Feature

Determining Life Expectancy of In-Situ Slate Roofing

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INTRODUCTION

Hansee Hall, constructed in 1936, is the oldest continuously active residential building and also one of the largest residential structures, at 111,364 ft² (10,346.05 m²), on the University of Washington Seattle campus. Designed in the Collegiate Gothic style by John Graham and David Myers and supervising architects Bebb & Gould, it is a cast-in-place concrete structure with a multi-toned brick veneer, multi-lite steel windows, and a Vermont slate roof.

The four-story building with a partial basement and a crawl space features an H-shaped plan with wings (**Fig. 1**). Overall, the massing of Hansee Hall is complex, with many wings, bay and oriel windows, dormers, and steep rooflines throughout. The level of roof detailing is consistent throughout the building, featuring detailed ornamentation work at window bays, dormers, and parapets, and a central spire clad in chevron-patterned copper sheets.

Hansee Hall's original slate roof is a commercial standard slate roof composed of slate approximately $^{3}/_{16}$ in. (0.48 cm) thick laid in a Dutch lap pattern. Hip slates are smaller slates set in a comb-ridge method laid with butt joints and roof dormers with fantailed hip detail. Open valleys are copper. Copper slating nails in two sizes, 1½ in. (3.81 cm) at the field and 3¼ in. (8.26 cm) at the ridge, were used. Slate courses consist of various sizes ranging in width from 9 in. (22.9 cm) to 20 in. (50.8 cm) with a consistent length of 20 in. Tile colors range from grey to green, yielding to a red tone when weathered, as well as some purple accent slate.

Dormers on all elevations of Hansee Hall have walls and roofs clad in slate with exposed fluted copper sheet flashing, fluted copper sheet window surrounds, and fluted copper sheet profiles.

PROJECT SCOPE

In 2023, Hansee Hall's interior plaster walls and plaster ceilings were exhibiting signs of water intrusion, and the University of Washington was concerned that the water migration was from the 87-year-old slate roof. Peter Meijer Architect PC (PMA) was retained to review previous building enclosure reports, evaluate the existing conditions of the roof, and recommend a path to mitigate the water intrusion.

Of interest to the University of Washington was a request for PMA to provide a professional opinion on the "remaining life expectancy" of the existing slate roof system. In referencing National Slate Association publications, slate roofing industry standards recommend replacement when failure rates are approximately 20%.[7] PMA was unaware of any professional studies for slate roofs that included an evaluation of longevity based on laboratory testing data.

Since previous building enclosure reports were based on visual observations without in-depth knowledge of slate roof design, performance, and historical industry standard installation methods, PMA approached the process from both a research perspective and an as-built investigation perspective. Our first step was to commission a laser scan point cloud and photogrammetry record of the entire roof design, surfaces, and exposed conditions. Combining the dimensional accuracy of laser scan and precision of photogrammetry eliminated the need to physically access the entire slate surface and provided a means to document all visible deficiencies with an accuracy of $^{1}/_{8}$ in. (0.32 cm). These tools allow for more methodical in-office review of the roof components and provide a higher degree of accuracy for capturing deficiencies in difficult-to-access areas.

After the digital captures, PMA guided the selective removal, with the assistance of a

