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Objekttyp: **Article**

Zeitschrift: **IABSE reports = Rapports AIPC = IVBH Berichte**

Band (Jahr): **73/1/73/2 (1995)**

PDF erstellt am: **29.05.2024**

Persistenter Link: https://doi.org/10.5169/seals-55252

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Repair Methods for Deteriorated Sandstone Facades

Procédés de réparation de façades en grès endommagées

Reparaturtechniken für beschädigte Sandsteinfassaden

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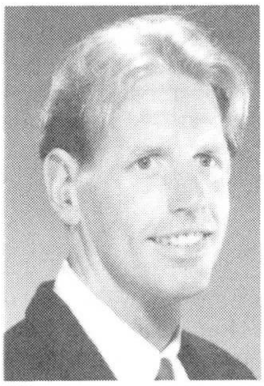

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SUMMARY

A local sandstone was used to clad many San Francisco buildings constructed around the turn of the century. Today, many of these facades are deteriorating, and the stone is cracking, spalling and weathering away, creating a hazard for those walking below. This paper describes the field and laboratory investigations and the facade repair at the St. Francis Hotel. The sandstone cladding had deteriorated due to the effects of water on the stone's mineral constituents. The lifespan of the facade was extended by repairing damaged areas, applying a surface treatment to the stone and by reducing the water infiltration into the stone at horizontal ledges.

RÉSUMÉ

Un grès dur local fut utilisé vers la fin du siècle dernier pour le revêtement d'innombrables immeubles de la ville de San Francisco. De nombreuses façades ont été endommagées par les intempéries, faisant apparaître des fissures et des éclatements dont les projections sont dangereuses pour les piétons. Cet article présente l'examen effectué pour l'hôtel St. Francis, sur le site et en laboratoire; le grès de ce bâtiment s'est décomposé en partie, par l'effet de l'eau. Il a été prévu de réparer les parties de la façade endommagée par un traitement superficiel de la pierre et une étanchéité pour réduire les infiltrations d'eau de pluie dans les moulures.

ZUSAMMENFASSUNG

Für die Verkleidung vieler Gebäude wurde im San Francisco der Jahrhundertwende ein örtlich gewonnener Sandstein verwendet. Heute sind viele dieser Fassaden verwittert, Risse und Abplatzungen treten auf, die die Fussgänger auf der Strasse gefährden. Der Beitrag beschreibt Feld- und Laboruntersuchungen am St.Francis Hotel, wo der Sandstein sich infolge wasserempfindlicher Mineralbestandteile zersetzte. Die Lebensdauer der Fassade wurde durch Reparatur der geschädigten Flächen, durch eine Oberflächenbehandlung des Steins und durch Abdichtung der horizontalen Leisten verlängert.

1. INTRODUCTION

Sandstone was a popular cladding material for many buildings constructed in the United States around the turn of the century. The stone was readily available and easily carved into ornamental shapes. A great belt of "Colusa Sandstone" is located just north of San Francisco, and many prominent San Francisco buildings, including the St. Francis Hotel, were constructed of this local stone.

Today, approximately ninety years later, the sandstone cladding on these buildings is experiencing severe deterioration. The deterioration represents a potential safety hazard for those walking below these buildings, and once the deterioration process has started, the damage progresses at an accelerated rate. This paper summarizes the field investigation, material analysis, design of repairs, and the ongoing restoration of the sandstone facade of the St. Francis Hotel.

1.1 Building Description

The St. Francis Hotel, shown in Figure 1, is a thirteen-story steel framed structure with brick infill and sandstone cladding on the street facades, and brick walls on the west facade. The typical sandstone walls have 30 cm courses with alternate courses projected out 2.5 cm (projecting course). The building was constructed in three stages: 1904, 1907, and 1913. The original drawings of the building were not available.

2. INVESTIGATION

The investigation consisted of a stone-by-stone survey of the entire building and a laboratory analysis of sandstone samples. First, the material analysis is presented then the field observations are related to the mechanisms causing the deterioration.

Figure 1 - St. Francis Hotel

2.1 Sandstone Material Analysis

2.1.1 Composition of Colusa Sandstone

Petrographic analysis of the stone found it to be a graywacke, or low grade sandstone, with a siliceous-argillaceous matrix. The matrix contains the clays kaolinite, illite and montmorillinite and small amounts of carbonate materials. The stone has fine grains of quartz and feldspars. It is moderately soft, quite porous and readily absorbs water.

