Evaluating Mortar Deterioration

Bernard Erlin and William G. Hime

Mortar has been around since the early days of man, shortly after he huddled on cold clods beneath clear, moonlit skies and found that certain muds, when mixed with sand, sealed cobbles placed adjacent to, and on top of, each other. He later found that not all muds were the same; some washed away, while others remained strong.

The Egyptians found that burnt gypsum, when gauged with water, hardened and could seal limestone blocks (hence used in some of the pyramids). The Romans found that light-burned-lime was better, and better yet when volcanic ash and sand were mixed with the lime.

Among early brick masonry structures that remain today is the Cathedral of Florence, built around the time of Columbus. A petrographic examination of that mortar, done for an "archeological engineer" who "borrowed" a thimblefull, revealed that the cementitious component was relatively pure hydrated lime (long since entirely carbonated by normal atmospheric carbon dioxide), plus, surprisingly, a small amount of sodium carbonate.

It is interesting that sodium carbonate is a potent accelerator of portland cement hydration. The mortar of the Cathedral was reported to have had "unusual" properties. From whence the sodium carbonate came may never be known. Whether a natural component of the lime or a purposeful addition, its presence is interesting.

The Great Wall of China is of brick masonry construction. A tiny sample, examined using petrographic methods, revealed it to be carbonated hydrated lime containing trace to minor amounts of residual ferruginous material.

Mortars have come a long way since the time of early man, the construction of the Great Wall, and the erection of the Cathedral...or have they? The lime mortars of the past are long gone. Today, "modern" ASTM C270 mortars are typically composed of either mixtures of portland cement, hydrated lime, and sand, or masonry cement and sand. Occasionally, an oddball creeps in and causes more problems than do the ASTM C270 mortars.

There is a need today to identify the composition of mortars, to closely match that in old structures during rehabilitation, or to investigate why failures occurred. Restoration dollars should not be spent on repairs without clearly understanding the existing materials so that the "repairability" of materials can be evaluated.

Analyzing Mortar

The analysis of mortars is difficult, but a lot of data can be obtained using modern and not-so-modern methods. The "modern" includes petrographic microscopy, x-ray diffractometry, atomic absorption spectroscopy, and differential thermal analysis. The not-so-modern includes classical "wet" chemistry.

The old and the modern are of equal importance in identifying and quantifying the mineralogical and chemical make-up of mortars. In the deft hands of those who cannot only analyze, but also understand and decipher the analytical data, very meaningful information can be obtained. That information can be used to make sense out of apparent chaos, and provide necessary answers.

Petrographic Microscopy

Using methods of petrographic microscopy, the mineralogy of the aggregate and, thus, the presence of minerals that interfere with certain chemical and physical analyses can be identified, and the mortar type can be indexed. For example, calcareous components, such as limestone and dolomite, are digested (or partially digested) during certain of the chemical analyses. The chemical and physical data thus obtained could cause overestimation of the amount of cementitious components and underestimation of the amount of sand. An advance warning of these chemical interferences by petrographic identification of interfering minerals can shorten the analysis time and avoid misinterpretation of the data.

What the Analysis Reveals

Using suitable methods of analyses, as appropriate for the mortar under study, the following information can usually be obtained:

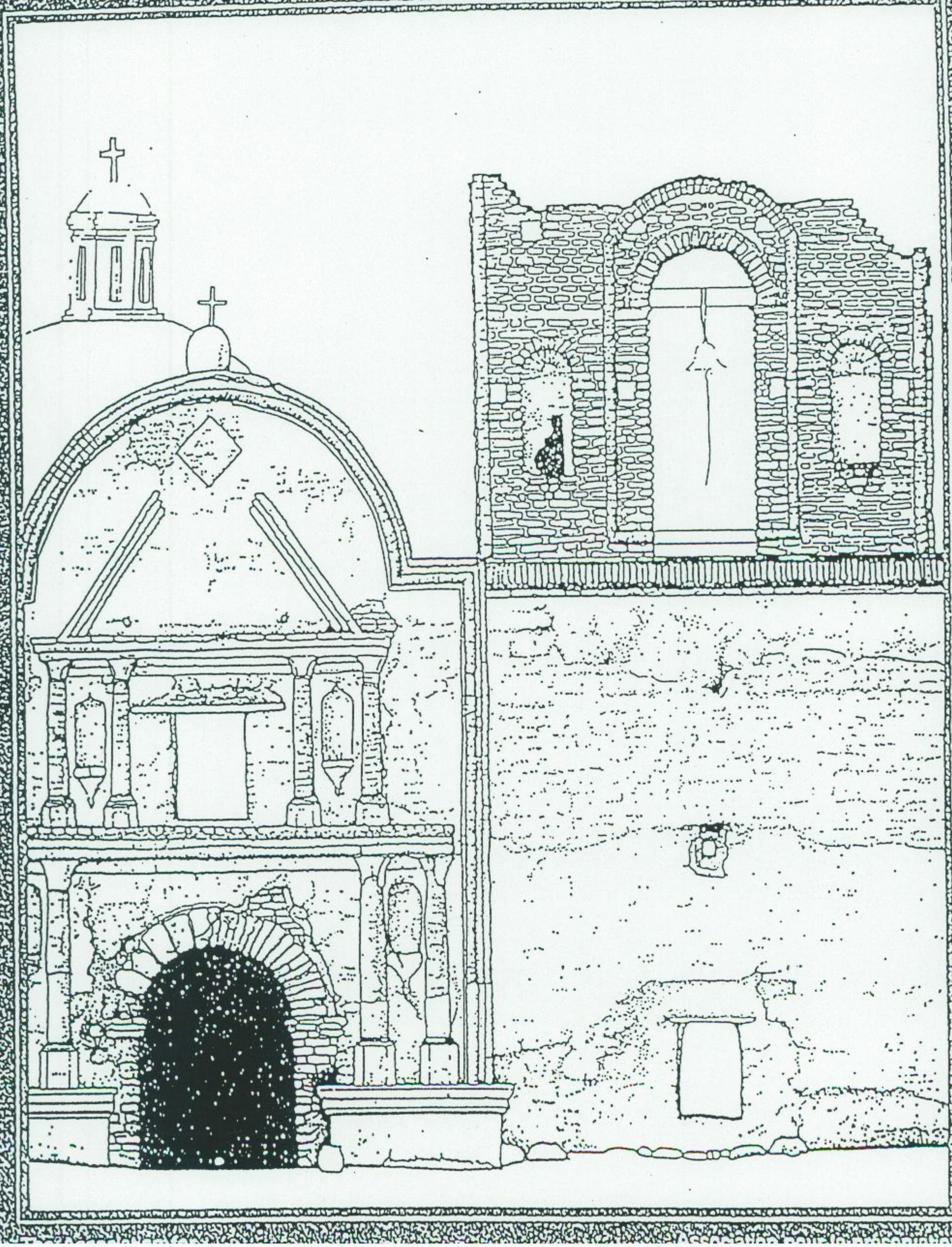
- Mineralogical composition and gradation of sands
- Components originally used to make the mortars
- Proportions by weight and by volume of original components used to make the mortars
- Air-void parameters
- Degree of portland cement hydration and paste carbonation
- Presence of contaminants
- Use of organic and/or inorganic substances such as calcium chloride or integral water-proofers, etc.
- Type and amount of destructive chemicals
- Manifestations of the effects of destructive agents such as cyclic freezing, free lime, periclase, or sulfate attack
- Retemperings

Methods for analyzing mortars are presented by Erlin and Hime in "Methods for Analyzing Mortar," *Proceedings of the Third North American Masonry Conference*, sponsored by the Masonry Society, 1985.

Once the petrographic, chemical, and physical data have been obtained, evaluations of the following can be made:

APT Bulletin

Vol. XIX No. 4 1987



- Compositions of "historical" mortars
- Conformance of mortar to specifications
- Make-up of masonry cements used for making mortars
- Use of low- or high-magnesium hydrated limes.
- Mineralogical make-up and gradation of sand
- Volumetric proportions of original mortar-making components
- Type of mortar per ASTM C270 specifications
- Presence and amounts of admixtures, such as accelerators (e.g. chlorides), retarders, water-retention chemicals, air-entraining agents, and "integral" water-proofers
- Degrees of cement hydration and paste carbonation
- Air contents and characteristics of air-void systems
- Degree of intimacy of bond between mortar and masonry units
- Adverse chemical reactions, such as due to free lime, magnesia, alkali-silica aggregate reaction, and sulfate attack
- Early freezing of plastic, semi-plastic, or semi-rigid mortar
- Cyclic freezing damage
- Corrosion of embedded metals
- Others

The following examples demonstrate the use of analytical techniques in resolving problems.

Mortar in a Failed Wall

When the walls of a very large outside rectangular enclosure came "tumbling down" in Indiana, interest was expressed about the cause(s) so that suitable repairs could be made.

