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

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Learning Objectives

- Translating the visual clues to theory of damage
- How to systematically test the theories
- Linking field evaluation to lab analysis
- What to do when the results are not what you expected
- Avoid leaping to a conclusion

Background

Visual Observation - Theory

Brick Manufacturing

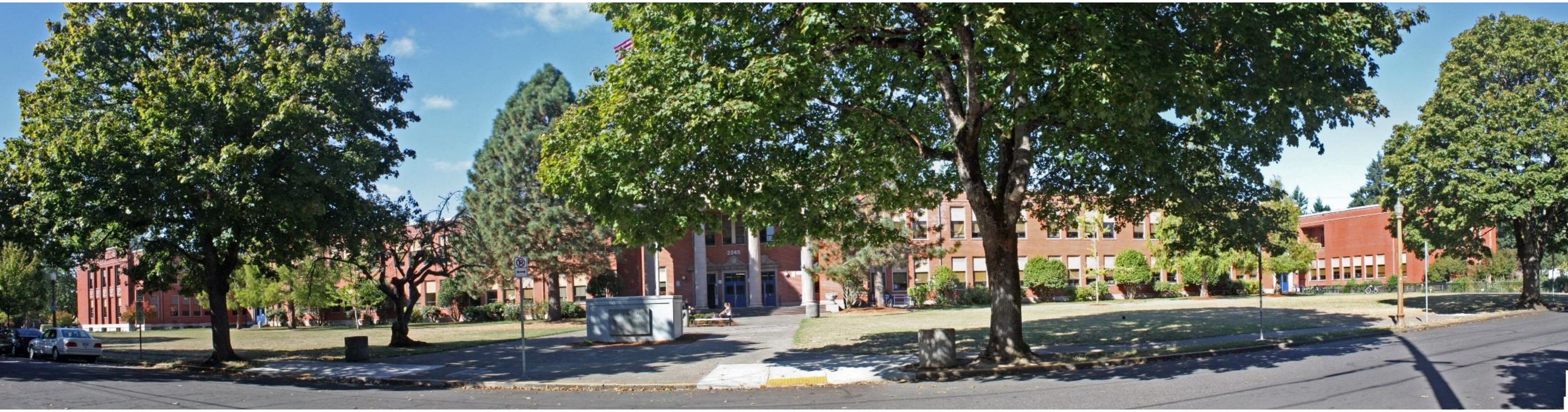
Mapping

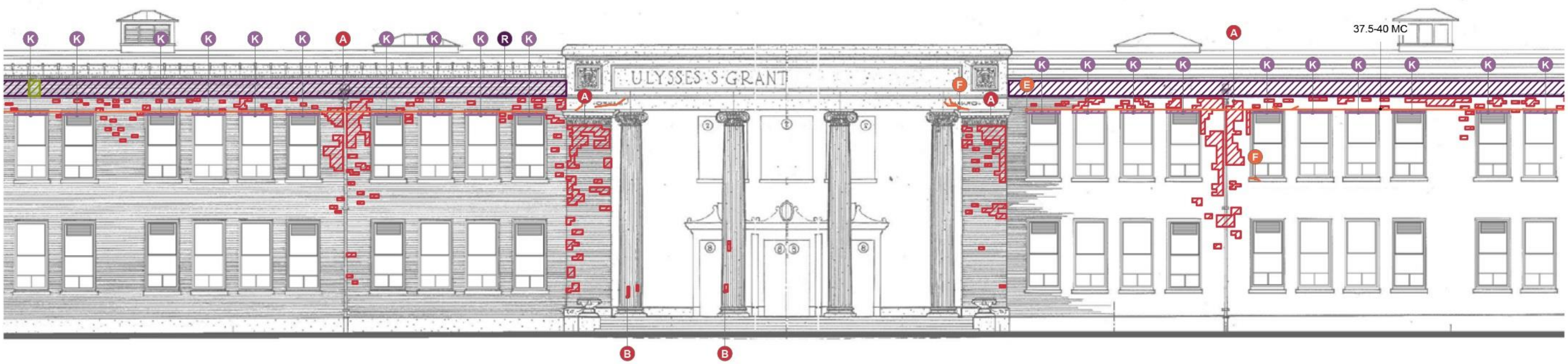
Lab Testing

Linking Field to the Lab

Outline

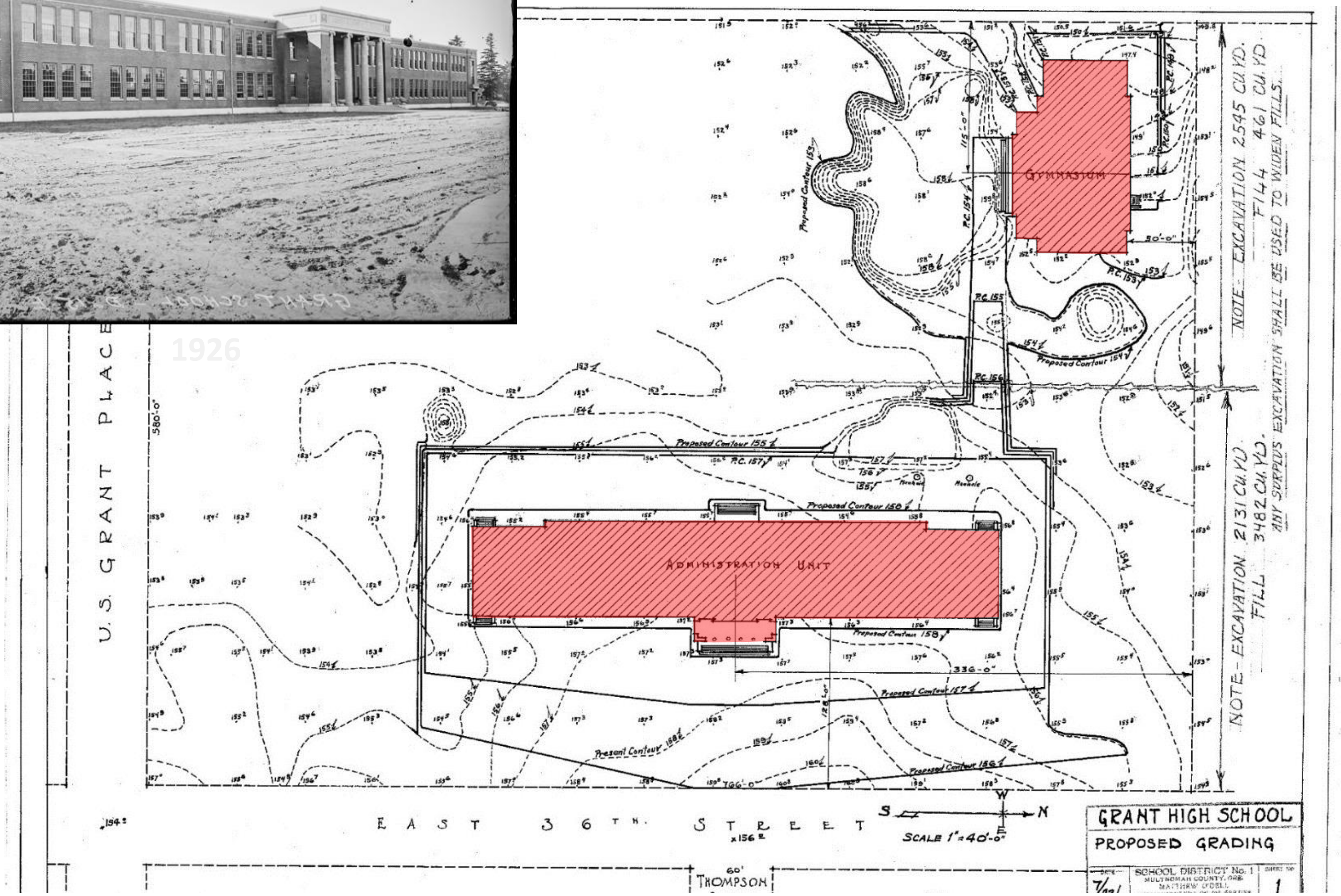
Background





Historic High School