2.1.2 Deterioration Mechanism

The deterioration mechanism, shown in Figure 2, begins when water enters the stone. The water dissolves elements in the binding matrix while acidic pollutants in the water alter the calcite portion of the binder into gypsum. As the water evaporates during repeated wet-dry cycling, the gypsum is deposited at the surface of the stone and forms a surface crust approximately 2 mm thick. The process of forming the surface crust is known as "surface induration." Behind the crust, a layer of disaggregated stone is formed as the calcite binder is lost. Once formed, the crust will expand in all directions due to two mechanisms: -1 the gypsum expands as it incorporates water into its crystal structure, and -2 the montmorillinite clay expands in the presence of water. The crust is not as hard as the original stone, but it is much harder than the layer of disaggregated stone. Expansion of the crust cannot be restrained by the stone and eventually the crust exfoliates, and falls away from the body of the stone.

2.2 Field Investigation

In 1987, a condition survey of the entire sandstone facade was made from swing stages, and the condition of over 30,000 stones was recorded. The condition of each stone was recorded on scaled building elevations prepared using rectified photography. During the survey, loose pieces of stone were removed and stainless steel anchors were installed to alleviate immediate hazards. Four years later, selected areas were resurveyed to evaluate the progress of the sandstone deterioration and to set priorities for the repairs.

The most severe deterioration was found in areas experiencing frequent wet-dry cycles. The resurvey revealed that once a stone forms surface cracks, more water can penetrate behind the surface and the deterioration spreads rapidly into the stone. The most common forms of deterioration include:

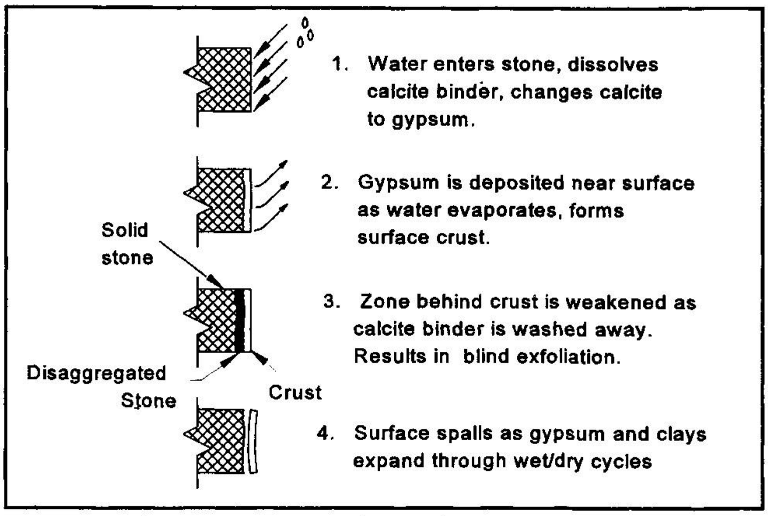

Figure 2: Deterioration Mechanism

2.2.1 Surface cracks, blind exfoliation and shallow spalling.

The most widespread type of deterioration results from the surface induration process. The deterioration first appears as fine, shallow cracks near the perimeter of the blocks. Tapping on the stone near the crack often reveals a hollow sounding area, indicating the presence of a disaggregated zone and a "blind exfoliation." The blind exfoliation increases in size until the crust falls away, creating a shallow spall or exfoliation.

Stones that are particularly vulnerable to this type of deterioration are the quoins at the corners of the building, due to their many exposed edges, and the parapet, due to the harsh exposure. Roughly 60% of all stones had formed surface cracks and roughly 45% of all stones required repair due to the surface cracking. The number and length of cracks, as well as the amount of blind exfoliation increased from 1987 to 1991.

2.2.2 Weathering

Weathering appeared as a disintegration of the stone surface. It occured most often at the bottom edge of stones that are set above the small ledge created by a projecting course below. The ledge collects water which then wicks up into the stone above. The weathering leads to loss of surface detail such as carvings and sharp corners.

2.2.3 Deep spalls

Deep spalls were found on stones with multiple surfaces exposed to the weather. The intricate shapes of these ornamental stones create areas where dirt and moisture can collect. Cracks originating from several exposed surfaces joined to spall off projecting corners. This spalling especially occured on watertables, where deteriorated mortar joints exposed multiple stone surfaces. Deep spalls were typically limited to projecting ornamental stonework, but they are one of the more hazardous types of deterioration.

Deep spalls can also be caused by expansion of corroding embedded steel anchors. These spalls were found on the balcony railing supports and on the sandstone brackets under the balconies.

