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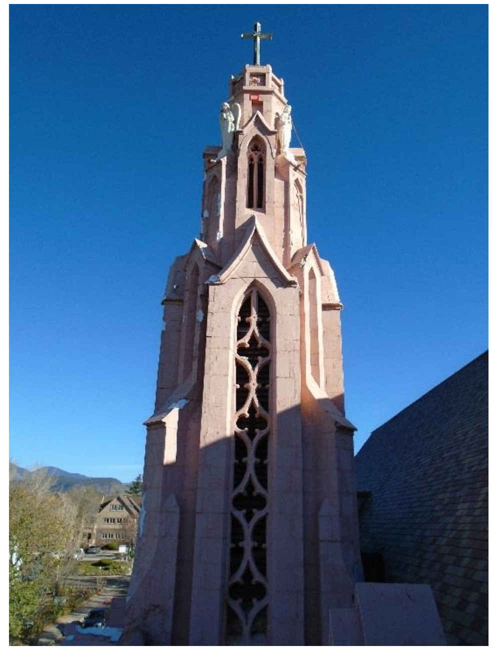

FACADE REHABILITATION PRE-DESIGN INVESTIGATION AND CONDITIONS ASSESSMENT

Nativity of the Blessed Virgin Mary Chapel
Flagstaff, Arizona
1 May 2017

SGH Project 167283

SIMPSON GUMPERTZ & HEGER
Engineering of Structures and Building Enclosures

PREPARED FOR:

Father Patrick Mowrer
San Francisco de Asis
Catholic Parish
1600 E. Route 66
Flagstaff, AZ 86001

PREPARED BY:

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1 May 2017

Father Patrick Mowrer
San Francisco de Asis Catholic Parish
1600 E. Route 66
Flagstaff, AZ 86001

Project 167283 – Facade Rehabilitation Pre-Design Investigation and Conditions Assessment, Nativity of the Blessed Virgin Mary Chapel, Flagstaff, AZ

Dear Father Mowrer:

Enclosed please find our final Investigation and Conditions Assessment report for the above-named project.

Sincerely,
SIMPSON GUMPERTZ & HEGER INC.

Carolyn L. Searls, P.E.
Senior Principal
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ABSTRACT

Simpson Gumpertz & Heger Inc. (SGH) have completed a conditions assessment of the facade of Nativity of the Blessed Virgin Mary Chapel in Flagstaff, Arizona. Roberta Wallace initially contacted SGH because a contractor had observed severe cracking and spalling of the precast concrete exterior cladding. We performed an investigation of the precast concrete and other facade and roofing materials. Our scope consisted of reviewing previous drawings and reports, performing an up-close conditions survey of the walls and roofs, removing samples and performing laboratory testing of the precast concrete, and providing our conclusions and recommendations in this report. We summarize our findings below.

Steep-slope roofs: The slate roofs are generally in good condition but deferred maintenance will need to be addressed if not immediately in the near future to prevent leakage and damage to the interior.

Low-slope roofs: The low-slope roofs are in fair condition but suffer from faulty and deferred maintenance. Deferred maintenance will need to be addressed if not immediately in the near future to prevent leakage and damage to the interior. When low-slope roofing is replaced, it should be designed with improved details for better durability and water tightness.

Precast concrete: The precast concrete is deteriorating primarily due to Alkali Silica Reaction (ASR). This is a chemical reaction between the alkali in the cement and the silica in the aggregate (both constituents of the precast concrete) that produces an expansive gel. The gel expands within the concrete blocks and produces cracks and spalls. ASR is a chronic condition that will continue to crack and spall the blocks; it can only be managed (not cured). Some precast blocks, specifically the gargoyles and some statues, are too cracked and deteriorated to remain and should be replaced in-kind. With the other blocks, there are two repair options:

1. Preservation: Repairs to retain blocks where feasible include – remove the existing coatings, repair cracks and spalls, repoint joints, and paint the blocks with a breathable elastomeric coating. This approach will only slow down the deterioration from ASR. Periodic repairs, including patching new cracks and spalls and recoating will be required every 7 to 10 years. While the up-front cost is lower than the replacement option, significant periodic maintenance will be required.

2. Replacement: The only other viable corrective action for ASR is wholesale replacement of the affected architectural veneer and features. The advantage of replacement is that it will indefinitely solve the problem. However, upfront costs will be much higher.

Volcanic rock and cement plaster walls: These walls are generally in good condition and need routine maintenance. However, at the top of the chimney there is some loose masonry and mortar that should be repaired, as it is a falling hazard.

Windows and doors: Windows and doors require new perimeter sealant, new glazing sealant at the protective glazing, and minor repairs. The stained glass windows show some signs of distress and should be evaluated by a stained glass conservator.

Our report contains these recommendations and prioritizes the work based on risk to the integrity of the building envelope and the estimated remaining life cycle of the material or system. Details, specifications, and other descriptive design information are required prior to formulating accurate repair pricing, bidding, and construction.

TABLE OF CONTENTS

Letter of Transmittal

ABSTRACT

CONTENTS			**Page**

**FACADE REHABILITATION PRE-DESIGN INVESTIGATION
AND CONDITIONS ASSESSMENT
NATIVITY OF THE BLESSED VIRGIN MARY CHAPEL
FLAGSTAFF, ARIZONA**

1. INTRODUCTION

1.1 Building Description

Completed in 1930, the Gothic style Nativity of the Blessed Virgin Mary Chapel (chapel) adopts cruciform plan with a large, asymmetrical buttressed tower topped by a cupola (Photos 1 and 2). The building walls are cast-in-place concrete finished with local coursed rubble volcanic rock and precast concrete cladding and ornamental features. A high-pitched gable roof covered with slate shingles surmounts the volcanic stone walls. Stained glass lancet windows punctuate the east and west walls of the nave and transept. The south elevation features an arched stained glass tracery window and wooden main entry doors framed by a precast concrete arch with inset branch tracery at the upper border (Photo 3). Other window openings include arched and flat-arched, leaded, casement windows with amber glass. Most of the window openings have been covered on the exterior with aluminum framed, plexi-glass protective glazing.

1.2 Background

In 2015, Roberta Wallace contacted Simpson Gumpertz & Heger (SGH) and reported that a building contractor employed by the chapelchapelhad observed cracks and spalling of the precast concrete exterior cladding and ornament. The contractor, RestoreGroup dba Preservation Arts (aka CK Arts Inc.) had been employed with the chapel through two distinct phases of work. The contractor first conducted a visual survey and conditions report of the exterior precast concrete. Subsequently, the contractor conducted immediate priority stabilization repairs to mitigate falling hazards. You provided documentation including the report and photos of the survey and temporary repairs to us.

The report provided a thorough initial overview of the range of deficiencies found on the precast concrete and conclusions as to the various potential causes of decay (e.g., entrapped moisture and freeze-thaw cycles). However, we noted that the contractor's conclusions were supported by limited visual observations only, and therefore, did not reach a conclusive answer about the underlying mechanism of decay found in the precast concrete. The contractor's observations also were limited to the precast concrete. Therefore, in our discussions with the chapel regarding the appropriate next repair design steps, we recommended an additional pre-design investigation to fully understand the cause and extent of problems with the entire building envelope including the underlying causes of the precast concrete deterioration.

The primary objective of this investigation is to fully understand the cause and extent of problems with the complete building envelope including the precast concrete and to ascertain appropriate recommendations for repairs. We conducted a field survey of the exterior building envelope and laboratory testing of precast concrete cores to determine building material conditions, defects, and potential modes of failure leading to leakage and/or deterioration.

To accomplish these objectives our scope of work consisted of the following:

- We reviewed available background materials (e.g., architectural drawings, reports).
- We conducted an up-close exterior conditions survey of the walls, ornament, and roofs including specifically the following building components: steep-slope slate roofs, flashing and gutters; low-slope roofs; precast stone and lava rock wall cladding and ornamentation; window and door opening perimeters; and limited interior surfaces such as walls that correspond to exterior deficiencies and potential leakage. We observed walls and roofs from the ground level and up-close from a boom lift. We conducted a limited interior visual survey of selected areas.
- We performed laboratory testing of five concrete core samples removed from the building. Laboratory testing included carbonation and chloride testing to determine the depth of carbonation. We conducted petrographic examination to look at the contents of the concrete, air entrainment, and potential forms of distress.
- We summarized our findings and recommendations in the following report. The report includes our repair recommendations and sets priorities for maintenance and repair to be included in a rehabilitation program.

2. INFORMATION FROM OTHERS

During our site visit we discussed building maintenance history and issues with building staff. Maintenance staff reported that:

- Clear water repellants have been applied to the volcanic rock in the past.
- We understand water enters the basement during heavy rains and is directed out of the interior space through a trench.
- The operable windows on the north elevation and northwest elevation of the rectory were sealed shut and the stained glass was removed in order to prevent vandalism and potential water and air leaks. We understand the owner does not wish to restore these windows to be operable again.
- Maintenance staff notified us that they replace the mastic on the east low-slope roof adjacent to the lancet windows approximately once per year (due to leakage). We understand that they have not observed additional leaks into the interior below these windows since they began replacing the roof mastic.
- The lancet windows on the east and west elevations were last re-glazed prior to the mid-1980's when current maintenance staff began working at the Chapel.

The owner provided a conditions survey report of the precast concrete from RestoreGroup dba Preservation Arts (aka CK Arts Inc.) (CK Arts: 15 May 2015). In April 2015, the contractor conducted an up-close (hands-on) visual survey and stabilization of the precast stone and volcanic rock. Incipient spalls were removed and painted over to prevent fall hazards. The report contained the following pertinent information:

- General deterioration was concentrated around the bell tower.
- Over time the precast blocks have received multiple applications of repair mortars and coatings.
- The coatings have "trapped moisture inside the substrate below the surface." During freeze-thaw cycles, the interior moisture freezes, expands and breaks down the portland cement matrix of the precast stone causing loss of the inner substrate material. The contractor provided photos of freeze-thaw examples that show internal degradation and scaling of the precast concrete typical of freeze-thaw deterioration. Photos also illustrate delamination of coatings and efflorescence.
- Internal corrosion of rebar also contributes to the decay of precast features. The report depicts a statuette and gargoyles with spalling concrete caused by corroded rebar. The report did not draw any conclusions as to the cause of corrosion.

- The report implies that that masonry decay is due to the application of “elastomeric coatings” though it does not demonstrate through visual examination or petrography how many layers of paint may have been applied or how thick.

- Based on initial review, the report recommends: removing the paint coatings, fully assessing damage, repairing precast units to remain, and replacement of up to 50% of the precast blocks with new matching units. Furthermore, the report recommends the installation of caulk and flashing at appropriate locations (though it didn’t say where). To enhance resistance to moisture penetration, the entire facade should be treated with a penetrating water-repellant. The report also recommends applying penetrating rust inhibitors and silica reactive consolidants to blocks that will be retained.

The contractor’s conclusions were supported by limited visual observations only. Based on our review of the submitted photos, we agree freeze-thaw is likely related to some of the decay. However, visual and laboratory analysis evidence also supports that other modes of decay are at work and may be more detrimental to the concrete.

The owner provided us with historic architectural drawings of the chapel entitled: “Chapel of the Nativity” by Emmet G. Martin, September 14, 1929. There are fourteen total sheets consisting of general plans, elevations, enlarged elevations, a window/door schedule, and an electrical layout. We have the following comments on the drawings:

- There was no cover or index sheet so there is no way to confirm whether this is a complete set. The set lacks enlarged structural and architectural details including how the precast blocks are anchored.

- The building foundation and tower walls are reinforced concrete walls.

- The architectural drawings require the cast stone contractor to submit shop drawings for all stone work and jointing.

3. OBSERVATIONS

SGH engineers conducted a visual survey of the walls and roofs November 7 and 8, 2016. We obtained up-close access to select portions of the walls and roof eaves on the south, west and east elevations using a boom lift. We accessed some low-slope roofs and select window openings using ladders. We did not survey every window opening as a window condition survey was not a part of our scope of work. In general, the conditions observed at select windows were assumed to be typical.

3.1 Interior

We observed the following conditions on the interior of the building:

3.1.1 Basement

- Efflorescence and water stains on the basement walls and floor (Photo 4).

3.1.2 Nave, Transept, Vestry, and Balcony

- Water stains on the interior walls below the lancet windows on the east and west elevations of the nave and balcony (Photos 5 and 6; Figure 1, (a, b)).
- Paint peeling and staining on the surface of the interior wall and coating at the west elevation of the nave (Photo 7; Figure 1, (c)).
- Water damage at the ceiling of the east alcove enclosing the baptismal font (Photo 8; Figure 1, (d)). Based on discussion with building maintenance personnel, we understand portions of the plaster previously fell from the ceiling at this location due to water damage (Photo 9).
- Staining and paint peeling at the ceiling and walls of the west entry vestibule (Photo 10; Figure 1, (e)).
- Minor staining and paint peeling on the northeast ceiling of the vestry adjacent to the support column (Figure 1, (f)).
- Horizontal cracks in the walls throughout the nave (Photo 11).
- Water damage and deteriorated drywall behind a statue in the east transept (Photo 12; Figure 1, (g)).
- Water damage and staining at the southwest corner of the balcony wall (Photo 13; Figure 1, (h)).

3.2 Exterior

We observed the following conditions on the exterior of the building:

3.2.1 Steep-slope Roofs

- The steep-slope roofs are primarily covered with multi-colored, slate roof tiles set in a graduated pattern. The roofs generally feature lead coated copper sheet metal ridge caps and open valleys lined with sheet metal. Overall, the slate tiles are in good condition (Photos 14 – 16).

- At isolated locations, we observed missing/displaced roof tiles exposing the underlayment (Photos 17 and 18). In one location, the roof sheathing was visible (Photo 17).

- Some repairs have installed tiles with improper or insufficient laps. Photo 19 shows an overly exposed joint lap due to the narrow width of the above tile (Photo 19).

- In isolated locations we observed exposed fasteners through the roof tiles (Photos 19 and 20). Some of the fasteners also appear to be steel (ferrous) roofing nails.

- Broken roof tiles have often been repaired by salvaging, turning, and reinstalling the tiles (Photo 21). The exposed fastening holes are visible in the middle of the exposed face of the tile.

- We observed underlayment under the slate tiles in several locations. The underlayment consisted of (in different locations) either roofing felt or bituminous roofing (Photo 22).

- There are no rake or roof edge flashings at the roof edges. In general, wood fascia boards are fully exposed at these locations (Photos 22 – 24).

- The main roof features a copper sheet metal ridge cap. The ridge cap is buckling and warped in some locations leaving a small gap between the cap and tiles. We observed a split in the sheet metal (Photo 25). There are several unsealed screw fasteners penetrating the surface of the sheet metal.

- Confined rakes around buttresses and parapets incorporate sheet metal step counterflashing. The step-flashing is set in recessed, sealant-filled, reglets formed out of the precast stone joints (Photos 26 and 27). The flashing generally was in good condition, but the sealant was in fair to poor condition. Sealant repairs were often surface applied.

- There are sheet metal crickets behind the buttresses with sheet metal counterflashing integrated with the rake flashing. Some of the seams joining the counterflashing were bent open at the side (Photo 27).

- The main steep-slope gable roof drains into built-in gutters with a copper sheet metal lining. The gutters drain through open sheet metal copper scuppers fed through precast gargoyles (Photo 28). We observed significant staining and some buckling of the metal around the connections of the scupper to the gutters. Some of the connection(s) do not appear to be water tight.

- In some locations, heat-trace wiring in the gutters and scuppers appears to be loose (Photo 28).

- The gutter edges are sagging in the middle of the runs between buttresses and scupper outlets (Photos 29 and 30). There are no snow guards at the eaves (Photo 30), but heat-trace wires are installed in the gutter liners and around the buttress flashing (Photo 31).

- Vestry rooms appended to the rear of the chapel are covered by steep-slope shed roofs that terminate at the stone walls of the main chapel. The lower roofs are finished with slate tiles (on the west elevation) and asphalt shingles (east elevation) (Photos 32 and 33).

- Most pitches of the transept and vestry roofs, and the back portion of the main roof (e.g., portion north of the transept) do not incorporate gutters (Photos 24, 34 and 35).

- A portion of the vestry roof on the east elevation drains to a gutter that has become detached and now maintains a negative slope from the outlet (Photo 36).

- The lower vestry roof terminations at headwalls and inside rakes are counterflashed with sheet metal set in a recessed saw-cut, sealant-filled, reglets cut into the volcanic stone walls. In several locations, the original application of sealant was experiencing cohesive failure. However, in most locations the reglet has been patched over with multiple surface applications of liquid flashings, black and grey roofing mastic, and/or sealants (Photos 37 – 39).

- Similar conditions exist at the counterflashing around a stone chimney that projects into the sloped roof plane (Photo 39). A cricket is formed behind the chimney. There is patching mastic on the base flashing at the roof-to-wall turn-up. There are wrinkles in the base flashing and it does not appear well adhered to the wall or cant strip. A wood frame scaffold is installed on the roof in the same location.

- On the east side, the steep-slope vestry roof partially drains directly on to the low-slope roof of the addition, with another portion of the vestry roof extending below the low-slope roof forming a closed rake along the wood siding wall of the addition. There is sheet metal counterflashing applied to the surface of the wood siding that is sealed at the top with a flush sealant joint (Photo 40). We observed exposed fasteners through the flashing and some adhesive failure of the sealant.

3.2.2 Low-slope Roofs

- A low-slope built-up roof with mineral surface cap sheet surmounts a contemporary one-story addition on the north east side of the chapel (large low-slope roof) (Photo 41). Nearby, a distinct L-shaped low-slope built-up roof covers a small appendage to the south side of the east transept (small low-slope roof) (Photo 42). The low-slope roofs share similar roofing materials and construction characteristics. Where applicable, we have therefore grouped some observations together.

- In general the built-up roof membranes are in good condition however, the membrane systems do not contain distinct base flashings or sheet metal counterflashings (Photos 41 and 42).

- In general, the roof membranes turnup the walls 6 – 8 in. high and terminate with liquid counterflashing and/or grey roof mastic (Photos 41 and 42).

- At the large low-slope roof there is a skylight where the curb has less than an 8 in. roof membrane turnup (Photo 41).

- At the large low-slope roof, the roof membrane turn-ups are less than 8 in. high at several window openings. The roof membrane terminates at the window glazing and conceals the window sill (Photo 43). There are areas where the flashing mastic has been patched with sealant.

- At the small low-slope roof, the roof membrane laps up and on top of a parapet wall (Photo 44). In some areas there are wrinkles and the membrane does not appear well adhered. We could see that the membrane was split at an outside corner. The seam at the same corner has been patched with roof mastic.

- In multiple locations the roof membrane counterflashing has been patched over with multiple surface applications of liquid flashings, black and grey roofing mastic, and/or sealants (Photo 45).

- In isolated locations, there were cracks in the liquid flashing (Photo 46), some in areas that potentially correspond to staining seen on the interior ceiling and walls.

- At the small low-slope roof, the roof membrane turn-ups are less than 8 in. high at several window openings. The roof membrane terminates at the precast window sill which is coated with peeling liquid flashing (Photo 47).

- The small low-slope roof is drained through a 10 in. wide scupper in the parapet. The large low-slope roof drains to hung gutters.

3.2.3 Precast Concrete, Volcanic Rock Masonry Walls, and Cement Plaster Parge Coat

- The chapel features precast concrete cladding and architectural ornamentation. A prominent feature of the building, the bell tower, is comprised entirely of precast concrete blocks (precast blocks) forming individual features such as buttresses, tracery, ashlar veneer, and a cupola (Photos 48 and 49).

- Other precast blocks are found at the buttresses, window and door surrounds, window sills, coping at parapet walls (at gable ends), and a water table (Photo 50).

- In general, the majority of deficiencies we observed were found on the precast blocks that comprise the tower veneer (Photo 51). However, we observed most types of deficiencies on all blocks though with less frequency than at the tower. Our observations that follow are described in general (as they apply to all precast blocks) unless otherwise noted.

- On the tower and buttress precast blocks, we observed vertical, horizontal and map cracking (Photos 51 – 54). There are open cracks that range from 0.012 in. to greater than 0.040 in. wide (Photos 55 and 56). Approximately 75% or more of the tower blocks, and 50% of the buttress blocks, contain cracks or spalls.

- In general, the cracking found at blocks lower on the building such as at window surrounds and the water table were not as frequent or severe. Many of the cracks were less than .012 in. wide (Photos 57 and 58). The number of blocks that are cracked or spalled may be as low as 5%.

- Some of the cracks were repaired/filled or partially filled with epoxy (Photo 59).

- A statuary ornament we observed contained an open vertical crack through the shoulder and head (Photo 60).

- In the vicinity of vertical, horizontal, and map cracks, we found isolated incipient spalls on the precast surface (Photos 61 and 62). The spalls were located within the field of blocks and at corners.

- Multiple spalls have been removed, leaving exposed precast block substrate (Photos 63 and 64). Many of the spalls have been painted over as a form of repair (Photo 65).

- The gargoyles are severely damaged due to severe cracking and spalling. Several of the ornaments are missing their heads (Photo 66). Cracks can be seen to extend through the entire neck of specific gargoyles (Photo 67). On some of the gargoyles, spalling or missing parts of the feature has exposed the rebar. The gargoyles contain a single piece of steel rebar that extends down the core of the ornament. We could see that the steel was corroded (Photo 68).

- All of the precast blocks have been painted with some areas showing multiple layers of paint coatings. In multiple areas of the wall the paint coating(s) are bubbling (Photo 69 and 70) and peeling (Photos 71 and 72).

- The coatings are eroded away at the window sills (Photo 73).

- In general, the coatings have covered the mortar joints between individual precast blocks. However, in some areas the coatings are deteriorated at the mortar joints exposing the mortar and the mortar has subsequently deteriorated (Photo 74).

- At select window sills and the cupola dome, sky facing mortar joints are covered with lead joint covers set in sealant or mortar (Photos 75 and 76). In general the sealants were experiencing adhesive and cohesive failure.

- The blocks forming the “roof” of the cupola are cracked (Photo 76).

- A metal cross with a painted galvanized sheet metal base surmounts the cupola. The paint is peeling (Photo 77).

- In general, the volcanic rock masonry and mortar pointing was in good condition.

- In one isolated location, we observed a horizontal open crack (> 1/32 in. wide) extending through mortar joints and one small stone (Photo 78). Isolated mortar joints were cracked or deteriorated (Photo 79). Some isolated examples of repointing overfill the mortar joints. This results in mortar that is floated onto the surface of the rusticated surface of the volcanic rock (Photo 80).

- Mortar parging and brick and stone rubble coursing at the top of the chimney are spalled and broken (Photo 81).

- On the north elevation, the concrete foundation is exposed and coated with a thin parge coat of cement plaster. The cement plaster is cracked and spalled in several locations (Photo 82).

3.2.4 Windows and Doors

We conducted a limited visual survey of window and door openings in order to establish an understanding of typical conditions. We observed the following conditions:

- Lancet windows glazed with leaded stained glass comprise the primary window openings. A majority of the windows are covered on the exterior with plexi-glass protective glazing set in aluminum frames (Photo 83).

- Leaded casement and leaded amber or obscure glass windows are typically found in support spaces of the chapel (Photos 84 and 85). Some of these windows contained plexi-glass protective glazing set within the steel framing (Photo 84).

- At all windows we observed, there was adhesive failure of the perimeter sealant joint between the outer glazing frame and the precast surround (Photos 84 and 86).

- There was often adhesive failure of the sealant joint (glazing joint) between the plexi-glass and aluminum frame (Photo 87). In many locations the glazing sealant (joint) was deteriorated or missing (Photo 88).

- We observed a stained glass panel up-close from the interior. Some of the lead cames were sagging and broken. Several glass panels were bowing. The glazing putty was brittle and deteriorated. At one panel we counted at least three broken pieces of glass.

- At multiple doors there was either no sealant joint between the wood frame and precast surround or the existing sealant was experiencing adhesive failure (Photos 89 and 90).

- At one isolated location on the west elevation, the exterior wood trim around the door frame is checking, split, and detached (Photo 91).

- On the west elevation, the base of a door frame is rotted (Photo 92). The perimeter sealant between the door frame and precast surround is deteriorated.

- The threshold at the west entry door is reverse sloped into the interior space where there is evidence of water stains (Photo 93).

4. SAMPLES AND LABORATORY TESTS

We removed five concrete core samples from select locations of the precast concrete blocks for observation and testing in our laboratory. We removed the samples from different elevations and locations of the building in order to gain a variety of weather exposures. Furthermore we selected samples from concrete blocks with varying levels of deterioration (e.g., cracking) so that we may compare results. Samples # 1 – 4 were removed using a core drill and sample #5 was cut out of a block. The samples are as follows:

Sample #1: Sample #1 is a 3 in. diameter core removed from an ashlar block on the west elevation of the bell tower. In general, the block was intact with some paint bubbling and peeling. Photos 94 and 95 illustrate the block prior to removal.

