. This gradual, almost imperceptible, change in grade was a significant aspect of the building's design.

When the building was relocated on the site, it was placed on a raised foundation. Because the moved building sits higher than the surrounding grade, steps have been added at the depot's exit onto the former train platform. The new difference in grade also required adding railings between the columns of the formerly open arcaded area. New planters, fountains, diverse paving patterns, and other new features also created an elaborate landscape that is not compatible with the simple and functional setting of the historic depot.



Site plan showing new construction as dark shaded areas.

New landscape plan showing new paving patterns and raised planters (shown in green).

View from northwest corner of depot after rehabilitation showing the surrounding new construction.

Furthermore, the formerly expansive, almost pastoral, landscape that surrounded the depot consisting largely of grass-covered areas dotted with small shrubs, olive trees, and clusters of palm trees has been drastically reduced by the new construction. In addition, the height, massing, scale, and proximity of the new construction dwarf the historic depot building. The cumulative effect of all these changes negatively impacts the historic character of the former depot. Accordingly, the project does not meet the Standards.

Antonio Aguilar, Technical Preservation Services, National Park Service

National Park Service
U.S. Department of the Interior
Technical Preservation Services

ITS Number 51

Interpreting The Secretary of the Interior's Standards for Rehabilitation

Subject: **Installing New Systems in Historic Buildings**

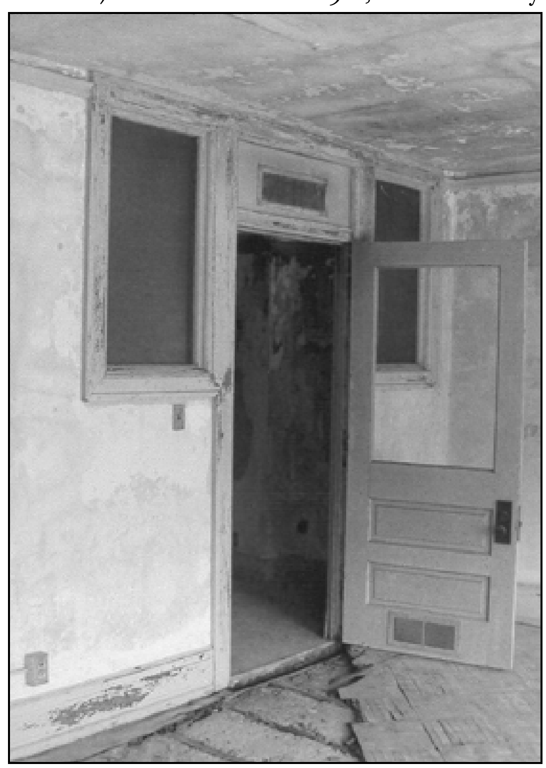
Applicable Standards:
2. Retention of Historic Character
5. Preservation of Distinctive Features, Finishes, and Craftsmanship
6. Repair/Replacement of Missing or Deteriorated Features

Above: The dropped ceiling has been partially removed, revealing the old ductwork running through the center of the hallway and branching into each office. The ceiling had been lowered from its historic height of 10 feet to just 7 feet.

Issue: In rehabilitating historic buildings, HVAC systems often need to be updated. In most old apartment, office, and retail buildings, such mechanical systems historically were installed so that either the distribution network was concealed or designed to appear built in. Later retrofits of forced air-handling systems typically continued in this tradition, concealing new ducts within existing walls or new chases, or placing new ductwork below existing ceilings with a dropped ceiling installed to conceal it.

A dropped ceiling can change the appearance of a historic space. It might obscure a decorative ceiling or cornice, change the proportions of a room, cover door transoms, and/or cut across windows. Such changes can alter a building's historic character and do not meet the Secretary of the Interior's Standards for Rehabilitation.