3. REPAIR DESIGN

The Colusa sandstone is inherently flawed in that it deteriorates in the presence of water. The objective of the repairs was to reduce potential hazards and reduce the rate of deterioration. The life span of the facade will be extended by: -1 repairing already damaged areas, -2 reducing the amount of moisture entering the stone, -3 improving details to reduce water seepage into the stone, and -4 implementing a periodic inspection and maintenance program. Throughout the design process the following issues had to be considered for each repair: -1 the historic nature of the building; -2 material compatibility and -3 constructability and cost.

Seismic considerations for the building's structural system had been previously addressed by structural engineers Chin & Hensolt. Lateral forces were considered in the design of anchors for existing and replacement stones.

3.1 Historic Nature of the Building

The St. Francis Hotel is a designated Historic Landmark, and the impact of all repairs on the historic fabric and character of the building had to be considered. The most important issue was the visual impact of the repairs. Nearly every square meter of the facade needed repair, so it was important that the repairs minimize any changes to the appearance of the facade.

Some deterioration was due to poor original detailing. The restoration is intended to correct the detailing while altering the appearance as little as possible. Since most of the original ornamentation was severely deteriorated, it was difficult to find stones to replicate. Bracing of stone elements had to be accomplished without exposing the brace and the introduction of new elements such as flashings had to be made without changing watertable profiles.

3.2 Material Compatibility

The facade was constructed at the turn of the century using traditional materials. Repairs using modern materials had to be carefully considered. Where new materials were used, the initial and weathered appearance of the new materials had to match the existing stone's color and texture as closely as possible. Mechanical properties such as thermal and moisture expansion and compressive strength had to be compatible with the original stone to avoid the introduction of new stresses. In general, the intent was to avoid introducing new materials when the original stone could be economically repaired. However, certain elements were so severely deteriorated that complete replacement of the unit was required. When large areas of new materials were introduced, the new elements were isolated from the adjacent stone to accomodate thermal or moisture movements.

Finally, the properties of the existing materials were required for the design of new attachments. For example, anchors for some replacement pieces were welded to the existing structural steel. Coupons of the steel were tested for chemistry to determine the welding procedures.

3.3 Constructability and Cost

The issue of constructability was especially important since this is an older building and no drawings were available. The general relationship between the stone, brick backup and steel frame was known from previous work, but the information was not specific enough for detailing purposes. In addition, many subtle, but important differences in the configuration existed between the three buildings. Issues such as the location of the steel frame, whether the stone blocks were supported by the steel frame or were self supporting, the location of internal bracing of ornamentation, the keying of the stone with the brick backup, and the construction of the cornice had to be determined by inspection openings before repairs could be detailed.

The repair details needed to be flexible to account for tolerances in the original construction. Design of replacement blocks considered such issues as hoisting and scaffold load capacities, scaffold clearances, and the ability of workers to lift and handle materials. Identification of deteriorated stone, color matching, lead time to revise details, and adequate cure times for cementitious materials were critical to the repair sequence.

The work on the building was divided into phases for cost monitoring purposes. The cost of each type of repair was monitored in the first phase, then the costs were projected for the entire building. Subsequently, adjustments were made to the repair procedure, the amount of stone repaired, or the budget to bring the project in at budget.

4. REPAIR SCHEMES AND IMPLEMENTATION

The restoration work was a monumental undertaking for the Hotel, felt by all staff members ranging from the general manager to the service personnel. Close coordination between the contractors, design professionals and hotel staff was required to maintain the quality of service provided by the Hotel.

Most of the repairs fall within three broad categories: -1 repair of deep spalls -2 repair of surface cracking, blind exfoliation and shallow spalls caused by surface induration, and -3 preventive repairs intended to delay and reduce future deterioration.

4.1 Deep Spalls

Several different repairs were used for deep spalls, depending upon the type of stone. Deep spalls on ashlar stones were typically repaired by use of mortar patches, sandstone dutchman patches were used at highly visible stones near street level, and parging was used at window sills. Mortar patching with a color matched cementitious mortar was used for most deep spalls.

The Colusa sandstone is notorious for its tendency to reject mortar patches. A good bond between the stone and patch is essential to achieve a reasonable service life. Thin, feather edge patches are the most prone to failure. A minimum patch thickness of 2.5 cm was established to insure that all deteriorated stone was removed, and good keying between the patch and the stone was provided. The compressive strength of the patch material was also checked to verify that it was not stronger than the stone.

Parge coatings are a specific type of mortar patch that cover the entire top surface of a window sill. The entire top surface is covered to avoid exposed joints between the sandstone and mortar that will eventually open due to mortar shrinkage and allow water infiltration below the parging.

Dutchman patches were much more costly and were used only at highly visible stones. The dutchman patches were made by cutting out the deteriorated area of the stone and inserting a new piece of stone into the void. Joints around the inserted dutchman were as thin as possible. The surface of the dutchman was then tooled to match the tooling pattern on the adjacent stone.