Sample #2: Sample #2 is a 3 in. diameter core removed from an ashlar block on the south elevation of the bell tower. The block contained some cracking and paint deterioration. Photo 96 illustrates the block prior to core removal.

Sample #3: Sample #3 is a 3 in. diameter core removed from a coping block integrated with a buttress on the west elevation. The block contained some cracking and paint deterioration. Photo 97 illustrates the block prior to core removal.

Sample #4: Sample #4 is a 3 in. diameter core removed from a block that originally surmounted a buttress on the south elevation. We understand that the block has been on the ground for approximately a year after falling from near the roof parapet during a lightning strike. The block contained cracking, spalls, and paint deterioration. Photos 98 (The block pictured in the lower half of the photo) and 99 illustrate the block prior to and during core removal. This sample was not utilized in the laboratory for testing.

Sample #5: Sample #5 was cut with a masonry saw from the same block described above. Photo 100 illustrates the block and sample during removal.

In our laboratory, we performed petrographic examination (ASTM C856 – Standard Practice for Petrographic Examination of Hardened Concrete), density absorption (ASTM 642 – Standard Test Method for Density, Absorption, and Voids in Hardened Concrete), and chloride testing (ASTM C1152 – Standard Test Method for Acid-Soluble Chloride in Mortar and Concrete) on select samples in order to gain a better understanding of the potential processes at work in concrete deterioration.

The pertinent results are summarized as follows and in Table 1 below:

- The samples are covered with a paint layer that is nominally 2 – 5 mil thick. The paint layer generally exhibits a poor bond with the concrete.

- Colored mortar (portland cement and sand) of varying thickness and layers (1 – 2 layers) forms the outer layer of the concrete samples.

- Samples #2 and #3 contain a 3/18 in. – 7/16 in. inner (second) layer of mortar that contains micro-cracks oriented parallel to the exterior face. The micro-cracks are representative of damage from freeze-thaw cycling. However, the mortars were tightly bonded with the substrate concrete.

- The concrete samples do not contain air entrainment (which protects against freeze-thaw damage). While we only observed freeze-thaw damage in the mortar layer, if the blocks become saturated and frozen, freeze-thaw damage will also occur in the concrete.

- Petrographic examination found that the samples contain evidence of alkali-silica reaction (ASR). ASR is a chemical reaction between alkalis in the cement and certain susceptible aggregates. The reaction forms alkali silicate which absorbs water to form a gel that exerts pressure on the surrounding material (causing cracks and spalls).

  - Sample #1: two air voids are partially filled with deposits that resemble ASR gel (we could not identify the source of the gel, however).
  - Sample #2: deposits that resemble ASR gel (we could not identify source however) and micro-cracking.
  - Sample #3: coarse aggregate particle of rhyolite with high density of internal cracks and areas of internal porosity that appear to be indicative of partial dissolution.
  - Sample #5: using scanning electron microscopy with energy dispersive spectroscopy (SEM-EDS), we confirmed that the white deposits that fill the cracks extending through the dacite particle and surrounding paste structure consist of ASR gel. We also confirmed that the layered white deposits that completely fill an entrapped air void located adjacent to the dacite particle consist of ASR gel.

- The concrete contains a moderately large amount of air voids (irregular air pockets). The high permeability of the concrete allows the ingress of water, which promotes deterioration due to alkali-silica reaction (ASR) and freeze-thaw.

- Samples 2 and 5 were tested for chloride ion content. Sample 5 contained higher concentrations of chlorides though the sample had been on the ground for some time and may have been exposed to additional chloride after removal from the structure (i.e., road de-icing salts). However, the outermost sampling depth of Sample 2, removed from the bell tower, has elevated chloride levels. The effect of elevated chloride is increased risk of corrosion of embedded steel and increased severity of freeze-thaw damage.

- In all the samples we examined, we observed carbonation of the paste at a depth from 1/2 in. to 1-5/8 in. from the face of the concrete. Reinforcing steel in carbonated concrete is more susceptible to corrosion.

Table 1 – Summary of Lab Observations

<table>
<tr><th>Sample No./ Location</th><th>Paint</th><th>Outer Mortar</th><th>Inner Mortar</th><th>Concrete – None have air entrain.</th></tr>
<tr><td>1/
Bell Tower: core from west elevation intact ashlar block with paint deterioration</td><td colspan="3">C642, Absorption, test. No observations conducted on outer layers.</td><td>Samples 1, 3, and 5 similar, C642-23% volume of permeable pore space = high, confirms high porosity;
ASR – Minor</td></tr>
<tr><td>2/
Bell Tower: core from south elevation cracked ashlar block with paint deterioration</td><td>3 – 5 mils, poor bond</td><td>20 – 40 mil Pink; microcracks parallel to exterior face; freeze/thaw damage</td><td>3/16 in. – 5/16 in.; micro-cracks parallel to exterior face, from freeze/thaw; tight bond with substrate conc.</td><td>Different than 1, 3, and 5; 6-7% air content-entrapped air voids; one micro-crack fractures fine aggregate; deposits resemble ASR;
ASR - Minor</td></tr>
<tr><td>3/
Core from west elevation buttress block with cracking and paint deterioration</td><td>2 – 5 mils, poor bond</td><td>20 – 30 mil Pink; microcracks parallel to exterior face; freeze-thaw damage</td><td>1/4 – 7/16 in. thick; maroon color; micro-cracks parallel to exterior face, from freeze/thaw; pocket of red patching mortar; tight bond with substrate conc.</td><td>10-11% air content – entrapped air voids; porous=water infill; one coarse ryhyolite particle with high density of cracks, internal porosity=ASR;
ASR - Minor</td></tr>
<tr><td>4/
Core from block that fell from buttress; had been on ground for approx. one year</td><td colspan="4">Not Used</td></tr>
<tr><td>5/
Sample cut from block that fell frombuttress; had been on ground for approximately one year</td><td colspan="3">SEM—EDS only. No observations on outer layers.</td><td>Coarse aggregate particles volcanic igneous rock; network of cracks through dacite particle; entrapped air void in cracks filled with white deposits; SEM-EDS confirms particles consist of ASR gel;
ASR – Significant</td></tr>
</table>

See Appendix A – Lab Report for a full accounting of the laboratory observations, test results, and discussion regarding our testing and examination of the samples.

5. DISCUSSION

5.1 Interior

We observed at least two locations of vertical staining under lancet windows (Photox 5 and 6, Figure 1, (a) and (b)). This type of staining could indicate window leakage or condensation. Building maintenance personnel did not report active leakage (during rain) at these locations. Furthermore, given that the windows contain protective glazing on the outside and there are no condensation trays, the evidence would suggest condensation is responsible. However, we observed that exterior protective glazing sealants are deteriorated and that in general the stained glass glazing putty is deteriorated. Though extra protective glazing is in-place, it is unlikely the glazing systems are watertight. See our discussion below on windows for further information regarding the condition of the protective glazing and stained glass.

Several of the interior staining locations we observed including plaster staining illustrated in Photos 8 and 9 (Figure 1, (d)), and 12 (Figure 1 (g)) are evidence of previous roof leakage. Based on interviews with building maintenance staff, both locations on the east elevation in the vicinity of the transept are associated with previous leaks in the roofs at the intersection with the masonry walls. At the low-slope roof (corresponding to location (g)) we observed a lack of base flashings which can stress the roof membrane at corners and up-turns. Furthermore, the counterflashing system only consists of liquid counterflashing. In general, at both locations counterflashing sealants were cracked and deteriorated and were often patched with layers of roof sealants/mastics. Based on discussions with maintenance personnel, application of the mastic at the counterflashing reglets has helped stem the leakage. However, we note that the layering of multiple sealants and mastics can lead to bonding issues and deterioration problems of the materials. In general, the sealants are spread over the joints with profiles that do not conform to manufacture or industry standards. Most industry standards including the National Roofing Contractors Association *Roofing and Waterproofing Manual* recommend sheet metal counterflashing at roofing turn-ups.

An entry vestibule located at the northwest corner of the building contains staining and peeling paint on the ceiling and walls (Photo 12, Figure 1, (e)). There is no active leakage reported in this location but the stains are suggestive of water damage. Above this area on the roof we observed face nailed roof tiles (Photo 20) and some roof tiles with improper laps (Photo 19). Nail heads that are left exposed and improperly lapped tiles can act as point of water entry. The exposed nail acts as a direct water conduit. Water passing through improper laps gains access to the underlayment where it accelerates deterioration and can gain access to other nail heads if left exposed on the underlayment. This area should carefully be monitored for leakage until the roof is properly repaired.

Staining on the upper interior southwest wall of the balcony is located under the built-in gutter servicing the main roof, and may be indicative of current or former leakage issues at that location (Photo 13, Figure 1, (h)). Maintenance personnel did not report active leaking at this location. At the gutter location on the roof we observed gaps between the scupper connection and gutter lining. Water leaking though this joint could gain entry into the masonry or wall cavity resulting in the observed staining. It is likely that water testing and observation would be required to confirm active leaking.

We observed some isolated minor paint peeling and stains on the upper back wall of the vestry hall (Figure 1, (f) and in the Nave along the lower west wall (Photo 7, Figure 1 (c)). No active leakage was reported at these locations and the stains are not located under windows or previously reported leak locations. With masonry clad concrete walls, through-wall seepage is always a remote possibility. Further monitoring and water testing would be required to confirm the source of the deterioration.

In summary, in the above-grade spaces there is evidence of water infiltration and minor damage. Based on interviews and preliminary investigation, none of the damage appears to be related to active leakage but is instead related to previous roof leakage that has been repaired. Nevertheless, in some areas such as under the roof-to-wall intersections and gutters that have been repaired, the staining are signs of potential leak trouble that could reoccur. Other areas of staining, such as the vestibule under the steep-slope roof with exposed nail heads will need to be closely monitored and the roof repaired as early as possible. Additional related discussion is found in the following "Roofs" section. When or if the lancet windows are restored, upgrades should include interior condensation trays at the sill to prevent staining at the wall below.

While the below-grade is generally out of the scope of our study we can make a few general remarks based on our interior observations of staining there. We observed staining and efflorescence on the basement walls and floor. From discussions with building maintenance personnel we understand that water enters the space during heavy rains. Efflorescence occurs when soluble salts are brought to the surface by moist conditions, in this case most likely the periodic leakage that occurs. A trench diverts water out of the space. Based on current limited programming needs and use, the current water management program may be sufficient provided there is no damage to the concrete (e.g., spalls, corrosion). Otherwise, based on the current evidence it would appear likely that the below-grade waterproofing on the concrete basement retaining wall is insufficient or failing. Additional investigation (e.g., digging out several locations around the foundation to observe the condition of the waterproofing) would be required to determine the condition of the waterproofing and to develop appropriate solutions.

5.2 Exterior

5.2.1 Steep-slope Roofs

A steep-slope, graduated slate tile roof surmounts the walls of the chapel. We found that in general the slate tiles were in good condition with minimal weathering. Primary deficiencies included isolated broken or missing tiles (Photos 17 and 18), isolated improperly lapped tiles (Photo 19), and face nailed tiles with nail heads exposed (Photo 20). Exposed nails can act as direct water conduits through the underlayment membrane. Water passing through improper laps can gain access to the underlayment where it accelerates deterioration of the membrane and can come in contact with other exposed nail heads. Broken tiles allow water to pass directly to the underlayment accelerating deterioration. If not addressed through repairs, all of these deficiencies can develop into leakage and subsequent damage to building finishes.

In the areas we observed, the roofing felt underlayment was in good condition. However in one case, we observed what appeared to be exposed sheathing resulting from a damaged roof tile (Photo 17). The underlayment appears damaged and will need repair with appropriate overlaps. If not repaired, this location is almost certainly destined to develop into a leak (if it hasn't already) and deterioration of substrate and interior materials.

Copper ridge-cap, rake-flashings, head counterflashings, and open valley flashings complement the steep-slope roof system. Damage and/or reduced maintenance threaten the integrity and functionality of some of these systems that in-turn may result in leakage to the building. The ridge cap contained numerous unsealed fasteners and a split in the surface of the sheet metal. Water leakage through these openings will introduce excess water to the underlayment and accelerate deterioration of the membrane. We observed the split surface and buckling in one location at the north end of the ridge-cap (Photo 25). It is possible that this is the result of a lack of provisions for expansion in the ridge-cap. The surface mounted fasteners we observed were fastened through the lap seams at the same sections as the buckling. With the lap seams mechanically secured, it is unclear how the section would expand/contract. To prevent further damage, the section of the ridge cap should be replaced and provisions for expansion should be restored.

Various head flashings and confined rake flashings (at walls and parapets) contain sheet metal counterflashing set in saw-cut reglets (cut into the volcanic stone walls) filled with sealant. The amount of patching observed at many reglet locations (Photos 37 – 39) suggests hasty multiple maintenance campaigns not always with compatible materials. Sealant and/or roofing materials are often lapped over each other. At many locations the sealants are cracked and/or deteriorated (Note: These conditions are similar at low-slope roofs).

A confined rake on the north wall of the transept on the northeast side of the chapel has been associated with an interior leak (Photos 37 and 38). At present, due to the patching repairs we understand it is not leaking. However, we note that the layering of multiple sealants and mastics at this location (Photo 38), and all similar locations, can lead to bonding issues and deterioration problems of the materials. In general, the sealants are spread over the joints with profiles that do not conform to manufacturer or industry standards and can lead to early failure. Leaks are likely to return if proper sealant joints are not installed and maintained. At this rake location we also observed that the asphalt sheet base flashing on the up-slope side of the chimney is wrinkled and there are open fishmouths filled with sealant (Photo 39). The lack of adhesion of the base flashing could allow for slippage and tearing of the membrane. The corner that relies only on sealant and not counterflashing is not a long-term watertight solution. In its current configuration, the base flashing is susceptible to leakage and it should be replaced with new base flashing and sheet metal counterflashing.

Rake flashings and crickets around buttresses incorporate sheet metal step counterflashings set in sealant filled reglets formed out of the masonry (precast) joints. At many locations the sealants are cracked or deteriorated. There are open gaps in isolated sheet metal lap seams. In general, these deficiencies fall into the category of deferred maintenance that should not be neglected. The rake flashings and crickets occur at particularly vulnerable locations susceptible to heavy water drainage and potential ice-damming. Leakage at these locations could enter the building but could also penetrate the precast block and concrete buttresses. To protect the watertight integrity of the roof and buttress masonry, repairs to the sealant joints should be considered a priority.

The intersection of the steep-slope and low-slope roofs contains surface mounted closed-rake counterflashing with exposed fasteners, some of which are not sealed. The counterflashing does not contain a surface mounted reglet to accommodate a profiled sealant joint (Photo 40). The existing sealant is deteriorated. Due to its reliance on shallow sealant profiles (if at all), the existing flashing will require consistent maintenance and is prone to leakage. Replace the existing flashing with a two-part counterflashing that incorporates a surface mounted reglet and proper sealant joint profile.

Numerous roof areas around the building do not contain rake flashings or drip edge-flashings (Photos 23 and 24). The wood trim at these locations is unpainted and rustic in nature. This appears to be a deliberate design choice suited to a craftsman aesthetic element of the building. These flashings would provide important closure of the roof-to-wall intersections. However, at present, there does not appear to be any related significant damage due to the lack of these flashings. Some checking and deterioration of the wood trim pieces was observed and expected given the nature of exposed unpainted wood. It may be possible to extend the life of some of the wood trim by painting the wood with a wood stain preservative. However, there is some severe checking and certain sections will need to be replaced.

The main steep-slope roof drains into copper sheet metal built-in gutters with scupper outlet liners that feed through precast gargoyles (Photo 26, 29, and 30). For the most part the gutter sections we observed appeared intact and in good condition. With exception of the heat-trace wiring, the gutter liners were mostly clear of debris. Some of the gutters are warped at the edge possibly due to the build-up of clinging ice (Photo 29). At present, the warping does not appear to be altering the drainage slope of the interior liner. But continued weight on the gutters due to ice could split seams or alter drainage slopes. It is possible that heat-trace wiring at these locations is insufficient or not functioning properly. We did observe that many of the wires are loose which may lessen their impact. The existing heat-trace system should be checked to confirm that it is operable and adequate. Reattach heat-trace wires so that they are snugly in contact with adjacent flashing and gutter metals.

We observed that some connections of the scupper outlets are split from the face of the gutter allowing for leakage directly into the precast gargoyle (Photo 28). In some cases, the copper outlet liners are also loosely fitted into the top channel of the gargoyle leaving an open joint between the sheet metal liner and precast concrete. The open sky facing joint(s) is allowing excessive water into the precast gargoyles channel which may be contributing to their accelerated deterioration (see our discussion on precast concrete below). It is possible that the deficiencies found at the scupper connection furthest to the south on the west side are responsible for the interior staining/leakage that appear on the upper southwest wall of the balcony. An investigation, including water testing, would be required to confirm the source of the leakage. Either way, open seams and joints in the scupper connections and liner should be sealed to prevent run-off into the masonry wall and features.

Some of the lower steep-slope roof pitches do not contain gutters including the roofs over the vestry and transepts spaces (Photos 24, 34, and 35). There is no code provision that requires gutters, however gutters generally facilitate proper water management and are good building conservation practice. There do not appear to be issues with above-grade walls related to the lack of gutters. However, the vestry roofs, which also collect some water from the transept roofs may drain excessive water directly onto the foundation areas exacerbating below-grade wall leakage. If the below-grade leaks become a problem, roof drainage run-off will be one factor that may have to be reconsidered in an effort to mitigate the problems.

One steep-slope roof contains a hung gutter that is detached and sloping away from the drain outlet. Water and debris are ponding in the gutter (Photo 36). The gutter is a conduit for snow and ice damming. Overflowing water will be directed into the wall. The gutter should be repaired and the positive slope to outlet drain restored.

5.2.2 Low-slope Roofs

The low-slope roofs are built-up roofs with mineral surface cap sheets that are generally in good condition. In the field, the membrane is adhered to the substrate. We did not see any evidence of blistering, cracking, or failed seams. The roofs slope to gutters or scupper outlets. However, we did observe that the roof membranes generally do not incorporate base flashings (Photo 41). The lack of a base flashing can result in undue stress on the field membrane which is turned-up the wall as a substitute. This can lead to early debonding or wrinkling of the membrane at the vertical surface. At present we did not see any visual evidence of the membrane debonding, but there have been problems with the liquid counterflashing (discussed below) that could be indirectly related to movement and the lack of a base flashing.

Furthermore, the membrane does not always achieve the industry standard 8 in. vertical turnup at the walls (Photos 43 and 45). This is predominantly due to the presence of window openings and sills, and a skylight close to the roof surface. The windows are at high points on the roofs and as long as the roofs are draining properly the low turn-ups might not be a problem.

Liquid counterflashing and/or roof mastic provides the only counterflashing to the roof membrane (Photo 41 and 43). We observed an open crack in the flashing (Photo 46) and the flashing has often been repaired with other sealants and/or roof mastics (Photo 45). The roof repairs occur over previous leak areas in the east transept. We understand that the roof currently does not leak. Nevertheless, the existing counterflashing system which exhibited cracking and frequent repair seems prone to failure. Though difficult to assess (without removing materials), faulty installation of the liquid flashing to the rough stone substrate may be complicit in the failure of the flashing. At minimum, for the liquid counterflashing system to be successful, the system should comprise a single material applied to as smooth a substrate as possible. Future repairs should start over with application at a clean smooth substrate. Furthermore, future designs may consider incorporating a sheet metal counterflashing as an additional means of protection. The lack of base flashing also may be causing slippage of the upturned membrane where cracks would form at the liquid flashing (or mastics). For a long-term solution, replace the membranes at these roofs with a properly detailed and warrantied system.

The parapet wall at the small low-slope roof has a dedicated base-flashing. The flashing is rolled up onto the top of the parapet and around inside and outside corners (Photo 44). There is no coping so the flashing also serves as coping. We observed moderate wrinkles in the horizontal area of the flashing as well as some cracks and splits in the mastic and membrane at the corner seams (Photo 44). These issues could be related to poor installation, lack of anchoring at the vertical wall, movement or all of the above. At present they are not associated with any leakage but could lead to accelerated membrane deterioration. A better designed detail that incorporates sheet metal coping over an anchored membrane would likely alleviate these problems and provide longer service.

In summary, no reported active leaks are currently associated with the low-slope roofs. However, staining on the interior under specific low-slope roof areas and signs of repetitive maintenance repairs on the exterior provides evidence that the roofs have been subject to periodic leakage. The low-slope roofs contain a number of deficiencies from weathering at the liquid flashings and repair sealants, poor maintenance, and faulty installation which will reduce service life and potentially result in further failure of roof components and leakage. The roofs should be replaced and ungraded during the next roofing repair cycle.

5.2.3 Precast Concrete, Volcanic Rock Masonry Walls, and Cement Plaster Parge Coat

5.2.3.1 Cracking and Spalling in the Precast Ornament

The chapel features precast concrete cladding and architectural ornamentation. The bell tower is comprised entirely of precast concrete blocks (precast blocks) (Photo 49). The buttress caps, gargoyles, water table, parapet copings, window and door surrounds, and window tracery are also comprised of precast blocks (Photo 5). All of the blocks have been painted with the paint extending over and mostly obscuring the mortar joints. Based on discussions with building maintenance, the blocks have been painted in effort to prevent their deterioration most of which is characterized by cracking and isolated spalling.

Cracking is found extensively throughout all elevations of the tower. We would estimate that approximately 75% of the blocks contain multiple cracks. This number is probably higher as not all cracks project through the paint coating and are therefore not currently visible. To a lesser extent we observed cracking on all sides of the buttress caps and gargoyles. Here approximately 50% of the blocks contain multiple cracks. Cracking was minimal (though not completely absent) on all other features (e.g., window and door surrounds). At the window surrounds and water table the number of cracked blocks may be as low as 5%. The fact that precast blocks lower on the building are in better condition suggests that location on the building and exposure is a factor in their deterioration. As a general rule, the higher up on the building, or more exposed the block, the more cracks could be found.

The cracking is found in various forms including: open vertical and horizontal cracks that range from .012 to greater than .04 in. wide (Photos 55 and 56) and map cracking that spreads throughout a block (Photo 53). Cracks that have emerged near block corners and have joined together have frequently developed into spalls (Photo 62). Concrete spalls occur when pieces of the concrete substrate become detached from the surface of the concrete substrate and fall. We observed incipient spalls (Photo 61) and spalls that have been removed or have fallen (Photo 53). At the numerous spalls that were removed on the tower we did not see any rebar or rust stains indicating that most of the blocks do not contain rebar reinforcement and that other factors are at work in the formation of cracks and spalls. The one exception are the gargoyles where cracks and spalls could be linked directly to corroded rebar (Photos 66 and 68). When the embedded steel rebar rusts the corrosion product expands cracking the concrete. The cracks from rebar generally follow the path of the rebar parallel to the neck of the feature. Damage was so severe at the gargoyles that many of the heads have been removed. Even so, we observed multiple cracks that also run perpendicular to the rebar (and gargoyle neck) (Photo 67) suggesting that other factors are at work in forming the cracks.

Other factors are causing cracking and spalling include damage from freeze-thaw cycles and alkali-silica reaction (ASR). ASR is a chemical reaction between alkalis in the cement and certain susceptible aggregates in the concrete mix. The reaction forms alkali silicate which absorbs water to form a gel exerting pressure on the surrounding material (that causes map cracking and spalling of circular areas of the concrete). Water is necessary for the full reaction to occur and to form the expansive product. The reaction can take years to occur.

Our laboratory observed evidence of ASR in all four samples that were analyzed with the most significant evidence present in Sample #5. Using SEM-EDS to examine a polished sample the laboratory found white deposits that consist of ASR gel that filled cracks extending through the sample. We also confirmed that the layered white deposits consisting of ASR gel completely filling an entrapped air void. Samples #1, #2, and #3 all contained evidence of ASR including deposits that resemble ASR including ASR gel in #1 and #2 and particles of cracked rhyolite (suggesting dissolution) in Sample #3. Samples #1, #3, and #5 all include coarse aggregate that contain dacite and rhyolite which have a high susceptibility to ASR due to the presence of microcrystalline silica.

Differences in the amount of ASR detected between samples may be explained by exposure on the building, the sampling location, the level of advancement of ASR deterioration, and/or a combination of all of the above. For instance, Sample #5 was removed from a gablet originally located on the south elevation of the building at the top of a parapet wall. This feature, which sheds water from an upper portion of the building, has a high exposure to rain. Features such as the gablet exposed to weather are more susceptible to water infiltration and ASR which is activated by water. Therefore, one would expect ASR to be more prevalent at features that are more exposed to water infiltration. On the contrary, Sample #2 was removed from a protected ashlar block on a recessed panel on the upper wall of the tower. The variation of ASR evidence in the samples then is symptomatic of how advanced the ASR is from block-to-block on the building. This is important, because the laboratory results can be interpreted to mean that not all blocks on the building are as advanced in ASR deterioration as Sample #5. Blocks that resemble the minor evidence and deterioration found in Samples #1 and #2 may be candidates for stabilization. Laboratory results correlate with our field observations: We observed the most severe cracking and spalling at higher, most-exposed concrete blocks.