Application (*Compatible treatment*): Constructed in 1918, this five-story bank building retained many of its historic features and materials despite years of abandonment and water damage. Historically, the ground floor lobby contained the customer service area, while the top four floors were offices. By the early 1970s, the original steam heating system which utilized room radiators was replaced with a central forced-air HVAC system that relied upon a network of ceiling distribution ducts. As a cost-cutting measure, the main distribution ducts were run along the corridors, below the existing ceiling, and branched off into the individual offices. Rather then cutting through the walls to add the necessary room vents, the vents were installed through the transoms above the office doors. The very low suspended ceiling that was added to conceal the ductwork also obscured the transoms and cut across the windows in the corridors. This dropped ceiling dramatically and negatively impacted the historic appearance of the corridors.



Above: Prior to rehabilitation the offices had air supplied through vents installed in the original door transoms.

In the current rehabilitation, the design team took an alternative and very sensitive approach to provide climate control in the office spaces. The new HVAC ductwork was routed along the building's perimeter walls at floor level and concealed in a new built-in feature that contained not only the air supply and return, but also included new electrical service and voice and data lines. The design for the new interior built-in feature drew on the appearance of the old window seat-styled radiator covers that were common in buildings of the era and even incorporated the original, historic baseboards in its design. This design provided for an unobtrusive and aesthetically pleasing appearance for the new built-in feature.

This treatment enabled the offices to retain their historic ceiling height. And, by removing the existing ductwork from the corridors, it was possible to significantly raise the corridor ceiling height, even though the corridor ceilings could not be raised to their full original height due to the sprinkler piping and lay-in light fixtures above. Removing the ductwork and raising the ceiling in the corridors also uncovered the door transoms and fully exposed the hallway windows. This HVAC installation not only recaptured the historic character of the corridors but also retained the character of the office spaces and, therefore, meets the Standards for Rehabilitation.

Top left: *The rehabilitation raised the ceiling above the door transoms. This not only uncovered the historic, character-defining transoms, but also allows more natural light into the corridors.*

Top right: *The offices now have heating/cooling vents located in a window seat-like feature which also incorporates the original baseboard. Note the integrated electrical outlets and voice and data jacks on the front of this built-in feature.*

Bottom: *In this corner office the multiple vents are installed in a single, wrap-around feature that provides a continuity of design and allows for even air distribution.*

Dan Bruechert, Technical Preservation Services, National Park Service

National Park Service
U.S. Department of the Interior
Technical Preservation Services

ITS Number 53

Interpreting
The Secretary of the Interior's Standards for Rehabilitation

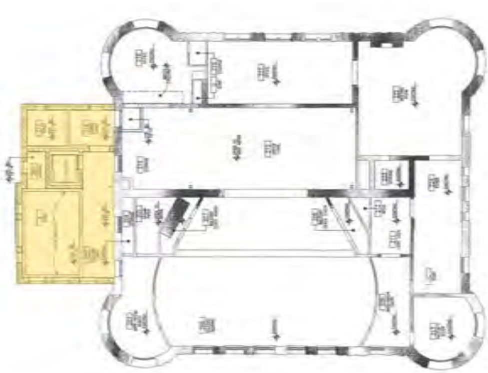
Subject: Designing New Additions to Provide Accessibility

Applicable Standards:
2. Retention of Historic Character
5. Preservation of Distinctive Features, Finishes, and Craftsmanship
9. Compatible New Additions/Alterations
10. Reversibility of New Additions

Issue: In the course of a rehabilitation project, it may be necessary to make a building accessible and to provide additional means of egress. Historic buildings are sometimes inaccessible to those with special needs and were often built with fewer exits than required by modern codes. In most cases, these requirements can be met within the historic building. If they cannot, or if inserting a ramp, stair, or elevator would destroy important historic interior fabric, then an addition may be considered for the exterior of the building. New additions must be compatible with the historic building to meet the Secretary of the Interior's Standards for Rehabilitation.

The new addition should be placed on a secondary façade and be minimally visible from the public right of way. The Secretary of the Interior's Guidelines for Rehabilitating Historic Buildings recommend locating new additions so that they do not obscure, damage, or destroy character-defining features of a historic building. Further guidance on new additions advises that the design should be compatible with the massing, size, scale, and architectural features of the historic building. The addition should remain secondary to the historic building and should not detract from it. It must be recognizable as a new addition and must not attempt to copy the historic building. Additions should be compatible, yet differentiated from historic buildings.