Large areas of projecting ornamentation such as quoins and watertables had extremely deep spalls that could not be effectively or economically patched. These areas were repaired by removing the deteriorated stone (sometimes the entire unit) and installing glass fiber reinforced concrete (GFRC) cover panels. GFRC was chosen since it provides the best color and texture match and is most easily adapted to the varying support conditions. Since such large areas of the facade received GFRC panels, considerable effort was spent developing the best color and texture match. Accelerated weathering tests were done to expose the potential of severe degradation in the color or texture of the panels due to long term weathering. Care was taken to isolate the GFRC from the adjacent materials to eliminate the buildup of internal stresses caused by temperature and moisture expansion and contraction. The GFRC panel connections were made either with anchors set in the backup masonry walls or with anchors welded to the existing steel frame. Special inspection was performed for all welding.

4.2 Surface Cracking, Blind Exfoliation, Surface Spalling.

Where deterioration had not progressed deeply into the stone, the stone was repaired by retooling the surface of the stone. This repair method is superior to mortar patching since it retains the original material, corrects detailing problems, provides an ideal surface to receive preventive surface treatments and has a low visual impact. The insitu retooling of stone, particularly on this scale, had never been attempted in San Francisco; therefore considerable effort was spent by the contractor in developing tools and procedures to make the repair cost effective. The initial retooling cost was quite high since the commonly available tools were not adapted to nor sturdy enough for the production work needed to achieve a reasonable cost. In addition, highly paid and skilled stone sculptors were needed to perform the work. During the initial phase of the project the sculptors developed tools and procedures that significantly increased the production rate and could be learned by typical masons on the job. Eventually, the unit cost for retooling became less expensive than patching.

Retooling by its nature changes the stone profile, only certain stones can be retooled without disturbing the overall appearance. Retooling was used at specific stones as follows: For surface cracks at the top edges of projecting ashlar blocks, the top edge of the stone was cut off with a beveled edge to remove the loose piece and provide a slope away from the building. Where the disaggregated zone extended down the face of the stone, the surface of the stone was planned back roughly 1.25 cm until sound stone was reached. Then, horizontal tooling marks were applied to match adjacent stones. Ornate stones carved with floral patterns were retooled by hand using low impact dallet chisels.

4.3 Preventive Repairs

Several repairs were done to delay future deterioration. The underlying causes of deterioration cannot be completely eliminated but the service life of the stone can be increased by reducing the amount of water and pollutants that enter the stone. To reduce the pollutants on the surface of the stone, the entire facade was cleaned. Care was taken to choose a product and procedure that would not harm the stone. A mild alkaline cleaner was used and care was taken to monitor the pH level of the stone so that no chemical residue was left on the stone. The use of a mild cleaner reduced the amount of protection required by the contractor, and the cleaner used was mild enough that it could be disposed of directly through the city sewer system.

To reduce the amount of water infiltration into the stone, all mortar joints were repointed and a penetrating liquid water repellant was applied to all stones. Test sample panels were installed in 1988 to test the effectiveness of various treatments. The panels were reviewed two years later and cores were analyzed to determine if the treatments were effective. The analysis revealed that the water repellant cannot penetrate deeply into the surface crust of the original stone surface but it is still effective in preventing water infiltration directly through the face of the stone. The shallow penetration will result in a relatively short service life for the water repellant, but the material and installation costs are low so it can be reapplied as needed. The newly retooled stones will benefit more from the repellant because of better penetration of the repellent on these stones.

Horizontal surfaces are especially vulnerable to deterioration due to increased exposure to water. To protect these areas, sheet metal flashings were added to the top surface of all watertables and a polyurethene coating was installed on the top surface of the balconies. The flashings and coatings provide a durable, low maintenance repair with minimal visual impact. In some areas, decorative moldings were added to the flashings to simulate the intricate carvings on the original stone.

5. PERIODIC MAINTENANCE

The forces that caused the initial deterioration of the stone will continue to act on the building and continue to cause deterioration. A periodic maintenance program is necessary to keep the preventive repairs intact and to address the ongoing deterioration. The maintenance program will incorporate the repairs used for the restoration, but the volume of maintenance work will be significantly less than was required for the restoration. The maintenance work can be performed from hanging scaffolds that are much less costly and less intrusive than the fixed scaffolds used for restoration.

At each maintenance interval, the facade will be cleaned and the water repellent reapplied. The integrity of the pointing, joint sealants, flashings, and coatings can be evaluated and repaired as required to keep water out of the stone. In addition, any new deterioration found will be repaired.