Many of the blocks on the tower and buttresses currently show evidence of ASR attack (75% and 50% minimum respectively). As noted above, precast blocks at window surrounds and the water table do not appear to be nearly as damaged. Furthermore, the ASR attack appears to be more advanced in some areas over others. This may have to do with exposure, possible differences in the aggregate used in the precast blocks (we did not test blocks at the window surrounds), the effectiveness of the paint coating as a water barrier at the window surround precast blocks etc., and/or a combination of all of the above.

Other findings by our laboratory revealed conditions that may play a secondary role in the precast concrete deterioration. The precast samples all contain a high level of permeability as evidenced by the depth of carbonation measured (1/2 in. – 1-5/8 in.) in the petrography examination. The C642 test measured a high 23% volume of permeable pore space in Sample #1 which provides further confirmation of permeability. High levels of permeability and water infiltration are key to activating ASR as well as other potential problems such as freeze-thaw.

We found that all of the samples lack air entrainment which when added via an admixture provides for evenly dispersed uniform air bubbles within the concrete paste to increase durability of the concrete. In particular, it helps prevent freeze-thaw from occurring. Furthermore, elevated chloride content detected in Samples #2 and #5 can increase the frequency of freeze-thaw cycles. The lab observed evidence of freeze-thaw in tightly spaced micro-cracks of the second mortar layer in the mortar coating in Samples #2 and #3. However, we note that in both these samples the mortar was well adhered to the concrete layer below and the cracks had not resulted in delamination as one would expect in freeze-thaw. Furthermore, in the field we observed very little spalling on the building that was distinctly representative of freeze-thaw damage such as scaling and exfoliation. Spalls previously observed and removed by the contractor resembled freeze-thaw damage. Some isolated areas of paint bubbling that we observed may be caused by freeze-thaw exfoliation. In these cases, the freeze-thaw appears to be limited and localized and secondary to the primary causes of deterioration discussed above.

Our lab measured carbonation at depths from 1/2 in. to 1-5/8 in. from the face of the concrete and it is likely carbonation plays some role in the corrosion of rebar and subsequent damage to the gargoyles. Carbonation of the concrete occurs when carbon dioxide from the air infiltrates and reacts with calcium hydroxide in the concrete to form calcium carbonate and water. (Carbonation is a normal process that occurs slowly in all concrete from the exterior surface inward.) The occurrence of carbonation at the level of embedded steel in concrete disrupts the normal protective concrete environment by lowering the pH level. If moisture and oxygen are available in the carbonated concrete, corrosion can occur.

From field observations we observed that the rebar in the gargoyles is typically embedded at a depth of 1 – 2 in. from the surface of the concrete. Photographs provided with the CK Arts report depict exposed corroded rebar embedded within a statue at the top of the tower. (Fortunately, other blocks appear to be unreinforced.) The rebar is generally within the measured carbonation depths resulting in lower pH and corrosion. The cracks and spalls in these components are directly related to the corrosion of embedded steel (rebar). This failure mechanism was either obvious by the presence of exposed rebar, corrosion stains, and/or the presumed path of the rebar through the gargoyle. The spalls are caused by the expansion of corroding rebar. The corrosion product occupies more volume than the original steel rebar; and the expansion pushing outward on the concrete initially causes cracks and eventually spalls. Damage has already resulted in the removal of up to 50% of specific gargoyle features. Existing cracking suggests that significant remaining portions of the gargoyles will require replacement with new features. In fact, deterioration of the existing gargoyles is so complex (due to corrosion, freeze-thaw and ASR) and pervasive, that we recommend replacement of all gargoyles. Replacement features should incorporate new stainless steel support/reinforcing and watertight joints to prevent future corrosion.

If no action is taken the precast blocks will continue to crack and form spalls. Assuming all of the precast blocks are manufactured with the same aggregate, they are all susceptible to ASR attack and will require some form of treatment or protection to deal with the problem. ASR is a chronic condition that can only be managed (not cured).

There are two possible courses of action to deal with the precast blocks:

1. Preservation option: Make repairs to existing damage and protect the blocks to slow the inevitable ongoing ASR.
2. Replacement option: At a minimum, replace all the blocks on the tower, the buttresses and the gargoyles and repair and protect the remaining blocks.

We discuss the pros and cons of these approaches below.

Preservation Option

As noted above, water is the primary activator of ASR. Therefore, one approach is to limit moisture access to the concrete by improving drainage and applying waterproof coatings to the precast blocks. If water can be kept out it is possible that the ASR could temporarily be neutralized and the cracking and spalling slowed. There are two potential problems with this approach at Nativity. One, the multiple openings and finishes on the facade are disruptions in the coating and therefore provide potential avenues for water infiltration. Water can leak through wall openings (e.g., windows, louvers) bypassing the coating and infiltrate back into the precast concrete blocks. Theoretically the porous volcanic rock masonry and mortar joints could provide a conduit to adjacent precast blocks at the water table and window surrounds. However, the minimal damage we are seeing at those locations suggests water seepage from the volcanic rock may present a low threat. Two, the waterproofing coating will need to be persistently maintained typically on a 7 – 10 year cycle. In other words, at a minimum the chapel would need to plan in their maintenance program for recoating the precast walls and ornament every 7 – 10 years. There are long-term cost and logistical considerations in the preservation approach that will have to be considered.

If the preservation approach is selected, in addition to the overall waterproof coating physical repairs (for blocks that remain), repairs will be required to address the spalls and open cracks to prevent water infiltration and further deterioration. At minimum, this involves patching the spalls and cracks with a concrete patching mortar that matches the composition and color of the existing concrete. Matching precast blocks is a difficult process and will require further petrographic evaluation of the samples removed from the building (to determine ratio of contents), making samples of patch mixes, and letting the sample mixes cure and weather to see if a match is achieved.

Based on our survey, it is evident that some select precast blocks are too cracked and spalled to be patched and must be replaced. The gargoyles that funnel the gutter scuppers are the most obvious example. Some of the statues at the tower are severely cracked (one with removed spalls) due to corroded rebar and because of the damage should be replaced rather than repaired. We did not do a block-by-block survey and after the paint is removed, each block should be carefully sounded to determine if it is intact. Blocks that have lost 50% or more of their concrete fabric should be replaced. Stainless steel helical anchors should be used to secure blocks with deep penetrating cracks.

Replacement Option

Wholesale replacement of the precast concrete blocks at the tower and buttresses will solve the ASR induced cracking and spalling. New precast blocks, if reinforced, should utilize stainless steel reinforcing. New blocks should be specified and detailed to meet current industry standards, including providing air entrainment for freeze-thaw resistance and testing of aggregates so that the ASR does not occur. The maintenance of new precast concrete blocks will be much less than maintenance of the existing blocks. However, upfront costs will be much higher.

5.2.3.2 Other Deficiencies that Affect the Precast Concrete

The precast concrete blocks and mortar joints are coated with a layer of paint that based on our lab observations is between 2 – 5 mil thick. Our lab also found that the paint is poorly adhered to the concrete substrate. Our field observations confirmed the poor adhesion and frequently saw peeling and bubbling paint mostly located at the tower. The bubbling paint suggests that some vapor (water) is being retained by the coating which can lead to damage of the precast block either through freeze-thaw cycles or erosion.

We presume the coating was originally applied to the building to keep water out of the blocks though based on the damage it appears to have been unsuccessful. We did not conduct field absorption tests on the coating to test the coatings performance as a barrier, nor do we know the manufacturer and specification for application thickness of the paint. However based on contemporary standard elastomeric paint specifications which typically require a dry mil thickness between 8 – 16 mil, it would appear that the paint currently on the precast blocks is applied at too thin a dry-mil thickness to effectively deter water.

Given the poor adhesion and probable lack of performance as a water barrier the existing paint coating will need to be fully removed from any original precast block(s) to remain. The precast blocks that remain will require a breathable coating that adequately adheres to the concrete substrate and serves as a weatherproof barrier. A breathable elastomeric coating will repel liquid water (rain) at the surface, but allow entrapped water vapor to evaporate from the blocks.

Lead caps set in mortar or sealants are installed at sky facing mortar joints at select window sills (Photo 75) and at the roof of the cupola (Photo 76). Similar to the paint coating, the lead caps also serve an important function to keep water from entering vulnerable joints in the precast cladding. The lead caps have been painted over with the paint coating which is cracked and deteriorated at the joints. We observed that the setting sealant or mortar was deteriorated at select joints potentially allowing water to enter the substrate. At the sills, the sealant should be replaced and the lead caps reset during repainting. The horizontal surfaces (and joints) at the cupola require a more robust waterproof surface to shed water. Sheet metal copper roofing and/or elastomeric waterproof coating reinforced at the joints would provide more durable surfaces for this location.

5.2.3.3 Volcanic Rock Masonry Walls and Cement Plaster Parge Coat

In general, the volcanic rock masonry walls were in good condition. We observed some isolated mortar joint deterioration (cracked and loose joints) and over pointing. These deficiencies result from deferred or faulty maintenance and can result in accelerated deterioration of the stone and sometimes internal leakage if enough of the joint integrity is lost. Repoint deteriorated mortar joints with compatible mortar and replace overpointing with compatible recessed profile joints to prevent further deterioration.

The exception is the presence of loose rubble masonry and brick at the top of the chimney on the northeast side of the building. The top of the chimney contains a sloped cement plaster parge coat that is cracking and spalled. The masonry has suffered from severe moisture infiltration and most likely freeze-thaw loosening masonry units. We do not know what led to the initial cement plaster cracking which is common. But lack of maintenance has led to rapid deterioration. Repairs will need to include: the removal and reinstallation of loose masonry and setting mortar; repointing deteriorated mortar joints, and removal and reinstallation of the cement plaster parge coat (sloped to drain). The cement plaster should be coated with a breathable elastomeric paint.

We observed an isolated open horizontal crack on the northwest corner of the building that mostly followed the mortar joint (Photo 78). None of the masonry was loose. Horizontal cracking can sometimes be associated with the corrosion of embedded structural steel. We do not have detailed enough structural drawings to compare the cracking with structural plans and therefore cannot draw any conclusions. If the cracking continues, the stone should be more closely inspected by removing the facing stone and observing the underlying steel, if present. The open crack can lead to water infiltration and it should be patched or pointed.

The alley elevation incorporates a concrete foundation wall finished with a painted cement plaster parge coat. In general, the plaster is in good condition but we observed one location where the cement plaster is spalling (and the paint is peeling). Spalls often originate from water gaining access to the substrate through cracks. The penetrating water can delaminate the cement plaster from the concrete surface. Patch cracks and spall to prevent further water infiltration and damage. All cement plaster crack and spall repairs will need to be repainted to match the existing wall. If aesthetics of these walls are important, the walls will need to be painted from corner to corner to better hide the patches.

5.2.4 Windows and Doors

Lancet windows glazed with leaded stained glass comprise the primary window openings. A majority of the windows are covered on the exterior with plexi-glass protective glazing set in aluminum frames. With a few exceptions (leaded obscure glass casement windows), other metal casement windows do not include protective glazing. All of the perimeter sealant joints and glazing sealant used on the protective glazing exhibit some form of adhesive or cohesive failure and will require replacement to prevent water infiltration.

At present, because the exterior protective glazing is not air tight and there are broken stained glass lites, the air pocket between windows receives ventilation from both the exterior and interior. With ventilation occurring from the exterior and interior, condensation between the protective glazing and stained glass panels does not appear to be a problem. However, if the windows are restored at some point and the exterior glazing resealed so that it is air tight effectively sealing off ventilation, condensation could be an issue. In general, in cold climates it is standard practice to ventilate the air pocket between glazings from the interior. When the time comes for restoration, the chapel should consult their stained glass conservator regarding appropriate means of ventilation.

The condition and scope of repairs of the stained glass panels was generally beyond our scope of work. However, at one lancet we observed that some of the lead cames were sagging and broken, several glass panels were bowing, the glazing putty was brittle and deteriorated, and there were at least three broken pieces of glass. While the lancet windows benefit from protection of the protective glazing, the bowing and sagging panel may indicate structural failure of the lead came matrix at this window. The failure could lead to more broken lites and a loss historic fabric of the window. Based on the age of the windows it is possible these conditions may be found at other windows. We recommend that the chapel employ a stained glass conservator to provide a condition survey of each individual window with prioritized recommendations to coincide with any facade repairs as budget allows.

At door openings in general there was either no sealant joint between the wood frame and precast surround or the existing sealant was experiencing adhesive failure. This is deferred maintenance and the sealants joints will need to be replaced to prevent water infiltration. At one door there was rot damage to the wood trim possibly due to the lack of properly maintained sealant joints. Patch or replace the wood trim section to match the existing section to prevent further damage to the frame and water infiltration. We observed staining on the floor at one door threshold and observed that the threshold maintains a negative slope. The threshold may be difficult to adjust, but a sweep or flashing strip applied to the bottom of the door may help prevent water from blowing under the bottom.

6. CONCLUSIONS AND RECOMMENDATIONS

We have the following conclusions and recommendations:

6.1 Conclusions

6.1.1 Steep-slope Roofs

The slate roofs are generally in good condition but deferred maintenance will need to be addressed, if not immediately, in the near future to prevent leakage and damage to the interior. Elements such as (but not limited to): broken and missing tiles, exposed nails, and unsealed fasteners at the ridge cap will need to be repaired.

The lack of metal rake and drip edge flashings in various locations does not meet industry standards which require metal flashings that integrate the roof membrane with the wall. Fortunately, this has not led to interior leakage. However, the lack of flashing has led to excessive deterioration of wood trim that will require selective repair.

With some minor exceptions, the main roof built-in sheet metal gutters appear in good condition and are functioning adequately. Evidence suggests that the heat-trace wiring may be insufficient in select areas and it should be checked before damage occurs to the gutters.

There are leakage problems at the gutter outlet connections and liners that cover the precast gargoyles. These will require repairs to prevent water from draining directly into the masonry wall and gargoyle scuppers.

A negative sloped hung gutter is a conduit for ponding and ice-damming. The gutter should be repaired and the positive slope-to-drain restored.

At present there are no reported active leaks associated with the steep-slope roofs. Interior staining under specific steep-slope roofs indicates past problems, and that properly conducted maintenance repairs should remain a priority.

6.1.2 Low-slope Roofs

The low-slope roofs are in fair condition but suffer from faulty and deferred maintenance. Deferred maintenance will need to be addressed, if not immediately, in the near future to prevent leakage and damage to the interior. Elements such as liquid counterflashings and counterflashing sealants will need to be repaired.

A poorly installed base flashing at the parapet wall will lead to accelerated membrane deterioration and leakage. Repairs are required including the installation of sheet metal coping to prevent the failure of the roof membrane at this location.

Inherent defects in the low-slope roofs installation contribute to accelerated deterioration including a lack of distinct base flashings and sheet metal counterflashings at roof turn-ups. Install a sheet metal counterflashing as part of short-term repairs to prolong the life of the current roof system and prevent continued leakage. Base flashings will need to be incorporated when re-roofing.

At present there are no reported active leaks associated with the low-slope roofs. Interior staining under specific low-sloped roof indicates past problems, and that properly conducted maintenance repairs should remain a priority.

6.1.3 Precast Concrete, Volcanic Rock Masonry Walls, and Cement Plaster Parge Coat

Based on visual observation and the laboratory analysis, we determined that ASR is primarily responsible for cracking and spalling found on the precast blocks. The reaction forms alkali silicate which absorbs water to form a gel exerting pressure on the surrounding material (causing cracks and spalls). Continuing cracking and spalling of the precast concrete will result in facade damage, water infiltration, and potential falling hazards. All the precast blocks are susceptible to ASR attack and will require some form of treatment or protection to deal with the problem. ASR is a chronic condition that can only be managed (not cured) if the precast blocks are to be preserved.

Some precast blocks, specifically the gargoyles and some statues, are too cracked and deteriorated to remain and should be replaced in-kind. With the other blocks, there are two repair options:

1. Preservation: Repairs to retain blocks where feasible include – remove the existing coatings, repair cracks and spalls, repoint joints, and paint the blocks with a breathable elastomeric coating. This approach will only slow down the deterioration from ASR. Periodic repairs, including patching new cracks and spalls and recoating will be required every 7 – 10 years. While the up-front cost is lower than the replacement option, significant periodic maintenance will be required.

2. Replacement: The only other viable corrective action for ASR would be wholesale replacement of the affected architectural veneer and features. The advantage of replacement is that it will indefinitely solve the problem. However, upfront costs will be much higher.

The deteriorated sky-facing joint caps at select window sills and the roof of the cupola will allow water to enter the substrate potentially causing damage noted above. Repairs are required to prevent water from entering the joints and seeping through the horizontal surfaces.

With a few minor exceptions, the volcanic rock and cement plaster parged concrete walls are in good condition. Isolated routine maintenance including some minor repointing is required to prevent moisture infiltration into the masonry walls.

At the top of the chimney, water infiltration and freeze-thaw has resulted in loose and detached mortar and masonry. The loose masonry is a fall hazard. Repairs are required to restore the masonry and waterproofing protection.

6.1.4 Windows and Doors

All of the perimeter sealant joints and glazing sealant used on the protective glazing exhibit some form of adhesive or cohesive failure and will require replacement to prevent water infiltration.

All of the perimeter sealant joints around windows and doors exhibit some form of adhesive or cohesive failure (or is missing) and will require replacement to prevent water infiltration.

There is isolated minor damage (rot and missing element) to the wood door trim at two doors that reflects a lack of routine maintenance. The trim will need repairs to prevent further damage to the trim or leaks to the interior.

Based on our review of one stained glass window, there is enough significant damage to the panel to affect the integrity and waterproofing ability of the glazing unit. The windows should be evaluated by a stained glass conservator to assess conditions and set priorities for repair.

The stained glass lancets are currently not formally vented (incidental ventilation occurs because the window glazing is not airtight). Sealing and restoration (reglazing if planned) of the stained glass lancets may introduce condensation issues in the cavity between the glazing units that would be detrimental to the glazing units. Consult the stained glass conservator about the proper means of ventilation as part of the restoration program.

7. REPAIR RECOMMENDATIONS

We have the following specific and general repair recommendations.

7.1 Steep-slope Roofs

The following repairs should be conducted by experienced slaters, sheet metal workers, and sealant installers as applicable.

- Replace damaged, cracked, and missing tiles with in-kind replacement tiles.
- Replace face nailed/punctured tiles with in-kind replacement tiles.
- Replace or reinstall improperly lapped tiles.
- Remove and replace deteriorated sealants at head and rake counterflashing reglets with a proper sealant joint over backer rod.
- Remove and replace deteriorated sealants at step flashing counterflashing reglets with a proper sealant joint over backer rod.
- Replace deformed and split section of ridge-cap; restore expansion capacity.
- Seal exposed fasteners on rake flashing.
- Seal exposed fasteners on ridge cap flashing.
- Replace asphaltic base flashing around chimney with new base flashing adhered to wall.
- For optimal protection of the wood, install sheet metal drip edge over wood trim.
- Otherwise, paint wood edge and rake trims with wood preservative.
- Replace severely checked or rotted sections of wood edge and rake trim in-kind with new wood trim.
- Replace copper sheet metal scupper outlet liners. Mechanically fasten and solder to gutter watertight. Integrate with elastomeric waterproof coating used to coat gargoyle outlet channels.
- Install reinforced elastomeric waterproof coating in gargoyle outlet channels.
- Remove and reinstall hung gutter so that it slopes to drain.
- Continually monitor stains at northwest entry vestibule and southwest balcony for increase in evidence of leakage and damage. Persistent or reoccurring leakage after roof repairs will require verification of leak locations through water testing.

- Reattach all heat-trace wires so that they are attached snug to adjacent metals. Inspect heat-trace wires at main gutters (particularly on east side). Confirm that it is operating effectively.

- Clean gutters at least once a year.

- Professionally inspect roofs every 7 – 10 years.

7.2 Low-slope Roofs

The following repairs should be conducted by experienced roofers, sheet metal workers, and sealant installers as applicable.

- Remove and replace deteriorated sealants at head and rake counterflashing reglets.

- Where sheet metal counterflashing does not occur, remove and replace liquid counterflashing at roof membrane terminations. Add sheet-metal counterflashing set in a saw-cut reglet filled with sealant.

- Remove and reinstall asphalt sheet base flashing at roof parapet with vertical anchoring and sheet metal coping.

- Within 10 years replace roofs with new sheet membrane incorporating proper base flashing and sheet-metal counterflashing details. Incorporate flashing with window repairs where window sills are close to roof.

7.3 Precast Concrete Walls, Volcanic Rock Masonry Walls, and Cement Plaster Parge Coat

The following repairs should be conducted by experienced masonry or waterproofing contractors as applicable.

<u>Preservation Option</u>

- Remove existing paint coating from precast blocks using a chemical paint remover. Allow concrete to dry.

- Conduct a block-by-block survey to assess condition of precast blocks. Identify precast blocks that are cracked and/or damaged beyond repair. Replace precast blocks that are damaged beyond repair in-kind to match profiles of existing.

- Patch and repair spalls using a custom patching mortar designed to match the texture, color, and mix ratio of the existing concrete (select compatible and appropriate low alkali aggregate).

    - Patch Type I (< 1.5 in. deep) spalls using a patching mortar only.

    - Reinforce Type II (>= 1.5 in. deep) spall patches using stainless steel anchors and wire.

- Route and patch open cracks (>= 0.02 in. wide) with a custom patching mortar designed to match the texture, color, and mix ratio of the existing concrete (select compatible and appropriate low alkali aggregate).

- Repoint cracked or deteriorated mortar joints at the precast walls using a mortar that matches the composition of the existing.

- Remove previous defective repairs that use sealant or epoxy to seal spalls and/or cracks. Repair as noted above.

- Install stainless steel helical anchors through cracked (cracks) blocks (minimum one anchor per 12 in. crack). Counter-set anchor and fill hole with patching mortar.

- Replace precast blocks that are damaged beyond repair in-kind to match profiles of existing. At the present time, precast blocks known to fit this description include the gargoyles on the east and west elevations and at least one statue.

- Install a copper sheet metal roof and/or monolithic elastomeric waterproof coating over the precast roof of the cupola.

- Coat all the precast concrete blocks using an elastomeric, crack-bridging, vapor permeable, acrylic protective coating such as Sikagard Elastocolor 550W by Sika Corporation.

<u>Replacement Option</u>

- Replace all blocks exhibiting ASR deterioration with new precast concrete blocks. These include the entirety of the tower cladding, the buttresses, the gargoyles and select statues at the tower.

- Make minor repairs and coat precast blocks to remain.

<u>Repairs for Both Options</u>

- Reseal lead joint caps at window sills.

- Repoint cracked, deteriorated, and over pointed mortar joints at volcanic rock masonry walls.

- Patch spalls in cement plaster parged wall. Paint wall with a breathable elastomeric paint to match existing.

- Remove and reinstall the loose masonry and setting mortar at top of chimney. Repoint deteriorated mortar joints. Remove and reinstall the cement plaster parge coat (sloped to drain). Coat the cement plaster with a breathable elastomeric paint.

7.4 Windows and Doors

The following repairs should be conducted by experienced waterproofing and/or sealant contractors as applicable. We recommend waiting on stained glass window repairs until windows are examined by a conservator.

- Remove and replace perimeter and glazing sealant at all protective glazing found at lancet and casement windows.
- Remove and replace perimeter sealant at all casement windows and doors.
- Patch (dutchman) rotted section of wood door jamb to match existing.
- Replace missing trim section of wood door jamb to match existing.
- Consult a stained glass conservator to conduct a conditions survey of the leaded glass windows and set priorities for repair.

7.5 Implementing Repairs

In the previous section we made recommendations that address all of the material conditions, defects, and potential modes of failure we observed that may lead to leakage and/or deterioration. Some of the problems are potentially an immediate danger to the building fabric and/or even life safety and are more serious than others. Furthermore, we understand that limited immediate resources by the building owners may require phasing of repairs over time. With this in mind, in Table 2 below we have prioritized the repairs.

We divided repair priorities into high, occurring immediately (first year); medium, occurring in 2 – 5 years; and low, occurring in 6 – 10 years respectively. We divide repairs into repair categories based on their level of risk to the integrity of the building envelope and the estimated remaining life cycle of the material or system. The assumed effort and costs associated with construction mobilization also may influence the priority designation of certain items. For instance, for expediency replacing perimeter and glazing sealants at the lancet windows should occur at the same time work is completed on the adjacent precast blocks.

