WHEN FIELD PERFORMANCE OF MASONRY DOES NOT CORRELATE WITH LAB TEST RESULTS

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ABSTRACT

As a result of the hypotheses posed by past studies, a series of advanced lab tests was conducted on brick, mortar, and previous repair materials to assist in the determination of the failure mechanisms at a high school in Portland, Oregon. However, the results indicated a high-quality brick, severe weathering performance characteristics, no applied coatings, and low IRA. Whereas the brick is clearly failing on site in areas with high concentration of water, in-field performance of the brick is in conflict with lab test results for brick performance. This paper includes presentation of field observations, research conducted by the author, on-site material testing, and laboratory testing, including Fourier transform infrared spectroscopy (FTIR), freeze/thaw, and petrographic analysis.

SPEAKER

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PETER MEIJER has over 30 years of professional experience with an emphasis on the preservation and assessment of older, existing, and historic buildings. As a professional architect with a background in scientific research, Meijer has developed his career with a focus on the unique building sciences associated with existing and historic resources. He has become well-regarded both regionally and nationally as an expert on the diverse issues affecting older buildings.
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BACKGROUND

Ulysses S. Grant High School is located in the Grant Park neighborhood of northeast Portland. The 10-acre campus includes an extensive collection of educational buildings constructed between 1923 and 1970, including the original main building (circa 1923). Positioned within a flat, pastoral setting of trees and parkland, the buildings constructed in the 1920s at Grant High School (see Figure 1) form a core group of Classical Revival-style buildings. The buildings exhibit a variety of character-defining features, including a bilaterally symmetrical U-shaped plan, a bold portico supported by fluted Ionic columns with a broad terra cotta frieze, ancillary entries with terra cotta Ionic columns or pilasters and classical entablatures, a concrete foundation wall extending above grade, terra cotta string course, terra cotta cornice and coping, an interior entry with boxed beam ceilings, and the original gymnasium with its flush Ionic column-lined entry.

When it was completed, Grant High School was typical of the public high schools constructed in Portland in the pre-World War II era. Originally designed to be added onto over time, the main building at Grant High School would receive a north wing in 1925 and an auditorium and south wing in 1927. In addition to being an extensible school, the school was also reflective of fireproof construction through its use of a reinforced concrete structure with brick infill.

Even before construction began, difficulties emerged concerning the supply of bricks for the school. The Washington State-based Denny-Renton Clay and Coal Company could not supply the needed bricks for the school, and the school board was left to contract with another company in Montana to supply the bricks.

OWNER CONCERN

Over the last 15 years, Portland Public Schools (PPS) noted an accelerated degree of masonry face spalling on the original 1923 main building—particularly when adjacent to concentrated water flow areas. (See Figure 2). There appeared to be a direct correlation between spalling of the existing brick and areas of potential water intrusion. Such areas included brick beneath leader boxes and downspouts, parapet walls, areas near or beneath...
In addition to the original 1923 main building, similar near-surface spalls were occurring on the old gym (circa 1923), north wing (circa 1925), south wing (circa 1927), and auditorium building (circa 1927). Likewise, the masonry units of the circa-1952 addition to the north wing, new gymnasium (circa 1956), library wing (circa 1959), and the science building (circa 1966) were free of spalling (Figure 3).

In general, maintenance efforts concentrated on the repair of parapets, masonry beneath downspouts, wall-to-roof intersections, the portico entry roof, and other areas of direct visual correlation between high concentrations of water run-off and spalling. Previous repairs replaced long sections of masonry parapet, including attempts at replacement with exterior-grade wallboard. Other repairs to the brick spalls included patching the masonry faces with synthetic mortar products. When these potential water intrusion failures were repaired, the spalling did not stop. Repointing repairs have also failed in various areas, exposing the original lime-based bedding mortar. In addition, several isolated units of masonry in protected elevations away from weathering forces were also spalling. The isolated units had no direct correlation to each other, nor were the masonry units concentrated on specific wall elevations. Ahead of a major capital improvement program, PPS was interested in resolving the masonry spalling or at least understanding its cause.

MASONRY WALL

The original circa 1922 Grant High School construction drawings indicated a masonry wall between the concrete frame consisting of three wythes of brick laid in a common bond approximately 13 inches in depth, a 2-in. air gap, and a 2-in. interior finish face notated as tile. The bricks are typical unit sizes based on the era and are approximately 2¼ in. high x 8½ in. long x 311/12 in. deep with ½-in. bed joints. The concrete wall terminated at the bottom of the concrete roof slab. The masonry wall extended as a parapet approximately 3 ft. beyond the roof slab as a 13-in. solid masonry wall capped by a terra cotta coping stone.

Over the last 90 years, the original lime-based mortar has been replaced with flush-struck cement mortar. More recent repair mortars used for repointing are readily visible as a result of the use of different cement mortar colors. There is visual evidence of hard mortar repointing and subsequent damage to the brick edges during curing.