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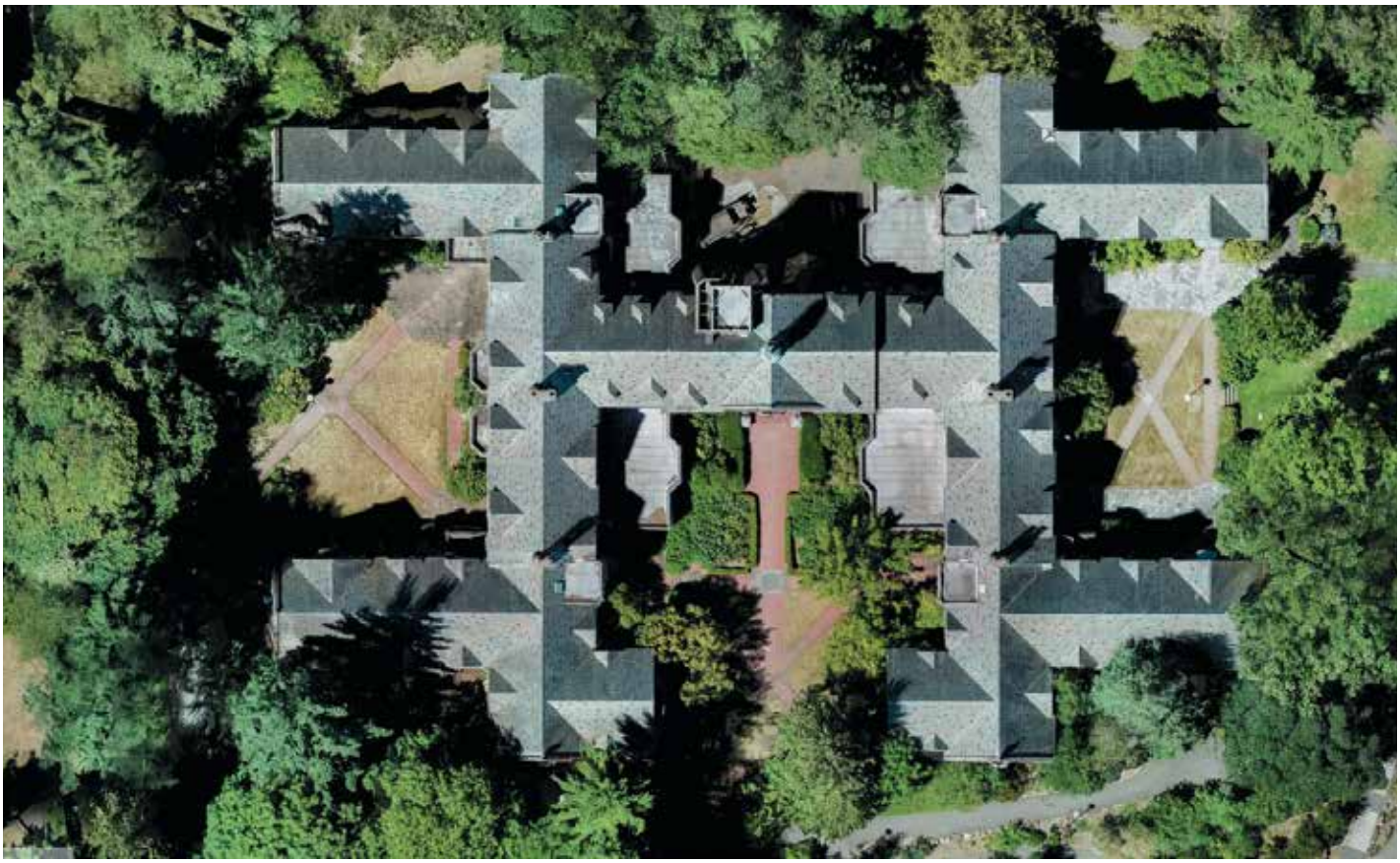


Figure 1. *Hansee Hall roof plan.*

premier slate roof contractor, of slate units in specific locations corresponding with different environmental exposures, different field locations, along the ridge, and adjacent to open valleys. The National Slate Association's *Technical Bulletin No. 7, Slate Roof Condition Assessment Surveys,* was referenced against PMA experience and standard methodology. PMA removed slate units in sufficient quantities to evaluate both deficiencies due to installation methods and provide units for laboratory testing.

Initial field observations indicated that the 1936 comb-ridge slates were installed incorrectly without an overlap, without elastic sealant, and with a ½ in. (1.27 cm)–wide gap along the entire length of the ridge, exposing the wood structural deck. From the ground, the gable ends of the roof appeared to have decayed material protruding from beneath the slate tile field. Upon further close observation, it was noted that a ¾ in. (1.91 cm) thick slate damp-proof course was set in mortar on top of the masonry veneer walls. There was no gable end edge flashing, thus exposing the bedding layers of the damp-proof course to weather and causing the cleavage planes to expand, shear, and fail.