Details, specifications, and other descriptive design information are required prior to formulating accurate repair pricing, bidding, and construction. Preconstruction work will also be required to determine a patching mortar mix that matches the existing properties of the precast block. Further analysis of the samples we removed can determine the mix design and constituents. A contractor will then need to find matching sand and a suitable aggregate and prepare patch mixes.

Table 2

RECOMMENDATIONS	PRIORITY
Steep-Slope Roofs	
Replace damaged, cracked, and missing tiles with in-kind replacement tiles.	High
Replace face nailed/punctured tiles with in-kind replacement tiles.	Medium
Replace or reinstall improperly lapped tiles.	Medium
Remove and replace deteriorated sealants at head and rake counterflashing reglets with proper sealant joint over backer rod.	Medium
Remove and replace deteriorated sealants at step flashing counterflashing reglets with a proper sealant joint over backer rod.	Medium
Replace deformed and split section of ridge-cap; restore expansion capacity.	Medium
Seal exposed fasteners on rake flashing.	Medium
Seal exposed fasteners on ridge cap flashing.	Medium
Replace asphaltic base flashing around chimney with new base flashing adhered to wall.	Medium
For optimal protection of the wood, install sheet metal drip edge over wood trim.	Low
Otherwise, paint wood edge and rake trims with wood preservative.	Medium
Replace severely checked or rotted sections of wood edge and rake trim in-kind with new wood trim.	High
Replace copper sheet metal scupper outlet liners. Mechanically fasten and solder to gutter watertight. Integrate with elastomeric waterproof coating used to coat gargoyle outlet channels.	High
Install reinforced elastomeric waterproof coating in gargoyle outlet channels.	High
Remove and reinstall hung gutter so that it slopes to drain.	High
Continually monitor stains at northwest entry vestibule and southwest balcony for increase in evidence of leakage and damage. Persistent or reoccurring leakage after roof repairs will require verification of leak locations through water testing.	High
Reattach all heat-trace wires so that they are attached snug to adjacent metals. Inspect heat-trace wires at main gutters (particularly on east side). Confirm that it is operating effectively.	High
Clean gutters at least once a year.	Medium
Professionally inspect roofs every 7 – 10 years.	Low
Low-Slope Roofs	
Remove and replace deteriorated sealants at head and rake counterflashing reglets.	Medium
Where sheet metal counterflashing does not occur, remove and replace liquid counterflashing at roof membrane terminations. Add sheet-metal counterflashing set in a saw-cut reglet filled with sealant.	Medium
Remove and reinstall asphalt sheet base flashing at roof parapet with vertical anchoring and sheet metal coping.	Medium
Within 10-years replace roofs with new sheet membrane incorporating proper base flashing and sheet-metal counterflashing details. Incorporate flashing with window repairs where window sills are close to roof.	Low

RECOMMENDATIONS	PRIORITY
Precast Concrete Walls, Volcanic Rock Masonry Walls, and Cement Plaster Parge Coat	
Preservation Option	
Remove existing paint coating from precast blocks using a chemical paint remover. Allow concrete to dry.	High
Conduct a block-by-block survey to assess condition of precast blocks, Identify precast blocks that are cracked and/or damaged beyond repair. Replace precast blocks that are damage beyond repair in-kind to match profiles of existing.	High
Patch and repair spalls using a custom patching mortar designed to match the texture, color, and mix ratio of the existing concrete (select compatible and appropriate low alkali aggregate).	High
Patch Type I (< 1.5 in. deep) spalls using a patching mortar only.	High
Reinforce Type II (>= 1.5 in. deep) spall patches using stainless steel anchors and wire.	High
Route and patch open cracks (>= 0.02 in. wide) with a custom patching mortar designed to match the texture, color, and mix ratio of the existing concrete (select compatible and appropriate low alkali aggregate).	High
Repoint cracked or deteriorated mortar joints at the precast walls using a mortar that matches the composition of the existing.	High
Remove previous defective repairs that use sealant or epoxy to seal spalls and/or cracks. Repair as noted above.	High
Install stainless steel helical anchors through cracked (cracks) blocks (Min. 1 anchor per 12 in. crack). Counter-set anchor and fill hole with patching mortar.	High
Replace precast blocks that are damaged beyond repair in-kind to match profiles of existing. At the present time, precast blocks known to fit this description include the gargoyles on the east and west elevations and at least one statue. See survey above.	High
Install a copper sheet metal roof and/or monolithic elastomeric waterproof coating over the precast roof of the cupola.	High
Coat all the precast concrete blocks using and elastomeric, crack-bridging, vapor permeable, acrylic protective coating such as Sikagard Elastocolor 550W by Sika Corporation.	High
Replacement Option	
Replace all blocks exhibiting ASR deterioration with new precast concrete blocks. These include the entirety of the tower cladding, the buttresses, the gargoyles and select statues at the tower.	High
Make minor repairs and coat precast blocks to remain	High
Repairs for Both Options	
Reseal lead joint caps at window sills.	High
Repoint cracked, deteriorated, and over pointed mortar joints at volcanic rock masonry walls.	High
Patch spalls in cement plaster parged wall. Paint wall with a breathable elastomeric paint to match existing.	High
Remove and reinstall the loose masonry and setting mortar at top of chimney. Repoint deteriorated mortar joints. Remove and reinstall the cement plaster parge coat (sloped to drain). Coat the cement plaster with a breathable elastomeric paint.	High

RECOMMENDATIONS	PRIORITY
Windows and Doors	
Remove and replace perimeter and glazing sealant at all protective glazing found at lancet and casement windows.	High
Remove and replace perimeter sealant at all casement windows and doors.	High
Patch (dutchman) rotted section of wood door jamb to match existing.	High
Replace missing trim section of wood door jamb to match existing.	Medium
Consult a stained glass conservator to conduct a conditions survey of the leaded glass windows and set priorities for repair.	Medium

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ILLUSTRATIONS

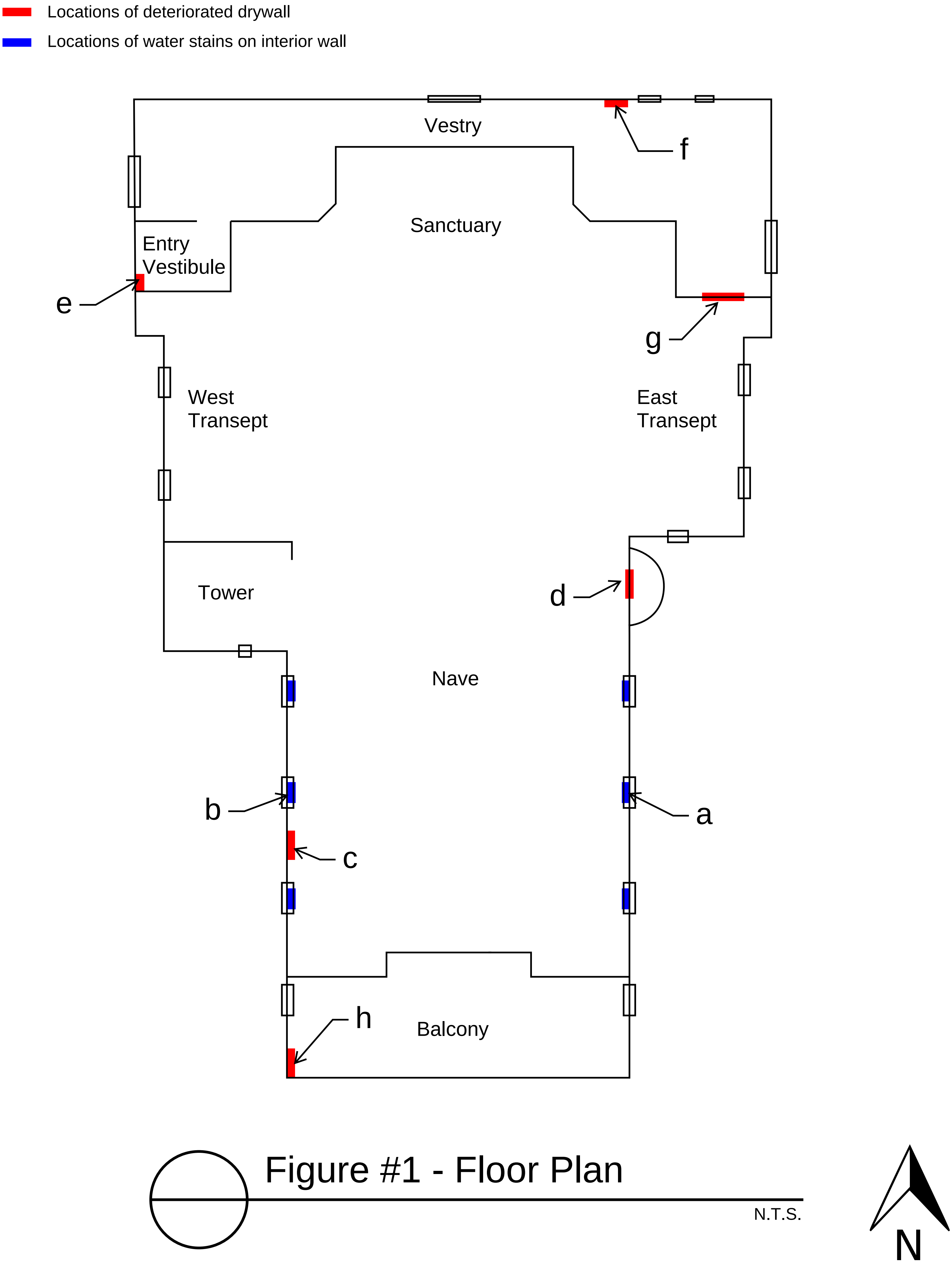


Figure #1 - Floor Plan

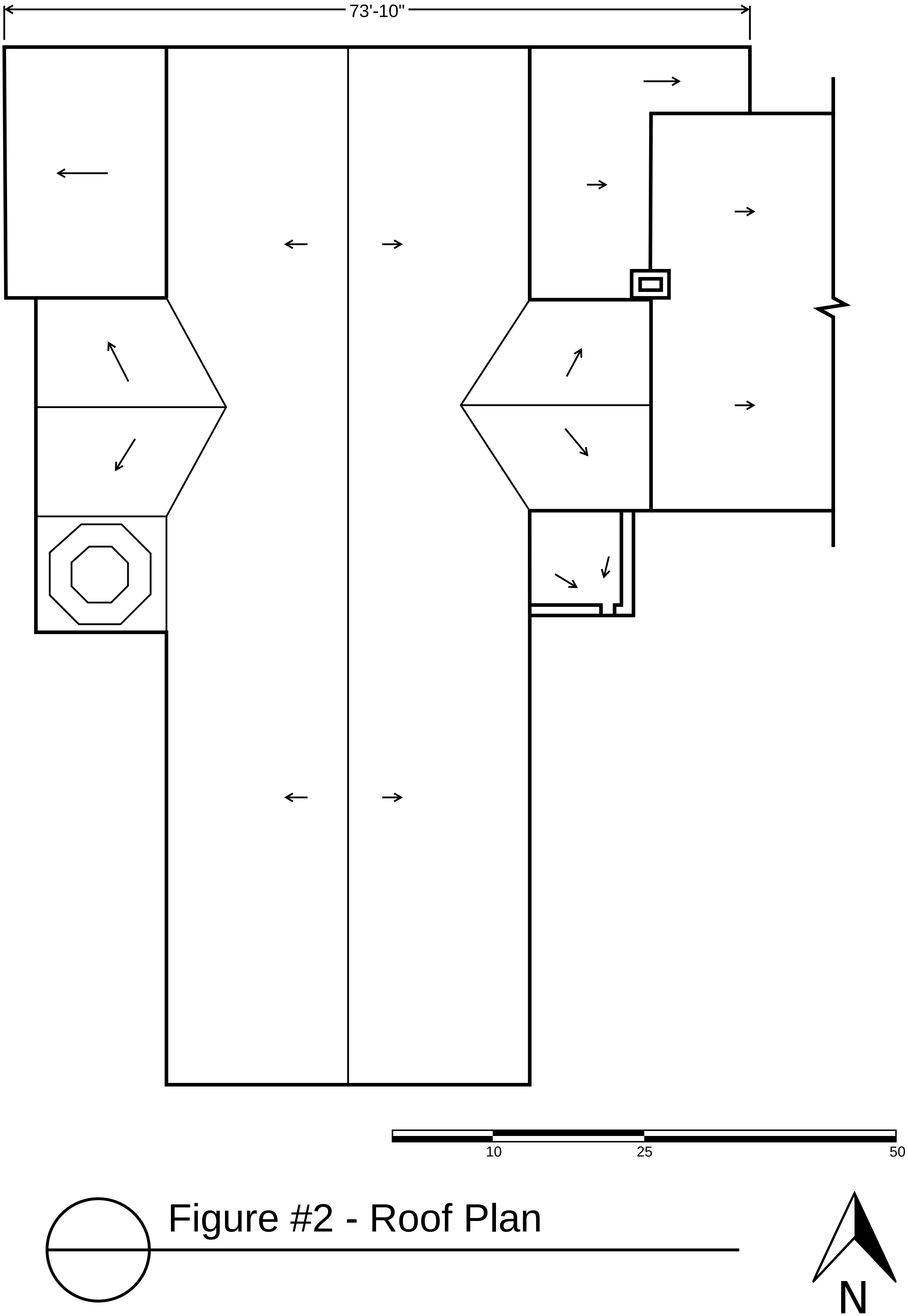


Figure #2 - Roof Plan

Photo 1

West elevation view.

Photo 2

View from the northwest.

Photo 3

South elevation view.

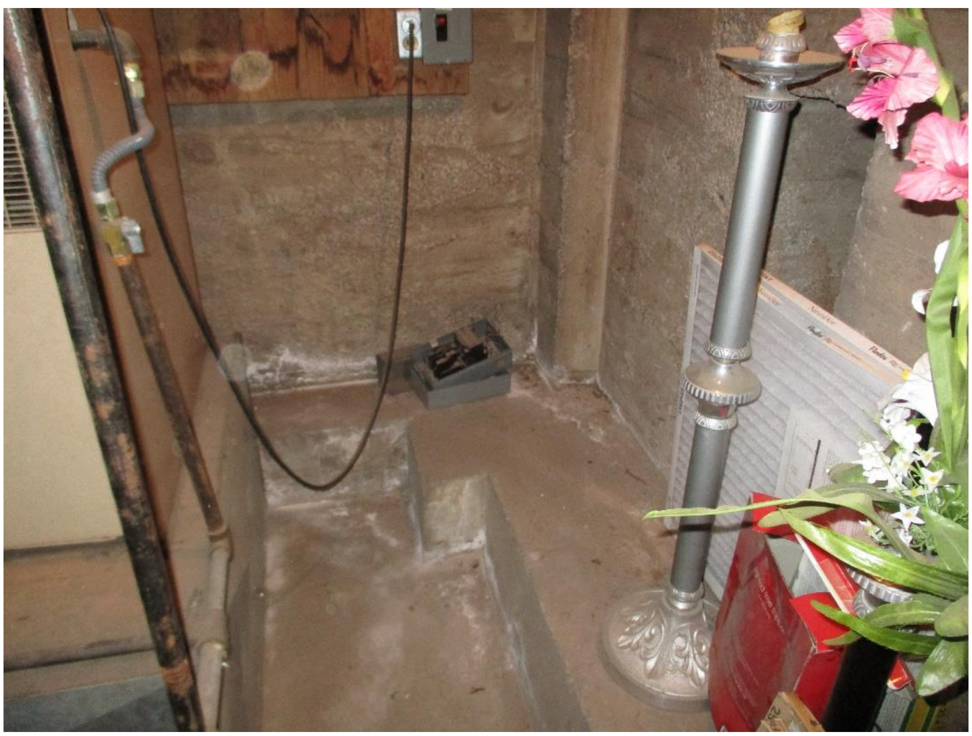


Photo 4

Efflorescence staining in basement.

Photo 5

Staining on wall below lancet window.

Photo 6

Staining on wall below lancet window.

Photo 7

Paint peeling and staining on the west wall of the Nave.

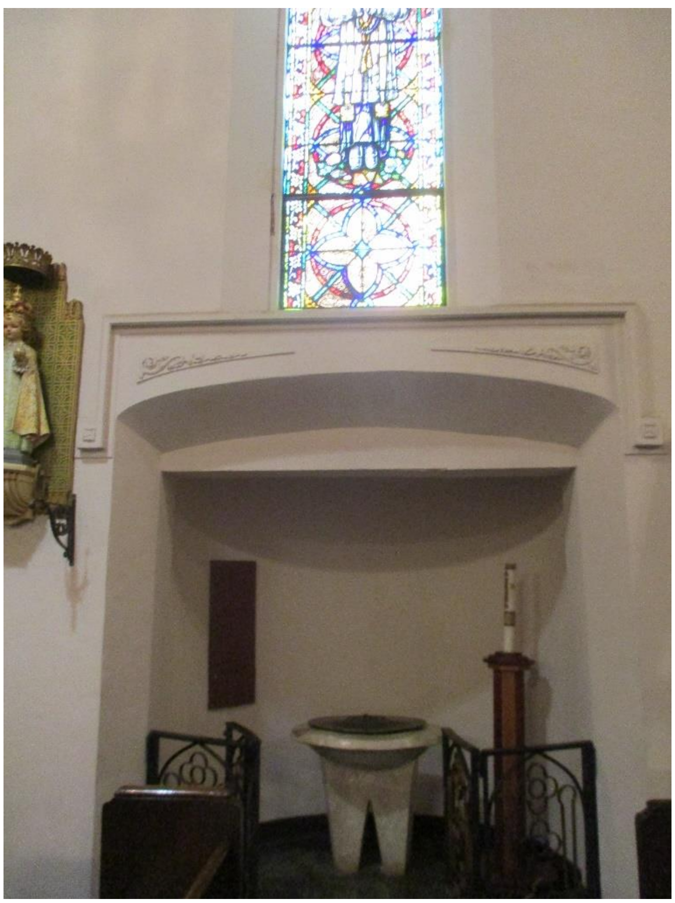


Photo 8

Baptismal alcove.

Photo 9

Water damaged plaster at baptismal alcove.

Photo 10

Staining and paint peeling at the northwest entry vestibule.

Photo 11

Typical horizontal crack in plaster wall.

Photo 12

Water staining at east transept.

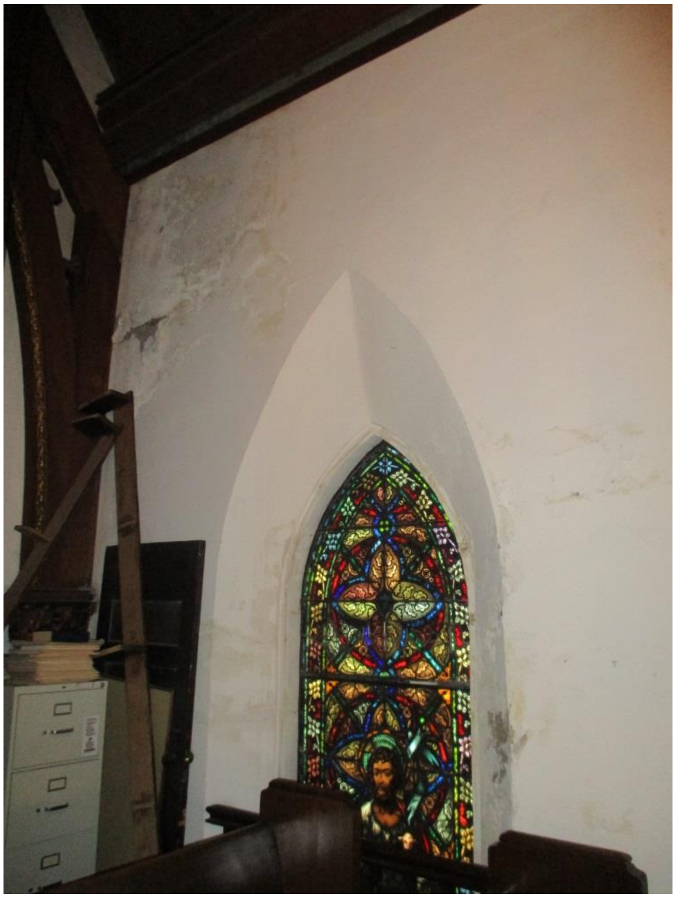


Photo 13

Water damage at balcony.

Photo 14

General view of main roof looking south.

Photo 15

General view of main roof looking north.

Photo 16

Typical condition of slate tiles.

Photo 17

Missing and dislodged tiles.

Photo 18

Missing, cracked, and dislodged tiles.

Photo 19

Exposed nail heads and holes in tiles.

Photo 20

Multiple exposed nail heads in tiles.

Photo 21

Turned tiles and exposed fastening holes.

Photo 22

Bituminous roofing underlayment.

Photo 23

Typical rake condition with no sheet metal flashing.

Photo 24

Typical roof edge condition with no sheet metal flashing.

Photo 25

Buckling ridge cap section and split in the sheet metal (shown with arrow).

Photo 26

Sheet metal step-flashing at confined rakes.

Photo 27

Seams joining the counterflashing bent open at the side.

Photo 28

Copper sheet metal gutter and scupper.

Photo 29

Sagging at the lip of the copper sheet metal gutter on the east elevation.

Photo 30

General view of copper gutter.

Photo 31

Heat-trace wires.

Photo 32

Steep-slope roof at rear of church.

Photo 33

Steep-slope roof at rear of church.

Photo 34

The transept and vestry roofs, and the back portion of the main roof do not incorporate gutters.

Photo 35

The transept and vestry roofs, and the back portion of the main roof do not incorporate gutters.

Photo 36

A detached and negative sloped hung gutter.

Photo 37

Flashing conditions at intersection of roofs-to-walls.

Photo 38

Flashing conditions at intersection of roofs-to-walls.

Photo 39

Flashing conditions at intersection of roofs-to-walls.

Photo 40

Flashing conditions at intersection of roofs-to-walls.

Photo 41

Large low-slope roof on the north east side of church.

Photo 42

Small low-slope roof on the north east side of church.

Photo 43

Liquid counterflashing and/or grey roof mastic.

Photo 44

The roof membrane laps up and on top of a parapet wall.

Photo 45

Patching of the roof membrane counterflashing.

Photo 46

Crack in the roof membrane counterflashing.

Photo 47

Roof membrane terminates at the precast window sill which is coated with peeling liquid flashing.

Photo 48

Typical view of bell tower.

Photo 49

Typical view of bell tower.

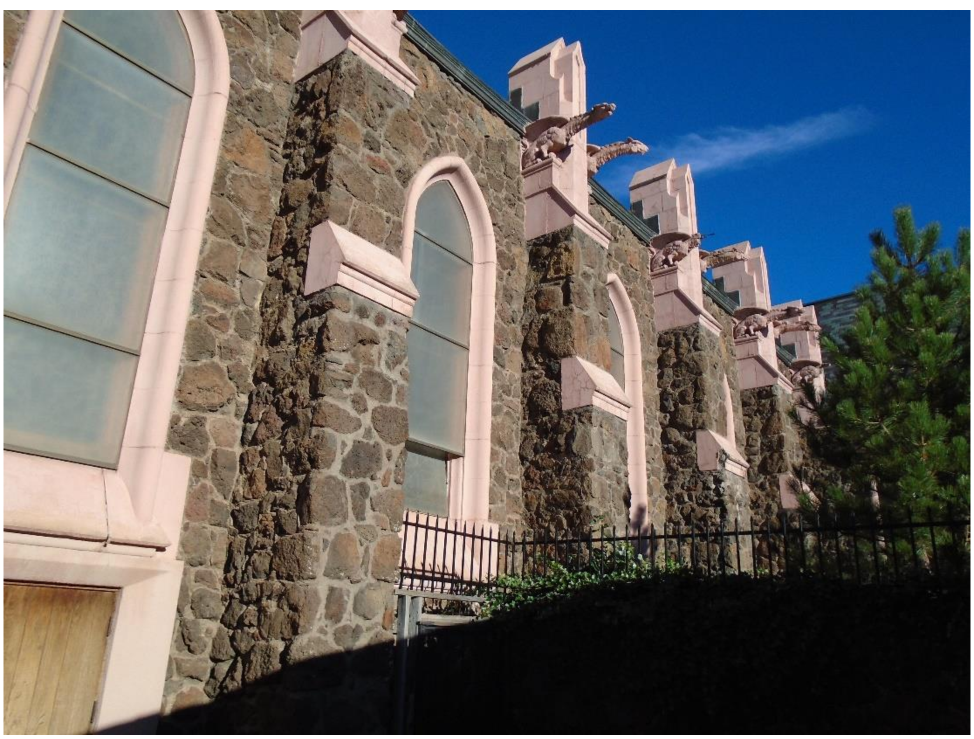


Photo 50

Precast concrete ornamentation.

Photo 51

Cracking and spalls at the tower.

Photo 52

Vertical, horizontal, and map cracking.

Photo 53

Vertical, horizontal, and map cracking.

Photo 54

Vertical, horizontal, and map cracking.