Application 1 (*Compatible treatment*): This Richardsonian Romanesque-style theater, built in 1890, underwent rehabilitation for continued use as a theater. Due to the highly ornate interior, it was not possible to accommodate the code-required elevator and stairway within the building. Thus, the rehabilitation included an addition on the rear to house a stair tower and elevator for accessibility. The addition was faced in the same ashlar-cut sandstone as the historic building. Several design techniques were employed to differentiate the addition from the historic building, including window and door openings that are simplified versions of those on the historic building. On the interior of the new addition, the former exterior masonry wall remains exposed and original window and door openings have been retained. Because the building is situated on a corner with two street elevations, the rear addition is visible, yet compatible with the historic theater. This rear addition meets the Standards while successfully meeting accessibility requirements.



Top: *Main façade of historic theater after rehabilitation.*
Middle: *Historic theater building with new rear accessible entrance.*
Bottom: *Plan of theater building showing new addition highlighted in yellow.*

NEW ADDITIONS

Application 2 (*Compatible treatment*): Built in 1922, this school building was rehabilitated for office use. Due to interior level changes and the absence of an elevator, an accessible entry was required. A small grade-level entrance was added to the rear of the building. The one-story addition relates to the historic building through its use of brick and limestone detailing. The addition is clearly differentiated through its use of modern window and door openings. By placing the addition on the rear, the symmetrical main façade remains unchanged. The new entrance leads to a newly configured lobby with access to a new elevator. The new rear addition is compatible with the historic building and meets the Standards.

Top: *Rear façade of school prior to rehabilitation.*
Middle: *Rear façade after rehabilitation. New accessible entrance is located on the far right.*
Bottom: *New accessible entrance. The same brick and limestone were used for the addition, while contemporary-styled windows and doors help to differentiate the new construction.*

Liz Petrella, Technical Preservation Services, National Park Service

National Park Service
U.S. Department of the Interior
Technical Preservation Services

ITS
NUMBER 56

Interpreting
The Secretary of the Interior's Standards for Rehabilitation

Subject: **Alterations without Historical Basis**

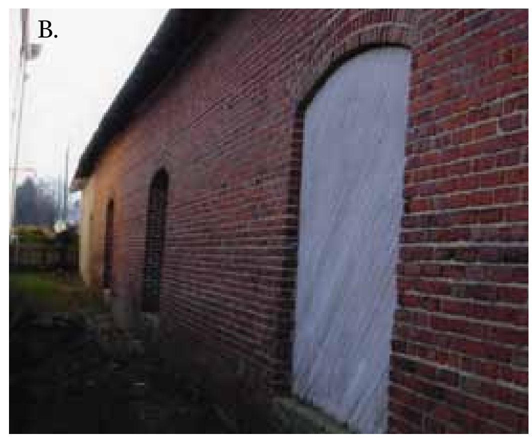
Applicable Standards:
2. Retention of Historic Character
3. Recognition of Historic Period
6. Repair/Replacement of Deteriorated or Missing Features Based on Historic Evidence
9. Compatible New Additions/Alterations

Issue: Alterations to a historic building made during rehabilitation for a new or a continuing use must not alter the historic character of the building. Distinctive historic features in one location should not be replicated in another portion of the building without documentary or physical evidence. Conjectural changes create a false sense of historical development and are contrary to the *Secretary of the Interior's Standards for Rehabilitation*. When there is no record of the historic appearance of a building, the rehabilitation should take into consideration its historic use and remaining evidence to design a compatible new or replacement feature.

Application 1 (*Incompatible treatment*): This early-twentieth century tobacco and cotton warehouse is sited on the main commercial street in a historic district. Prior to rehabilitation the front of the building featured one-over-one windows, two pedestrian doors and an incompatible recessed storefront that had been added in the mid-twentieth century. Original large, arched openings on a side elevation that had provided access to the warehouse area were still extant. When the warehouse was rehabilitated for retail use, one of the objectives was to create large display windows on the primary elevation. The owner chose to base the design of these new shop windows on the historic arched openings located on the side of the building. The front was further changed by the addition of a heavy new cornice to the stepped parapet. These conjectural changes–the new arched openings and the large cornice–diminish the historic utilitarian character of the property and convey a false sense of historicism. This project does not meet the Standards.