Visually, the green slate that has changed tone to red appears to be more weathered

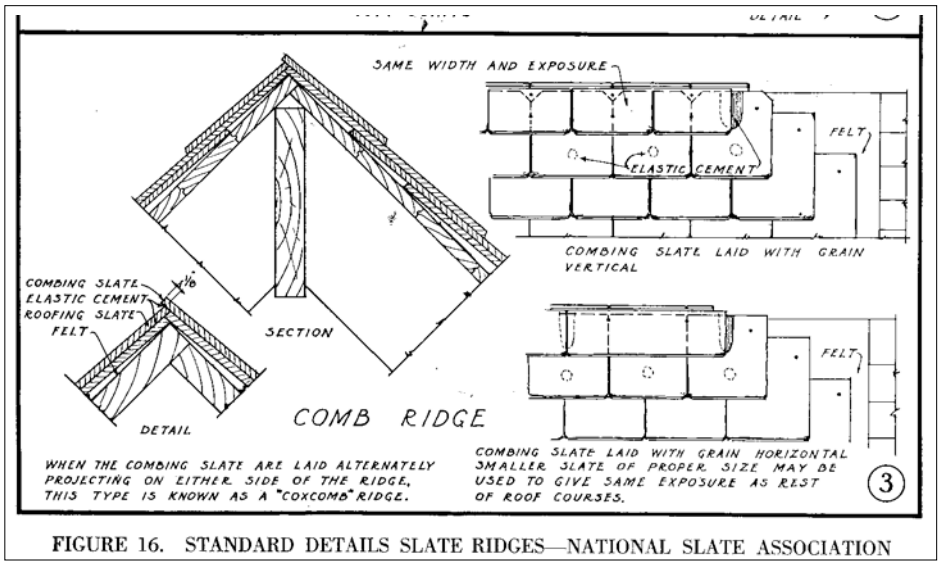


Figure 2. *1936 comb-ridge detail.*

than the other slate colors. In readily accessible roof areas, the slate roof field had numerous incorrect repairs, including face nailing, galvanized nails, and broken underlying slate courses, evidence of traffic on the slate without adequate protection. However, the only deficiency aligning with interior water intrusion was the open ridges at cross gables.

IN-SITU OBSERVATIONS

Existing copper nails pulled from slate were in good condition. Ridge nails were 3¼ in. (8.26 cm) long, and field nails were 1½ in. (3.81 cm) long. Previous repairs incorrectly used iron-based nails. Previous repairs also face-nailed some tiles and used flat copper retention bands in lieu of copper slate hooks (**Fig. 4**). Many areas had multiple incorrect repairs over time, including face nails,



Figure 3. *Existing ridge conditions.*



Figure 4. *Previous repairs.*



Figure 5. *Damp-proof layer.*

holes, iron fasteners, and other poor repairs. PMA observed cracked slate below the slate that was removed for testing. Due to previous repairs, it is likely some roof areas had more foot traffic, causing possible nonvisible damage and cracking to underlying slate tiles. The entire area will need to be replaced to ensure a successful repair.

There is significant rainwater drainage where the sloped roof intersects with the elevator tower, leading to ponding and backflow under the tile and below the copper flashing. The building paper is aged and brittle but appears in serviceable condition when undisturbed by repair work. During tile removal, damaged building paper was augmented with lead and copper sheets to protect damaged areas from water infiltration. The wood structure was visible under the building paper and appeared in sound condition. The built condition mirrors the historic drawings. There is no flashing at the transition from roof to gutter: The slate extends over the eave, and the gutter is attached directly to the top of the concrete structural wall.