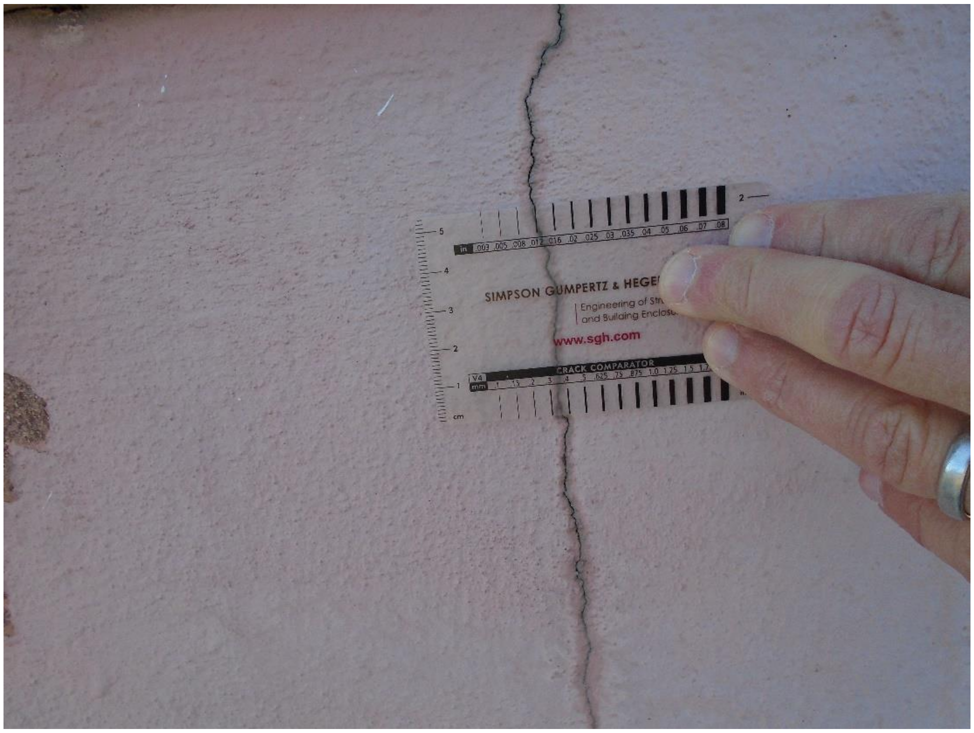


Photo 55

Typical crack.

Photo 56

Open crack.

Photo 57

Crack at window surround.

Photo 58

Crack at water table.

Photo 59

Partial epoxy crack repair.

Photo 60

Vertical open crack in statue.

Photo 61

Incipient spall formed between cracks.

Photo 62

Incipient spall formed between cracks.

Photo 63

Removed spall at water table.

Photo 64

Removed spall at buttress water table.

Photo 65

Typical painted over spall.

Photo 66

Missing gargoyle head.

Photo 67

Cracks in neck of gargoyle.

Photo 68

Exposed corroded rebar through gargoyles.

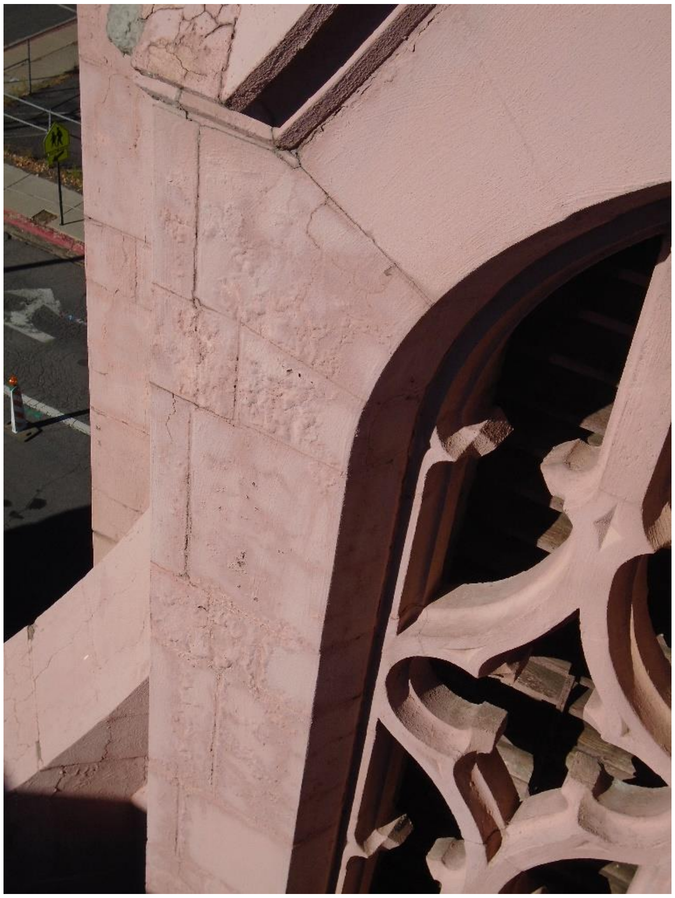


Photo 69

Bubbling and peeling paint coating.

Photo 70

Bubbling and peeling paint coating.

Photo 71

Peeling paint coating.

Photo 72

Peeling paint coating showing multiple layers.

Photo 73

Peeling and eroded paint at window sill.

Photo 74

Deteriorated mortar joints.

Photo 75

Lead joint covers (painted over) set in sealant or mortar.

Photo 76

Lead joint covers (painted over) set in sealant or mortar.

Photo 77

Roof of cupola.

Photo 78

Isolated crack in volcanic rock.

Photo 79

Cracked and deteriorated mortar joints.

Photo 80

Over-pointed mortar joints.

Photo 81

Loose and deteriorated coping at top of chimney.

Photo 82

Deteriorated cement plaster parge coat.

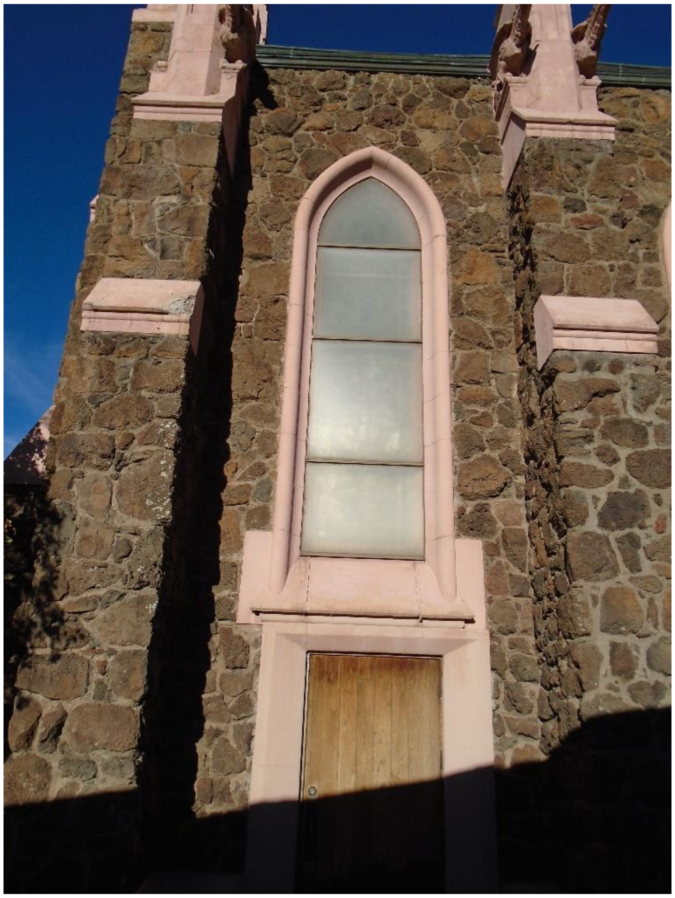


Photo 83

Typical lancet window.

Photo 84

Typical casement window.

Photo 85

Leaded glass window.

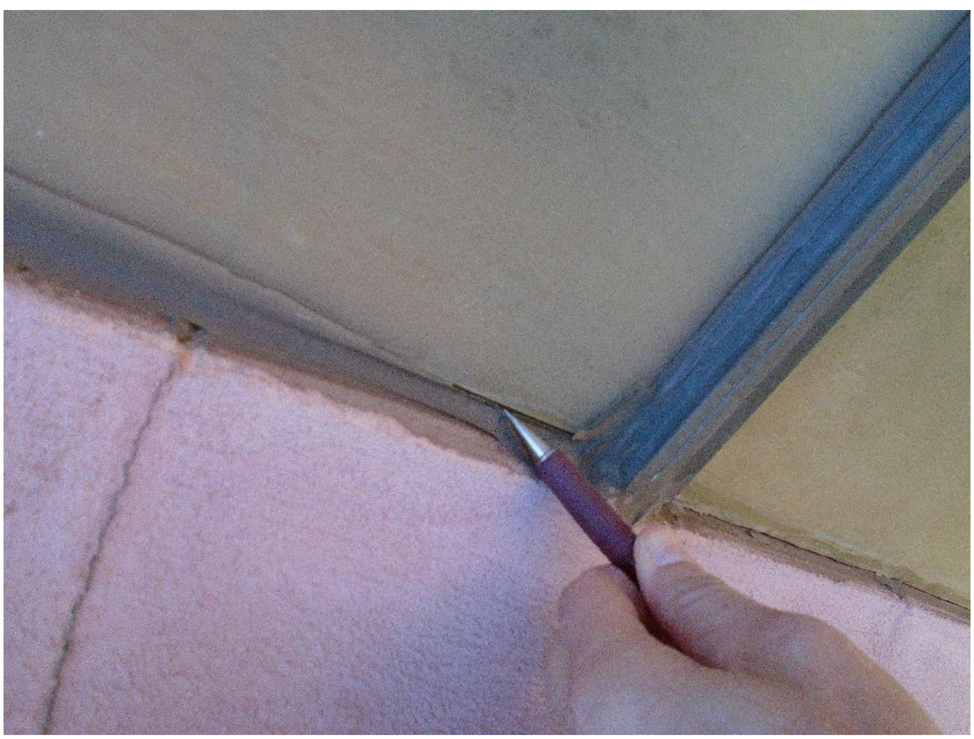


Photo 86

Perimeter sealant of protective glazing.

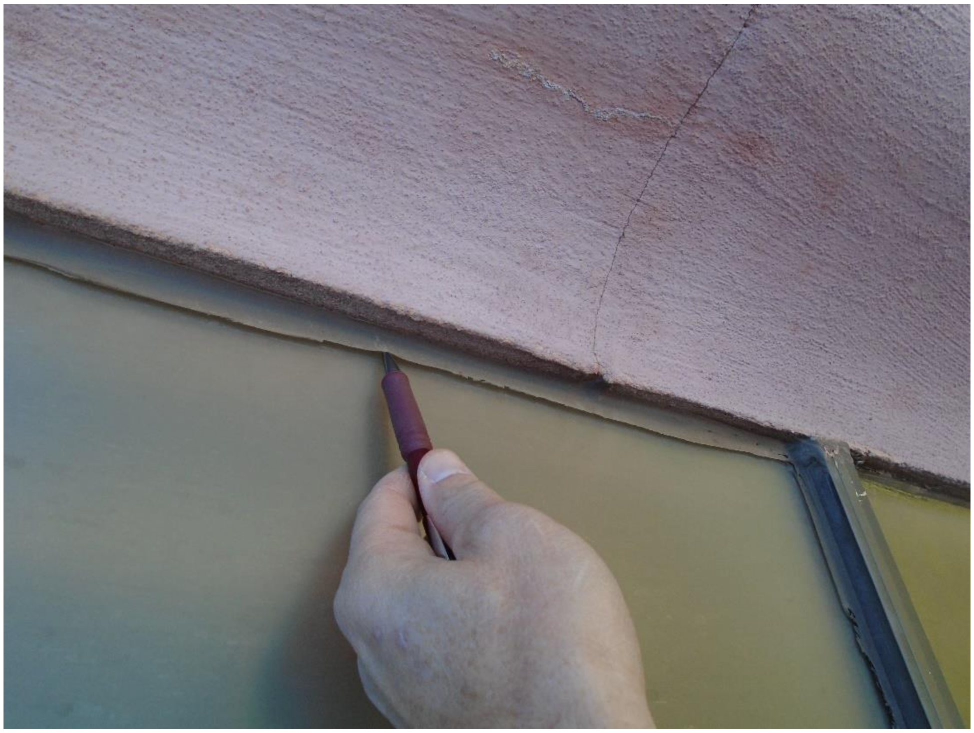


Photo 87

Glazing joint of protective glazing.

Photo 88

Glazing joint of protective glazing.

Photo 89

Wood door frame.

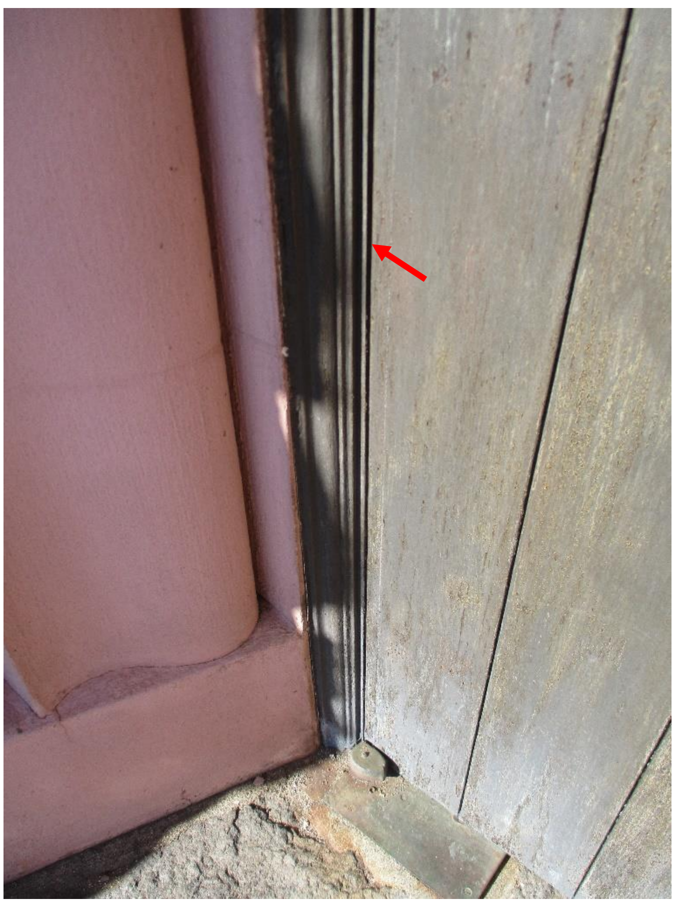


Photo 90

Wood door frame.

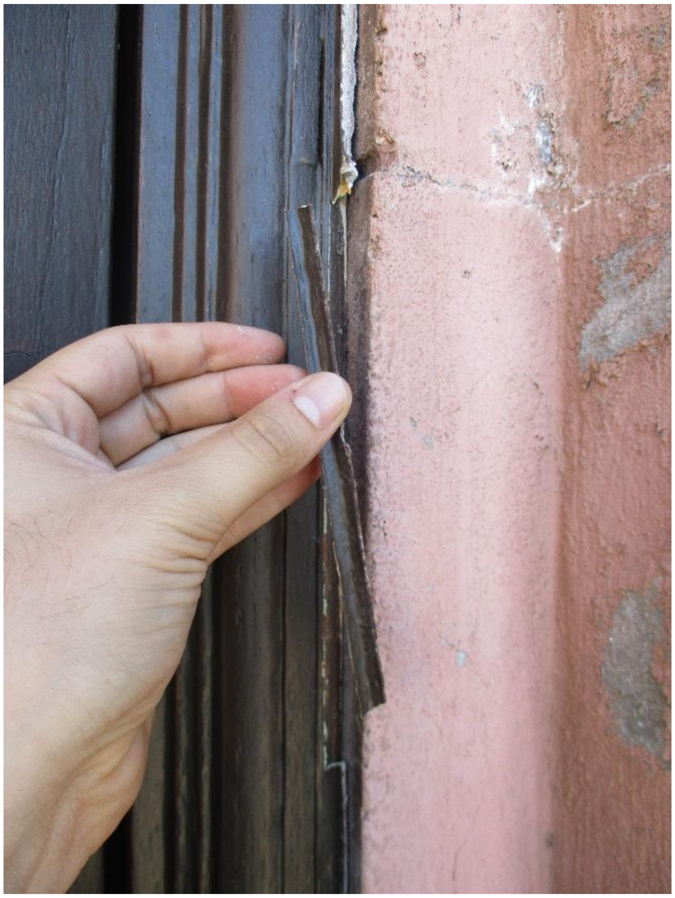


Photo 91

Broken-missing trim.

Photo 92

Rotted wood door frame.

Photo 93

Door threshold.

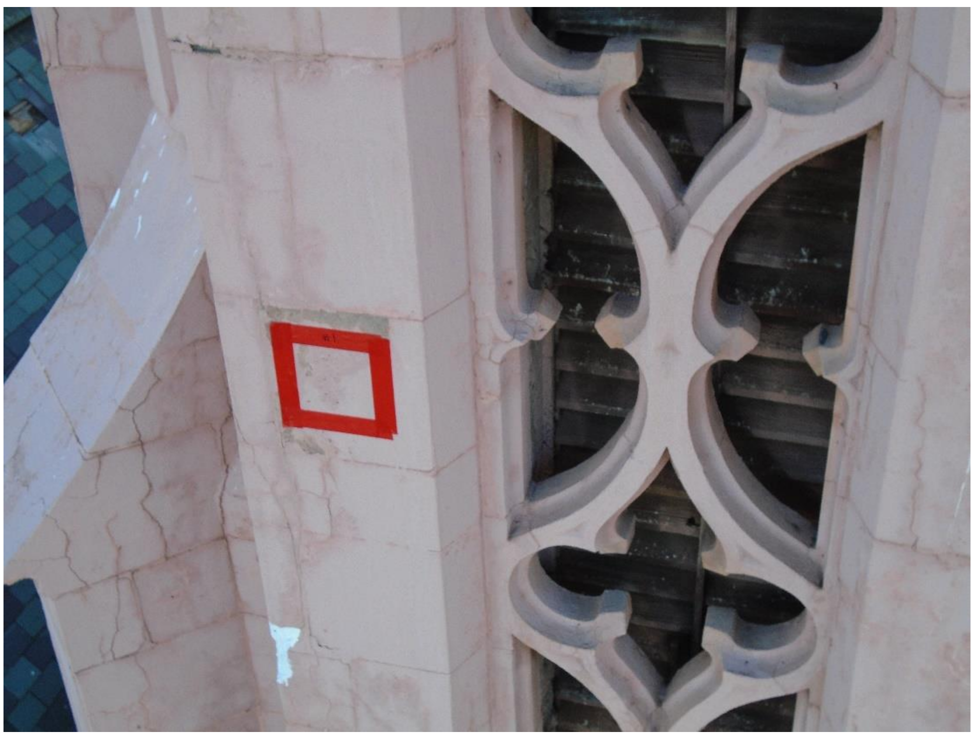


Photo 94

Sample #1 location.

Photo 95

Sample #1 location.

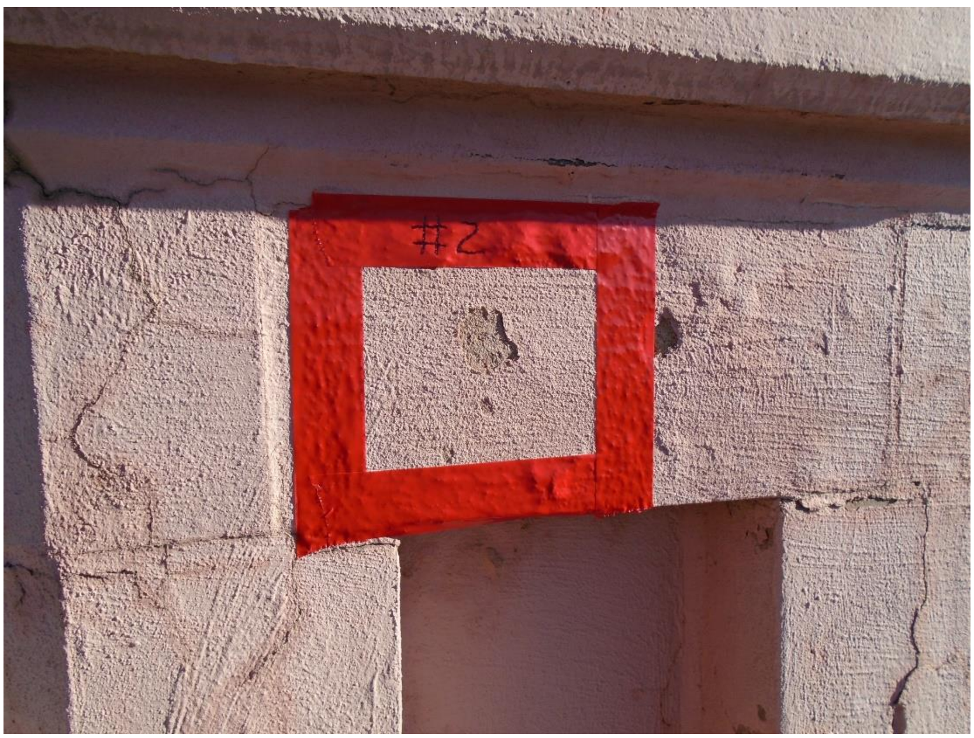


Photo 96

Sample #2 location.

Photo 97

Sample #3 location.

Photo 98

Samples #4 and 5 were extracted from the block on the bottom.

Photo 99

Sample #4 extraction.

Photo 100

Sample #5 extraction.

APPENDIX A

Laboratory Testing of Concrete Samples

Memorandum

SIMPSON GUMPERTZ & HEGER
Engineering of Structures and Building Enclosures

Date: 3 February 2017

To: LFCampbell and CLSearls

From: SWCarter

Project: 167283 – Facade Pre-Design Investigation and Conditions Assessment, Nativity of the Blessed Virgin Mary Chapel, Flagstaff, AZ

Subject: Laboratory Testing of Concrete Samples

On 17 November 2016, we received five concrete samples. We were asked to conduct a program of laboratory testing on the concrete samples, which consisted of:

- Petrographic examination on three samples (Sample 1, Sample 2, and Sample 3), in accordance with ASTM C856 – Standard Practice for Petrographic Examination of Hardened Concrete.
- Examination of Sample 5 using stereomicroscopy and scanning electron microscopy with energy dispersive spectroscopy (SEM-EDS).
- Determination of the acid-soluble concentrations of chloride in two samples (Sample 2 and Sample 5), in accordance with ASTM C1152 – Standard Test Method for Acid-Soluble Chloride in Mortar and Concrete.
- Determination of density, absorption, and the volume of permeable pore space on one sample (Sample 1), according to ASTM C642 – Standard Test Method for Density, Absorption, and Voids in Hardened Concrete.

This laboratory report summarizes our testing program and our findings.

1. SAMPLE DESCRIPTION

Three of the samples (Sample 1, Sample 2, and Sample 3) are nominal 2-3/4 in. diameter partial depth cores (Photos 1 through 6). On each of the three cores, one end exhibits a painted, formed face and the other end is an uneven, fractured face resulting from sample removal. The core samples were reportedly drilled horizontally with the painted, formed faces representing the exposed surface of the concrete. Both Sample 2 and Sample 3 were received in two pieces, reportedly because the samples broke during coring. Sample 5 is a saw-cut block with approximate dimensions of 5 in. by 4 in. by 2-1/2 in. and includes a painted, formed exterior face (Photos 7 and 8). Sample 5 was reportedly cut from one of the gablets of the structure that had been removed and left on the ground adjacent to the structure.

2. LABORATORY TESTING

2.1 Petrographic Examinations

We cut nominal 1-in. thick longitudinal sections from the center of Sample 2 and Sample 3. After completion of ASTM C642 testing on Sample 1, we also cut a nominal 1-in. thick longitudinal section from the center of the test specimen for Sample 1 (from which the outermost 3/8 in. to 3/4 in. had been removed prior to ASTM C642 testing). We then ground and roughly polished the sawed sections of Sample 1, Sample 2, and Sample 3 to create smooth, planar surfaces for our microscopic examinations (Photo 9). We examined the polished sections with the aid of a reflected-light stereomicroscope at magnifications of 7X to 115X. We also prepared blue-dye epoxy-injected ultrathin (20 to 25 µm) sections from representative portions of the outermost 2-1/2 in. of Sample 2, and Sample 3. In addition, we prepared a blue-dye epoxy-injected ultrathin (20 to 25 µm) section from the ASTM C642 test specimen of Sample 1 after testing. We examined the ultrathin sections with the aid of a transmitted-polarized-light microscope at magnifications of 12.5X to 400X.

Our petrographic observations are summarized below.