A.

B.



C.

Clockwise from top left:

A. *The primary elevation of the ground floor of this historic warehouse, which had been altered prior to rehabilitation, featured double-hung windows, two pedestrian doors and a recessed storefront.*

B. *Historically, the warehouse space was accessed from the side via large arched loading bays.*

C. *During rehabilitation, the original arched masonry openings on the side of the building were replicated on the front and a heavy cornice was also added to the parapet. These treatments resulted in a false sense of the historic appearance of the building.*

A.

B.

Application 2 (*Incompatible treatment*): This 1866, three-story, commercial building was first altered in 1914 when the façade was redesigned in the Neo-classical style. During the 1960s, the 1914 fenestration on the second and third floors was replaced with incompatible windows separated by an aluminum panel. As there was no historic documentation to guide the recent rehabilitation of the building, the decision was made to install a two-story, curtain-wall glazing system rather than to retain the existing separation between the second and the third floors. The installation of this two-story curtain wall went hand-in-hand with the removal of a portion of the third floor to create a two-story atrium. Taken together, these changes give the building an appearance at odds with its historic character on both the interior and the exterior and, thus, the rehabilitation fails to meet the Standards.

C.

Clockwise from top left:

A. *The historic windows on the second and third floors of this historic building had already been replaced in the 1960s with an inappropriate glass and metal panel system.*

B. *During rehabilitation, an incompatible curtain-wall window system was installed creating a two-story appearance rather than retaining the three-story historic appearance of the building.*

C. *The removal of a portion of the third floor gives that space the appearance of a mezzanine overlooking a newly created two-story space behind the new curtain wall.*

Practice Points NUMBER 06

Architectural Finishes: Research and Analysis

DOROTHY S. KROTZER

Introduction

The research and analysis of architectural paints — intended to understand their color, appearance, and composition — has been underway in the fields of architectural and fine-arts conservation for nearly a century. A. P. Laurie and R. J. Gettens were experimenting with techniques for cross-section analysis in the fine arts as early as the first quarter of the twentieth century.[1] In the 1960s renowned preservation figures such as Penelope Hartshorne Batcheler of the National Park Service and Morgan Phillips of the Society for the Preservation of New England Antiquities (now Historic New England) extended the scope of these earlier methods to historic buildings, and modern architectural-finishes research was born.[2]

The discipline of architectural-finishes research has come a long way since the early twentieth century. It is now widely regarded as an essential part of the documentation process for historic buildings. However, the ways in which finishes research is performed can be quite varied. There is no single approach or methodology for how such a study should be conducted or for what one should expect when commissioning one. The following article is intended to provide preservation practitioners, as well as their clients, with an understanding of what comprehensive finishes research should entail and what sort of product one should expect when hiring a paint conservator. It is by no means meant to be an exhaustive discussion of all paint-analysis techniques but instead is a brief overview of common procedures followed by conservators specializing in this area.

A quick word about terminology: The term *architectural finish* can include a wide range of materials, including opaque paints, varnishes or lacquers, wallpaper, and even decorative plaster treatments. For the sake of this article, however, the term will be used mainly in reference to opaque paint films. *Pigment* refers to the finely ground material dispersed throughout a paint film that contributes primarily color and opacity to a paint (e.g., yellow ochre or white lead).[3] *Binding medium* refers to the portion of paint that forms the film and binds pigment particles to each other and to the surface to which the paint is applied (e.g., linseed oil or animal glue).[4]

Fig. 1.
Historic photographs can yield a wealth of information to guide finishes research. For instance, this circa 1900 photograph taken of the occupants of The Oaks House in Jackson, Mississippi, shows that at the turn of the twentieth century the interior doors were grained, the door surrounds were painted a pale color, and the walls were covered with wallpaper. Photograph courtesy of The Oaks House Museum.