Petrographic analysis shows the imprint of ice crystals in mortar.

The petrographic and chemical analyses revealed that the mortar was non-air-entrained and had been made using portland cement, hydrated lime, and natural siliceous-calcareous sand. Detected in the hydrated lime component were particles of incompletely hydrated periclase (MgO) particles, their hydration product brucite ($Mg(OH)_2$), and strained calcium hydroxide ($Ca(OH)_2$). The features of the brucite and calcium hydroxide were indicative of *in situ* hydration of periclase and free lime (hard-burned lime). The *in situ* hydration involves an attendant solid-to-solid volumetric increase of about 100 percent – a doubling of volume. Quicklime had been slaked on the job using "methods of old" – the addition of water to the quicklime in a barrel. The "methods of old" required frequent stirring to break up lumps, which invariably formed, so that the water could get to all of the quicklime, and thus hopefully prevent "nests" of hard-burned lime and periclase. But those methods require considerable effort, timing and experience.

Incomplete slaking of the quicklime resulted. Subsequent *in situ* slaking of quicklime remnants and unhydrated free lime and periclase were judged to be the primary contributors to the wall failure. The contributions were: (1) distention of the mortar, thus opening it to moisture uptake and subsequent cyclic freezing damage; and (2) expansion of the masonry walls, which although originally straightly aligned, became bowed. Other factors also probably contributed, but are inconsequential with respect to mortar performance.

Water Penetration

In another example, masonry walls of an expensive residential home leaked excessively, so that even during light rains, water infiltrated the walls.

Analyses of the mortar revealed that

it was non-air-entrained and had been made using portland cement, hydrated lime, and natural sand, proportioned so that it conformed to an ASTM C270 Type N mortar. Mortar components were sound. Mortar joints were full, and there was intimate contact of mortar to flanking bricks. The mortar was hard and firm.

The petrographic studies, however, also further revealed that long, slender, micro-sized imprints were present throughout the mortar. The imprints were casts of former ice crystals. Thus, the mortar had been placed during a winter construction period, on unprotected walls, but it had been subsequently adequately cured, as demonstrated by the firmness of the mortar.

The ice crystal imprints provided channel ways for rainwater contacting the outside face of the walls, and their fine sizes caused them, in part, to act as capillaries that readily transferred the water through the mortar joints.

Repointing the joints with carefully selected, compatible mortar resolved the problem.

Metal Corrosion

Corrosion of reinforcement and other types of wall ties and anchorage systems (galvanized or not) can present a structural problem. Although some corrosion of metal items may be expected in any structure, it is usually a very slow (if at all) process and should not become a major problem during the life of the building (e.g. 100 years or so).

The rate and magnitude of corrosion are dependent on a number of factors. Major ones are chloride, moisture, the frequency of cyclic wetting and drying, and the degree of carbonation of the mortar around the steel. The foremost contributor is chloride, the greatest promulgator of corrosion in the world.

A recent example of corrosion of masonry involved spalling of a multi-walled, two-story brick masonry building. The initial problem that prompted an investigation of the walls was phenomenally extensive efflorescence.

Petrographic and chemical studies revealed that the mortar was air-entrained and was made using masonry cement and natural siliceous sand and that it conformed to ASTM C270 specifications for a Type S mortar, as required. Joints were not well filled, and intimacy of contact of mortar to brick was extremely poor. Water infiltration along mortar-brick interfaces was extensive, as evidenced by prominent secondary calcite deposits on surfaces of mortar that interfaced the bricks. The extensive efflorescence on outside masonry surfaces consisted primarily of thenardite and other sodium sulfates, and thermonatrite (sodium carbonate hydrate).

As based upon chemical studies, the efflorescence salts were derived principally from the masonry cement component of the mortar. The petrographic studies also revealed that trace amounts of halite (sodium chloride) and sylvite (potassium chloride) were also present.

The presence of the chloride salts and of advanced corrosion of galvanized anchors resulted in analyses of the mortars for chlorides. Amounts of chlorides present were indicative of the purposeful addition (in most cases) of calcium chloride at amounts from one-half to two percent by weight of the portland cement component of the masonry cement. Those chloride levels are enormous with respect to triggering and accelerating corrosion of metals embedded in mortar. That was demonstrated at the job site by the advanced corrosion of the galvanize (zinc coating) on the steel, and of the underlying steel itself.

Unfortunately, the solution to the problems involved removing and replacing the walls with well-constructed masonry made with components relatively free of chlorides.