PMA observed gable end conditions where a slate waterproofing layer was set in mortar below slate roof tiles. This layer is composed of a thick mortar layer placed on the sky-facing top of the masonry veneer. A ¾ in. (1.91 cm) to 1 in. (2.54 cm) thick slate tile, approximately 5 in. (12.7 cm) wide by 10 in. (25.4 cm) long, is set in the mortar as a waterproof layer (**Fig. 5**). The roof tile is set on top of the waterproofing slate. The bedding planes of the slate waterproofing layer are exposed to weather, leading to expansion and fraying of the slate layers. The condition is pronounced on south elevations and exposure to Seattle's heavy winter rains.

SLATE ROOF TESTING METHODOLOGIES

Slate roofs have been documented to last for 1,000 years. The oldest extant slate roof is the Saxony chapel in Bradford-on-Avon. Slate roofs originating from the same quarry as Hansee Hall are documented to be over 200 years old. Therefore, in theory, Hansee Hall's slate has a potential life expectancy of another 100 years. The challenge of relying on ASTM C406, *Standard Specification for Roofing Slate,* to correctly evaluate historic or aged slate is that the current test is designed for new slate recently cut from the quarry. All historic assemblies, from windows to wall systems, will fail modern ASTM testing. The tests, by themselves, do not provide accurate evaluations of historic assemblies, but they are good sources of empirical data.

A critical aspect of determining the life expectancy of archaic or older material is understanding the limitations associated with modern ASTM test methods. ASTM standards are not always accurate predictors of remaining slate life quality. As previously mentioned, the ASTM tests are designed for new, recently quarried slate. PMA used our experience and broadened our research into longevity by including testing means and methods from Europe and other countries outside the US with longer histories of slate testing. The standards in use on the market to certify slate are the European EN 12326, *Slate and Stone for Discontinuous Roofing and External Cladding* (parts 1 and 2), and the American ASTM C406/C406M-15, *Standard Specification for Roofing Slate,* including ASTM C120, *Test Methods of Flexure Testing of Slate, ASTM* C121, *Test Method for Water Absorption of Slate,* and ASTM C217, *Test Method for Weather Resistance of Slate.* Other countries have their own standards, such as the Chinese GB/T 18600 and the Indian IS 6250. Brazil, the second-largest producer of slate in the world, does not have its own roofing slate standard. Further compounding the varying results from each of the testing standards is that some studies have shown that there is a low correlation between expected service life and test results.

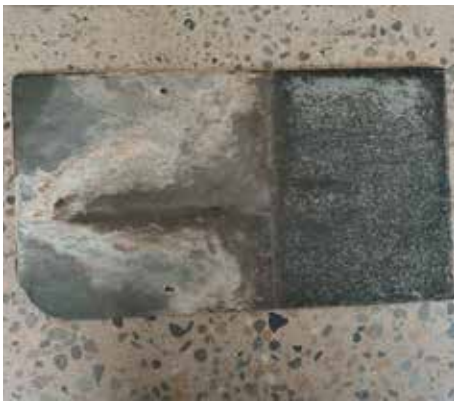


Figure 6. *Slate unit for testing.*

Water absorption testing is the only common test approach to all the test standards. However, the European water absorption results always yield a higher performance than the ASTM water absorption test results. This is due to the higher drying temperatures required of the European standard versus the ASTM standard. Higher drying temperatures remove water within the stone, and the temperatures are higher than any sustained temperatures reached in situ.

In addition, as slate ages, the interstitial water within the stone layers evaporates, increasing the ability of the slate to absorb more water without damage. Water absorption tests remain one of the essential tests for determining longevity in the field. Given the natural durability and low absorptive qualities of roofing slate, it is widely accepted that freeze-thaw test results have little to no impact on slate roofing lifespan.

TESTING

PMA sent slate samples (**Fig. 6**) to St. Lawrence Testing & Inspection Co. Ltd. in Cornwall, Ontario, to conduct standard grading according to ASTM C406, *Standard Specification for Roofing Slate,* including ASTM C120, *Test Methods of Flexure Testing of Slate,* ASTM C121, *Test Method for Water Absorption,* and ASTM C217, *Test Method for Weather Resistance of Slate.* Petrographic examination was also conducted, specifically looking for calcite content and the presence of carbonaceous ribbons.