Objectives of Finishes Research

Before commissioning architectural-finishes research, one must first identify the reasons for doing so. Finishes research can reveal a wealth of information, so it is best to have a clear idea of the goals for the study from the onset of such a project. This objective is most effectively achieved through collaboration amongst the project stakeholders — the owner, architect, conservator, and painting contractor. Working together, the project team can establish a guide for the scope of work, the quantity of samples taken and their locations, the type of analysis that will be necessary in order to achieve the goals, and, lastly, the overall cost.

Typically, finishes research is performed in order to document the color scheme associated with a particular period of significance for a historic building (most often its original paint scheme). This documentation is achieved through a combination of historical research, in-situ investigation, and laboratory analysis. However, finishes research can serve many other purposes. Analysis of a paint sample's layering sequence can reveal valuable information about a building's construction chronology by comparing the sequences of samples removed from different portions of the building relative to each other. Documentation of paint-layer se-

Fig. 2. *Removal of overpaint can often reveal very different previous finishes for a space. At the New Haven County Court House in New Haven, Connecticut, an immense Beaux-Arts–style building dating to 1909, a rectangular "window" exposed the original six-color, stencil-painted border and banded center field beneath approximately three layers of overpaint. Exposure work performed by and photograph courtesy of Melissa McGrew, Building Conservation Associates, Inc.*

quences can also provide an essential guide for paint-removal projects in which an earlier finish is being exposed. Lastly, understanding the composition of a paint finish, primarily its binding medium and pigments, is vital to the process of designing an appropriate cleaning or conservation program and can also have implications for replication of the finish.

Whatever the reason may be for performing finishes research and analysis, some degree of interpretation of the findings should be expected. Oftentimes the research will provide the client simply with the facts collected during the study, which will require some amount of subjective interpretation in order to relate the findings to the building's current context. For instance, a finishes analysis may reveal that the exterior woodwork on a building was originally painted to match the color of its stone trim, which has weathered to a darker color than when originally installed. A subjective decision may have to be made by the project team as to which color is the more appropriate choice to repaint the woodwork — the original color, which would no longer match the existing stone, or a darker color to match the weathered appearance of the stone. The conservator should provide the greatest amount of objective information possible to the client so that the inevitable subjective interpretation of results can be well founded.

What can be gained from performing an architectural-finishes analysis?

- documentation of a color scheme associated with a particular significant historic period for a building
- construction chronology of a building
- the original aesthetic intent of the building's designer or occupant
- new information on traditional painting materials and techniques
- information to guide paint-removal projects and on-site exposures of earlier finishes
- information for cleaning or conserving a specific finish

Historical Research

One of the most essential components of architectural-finishes research, which is undertaken prior to any physical investigations, is the gathering of historic documentation, including written accounts, historic images, and building specifications. These primary documents can yield clues about earlier finishes that have long since been covered, and they can guide the conservator in site investigation and sampling. Historic images often contain information about color schemes and the location of decorative painting. Original building specifications can contain information on the type and even the color of the original paint. They also offer a glimpse into the original design intent of the architect, information that can be useful when interpreting the results of a finishes analysis and making recommendations for a restoration paint scheme (Fig. 1).

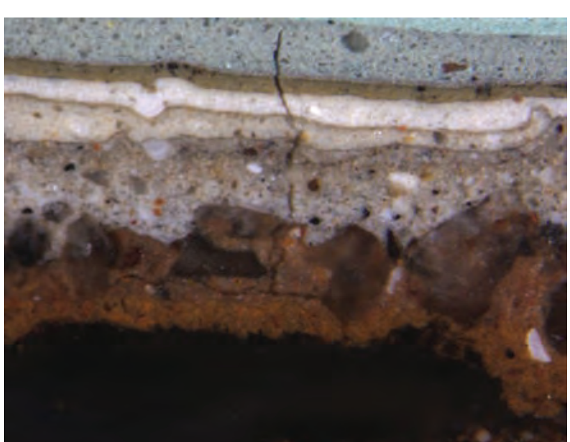


Fig. 3. *This photomicrograph of a sample removed from Towell Library at the College of Charleston in South Carolina shows that a sand paint intended to imitate brownstone was the first finish on the exterior woodwork. The grains of sand can be seen embedded in the top layer of brown paint at the bottom of the photograph. Subsequent paint layers include grays, creams, and a pale brown (110x, visible light). Photograph by author.*