Sample 1

Substrate Concrete

- The concrete contains 1/4 in. nominal maximum sized particles of coarse aggregate.
- The coarse aggregate consists of natural gravel, as indicated by the subangular to subrounded shapes of the aggregate particles.
- The coarse aggregate is composed of particles of volcanic igneous rocks, primarily consisting of basalt with a lesser amount of dacite and rhyolite.
- Several of the coarse aggregate particles exhibit dark rims, and a few also exhibit internal cracks. The internal cracks in these aggregate particles generally do not extend into the surrounding paste structure.
- The fine aggregate consists of natural sand with subrounded to subangular particles.
- The fine aggregate is primarily composed of feldspar, with a lesser amount of quartz, mica, and pyroxene, as well as sand-sized particles of the rock types observed in the coarse aggregate.
- The coarse- and fine-aggregate particles are uniformly distributed throughout the core.
- The cement paste is composed of particles of portland cement that exhibit normal hydration. We did not observe additional cementitious or pozzolanic materials, such as slag or fly ash, in the concrete.

- We are unable to estimate the w/cm based on the characteristics of the paste structure exhibited in the ultrathin section because the C642 testing may have altered the paste structure of the specimen, including the distribution of hydration products, as well as the extent of carbonation.

- We are also unable to evaluate secondary deposits that may have been present in Sample 1 because the full saturation of the test specimen with water during C642 testing may have resulted in the alteration or removal of the secondary deposits.

- On fresh fracture surfaces of pieces of Sample 1 that were trimmed prior to C642 testing, the paste structure exhibits a color and texture that is comparable to that observed on Sample 3. Therefore, it is likely that the w/cm of Sample 1 is comparable to that of Sample 3.

- The concrete does not contain air entrainment. However, the concrete contains a large amount of entrapped air voids. Based on image analysis of photomicrographs, we estimate that the total air content of the concrete is in the range of 10% to 11%.

- In our examination of the ultrathin section, we observed two air voids that are partially filled with deposits that resemble ASR gel (Photo 10). We could not identify the source of the potential ASR gel in the ultrathin section.

- We observed a few short (less than 1/8 in. in length), narrow (less than 0.5 mil in width) microcracks that are distributed throughout the paste structure with random orientations.

Sample 2

Paint

- The exterior face of the sample is covered with layer of pink colored paint. In our examination of the ultrathin section, we observed that this layer is nominally 3 mils to 5 mils in thickness (Photo 11).

- The paint layer generally exhibits a poor bond with the outermost layer of mortar.

First Mortar Layer

- A relatively thin (20 mils to 40 mils in thickness) layer of mortar occurs under the paint (Photo 11). The mortar contains portland cement and siliceous sand.

- The fine aggregate consists of natural sand with subrounded to subangular particles and is composed almost entirely of quartz.

- The paste of the mortar exhibits a pink color (Photo 9). In our examination of the ultrathin section, we observed that the paste contains very fine (sub-micron) red colored pigment particles.

- The mortar exhibits a moderate amount of entrapped air (Photo 10).

- The first layer of mortar intermittently exhibits a tight bond with the second layer of mortar, with a well-defined bond line.

Second Mortar Layer

- A relatively thick (3/16 in. to 5/16 in. in thickness) layer of mortar occurs under the thin, outermost layer of mortar (Photo 11). The mortar contains portland cement and siliceous sand.

- The fine aggregate consists of natural sand with subrounded to subangular particles and is composed of quartz, feldspar, mica, and pyroxene, with sand-sized rock fragments of granite and schist.

- The paste of the mortar exhibits a light maroon color (Photo 9). In our examination of the ultrathin section, we observed that the paste contains very fine (sub-micron sized) red colored pigment particles.

- The mortar exhibits a small amount of entrapped air.

- The outermost 70 mils to 80 mils of the mortar intermittently exhibits tightly spaced microcracks that are oriented parallel to the exterior face (Photo 12).

- The innermost layer of mortar exhibits a tight bond with the substrate mortar. The paste of the second layer of mortar grades into the paste of the substrate mortar, without a clear bond line.

Substrate Concrete

- The concrete contains a minor amount of 1/4 in. nominal maximum sized particles of coarse aggregate (Photo 9). The coarse aggregate content is low enough that the material could technically be classified as a mortar.

- The coarse aggregate consists of natural gravel, as indicated by the subangular to subrounded shapes of the aggregate particles.

- The coarse aggregate is composed of particles of igneous and metamorphic rocks, including granite and schist.

- The fine aggregate consists of natural sand with subrounded to subangular particles and is composed of quartz grains, with lesser amounts of feldspar, mica, and pyroxene, as well as sand-sized rock fragments of granite and schist. We also observed a trace amount of basalt particles in the fine aggregate.

- The concrete is sand-rich, with a relatively high fine aggregate content for the observed amount of cement paste.

- The fine-aggregate particles are uniformly distributed throughout the core.

- The cement paste is composed of particles of portland cement that exhibit normal hydration. We did not observe additional cementitious or pozzolanic materials, such as slag or fly ash, in the concrete.

- Based on the color, texture, and overall composition of the paste structure, we determined that the concrete generally exhibits a moderate w/cm that we estimate to be in the range of 0.45 to 0.55.

- The concrete does not contain air entrainment. However, the concrete contains a moderately large amount of entrapped air voids. Based on image analysis of photomicrographs, we estimate that the total air content of the concrete is in the range of 6% to 7%.

- An irregular zone of fully carbonated paste extends to depths of 1/2 in. to 7/8 in. from the exterior face.

- In our examination of the ultrathin section, we observed extensive partial carbonation of the paste structure below the zone of fully carbonated paste to the full depth of the ultrathin section (1-5/8 in.).

- Below the zone of fully carbonated paste, many of the air voids are partially to completely filled with secondary deposits of ettringite and calcium carbonate (Photo 13). We also observed layered deposits of calcium hydroxide lining a few of the air voids.

- In our examination of the ultrathin section, we observed one air void that is partially filled with deposits that resemble alkali-silica reaction (ASR) gel (Photo 14). We could not identify the source of the potential ASR gel in the ultrathin section.

- We observed one microcrack oriented roughly perpendicular to the exterior face that extends from the second layer of mortar into the substrate concrete to a depth of 5/8 in. from the exterior face. The width of the microcrack tapers from 2 mils near the exterior face to 0.1 mil near its point of termination. The microcrack fractures several fine aggregate particles along its path. Hydration products intermittently line the walls of the microcrack. Several very fine (less than 0.2 mil in width) secondary microcracks oriented roughly parallel to the primary microcrack occur along the margins of the upper half of the primary microcrack.

Sample 3

Paint

- The exterior face of the sample is covered with layer of pink colored paint (Photo 9). In our examination of the ultrathin section, we observed that this layer is nominally 2 mils to 5 mils in thickness.

- The paint layer generally exhibits a poor bond with the outermost layer of mortar.

First Mortar Layer

- A relatively thin (20 mils to 30 mils in thickness) layer of mortar occurs under the paint (Photo 15). The mortar contains portland cement and siliceous sand.

- The fine aggregate consists of natural sand with subrounded to subangular particles and is composed almost entirely of quartz.

- The paste of the mortar exhibits a pink color (Photo 9). In our examination of the ultrathin section, we observed that the paste contains very fine (sub-micron sized) red colored pigment particles.

- The mortar exhibits a moderate amount of entrapped air.

- The outermost 5 mils to 10 mils of the mortar intermittently exhibits microcracks that are oriented parallel to the exterior face.

- The first layer of mortar intermittently exhibits a tight bond with the second layer of mortar, with a well-defined bond line.

Pockets of Mortar Infilling Surface of Second Mortar Layer

- A mortar that is distinct from the first mortar layer and second mortar layer occurs in small pockets between the first mortar layer and second mortar layer (Photo 15). These pockets are relatively shallow (4 mils to 15 mils deep) and appear to be filling rough areas of the surface of second mortar layer. Similar mortar deposits partially fill air voids that intersect the surface of the second mortar layer.

- The fine aggregate is composed almost entirely of fine sand-sized particles of limestone.

- The paste of the mortar exhibits a red color. In our examination of the ultrathin section, we observed that the paste contains very fine (sub-micron) red colored pigment particles, at a higher concentration than that observed in the first mortar layer and second mortar layer.

Second Mortar Layer

- A relatively thick (1/4 in. to 7/16 in. in thickness) layer of mortar occurs under the thin, outermost layer of mortar. The mortar contains portland cement and siliceous sand.

- The fine aggregate consists of natural sand with subrounded to subangular particles and is composed of quartz, feldspar, mica, and pyroxene, with sand-sized rock fragments of granite and schist.

- The paste of the mortar exhibits a light maroon color (Photo 9). In our examination of the ultrathin section, we observed that the paste contains very fine (sub-micron) red colored pigment particles.

- The mortar exhibits a small amount of entrapped air.

- The outermost 20 mils to 30 mils of the mortar intermittently exhibits tightly spaced microcracks that are oriented parallel to the exterior face (Photo 16).

- The innermost layer of mortar exhibits a tight bond with the substrate concrete. The paste of the second layer of mortar grades into the paste of the substrate concrete, without a clear bond line.

Substrate Concrete

- The concrete contains 1/4 in. nominal maximum sized particles of coarse aggregate.

- The coarse aggregate consists of natural gravel, as indicated by the subangular to subrounded shapes of the aggregate particles.

- The coarse aggregate is composed of particles of volcanic igneous rocks, primarily consisting of basalt with a lesser amount of dacite and rhyolite.

- Several of the coarse aggregate particles exhibit dark rims, and a few also exhibit internal cracks. The internal cracks in these aggregate particles generally do not extend into the surrounding paste structure.

- In the ultrathin section, we observed one coarse aggregate particle of rhyolite that exhibits signs of potential ASR, including a high density of internal cracks and areas of internal porosity that appear to be indicative of partial dissolution (Photo 17).

- Several of the coarse aggregate particles are surrounded by halos of light colored paste (Photo 9), which likely represent excess water contributed by slightly porous aggregate particles.

- The fine aggregate consists of natural sand with subrounded to subangular particles.

- The fine aggregate is primarily composed of feldspar, with a lesser amount of quartz, mica, and pyroxene, as well as sand-sized particles of the rock types observed in the coarse aggregate.

- The coarse- and fine-aggregate particles are uniformly distributed throughout the core.

- The cement paste is composed of particles of portland cement that exhibit normal hydration. We did not observe additional cementitious or pozzolanic materials, such as slag or fly ash, in the concrete.

- Based on the color, texture, and overall composition of the paste structure, we determined that the concrete generally exhibits a moderate w/cm that we estimate to be in the range of 0.40 to 0.50.

- The concrete does not contain air entrainment. However, the concrete contains a large amount of entrapped air voids. Based on image analysis of photomicrographs, we estimate that the total air content of the concrete is in the range of 10% to 11%.

- In our examination of the ultrathin section, we observed extensive carbonation of the paste structure throughout the full depth of the ultrathin section (1-5/8 in.). Much of the paste structure is fully carbonated, and we were unable to identify a distinct carbonation front in the ultrathin section.

- Several of the air voids are partially filled with secondary deposits of ettringite (Photo 18). We also observed relatively large crystals of secondary portlandite (calcium hydroxide) in one of the air voids (Photo 19).

- We did not observe any significant microcracking in the paste structure.

2.2 Stereomicroscopic Examinations

During evaluation of Sample 5 for testing, we created several cut surfaces, one of which revealed a network of cracks extending through a coarse aggregate particle of dacite that is abnormally large (roughly 1 in. in size) relative to the rest of the coarse aggregate particles (nominally 1/4 in. to 5/16 in. in size). We roughly polished the cut surface that that contains this dacite particle (Photo 20), and we then examined the aggregate and the associated cracks with the aid of a reflected-light stereomicroscope at magnifications of 7X to 115X.

During our stereomicroscopic examination, we observed the following features:

- In terms of composition, the overall population of coarse aggregate particles in Sample 5 is similar to those in Sample 3 and Sample 1 and consists of volcanic igneous rock particles.

- The large (roughly 1 in. in size) dacite particle is fractured by branching cracks, some of which are filled with white colored, semi-translucent deposits (Photos 20 and 21).

- The widest crack in the dacite particle is 10 mils in width and tapers to 4 mils in width as it extends into the surrounding paste structure. This crack is partially to completely filled with white colored, semi-translucent deposits, both in the dacite particle and in the surrounding paste structure (Photo 21).

- Entrapped air voids located adjacent to the dacite particle are partially to completely filled with white colored, semi-translucent deposits. Some of these deposits exhibit layered structures (Photo 22).

2.3 Scanning Electron Microscopy with Energy Dispersive Spectroscopy (SEM-EDS)

We used SEM-EDS to examine the polished section of Sample 5, focusing primarily on the materials filling the cracks. We confirmed the white deposits that partially fill cracks extending through the dacite particle and the surrounding paste structure consist of ASR gel (Figure 1). We also confirmed that the layered white deposits that completely fill an entrapped air void located adjacent to the dacite particle (Photo 22) consist of ASR gel.

2.4 Chloride Ion Content Analysis

Prior to determination of the chloride ion content in accordance with ASTM C1152 – Standard Test Method for Acid-Soluble Chloride in Mortar and Concrete, we cut 1/2 thick slices of concrete at two depths in each of the concrete samples. The outermost depth in both samples includes the near-surface layers of mortar and the substrate concrete. Table 1 summarizes the nominal sampling depths and the individual test results.

Table 1 – Chloride Ion Content Results

Sample ID	Depth (in.)	Chloride Content by Weight of Concrete (%)
2	0 - 1/2	0.023
2	1 - 1-1/2	0.006
5	0 - 1/2	0.172
5	1 - 1-1/2	0.013

A copy of the full laboratory chloride test report is attached for reference.

2.5 Determination of Density, Absorption, and Voids in Hardened Concrete

We tested Sample 1 following the procedures outlined in ASTM C642 – Standard Test Method for Density, Absorption, and Voids in Hardened Concrete. Table 2 summarizes our results.

Table 2 – Density, Absorption, and Volume of Permeable Pore Space (Voids) Results

Sample ID	Absorption (%)	Bulk Density (lb/ft^3)	Volume of Permeable Pore Space (%)
1	7.6	127.3	22.72

The full ASTM C642 testing report is included in Appendix C.

3. DISCUSSION

3.1 Alkali-Silica Reaction (ASR)

The concrete of Sample 1, Sample 3, and Sample 5 represent a similar concrete mix consisting of portland cement, siliceous sand, and nominal 1/4 in. sized coarse aggregate composed of volcanic igneous rock particles, with no air entrainment. Although the majority of volcanic rock particles in the coarse aggregate consist of basalt, which has low susceptibility to alkali-silica reaction (ASR), the coarse aggregate also contains a small amount of dacite and rhyolite, which have high susceptibility to ASR due to the presence of microcrystalline silica. We observed minor evidence for ASR in Sample 1, consisting of deposits that resemble ASR gel in air voids, and in Sample 3, consisting of a coarse aggregate particle of rhyolite with signs of ASR deterioration. However, we observed significant evidence for deleterious ASR in Sample 5. In terms of the SGH index rating system for the severity of ASR in hardened concrete (1 to 6, with

6 as the highest rating; see Appendix D), the extent of ASR in Sample 5 best fits the criteria for a rating of 4, which is described as "Severe cracking (Severe evidence for deleterious ASR)." The criteria for the rating of 4 that are pertinent to Sample 5 include: cracks that form an extensive interconnecting system throughout the concrete and often exceed 100 µm (3.9 mils) in width; the presence of ASR gel deposits that partially to completely fill cracks; and the internal and peripheral cracking of reactive aggregates.

In terms of texture and aggregate composition, the concrete in Sample 2 represents a different concrete mix than that represented by Sample 1, Sample 3, and Sample 5. The concrete in Sample 2 is distinct from the concrete in Sample 1, Sample 3, and Sample 5 due to the very low abundance of coarse aggregate particles in the Sample 2 concrete. In addition, the concrete in Sample 2 contains different aggregate, in both the fine aggregate and coarse aggregate fractions. The few coarse aggregate particles that we observed in Sample 2 consist of granite and schist, and we did not observe any of the coarse aggregate particles of volcanic rock that we observed in Sample 1, Sample 3, and Sample 5. Although the fine aggregate in the Sample 2 concrete contains some of the same minerals observed in the fine aggregate in Sample 1, and Sample 3, the proportions of the minerals are significantly different. Whereas the fine aggregate in Sample 1 and Sample 3 consists primarily of feldspar grains with lesser amounts of quartz, mica, and pyroxene, the fine aggregate in Sample 2 consists primarily of quartz grains with lesser amounts of feldspar, mica, and pyroxene. We observed minor evidence for ASR in Sample 2, consisting of deposits that resemble ASR gel in one air void. The ultrathin section did not appear to contain the source of the potential ASR gel. The most likely ASR-susceptible mineral responsible for the potential ASR gel is strained quartz, which is present both as sand grains in the fine aggregate and as crystals in the granite and schist particles in the coarse aggregate.

3.2 Cyclic Freeze-Thaw Damage

Although Sample 2 and Sample 3 contain different concrete, they contain similar layers of pigmented mortar on top of their concrete substrates. In both Sample 2 and Sample 3, the second complete layer of mortar contains tightly spaced microcracks that are oriented parallel to the exterior face. These microcracks likely represent damage from cyclic freezing and thawing. Because neither the second layer of mortar nor the substrate concrete that it is intimately bonded to contain air entrainment, the near-surface region lacks any protection from cyclic-freeze thaw damage beyond the limited protection from moisture ingress that might be provided by the paint layer.

3.3 Concrete Permeability and Water Infiltration

The C642 testing determined that Sample 1 contains 23% permeable pore space in total, which reflects both the high entrapped air content of Sample 1 plus the inherent permeability of the paste structure. The porosity of the concrete facilitates the ingress of water, which in turn promotes both cyclic freeze-thaw damage and ASR. Collectively, the extensive carbonation and the secondary deposits of ettringite and calcium hydroxide that we observed in the Sample 2 concrete and the Sample 3 concrete constitute evidence that water has periodically infiltrated the concrete. All of the concrete that we observed contains moderately high entrapped air contents (6% to 7% in Sample 2; 10% to 11% in Sample 1 and Sample 3) and, accordingly, are likely to have high permeability.

3.4 Chloride Content

Sample 5 contains significantly higher concentrations of chlorides in comparison to Sample 2. Sample 5 was reportedly taken from a pinnacle that had been left outside at ground level and, therefore, may have been exposed to additional chloride after its removal from the structure. Nevertheless, the chloride content of the outermost sampling depth of Sample 2 (0.023%) is substantially higher than that of the innermost sampling depth (0.006%), and it is also close to the ACI 201 chloride corrosion threshold value expressed in terms of percent by weight of concrete (0.029%, assuming a nominal "six-sack" mix). The elevated chloride content of the outermost sampling depth could potentially represent: a) a higher intrinsic chloride content in one or both of the mortar layers on Sample 2; b) the ingress of chlorides from the exterior surface, most likely due to the atmospheric deposition of chlorides on the walls of the structure due to the remobilization of road salt residues as wind-blown particles;[1] or c) a combination of a and b. Because most of the concrete members on the structure reportedly do not contain embedded reinforcing steel, the ingress of chlorides does not represent a concern from the standpoint of corrosion. However, the elevated chloride content of the outermost 1/2 in. of Sample 2 may increase the severity of cyclic freeze-thaw damage by promoting an increase in the number of freeze-thaw cycles.

4. CONCLUSIONS

Based on all of our observations and findings, we conclude the following:

- The substrate concrete exhibits evidence of minor to severe ASR.
- The innermost layer of mortar and the substrate concrete are susceptible to cyclic freeze-thaw damage because they do not contain air entrainment.
- The substrate concrete is permeable, in part because of a relatively high content of entrapped air.
- It is crucial that future maintenance of the mortar and concrete provide protection against the ingress of water, because both the ASR in the concrete and the cyclic freeze-thaw damage in the mortar would likely be exacerbated by continued exposure to water.

[1] Williams, A.L. and G.J. Stensland, *Atmospheric Dispersion Study of Deicing Salt Applied to Roads*, Part II Final Report for Period July 2002 to June 2004, Physical Research Report No. 140, Illinois Department of Transportation, Jan. 2006.

Photo 1

Exterior face of Sample 1.

Photo 2

Side view of Sample 1. The exterior face of the core is to the left.

Photo 3

Exterior face of Sample 2 (left) and face of mid-depth fracture (right).

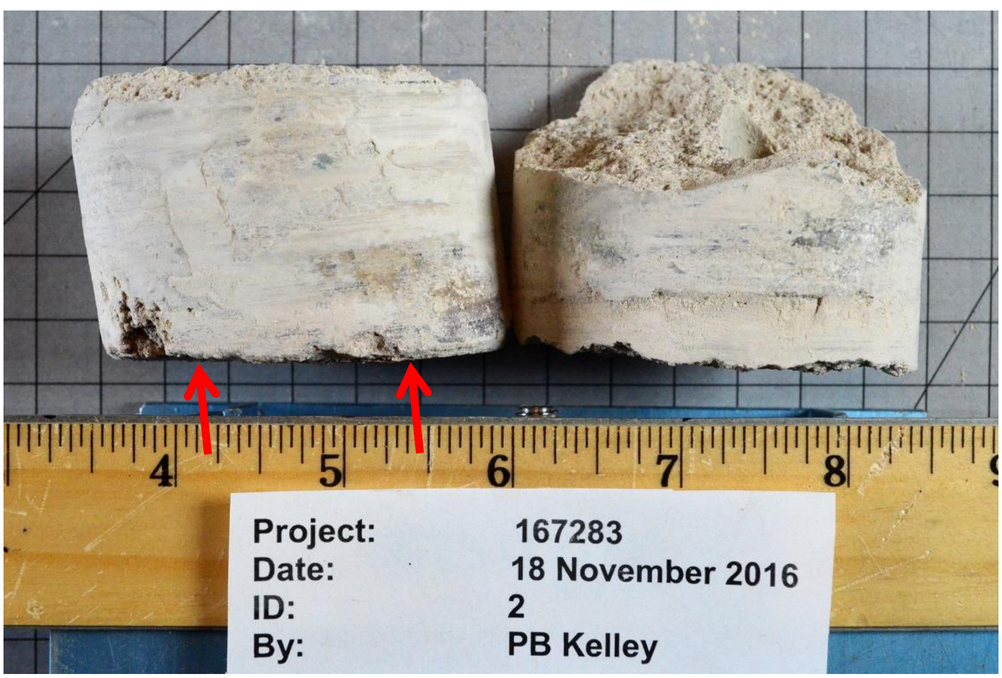


Photo 4

Side view of the pieces of Sample 2. The red arrows point to the exterior face.

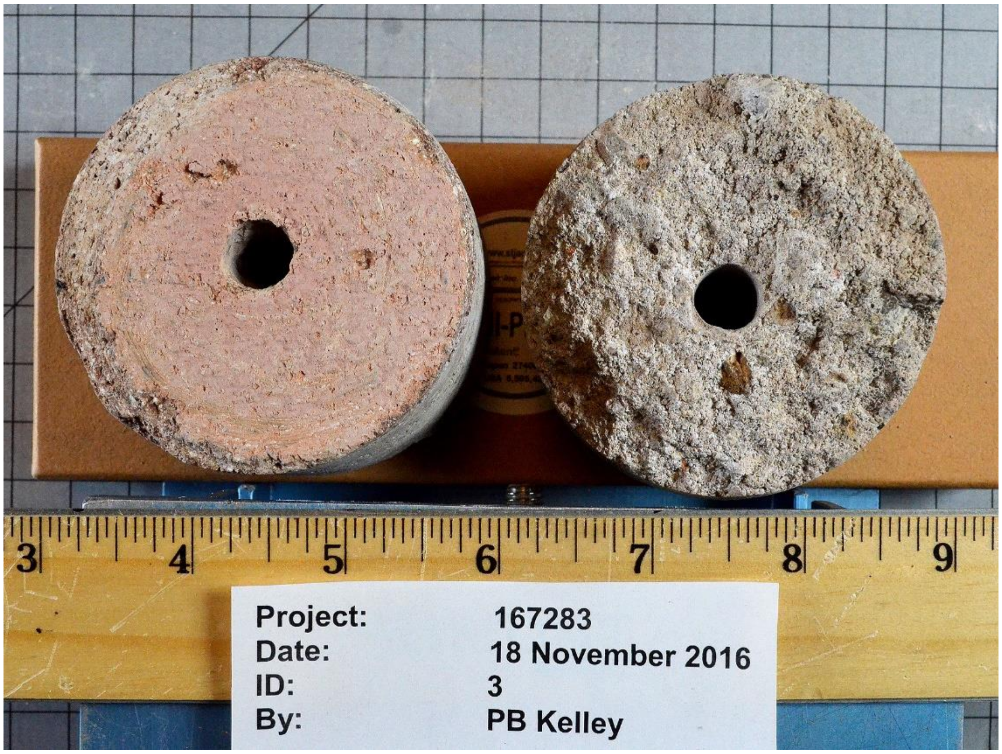


Photo 5

Exterior face of Sample 3 (left) and face of mid-depth fracture (right).