The slate samples were tested according to ASTM C406 for testing natural roofing slate. This standard calls for three ASTM tests to be conducted in order to classify the "grade" (relative quality) of the slate: ASTM C120, *Breaking Load (Modulus of Rupture);* ASTM C121, *Water Absorption;* and ASTM C217, *Weather Resistance (Depth of Softening).* Grading from the results of these tests predicts the future estimated life of the slate. Grading estimates material lifespans as follows: Grade S1 = 75+ years, Grade S2 = 40 to 75 years, and Grade S3 = 20 to 40 years.

Submitted slate samples were taken from around the building, including two from the north-facing slope, three from the south-facing slope, three from the west-facing slope, and one from the east-facing slope. It is assumed that the east tile had previously been replaced since it was attached with a copper-wire slate hook and has the appearance of a newer slate. Four tiles selected appeared in better visual condition, and five tiles appeared to be in poorer visual condition.

TEST RESULTS

As shown in **Figure 7,** only two slate samples passed all the ASTM C406 tests and met Grades S1 and S2. These tiles were visibly in good condition and were located on the east and north elevations. The other seven samples did not pass the required 575 lbf (2.6 kN) breaking load minimum required under ASTM C120. Since the slate tiles are 87 years old, they were not expected to pass the testing standards required for new slate. The following results were interpreted by PMA with this in mind.

TABLE 1. Required test values for each slate grade per ASTM C406.

	ASTM C120 Breaking Min (lbf)	ASTM C121 Absorption Max	ASTM C217 Weather Resistance Max
GRADE S1	575	0.25%	0.002
GRADE S2	575	0.36%	0.008
GRADE S3	575	0.45%	0.014