Panel Displacement

Panels of the travertine-faced walls cracked at anchorage kerfs, and panels were being outwardly displaced. In the kerfs was a white portland cement mortar made with non-staining quartz sand, and behind the panels was "spotting" mortar, specified to be of the same composition.

Petrographic studies revealed the mortar was non-air-entrained and contained vestigial structures of white portland cement, hydrated lime, natural quartz sand, and secondary ettringite ($CaO.Al_20_3.CaSO_4.32H_2O$) and thaumasite ($CaSiO_2.CaCO_3.CaSO_4.14.5H_2O$).

Ettringite and thaumasite, in this situation, are the end products of internal sulfate attack, and demonstrate that the mortar contained a grossly excessive amount of sulfate, such as from gypsum ($CaSO_4.2H_2O$) or plaster-of-paris ($CaSO_4.\frac{1}{2}H_2O$). Chemical analyses indicated that the sulfate content was equivalent to 12 to 15 percent of those sulfate compounds. Later information revealed that a "white powder" had been added to the mortar to cause it to set-up fast and facilitate placement of the travertine panels.

The ettringite and thaumasite crystallized as a result of chemical reaction between the calcium aluminates and silicates of the portland cement and the sulfates from the added calcium sulfate.

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is presented with museum restorations as well as contemporary interpretations of period rooms, but without critical evaluation, or even identification. Some of the captions read like those from popular shelter magazines, pointing out commercially available reproductions and popular collectible objects, but never commenting on the appropriateness of either.

The design of the book is a typographic nightmare. For example, the introduction to the Gothic Revival section contains no less than six different typefaces and weights. If this is an attempt to dazzle the reader with the variety of patterns and textures one finds in the subject houses, it fails. The designer should have limited the choices and simplified the layout to let the pictures speak for themselves.

That brings us to the good news. The photographs by Taylor B. Lewis are stunning. Page after page of color illustrations, properly lit, well composed and cleanly reproduced, show a range of details as well as overall massing and form. Clearly Mr. Lewis is not only technically competent, but also has the "eye" one needs to recognize the features, textures and patterns that define for us architecture of the Victorian period. Once again, however, don't read the captions! In one, a labeled lintel above a paired lancet window is called "an eyebrow protection." (pg. 13)

In conclusion, I would not recommend this as other than a "coffee-table" book. For the professional it will be maddening, and for the amateur it will be misleading. The photos are glorious. They would serve as inspiration for owners up to their ankles in plaster dust as they undertake the transformation of their own Victorian houses. But don't buy it to read. Its too-cute title, the self-imposed but often-violated restrictions, graphic disarray, and travelog captions, all make *Victorious Victorians* an utterly disappointing book. The subject and the photographs deserve better.

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The crystal growths are unaccommodative, and thus exerted localized stresses and caused bulk triaxial expansion of the mortar.

The expensive but necessary solution – removal of all travertine panels, clearing out of all kerf mortar and spotting mortar, and re-installation of the panels using mortar made in conformance to the specifications.

Comment

Analysis of mortars (and other building components) can be successfully accomplished using current analytical methods. However, knowledge of the shortcomings (and longcomings) of the analytical methods, of interferences to the analytical methods and how to overcome those interferences, and of the overall aspects of the mortar-making materials is a prerequisite for establishing a sound basis for interpretation of the analytical data. It is also helpful to have a working understanding of the effect of different chemicals, environmental conditions, and workmanship, on mortar performance.

(Continued from "Photographic Documentation, p.7)

Other arrangements may be acceptable when recordation is being done for private use. You may wish to specify that the photographer may make duplicate or copy negatives, but that reproduced images must carry a credit line (i.e. Matthew Brady, photographer, for HABS.) It must also be made clear to which agency, or to whom, the submission shall be made. Often the project is being undertaken by one entity, but the recordation is a requirement of another.)

It is advisable that the owner, or the entity undertaking the project, contract directly with the photographer for documentation. Documentation should not be a part of the general or demolition contract as this reduces the owners' control over the final product. However, it should be made a part of the construction contract (or any intra-agency agreement or permitting approval) that demolition not begin until the documentation is completed and approved.

The photographic documentation of cultural resources requires the combined skills of the artist, the technician and the preservationist. It also requires an understanding of the need for the documentation and the potential uses it may have in the future. Poor photos of an extant building have little value, but the error can be corrected. Photos of a property about to be destroyed are all we will have for future study; preserving its image accurately on film deserves our best efforts.

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