Photo 6

Side view of Sample 3. The exterior face of the core is to the left.

Photo 7

Exterior face of Sample 5.

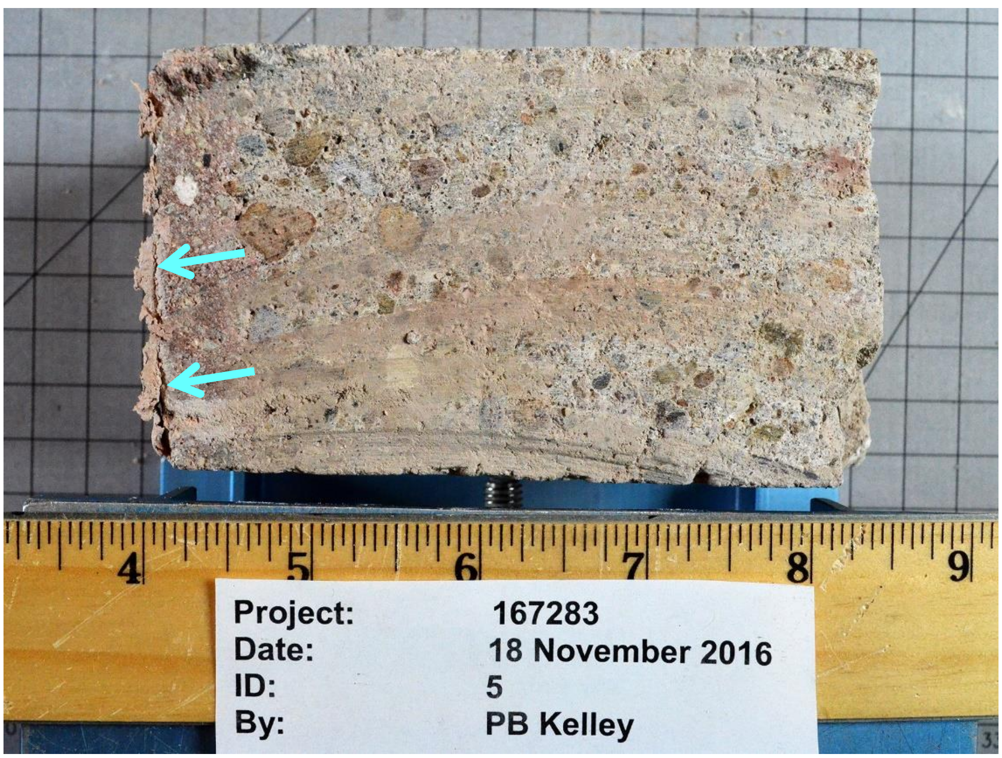


Photo 8

Side view of Sample 5. The exterior face of the sample is to the left. The light blue arrows mark the partially delaminated paint layer on the exterior surface.

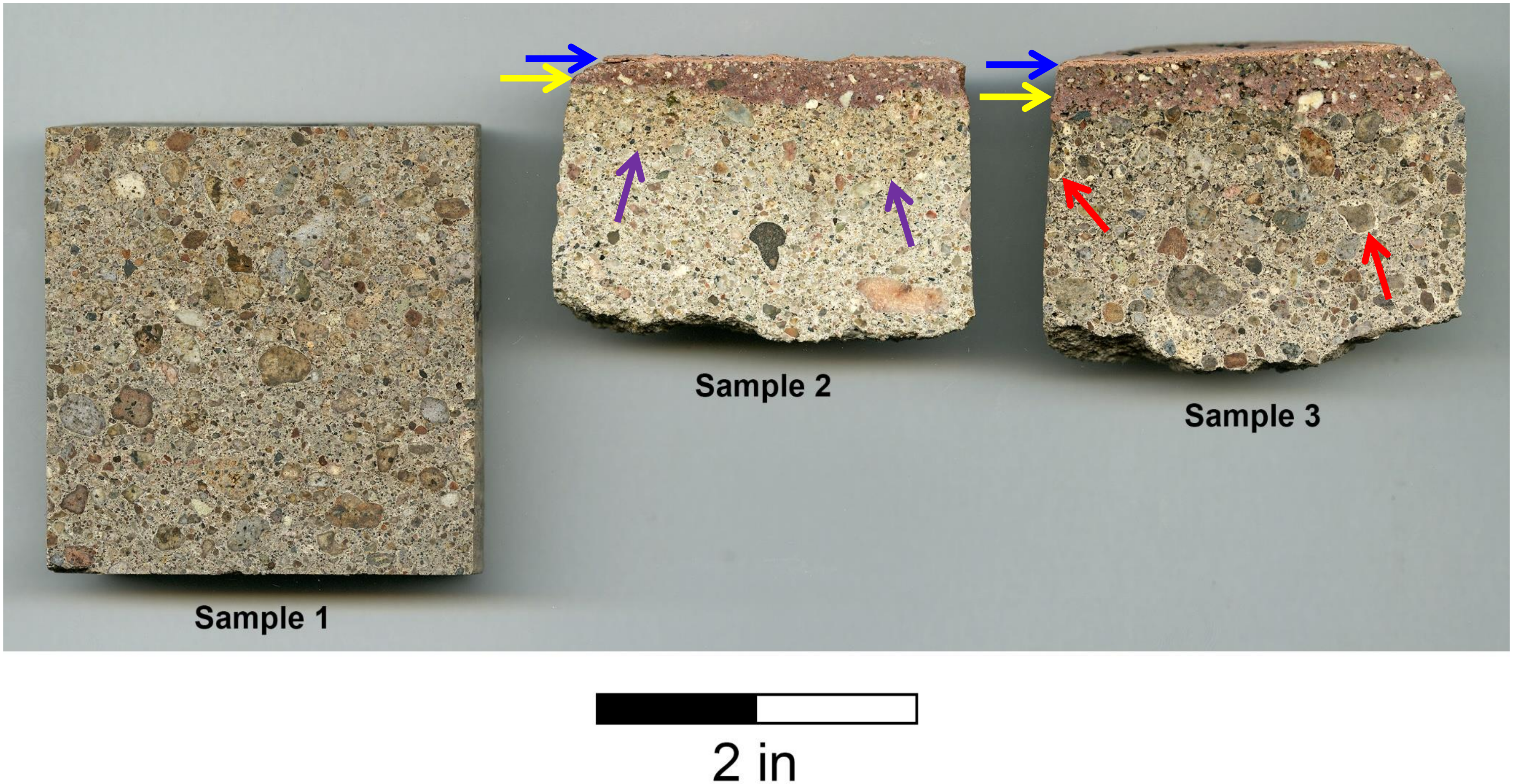

Sample 1
Sample 2
Sample 3
2 in

Photo 9

Polished full-depth longitudinal sections of Sample 2 and 3, as well as a polished longitudinal section of the C642 test specimen of Sample 1. The exterior faces of the samples are at the top. Note the layers of pink and maroon colored mortars on Sample 2 and Sample 3 (blue and yellow arrows). Also note the similarities between the concrete in Sample 1 and the concrete in Sample 3 in terms of coarse aggregate color, size, and abundance, as well as the relative lack of coarse aggregate in the concrete in Sample 2. The purple arrows mark the approximate lower boundary of the zone of beige-colored paste in Sample 2, which represents the zone of fully carbonated paste. The red arrows mark coarse aggregate particles in Sample 3 that exhibit halos of light colored paste.

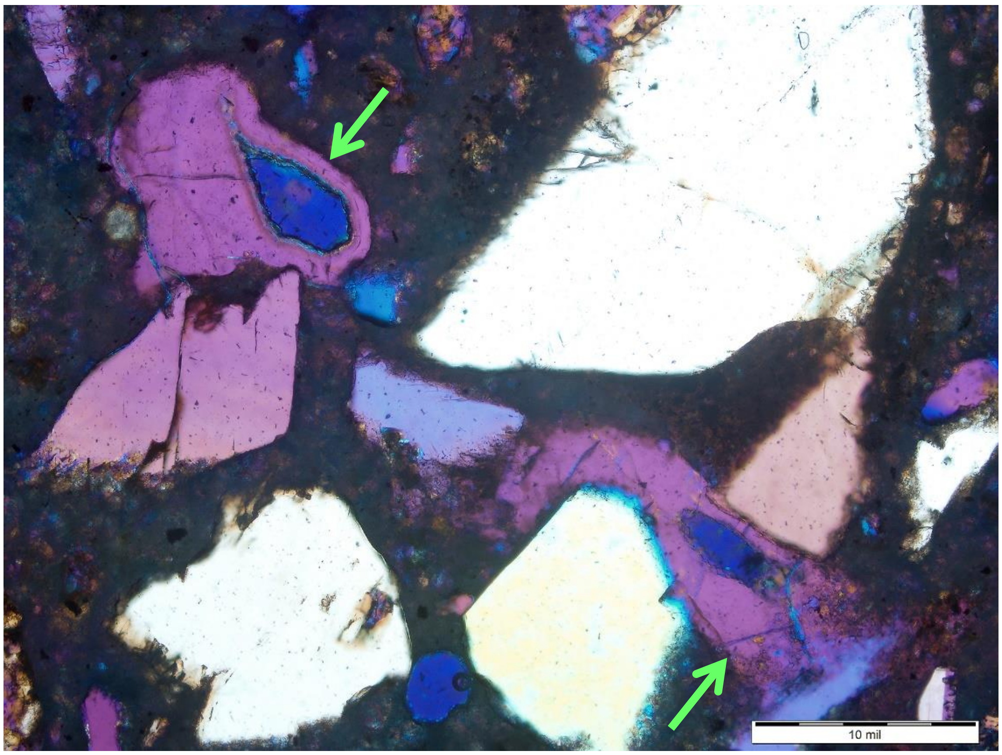


Photo 10

Photomicrograph of the ultrathin section of the Sample 1 C642 specimen, depicting entrapped air voids that are partially filled with deposits that resemble ASR gel (green arrows).

(Cross polarized light with full waveplate).

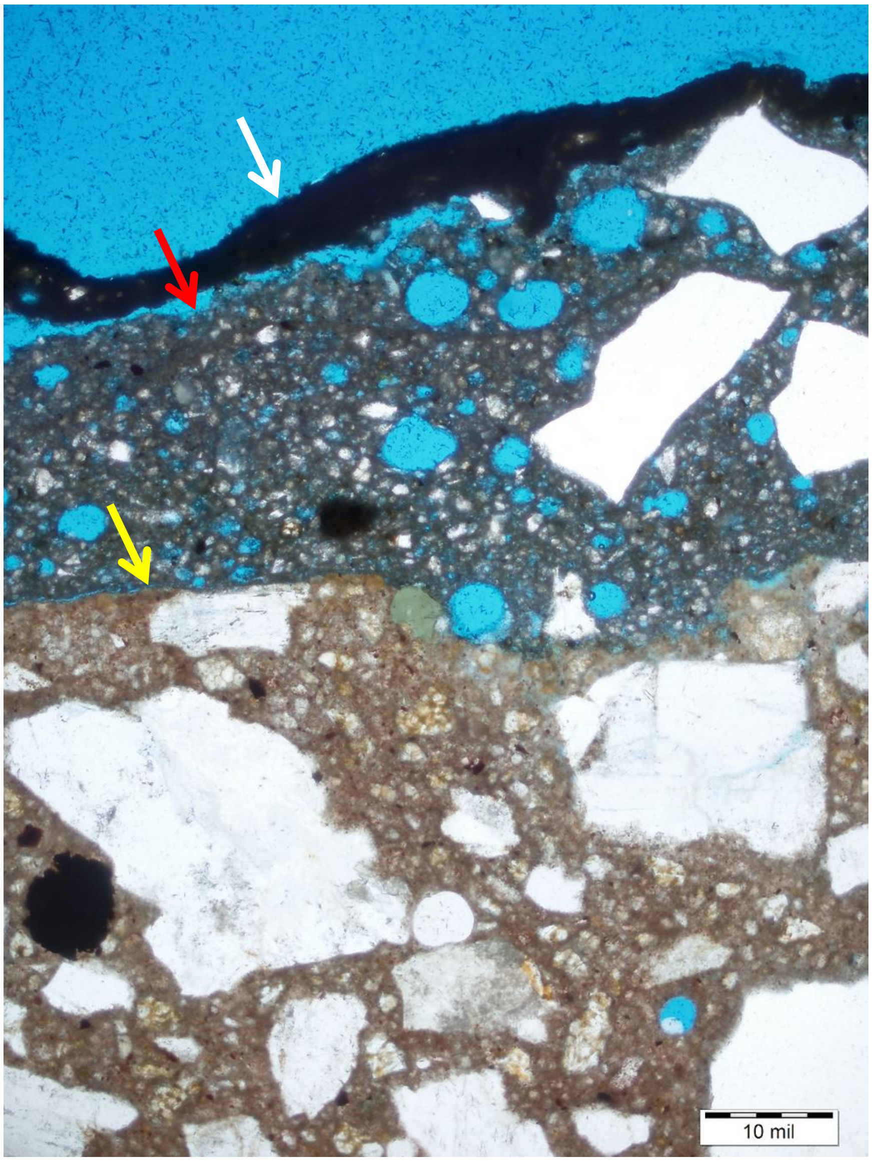


Photo 11

Photomicrograph of the ultrathin section of Sample 2, depicting the paint layer on the exterior surface (white arrow), the first mortar layer (red arrow), and the second mortar layer (yellow arrow).

(Plane polarized light).

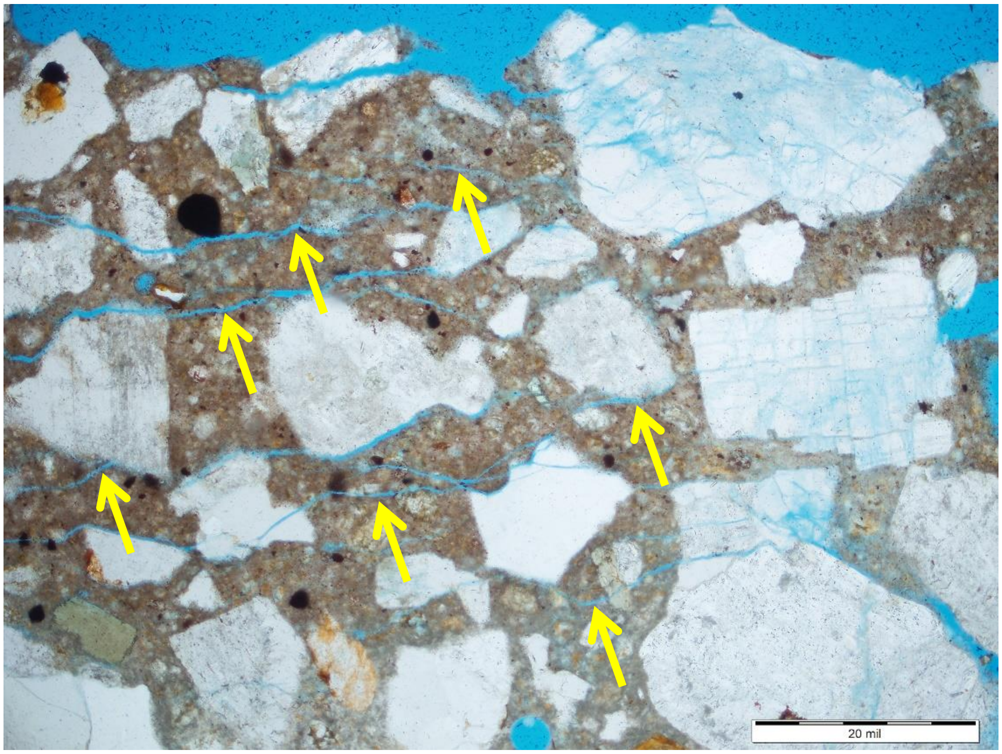


Photo 12

Photomicrograph of the ultrathin section of Sample 2, depicting the outermost zone of the second layer of mortar (the first layer of mortar is missing in this area). Note the tightly spaced, parallel microcracks (yellow arrows).

(Plane polarized light).

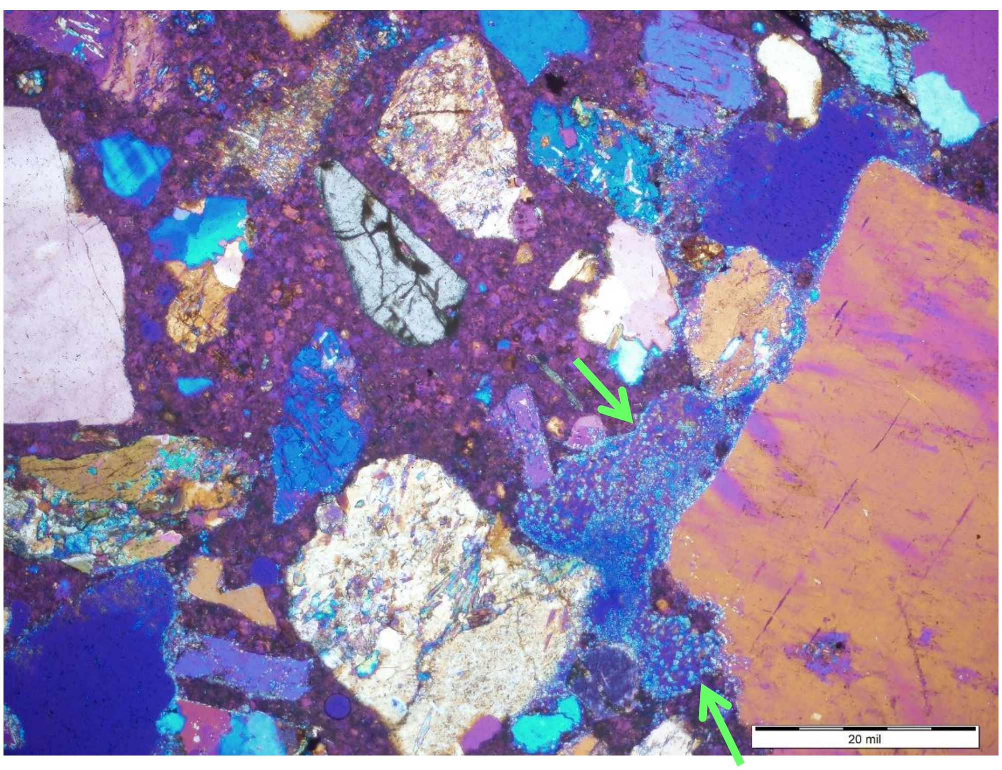


Photo 13

Photomicrograph of the ultrathin section of Sample 2, depicting an entrapped air void that is partially filled with deposits of secondary ettringite and calcium carbonate (green arrows).

(Cross polarized light with full waveplate).

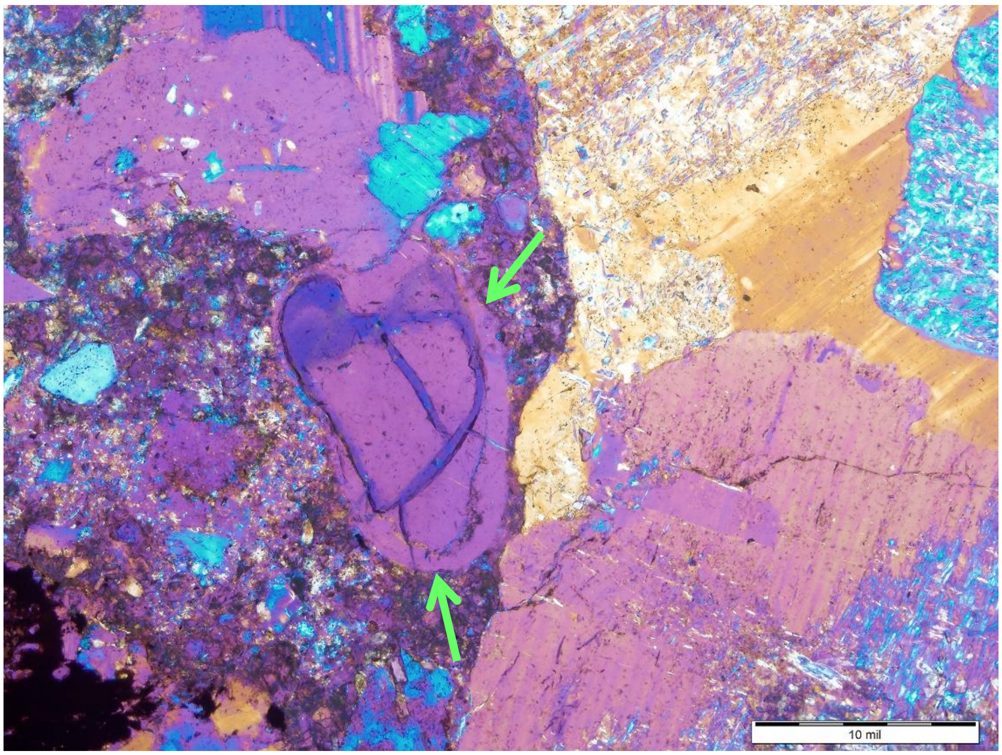


Photo 14

Photomicrograph of the ultrathin section of Sample 2, depicting an entrapped air void that is partially filled with deposits that resemble ASR gel (green arrows).

(Cross polarized light with full waveplate).

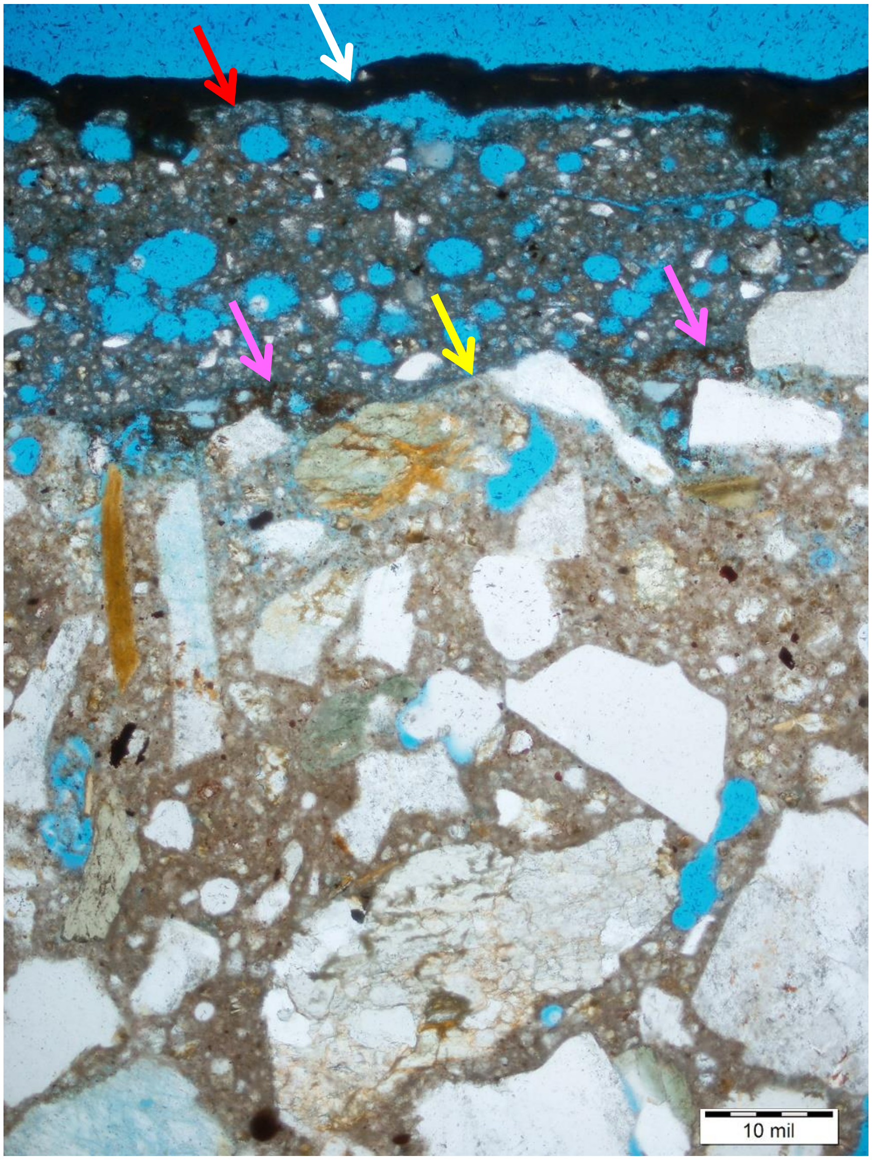


Photo 15

Photomicrograph of the ultrathin section of Sample 3, depicting the paint layer on the exterior surface (white arrow), the first mortar layer (red arrow), the second mortar layer (yellow arrow), and remnants of another mortar that is infilling pockets in the second mortar layer (pink arrows).

(Plane polarized light).