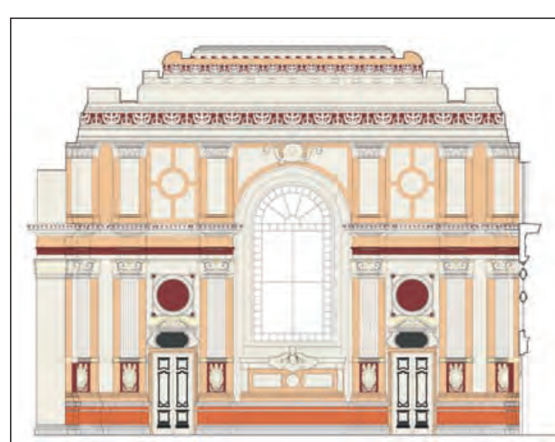
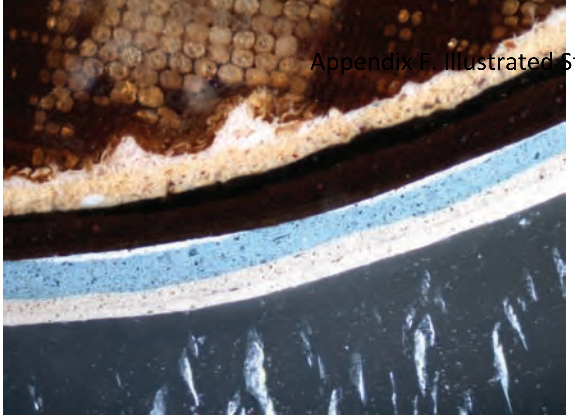


Fig. 4. *Sometimes it is necessary to prepare a visual representation of documented paint colors when the finishes scheme is particularly complex. In this case, computer software was used to indicate historic paint colors identified through paint analysis on an interior elevation of Memorial Hall in Philadelphia to illustrate the building's appearance during the 1902 period of interpretation. Image courtesy of Please Touch Museum/Kise Straw & Kolodner.*



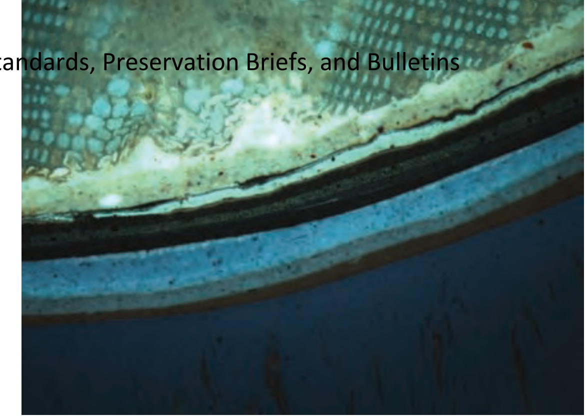


Fig. 5.
This photomicrograph (left) shows a paint cross section removed from the interior woodwork of the Coweta County Courthouse in Newnan, Georgia, in visible light. Courtesy of the author.

Fig. 6.
This photomicrograph (right) shows the same sample viewed through a "violet" filter cube EF4 V-2A Ex400/40 Dm430 Bar 450. The woodwork's original grained finish (composed of a ground layer, a figuring layer, and a layer of varnish) is more legible when viewed in ultraviolet light. The varnish layer in particular becomes easier to identify, with its characteristic blue-green glow. Courtesy of the author.

In-Situ Investigation

Once the historical research has been performed and a general understanding of the project's context has been established, the field investigation can begin. In-situ investigation of architectural finishes involves using a combination of techniques to reveal early paint histories and remove representative samples for further analysis. Revealing layers of paint on site typically includes removal of overpaint through mechanical scraping or solvent application, followed by visual assessment of the paint history using a field microscope. This technique provides an idea of the approximate number of layers present in a given area and can help to identify protected areas of preserved paint for sampling purposes. It is also useful in the identification of any decorative painting, which can sometimes be overlooked if performing only microscopic examination in the laboratory. However, using this type of "scratch and match" field investigation alone is typically inadequate for gaining a full understanding of all finish layers present. Removing samples and taking them back to the conservation laboratory so that they can be examined with a high-magnification microscope is the best way to confirm and supplement in-situ findings.