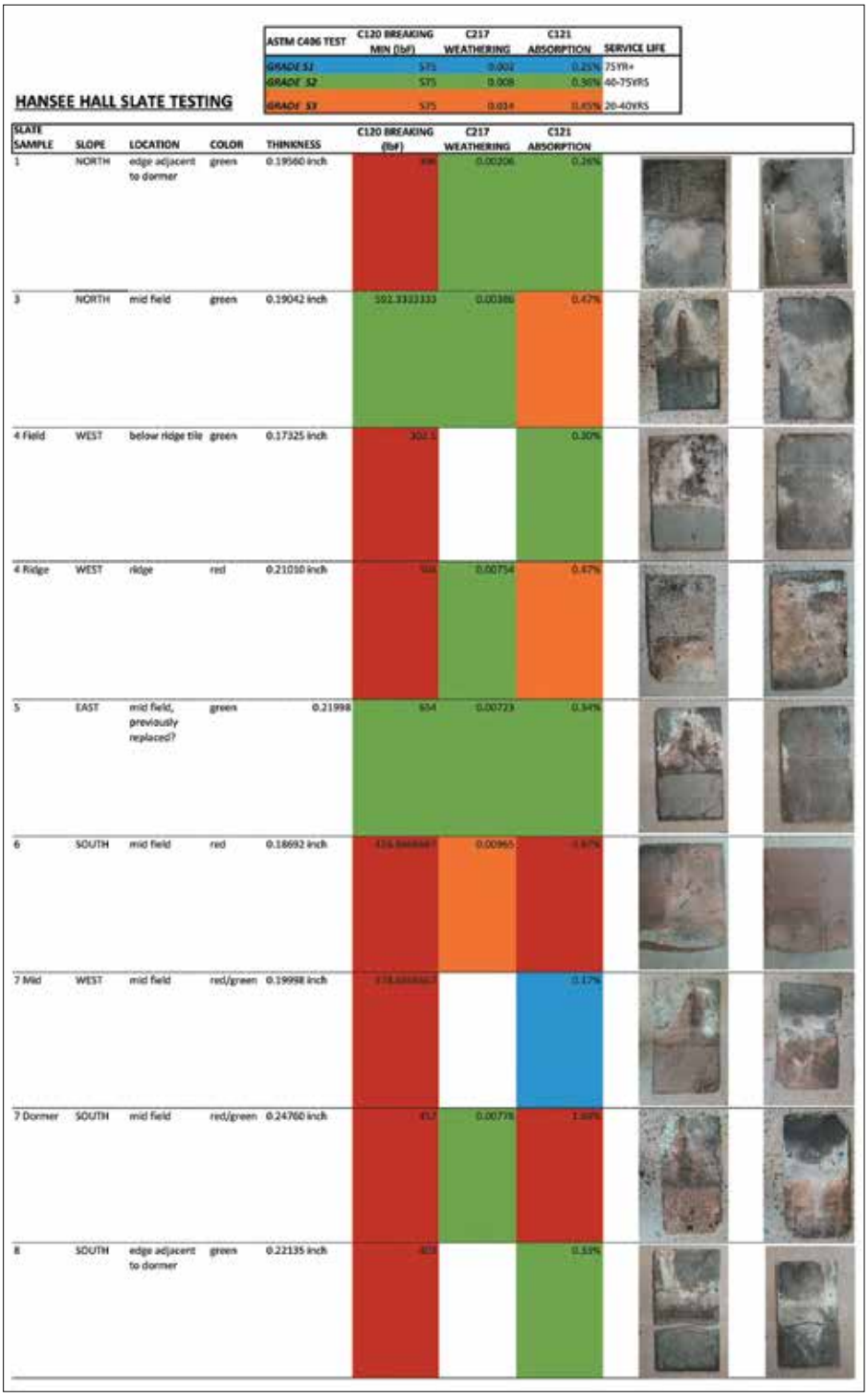


Figure 7. *Summary of overall results from ASTM C406 testing.*



Figure 8. *Summary of overall results from ASTM strength, weathering, and absorption testing.*

ASTM C120 BREAKING LOAD (lbf)

- All tiles tested
- 22% passed minimum 575 lbf (2.6 kN) required for S1, S2, and S3 (two out of nine tiles)

The results for the breaking load show an average decrease in strength of 26% compared to a newly quarried typical Vermont slate's original strength of 600 lbf (2.7 kN). The conversion from lbf to lb/ft² was used to evaluate slate capacity relative to typical code-required dead loads. The average breakage lb/ft² threshold is about 3,000 lb/ft² (144 kPA), well above the 300 lb/ft² (14 kPA) typically required for live roof loads. A study on the effect of freeze-thaw cycles on the bending strength of roofing slate tiles concluded that the mineral and petrographic microtexture of slate plays a more important role than strength testing in the prediction of the durability of slate.[4]

ASTM C121 ABSORPTION (Fig. 9)

- 11% met S1 (one out of nine tiles)
- 44% met S2 (four out of nine tiles)
- 22% were within 0.02% of meeting S3 (two out of nine tiles)
- In total, 78% met or were close to meeting Grade S3 or better (seven out of nine tiles)

Water absorption testing is the only common test approach to worldwide test standards. Water absorption tests remain one of the essential tests for determining longevity in the field. Of the slate samples tested for water absorption, one met S1, four met S2, and two were within 0.02% of S3. Two failed absorption grading tests. These results total approximately 78% at Grade S3 or better (minimum 20- to 40-year life expectancy).

ASTM C217 WEATHER RESISTANCE MAX (Fig. 8)

- Five out of nine tiles tested
- 20% met S1 (one out of five tiles)
- 80% met S2 (four out of five tiles)

CONCLUSION

As roof system observations and assessments were performed, and a review of the photogrammetry and laser scan was completed, it became apparent that the source of interior water did not result from an aged slate roof. Except for very specific locations, the slate roof was in good condition. Field tile failures were less than 4%. (As noted earlier, slate roofing industry standards recommend replacement when failure rates are approximately 20%.) PMA field observations included finding that original copper flashing systems were sound with no pinholes or galvanic corrosion noted. All copper sheets used for flashing, gutter linings, etc., were crimped by passing through heavy rolls to form $^{3}/_{16}$ in. (4.76 mm), V-shaped corrugations or ridges in the sheets in the direction of the short dimension following standard specifications of the period. Felt underlayment was in place, continuous, not broken but very brittle due to age. PMA did not test the underlayment for asbestos content (a common component of early underlayments) as hazardous material content was not a contributing factor of water infiltration. The construction means and methods conformed closely to the original design documents, allowing PMA to evaluate original design details for watertightness.