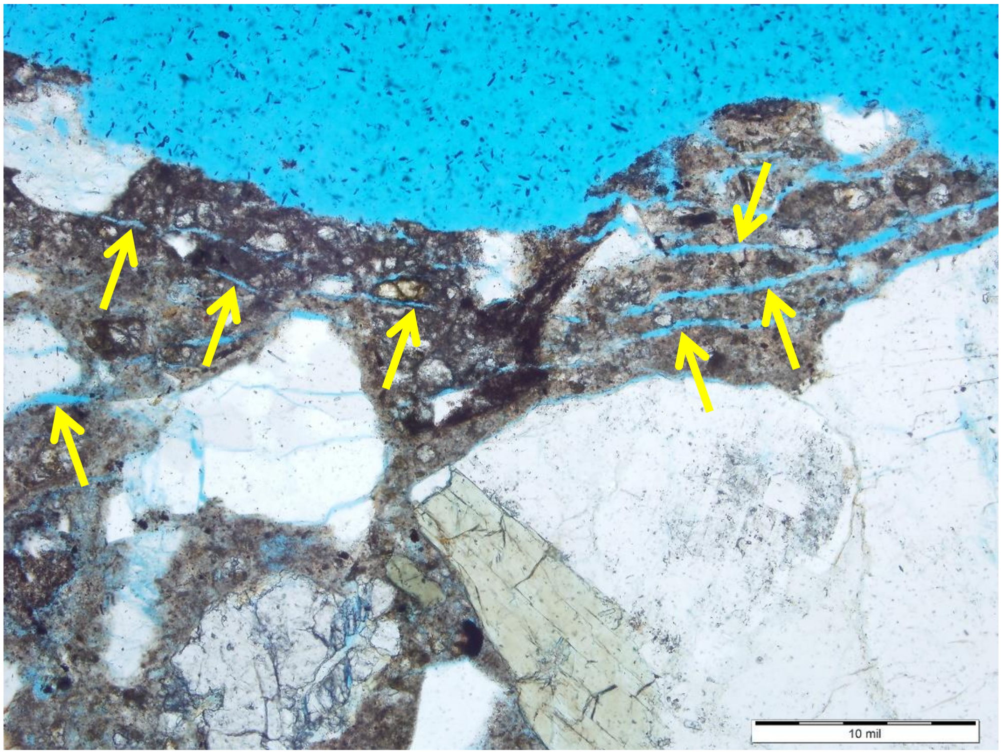


Photo 16

Photomicrograph of the ultrathin section of Sample 3, depicting the outermost zone of the second layer of mortar (the first layer of mortar is missing in this area). Note the tightly spaced, parallel microcracks (yellow arrows).

(Plane polarized light).

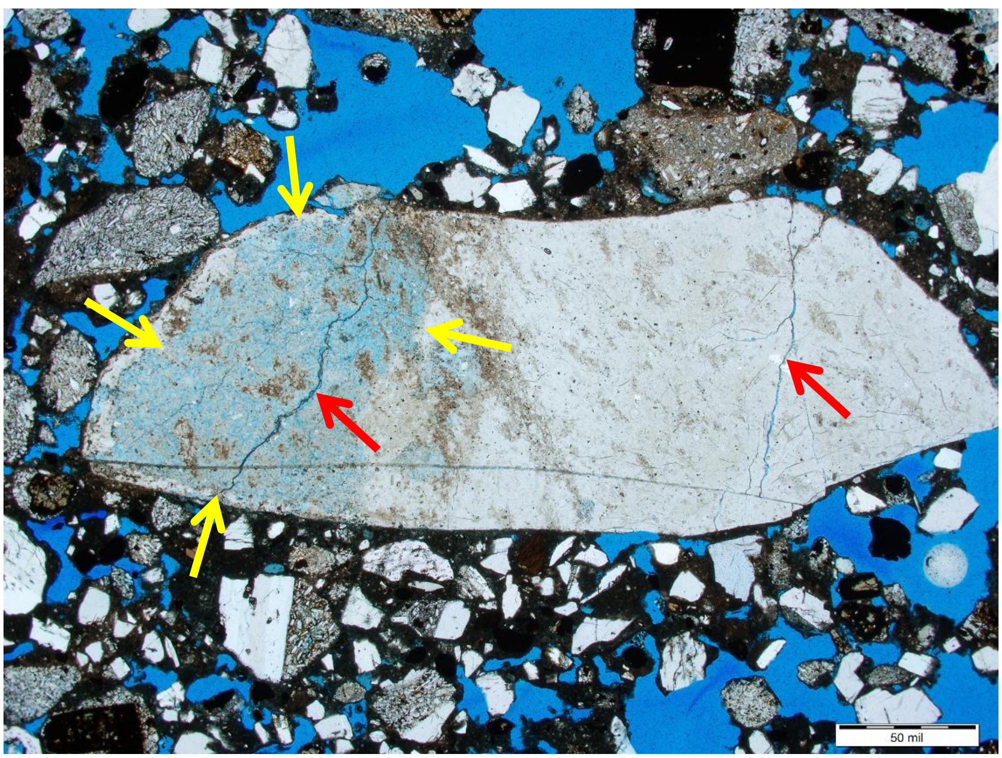


Photo 17

Photomicrograph of the ultrathin section of Sample 3, depicting a coarse aggregate particle of rhyolite that exhibits signs of ASR, such as a high density of internal cracks (red arrows) and localized high internal porosity (indicated by the stronger saturation of blue-dyed epoxy in the area bounded by yellow arrows).

(Plane polarized light).

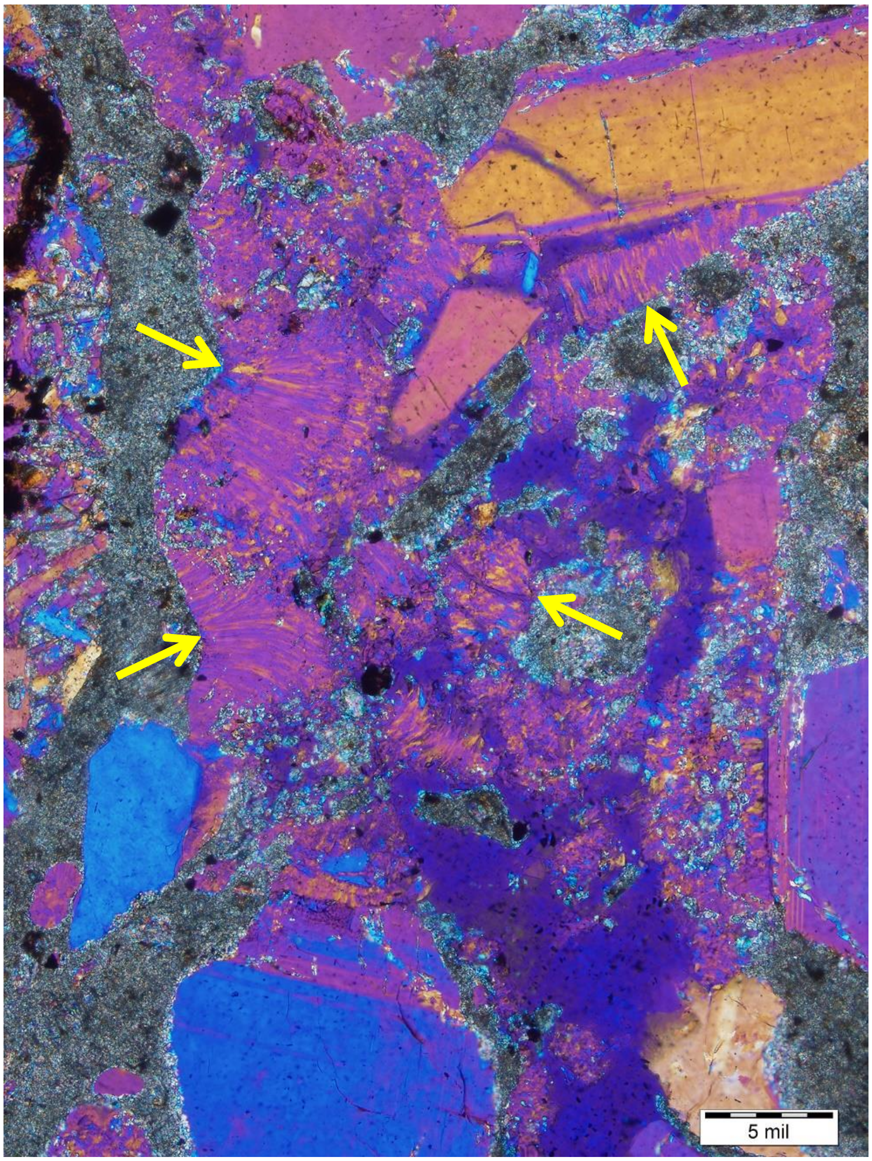


Photo 18

Photomicrograph of the ultrathin section of Sample 3, depicting entrapped air voids that are partially filled with deposits of secondary ettringite (yellow arrows).

(Cross polarized light with full waveplate).

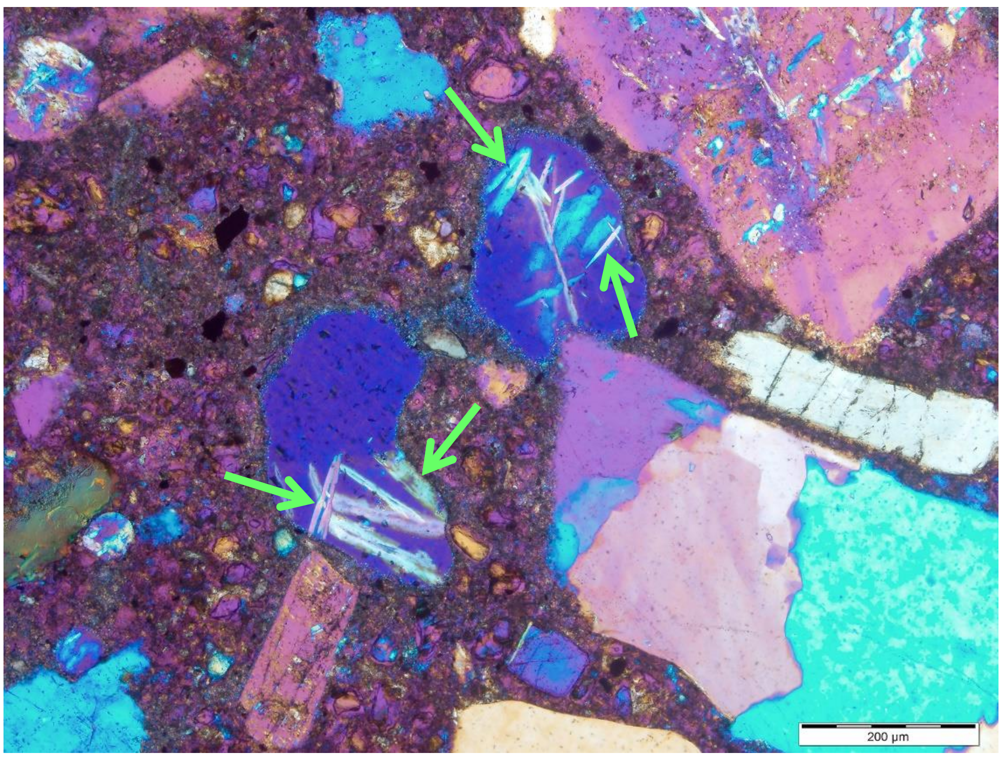


Photo 19

Photomicrograph of the ultrathin section of Sample 3, depicting entrapped air voids that are partially filled with crystals of secondary portlandite (green arrows).

(Cross polarized light with full waveplate).

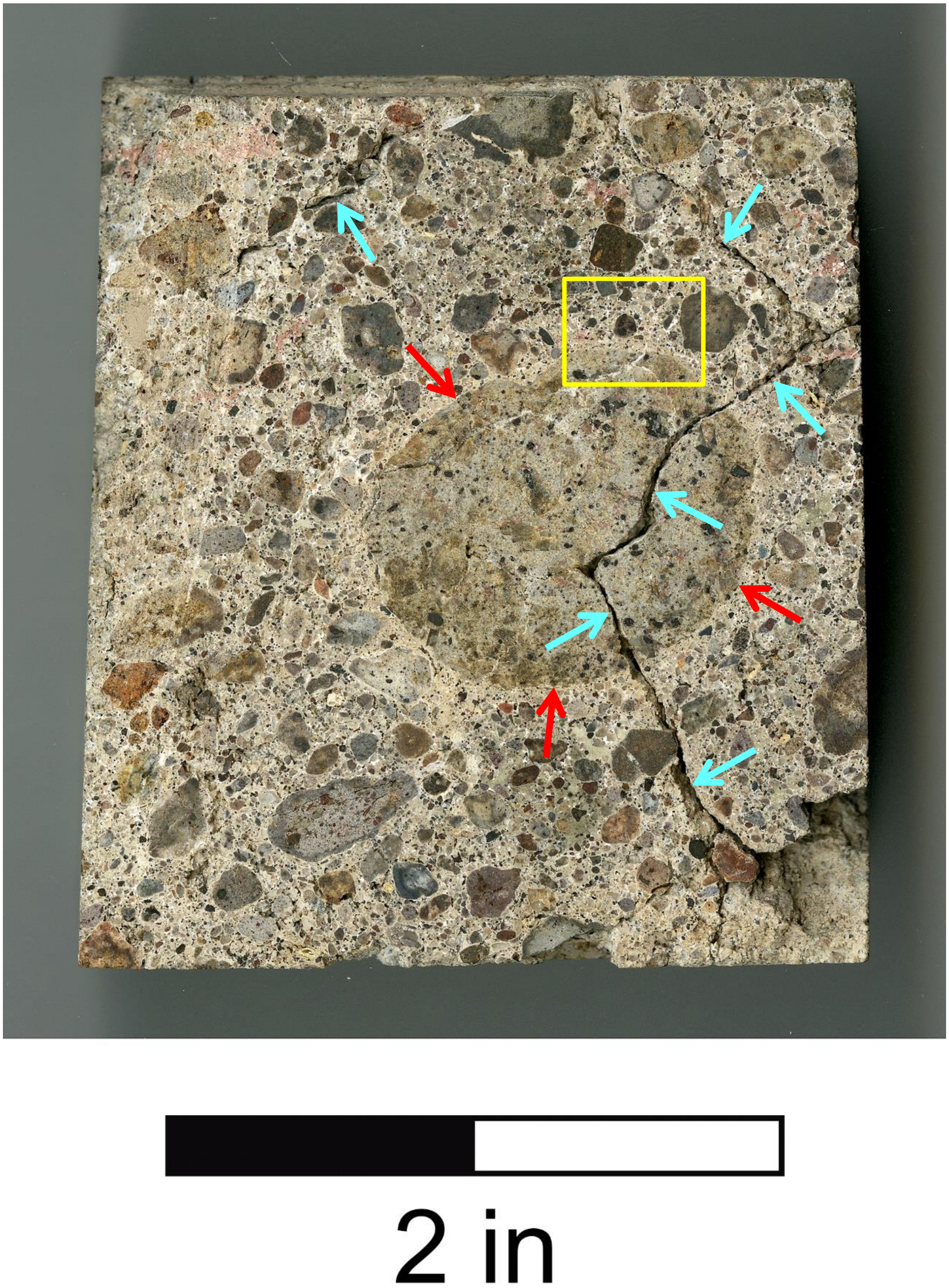


Photo 20

Polished section of Sample 5. Red arrows mark an abnormally large (nominally 1 in. in size) coarse aggregate particle of dacite. Note the network of cracks that extends through the dacite particle and into the surrounding paste structure (light blue arrows). The yellow box marks the area depicted in greater detail in Photo 21.

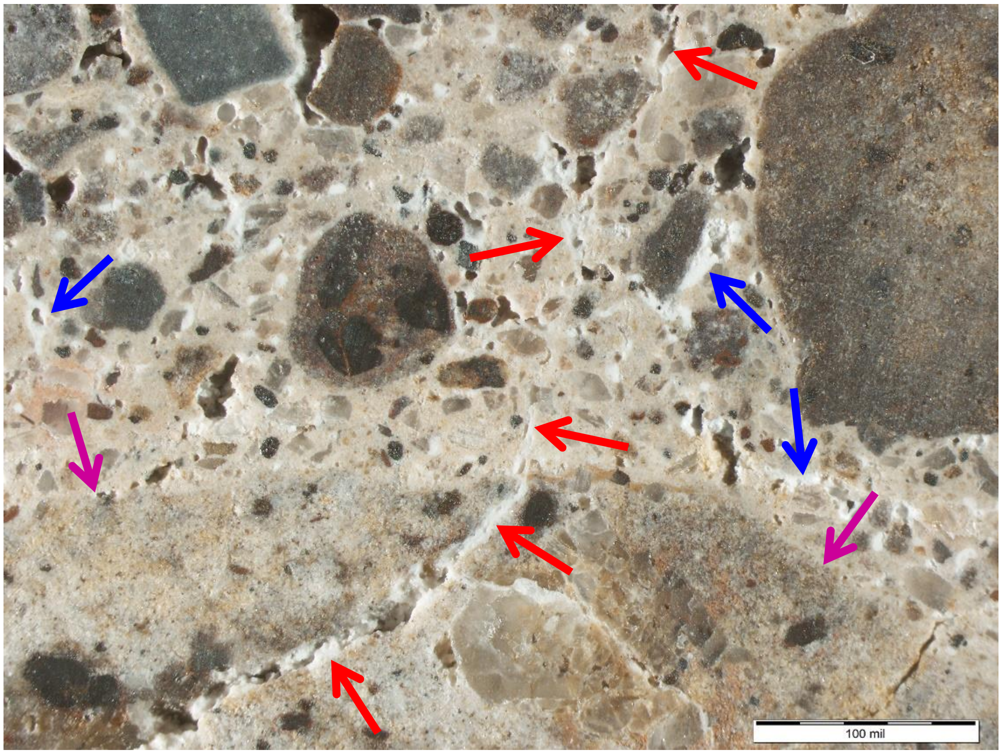


Photo 21

Detail of the polished section of Sample 5, depicting cracks filled with white colored deposits (red arrows) that extend from a coarse aggregate particle of dacite (lower third of image, bounded by purple arrows) into the surrounding paste structure. Also note the entrapped air voids that are partially to completely filled with white deposits (blue arrows).

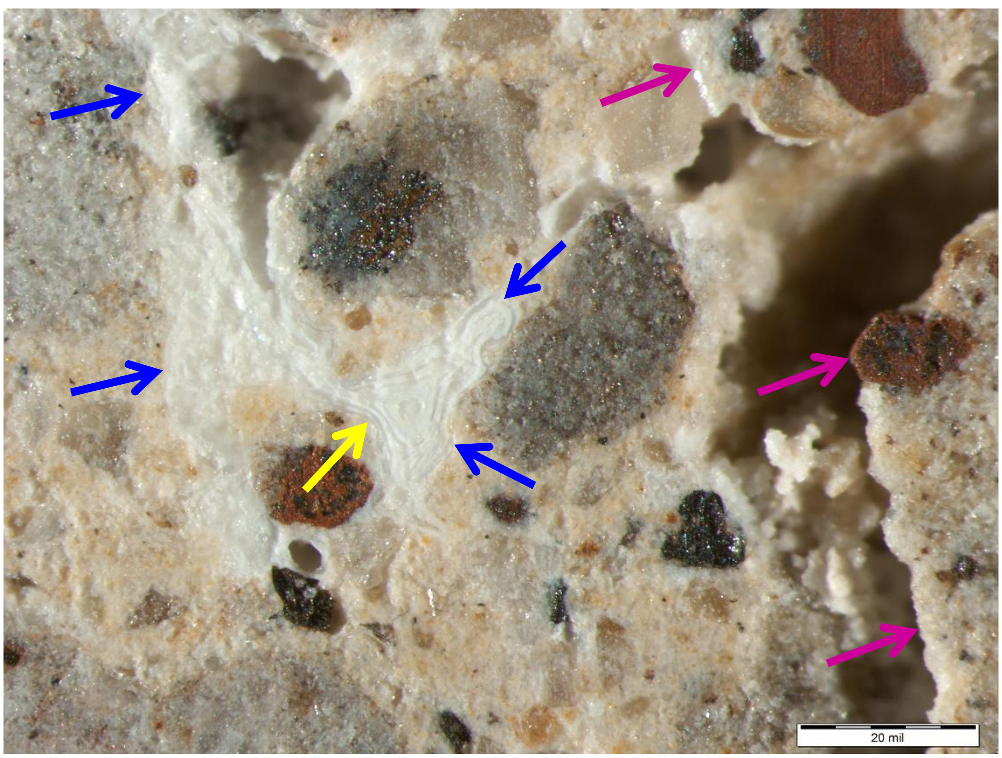


Photo 22

Detail of the polished section of Sample 5, depicting an entrapped air void (bounded by blue arrows) that is nearly completely filled with white colored, semi-translucent deposits. An edge of the dacite coarse aggregate particle depicted in Photo 20 is marked with purple arrows. Note that some areas of the white colored, semi-translucent deposits exhibit layered structures (yellow arrow).

SEM/EDS Data

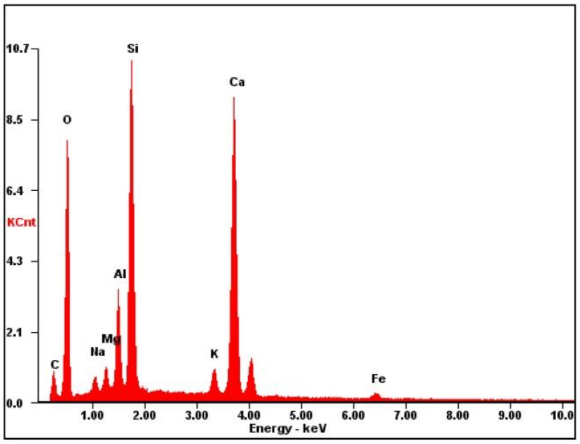
SIMPSON GUMPERTZ & HEGER
Engineering of Structures and Building Enclosures

Project: 167283

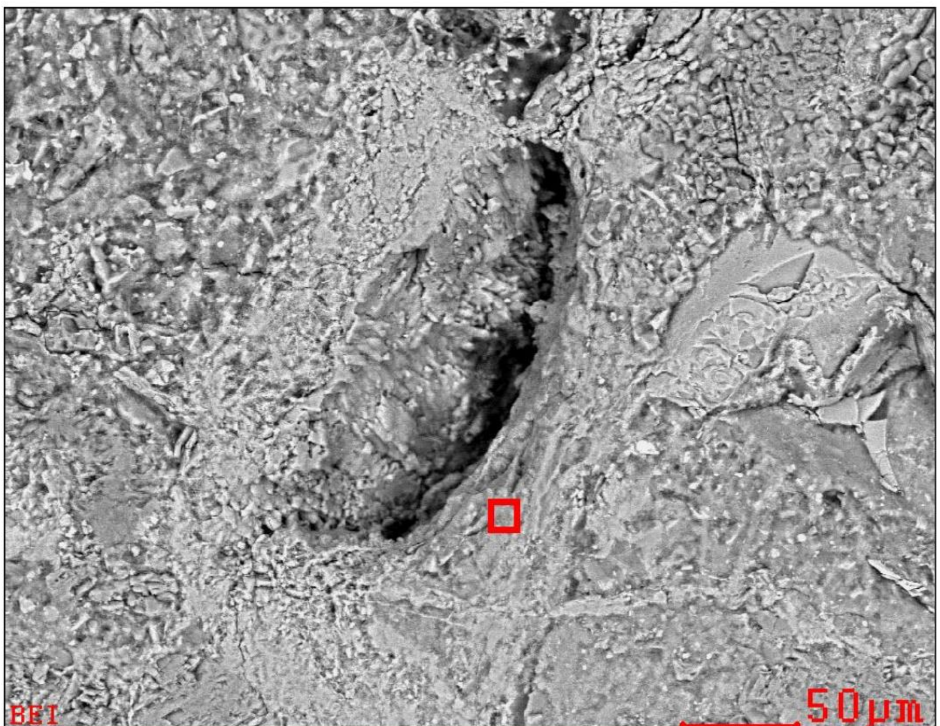
Prepared by: SWCarter

Date: 22 November 2016

Sample ID: Sample 5 – ASR gel in crack in dacite aggregate particle



Element	*Wt%*	*At%*
CK	07.59	12.58
OK	47.72	59.43
NaK	01.54	01.33
MgK	01.63	01.33
AlK	05.68	04.19
SiK	16.07	11.40
KK	01.48	00.75
CaK	17.41	08.65
FeK	00.90	00.32
Matrix	Correction	ZAF



300X 20kV SPOT 46 46Pa

Figure 1

SEM-EDS report for a spot elemental analysis of gel filling a crack that extends through a coarse aggregate particle of dacite in the polished section of Sample 5. The red box indicates the area of analysis for the elemental composition reported in the spectrum and table. The composition is consistent with alkali-silica reaction (ASR) gel.