Field investigation, including removal of overpaint to expose earlier decorative painting schemes, is an important part of many finishes-research projects. While some decorative painting can be identified when using cross-section analysis, a full understanding of its original appearance cannot be gained unless it is exposed in situ. For instance, the decorative treatment of wood graining can usually be identified in cross-section by its characteristic three-layer structure: the ground, the grain or "figuring" layer, and the varnish layer. However, to gain insight into the artist's application technique and the actual appearance, the layers of paint covering this finish would need to be carefully removed using a combination of mechanical scraping and solvent application. This process requires testing and an understanding of the composition of the more recent paint layers to ensure the use of a solvent that will dissolve later paint layers without affecting the original finish (Fig. 2).

The other primary objective of site investigation is the removal of paint samples for laboratory analysis. Removing appropriate samples can be the most challenging part of a paint study. Care must be taken that the samples are complete and that they are representative of the finishes being studied. There is a huge range in sample size, from a few millimeters to a couple of inches, depending on the site and the person taking the samples. When selecting a sample location, it is especially important to look for protected areas of paint build-up or hard-to-reach places, in order to avoid taking samples from locations that may have been previously stripped or were heavily weathered. It is always preferable to have the conservator who will be performing the analysis also remove the samples. Although sampling techniques vary widely among paint conservators, the goal remains consistent: to remove enough intact, representative samples of adequate size to be able to perform physical manipulation, microscopic examination, instrumental analysis, and color matching. Removal of the finish layers, as well as a portion of the substrate, is also essential to ensure that all layers are present in any given sample and that the nature of the substrate is understood, as well.

Oftentimes substrates, such as some forms of decorative plaster or hardwoods such as mahogany, were meant to be exposed or clear-coated instead of painted. To exclude the substrate in these instances would be to miss the original finish application altogether.

What should an architectural-finishes analysis include?

- a clear objective
- historical research
- an understanding of the context of both the building and the restoration project
- in-situ investigation
- laboratory analysis, including cross-section analysis supplemented by analytical and instrumental techniques
- a written report thoroughly documenting the analysis methodology and findings

Microscopic Examination of Paint Samples

Laboratory analysis begins once the research and field investigation have been completed, although additional trips to the site may be required. Paint samples are initially examined under a stereomicroscope (10x to 80x magnification) to gain a general understanding of the number and character of layers present in each sample. These raw samples can be manipulated and viewed at various angles to identify the sequence and color of layers, including dirt layers, points of fracture, and decorative finishes, such as gold leaf, which can be missed when viewed in cross section. This process

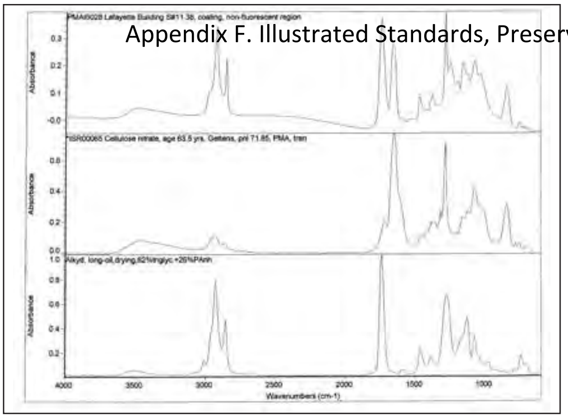


Fig. 7.
Fourier transform infrared spectroscopy (FTIR) can be used to characterize binding media in architectural finishes. This image illustrates typical spectra generated through this analytical technique. The top spectrum represents the sample coating, in this case a clear finish from wood paneling of a conference room in the circa 1940 Lafayette Building in Washington, D.C. The middle and lower spectra are reference spectra that were generated as possible matches to the sample, indicating that the coating was a nitrocellulose lacquer modified with an alkyd resin. Image courtesy of the Philadelphia Museum of Art Analytical Laboratory.