FIELD INVESTIGATION

Visual observations of all four elevations indicated equal dispersion of similar spalling around the building, leading to a conclusion that wind-driven rain and weather conditions were not a direct influence. In order to investigate wall areas and abstract materials that had not been previously damaged, a section of the east elevation was chosen that was more protected from the environment and relatively free of unit spalling. The wall area chosen for invasive testing...
and material removal had a clear height of approximately 140 courses of brick unbroken by window openings or other decorative shelf angles. Mortar beds were consistent in period of repointing, degree of weathering, and color.

The wall-let confirmed the assembly of a multiwythe masonry wall constructed in a typical fully bedded bond course with interlocking headers and no cavities between the first three brick courses. A hand-held metal detector picked up the location of hook-shaped, ¾-in. gauge, steel-wire masonry ties in alternating courses, approximately 12 inches on center ties, found to be in good condition with no deterioration. The absence of corrosion on the in-place brick wire ties indicated that little moisture was present inside the multiwythe wall. Bricks were well-bonded to each other on all surfaces. (See Figure 4.)

Several material samples were removed, including nine masonry units, four inches of face-pointing mortar, four inches of bedding mortar, two spalled ¼-in.-thick but intact brick faces, and 4 inches of previous patch material. A 4-in.-diameter diamond-tip circular saw and 8-in.-long helical drill bit were used to remove the brick. To evaluate samples free of observable defects against failed material, additional samples accessible from the ground were removed from two discrete locations adjacent to the primary sample façade.

Given the clear visual association of failure mechanism and high concentration of water, we cannot overlook the freeze/thaw dynamic. The characteristic of the masonry spalls, such as shallow depth (¼ in.), flaking in layers, and seasonal rate increases, are typically associated with freeze/thaw failure. Given Portland’s climate, however, freeze/thaw failure of masonry is relatively uncommon.

A PPS-commissioned study in 2011 hypothesized that the failure of the brick was potentially due to a number of separate or cumulative conditions, including 1) subfluorescence expansion of salts in the masonry, 2) freeze/thaw, and/or 3) low quality of the original 1923 brick.

As a result of these hypotheses and field observations, it was prudent to conduct a series of lab tests to the brick, mortar, and patch materials to assist in the determination of 1) the quality of the brick, 2) the physical composition of the brick, 3) the quantity of naturally occurring compounds in the masonry and mortar (particularly salts in the masonry), and 4) the quality of the mortar. The findings would help narrow the potential cause of the spalling and lead to a more focused repair and maintenance process.

**MATERIAL SAMPLES**

Brick units were removed for testing from two areas of the primary east façade: the south wall of the southern entrance, and the north wall of the northern entrance. Bricks were removed for absorption and freeze/thaw testing and petrographic analysis. Both pointing and bedding mortar samples, as well as the previous patching material, were removed and sent to Willamette Geological Service for petrographic characterization and physical composition of the materials. Two samples of the spalled face of the brick and one sample of patching material were sent to Chemoptix Microanalysis to determine if sealants were used on the brick and, if present, to determine the sealant chemical makeup. (See Figure 5.)

**TESTING AND RESULTS**

In addition to laboratory testing, field tests for preliminary absorption rates of the masonry can be conducted following RILEM protocols. RILEM works specifically with measuring properties, performance, and durability of various building materials.

During material removal, four RILEM tube tests were performed on masonry units to analyze the initial rate of absorption of the brick. The tests found that three out of four bricks exhibited no water absorption. The brick tested on its spalled surface had an absorption rate of ½ mL per 15 minutes. Similar field results with minimum to no water absorption typically indicate the presence of a surface sealer, since all natural clay materials absorb water under hydrostatic pressure. The presence of a surface coating may lead to retention of water within the brick, and thus prevent natural capillary flow, natural drying, and water evaporation. (See Figure 6.)

Samples sent to the lab for coating assessment were analyzed via episcopic light microscopy and Fourier transform infrared spectroscopy (FTIR) per ASTM D1245 and ASTM E1252. The results found no hydrocarbon or organic formulations used on the surface of the brick, but did find silica as surface-binding material. The presence of silica appears to be related to the initial firing process and normal secondary recrystallization of the brick. The fracture planes of the brick suggest that the silica may have recrystallized and hardened by subsequent atmospheric exposure.

The diagrams of the brick samples in the lab report show agglomerates distributed
Lab tests showed the patching material to be composed of quartz and calcite over the outer surface and a quartz and calcite-free interior. The patching material’s FTIR spectragraph has a spike at 1500 cm\(^{-1}\) Wave numbers, which is a contribution from calcium carbonate.

**PETROGRAPHIC ANALYSIS**

A petrographic analysis was performed in general conformance with ASTM C856 and ASTM C1324 (masonry mortar), and included petrographic analysis, chemical analyses, x-ray diffraction, and thermogravimetric analysis. First, each sample received visual examination, after which thin, polished, blue-dyed sections were analyzed under a polarized light microscope for information such as materials ratio and presence or absence of different deterioration mechanisms. These tests were used to assess the overall quality of material and determine the causes of its deterioration, including freeze/thaw damage, efflorescence, excessive retempering, cracking, ettringite formation, and alkali-silica reactivity.