As a result of the field assessment preliminary findings, the University of

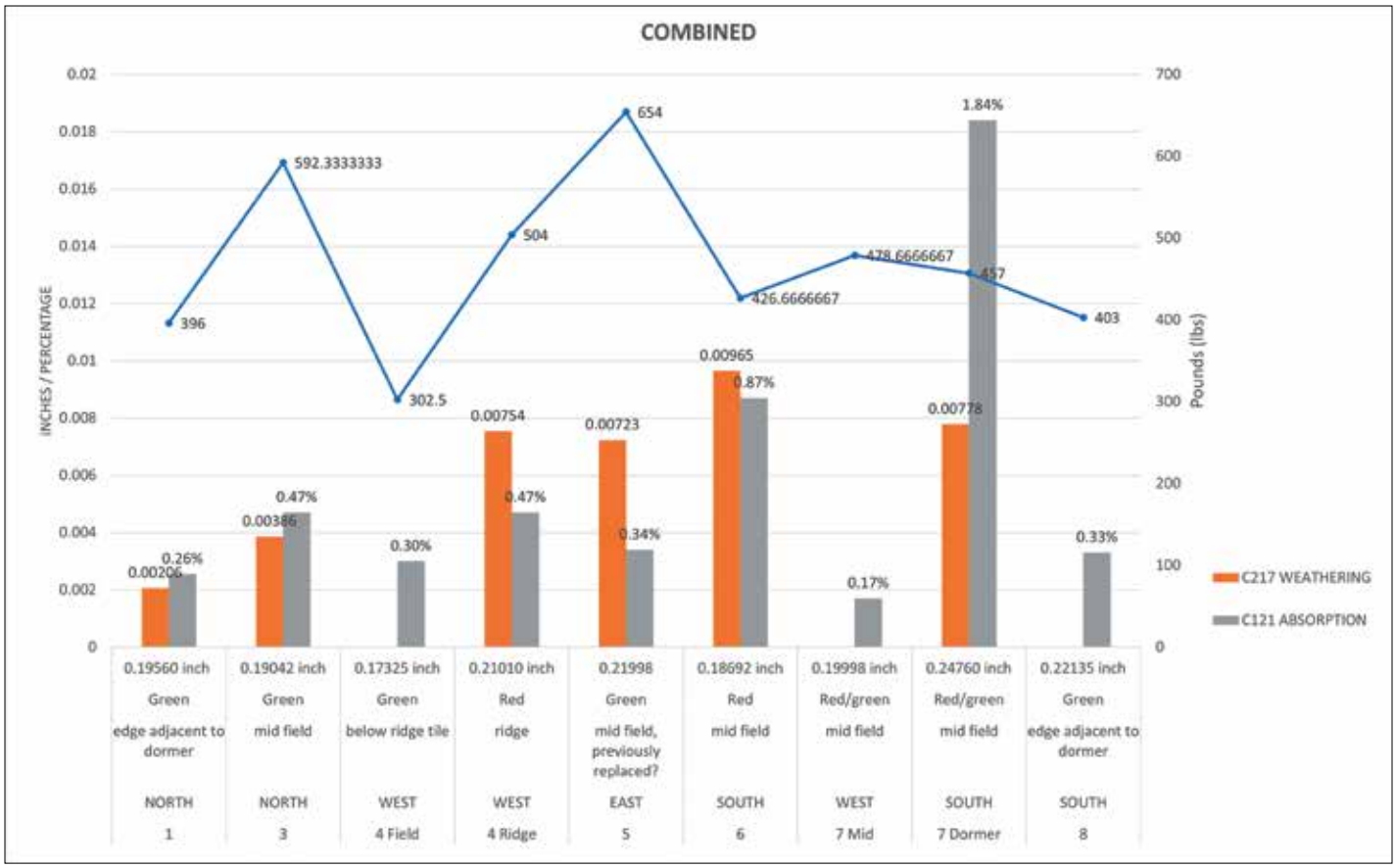


Figure 9. *Summary of overall results from ASTM absorption testing.*

Washington shifted its approach from a full roof replacement process to the question of what the remaining service life of the existing slate roof system would be. Would the system last another 20 to 25 years (the equivalent time of a typical new, non-slate roof system warranty)? To better evaluate future life expectancy, PMA augmented the on-site assessment with laboratory testing following ASTM C120 and ASTM C121. Based on ASTM recommendations and conversations with the testing lab, PMA removed 16 field slates from eight exposures around the building. The quantity of slate was removed from Hansee Hall in order to be evaluated in the lab to test for strength, absorption, and weather resistance. ASTM C406 establishes the "grade" of new roofing slate resulting from ASTM C120 and ASTM C121 testing methods. The grade ranges are as follows: Grade S1 = 75+ years, Grade S2 = 40 to 75 years, and Grade S3 = 20 to 40 years.

There are no field or lab tests that can predict the remaining lifespan of existing weathered slate. However, the ASTM C406 test results give a gauge of how the existing slate is performing. Based on statistical probability from the tested slate samples, Hansee Hall's slate roof tiles still have sufficient strength, weather resistance, and low water absorption to continue functioning as water-shedding roofing material for another 20 to 30 years, equivalent to slightly less than Grade 3 slate (20- to 40-year life expectancy).

PMA came to this conclusion by evaluating all the ASTM test results in comparison to relative performance. The average results from ASTM C121 (absorption) and ASTM C217 (weather resistance) were Grade S2, which has a minimum lifespan of 40 years. To factor in the decrease in the strength of slate (26% reduction), this reduction was applied to the minimum 40-year lifespan to reduce the average minimum lifespan to 30 years.

If the results are evaluated without the breaking load tests, 78% of the slate tested meets a Grade S3 or better (minimum 20- to 40-year life expectancy). Since the water absorption test is one of the essential tests for determining longevity, this is a good indication of the minimum remaining life expectancy of the majority of the roofing slate on Hansee Hall.