also allows the most-representative samples to be selected and processed for additional investigation, including cross-section analysis. Samples selected for cross-section analysis are cast in a permanent mounting medium, cut or ground to expose the edge of the paint sample, then polished to produce highly reflective cross sections of paint and substrate; the layer structure can then be easily deciphered. The polished cross sections are viewed using a high-magnification microscope, typically a stereomicroscope or compound microscope, with a coaxial stage and a wide range of magnification (25x to 250x) (Fig. 3).[5]

Cross-section analysis provides additional confirmation of the layering sequence preliminarily observed on site, as well as a more detailed examination of individual paint layers. Layering sequences can be recorded through photography or written notes, allowing for comparison of samples to establish general layering sequences and differences in individual stratigraphies. Special note can also be made during this examination of any distinguishing characteristics, such as degree of paint-film translucency/opacity, pigment-particle size and color, and paint-film thicknesses. Digital photomicrography has made the task of recording the layering sequences of samples much easier and more effective, because it permits direct visual comparison, sample to sample and layer to layer.

Once the layering structure of each sample has been recorded through these microscopy techniques, the analysis shifts focus to a more thorough understanding of the specific finishes identified as significant for that particular project. The extent of this additional research is dependent on the goals of the specific project or client. One project may require thorough documentation of all constituents in a given paint layer, while another could be interested simply in the color of a particular paint layer. When this additional research is requested, it typically involves color matching or analysis of paint composition.

Color Matching

The issue of color matching of historic paints is one of the most debated topics in the field of architectural paint conservation today. The dispute stems mainly from the fact that linseed oil–based paints (especially pale-colored paints) darken and yellow over time if not exposed to sunlight, including even oil-based finishes that have been covered with subsequent paint layers.[6] In addition, some pigments, such as Prussian blue and chrome yellow, change over time, greatly impacting the present and original appearance of a paint layer. However, the only way to determine if a paint layer contains a binder or pigment that may have changed over time is through identification of these components (discussed below).

Currently there is no standardized system for matching historic paint colors. However, conservators have worked out a methodology over the past few decades that attempts to make the color-matching process as objective as possible. First, the paint layer of interest is identified in cross section and exposed on a raw sample removed from the same area (the larger the area of exposure, the easier it will be to get an accurate color match). Following the creation of an exposure window, the color of the exposed paint layer is matched with a color system both visually and using a spectrophotometer or a colorimeter, a similar but simpler instrument. The visual match is typically made to both a standardized system, such as the Munsell color system, and a commercial-paint palette. Although the latter is subject to change, projects often require that a match be made to a readily available commercial paint. The spectrophotometer or colorimeter will provide a match to another standardized system, the CIE L*a*b* system. Taking a reading of the Munsell color chip or commercial color match is also recommended, in order to assess the difference between the color swatch and the actual paint color (Fig. 4).

Once the existing color has been documented, a subjective assessment is made as to whether or not the historic paint color may have changed over time through yellowing or some other type of discoloration. Such a conclusion cannot be arrived at without first identifying the binder medium or pigment composition of a paint. If the paint is identified as a linseed oil–based paint and it is believed to have yellowed over time, then some fairly simple measures can be taken to try to reverse the yellowing. By exposing the yellowed paint to a broad-spectrum fluorescent light or natural sunlight for approximately two weeks, the yellowing can be greatly diminished. However, it can be difficult to recognize the point at which the yellowing of the paint layer has been reversed but bleaching out of the color has not begun. In other words, there is really no effective way to know when to stop the lightening process to avoid bleaching. Nonetheless, some attempt to rectify the color change has to be made, and, as long as it is properly documented with before-and-after color readings, it is generally viewed as a necessary part of paint analysis. Any process used to reverse the yellowing of an oil-paint film should be fully documented by the conservator and included in the final paint-analysis report.

Analysis of Paint Composition

Some projects require additional investigation of the composition of a paint layer, including characterization of binding media and identification of pigments. This supplemental research is typically performed to pro-