Following modified ASTM standards, due to a limited number of physical samples, 24-hour immersion and 5-hour boil absorption tests were performed on the brick. The bricks have a very low percent of total absorption, at 9.5% for the 5-hour boil and 7.5% for the 24-hour test. The maximum saturation coefficient is 0.79, which is 0.01 over the maximum requirements for Severe Weathering bricks recommended for the Portland climate (ASTM C216-07a, Table 1). The initial rate of absorption (IRA) is 5.7g/min/30in\(^2\), which equates to a very low-suction brick or brick with low initial rates of absorption. The IRA lab tests correlated with field RILEM tube field test results. The freeze/thaw durability tests resulted in passing performance and, therefore, refuted the theory that below-freezing winter temperatures were the cause of masonry spalling.

The petrographic characterization resulted in the most unusual findings and the most relevant results related to potential failure mechanisms. The bricks tested showed very small rounded voids and planer voids. Performance of brick in the field is a result of both material properties and resistance to microclimates within the brick’s capillary void structure. Studies have shown a connection between small voids in the material property and susceptibility to internal freeze/thaw. Both rounded voids and planer voids are a result of the firing and manufacturing process and are not always associated with spalling. With natural absorption properties, the brick is taking in a small quantity of water in very small pores. 24-hour immersion results are very low (7.5%). Publication of more in-depth studies correlates maximum saturation values for brick with low 24-hour immersion values. The effect of low immersion values and small quantities of absorbed water may increase the susceptibility in brick with small-pore structure to freeze/thaw failure. (See Figure 7.)

The presence of small-pore structure and low-immersion values, combined with a potential cleavage plane, are likely the reasons the Grant High School brick are spalling. Brick with smaller pores are less capable of absorbing the expansive forces through brick, a course-grained volcanic rock.
of freezing water. Interlaced pores, creating linear plains parallel with the face of the brick, create stress failure points. (See Figure 8.)

CONCLUSION

Field observations of masonry failures generally correspond with known failure mechanisms. However, it is not unusual that further analysis reveals that in-field performance tests are in conflict with more refined laboratory test results for brick performance. In the case of Grant High School, masonry units were clearly failing on-site in areas with high concentration of water, but the lab testing indicated a very high-quality brick with ASTM classification ratings for Severe Weathering performance characteristics and low initial rates of absorption.

Upon closer visual examination, it was observed that individual units were failing in isolated protected areas of the wall surface. Failures in such areas could not be accounted for under direct correlation of heavy water intrusion and typical failure mechanisms. As a result, additional specialized laboratory testing was needed. Under these conditions, test methods must include FTIR and petrographic analysis. FTIR analysis tests for maintenance processes and applied-coating-induced deterioration. Petrographic analysis provides microscopic analysis of inherent material composition and manufacturing-induced flaws. Both tests provide more performance data to assess the difference between in-field and lab performance.

Since the characteristics of the brick resulted from the firing and manufacturing process, the brick will remain susceptible to microclimate freeze/thaw effects. The best corrective action is to minimize the amount of surface water with functional rain leaders and downspouts, proper flashing systems, and proper mortar joints and mortar composition. Prevention of heavy surface runoff water (overflowing roof drains) and internal leakage (poor flashing) will assist in controlling and managing future damage. Additional spalls are likely to occur in the future due to the accumulation of expansive forces over a long period of time. Low quantities of water contained in water vapor—either through atmospheric or interior environmental conditions—do not appear to be accumulating in sufficient quantities to be a contributing factor in the brick spalls. Liquid water trapped within the micro pore structure and rapid temperature fluctuation with microclimates are the major factors in surface spalling. Since liquid water is a contributing factor, surface coatings that retard the migration of trapped water within the masonry wall will not enhance the performance of the masonry.

Replacement of the spalled bricks is recommended over further patching. Leaving spalled brick in place will continue to worsen the condition over time and affect adjacent brick. Patching material will fail in both the short term and long term, as evidenced by the existing patch failures.

REFERENCES

2. Oregonian, June 23, 1923.
3. Tucker Emhart Parabolic Metal Detector.
5. RILEM is an acronym for Reunion Internationale des Laboratoires d’Essais et de Recherches sur les Matériaux et des Constructions (International Union of Testing and Research Laboratories for Materials and Structures) located in Paris, France. The RILEM test conducted on Grant High School was performed to determine the hydrostatic pressure applied to the test area. This pressure can subsequently be converted into a velocity or wind-driven rain speed. A cylindrical tube is filled to the “0.0 mL” graduation, exerting a pressure of 1139.36 Pa, or 98.1-mph wind-driven rain. This test is used to identify a point of entry of moisture to measure a wall’s resistance to wind-driven rain, the masonry’s rate of moisture absorption, and the application and/or effectiveness of applied water repellents.
6. No visible signs of corrosion on the embedded masonry ties.