PMA's visual observation of Hansee Hall's slate roof system concluded the slate appeared in good condition, estimating 3% to 5% is broken, missing, or cracked. Typical industry standards recommend slate for replacement when there is a failure rate of 20% or more.

The test results and visual assessment led PMA to conclude that there is more life left in the slate, and repair should be considered instead of replacement.

PROJECT TEAM

Founded in 2003 with an exclusive focus on existing built infrastructure, including historic properties, PMA recognizes that each resource will have its own character-defining features, physically defined through the use of materials and construction techniques or emotionally and culturally defined through community-shared values. The diverse experience of our staff, including conservators, architects, preservation planners, and designers, combined with our 20-year expertise in state and local building codes, historic construction means and methods, along with familiarity with architectural styles and eras, gave the University of Washington a building enclosure firm able to translate the value of the existing historic resource into economic and longevity terms.

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ABOUT THE AUTHORS



PETER MEIJER

Peter Meijer, *AIA, RP, has over 30 years of professional architectural and building science experience on the assessment, restoration, and adaptive reuse of existing, recent past, and historic buildings for public agencies, higher education institutions, K-12 facilities, cultural and historic resources, and private owners. 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 building material performance and advocating for sustainable reuse of existing resources. He is routinely enlisted by clients for his expertise on how to successfully get through the regulatory historic review process.*



HALI KNIGHT

Hali Knight *has 10 years of professional experience, primarily with a focus on restoration and building enclosure design for existing and historic structures. While at Peter Meijer Architect PC (PMA), she has led many projects that include assessments and repair recommendations for historic materials such as masonry, slate, and terra-cotta. Many of PMA's projects use material testing and on-site evaluation as tools to direct building enclosure repair methodologies and priorities. In addition to restoration work, she has worked on several large-scale renovation projects that include seismic upgrades and tenant improvements.*

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