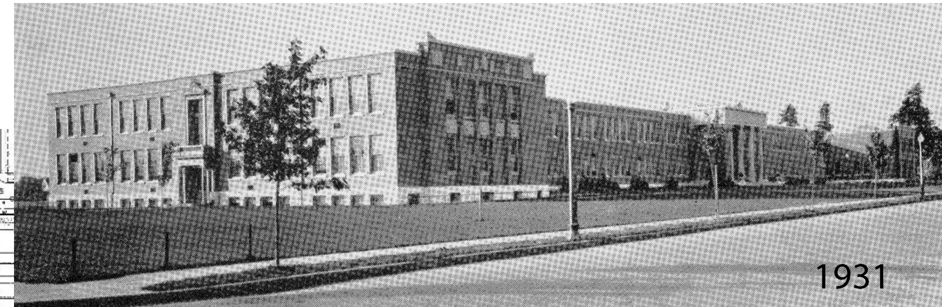
1924



1926

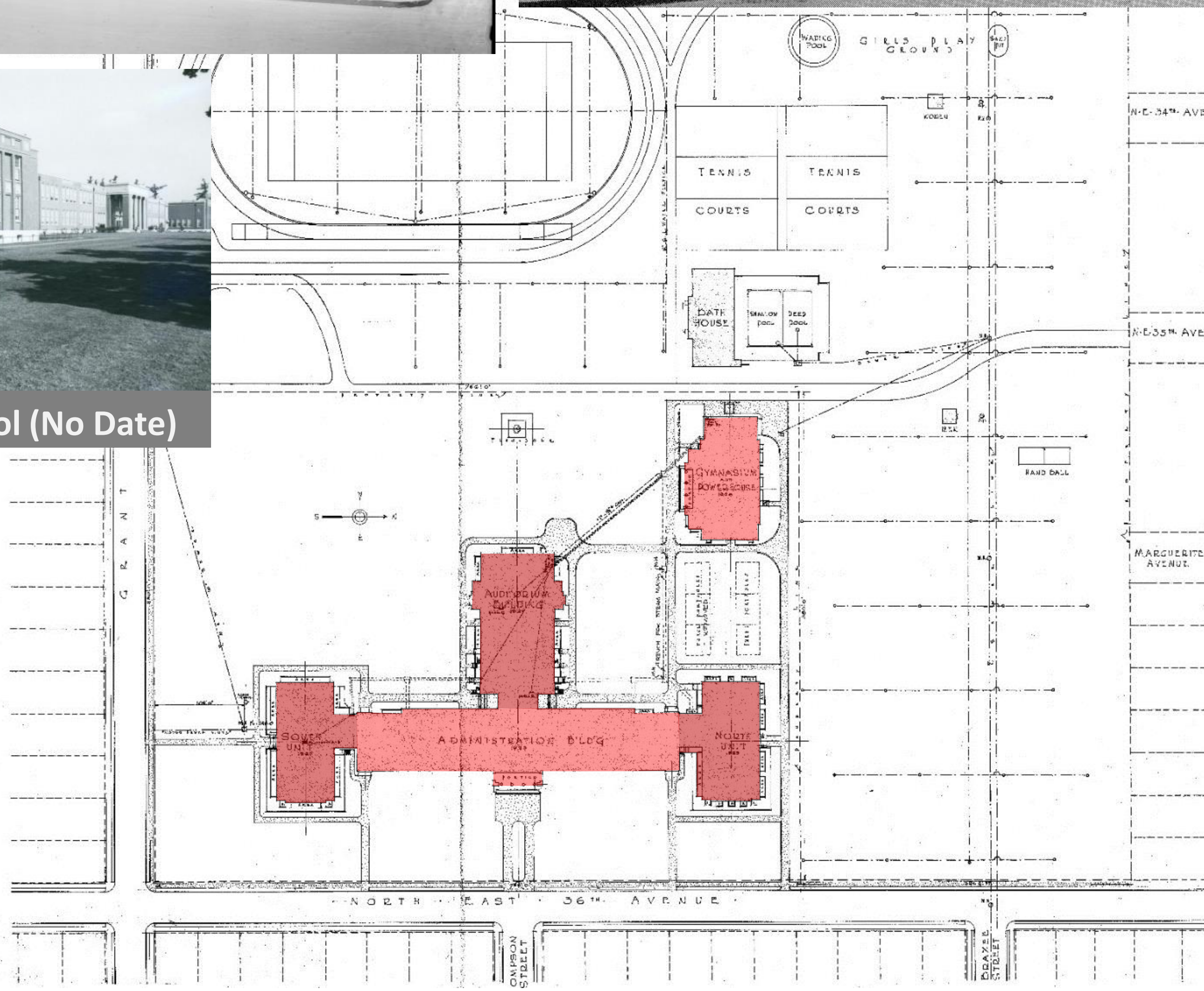
Alterations Over Time

1925

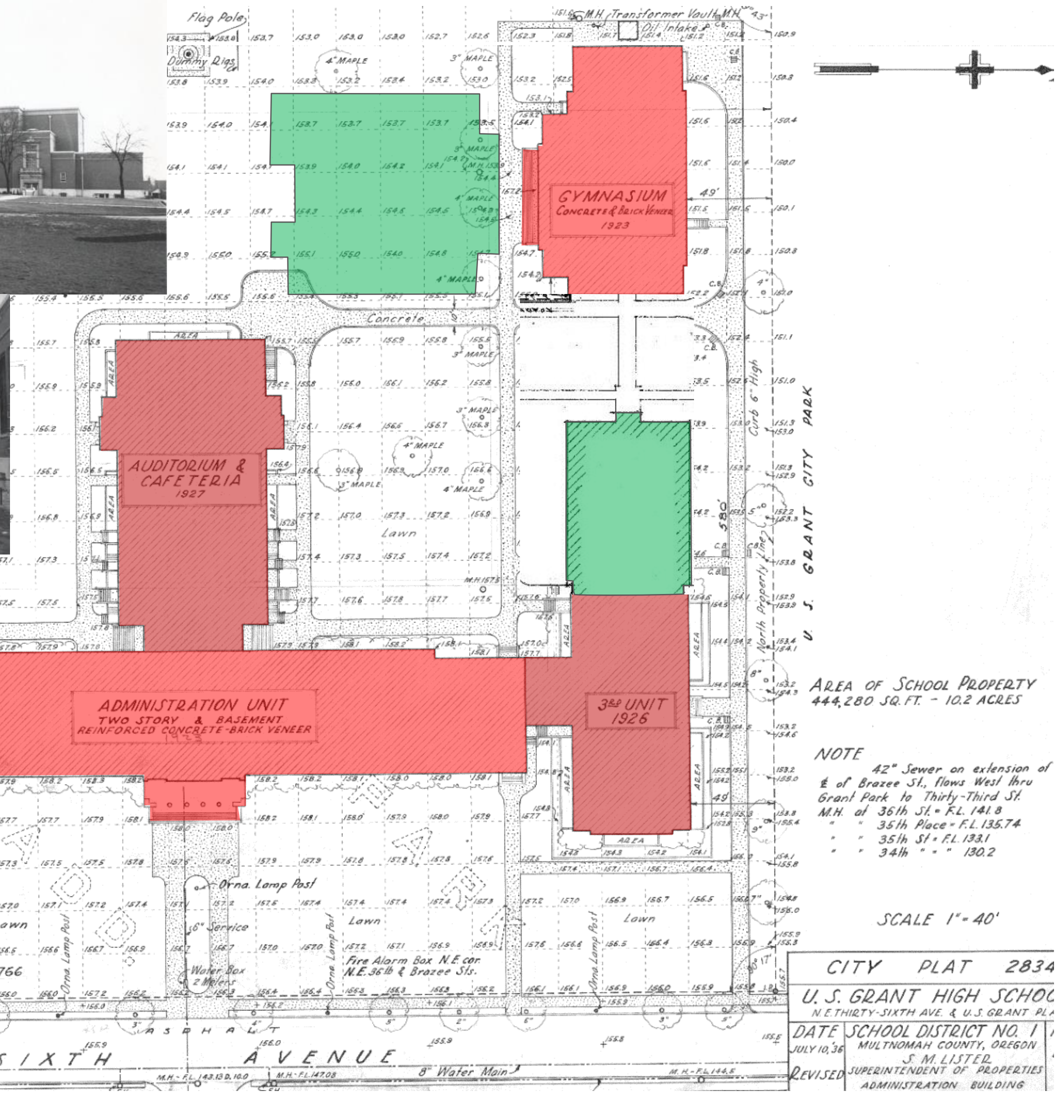


1931

SE corner of school (No Date)

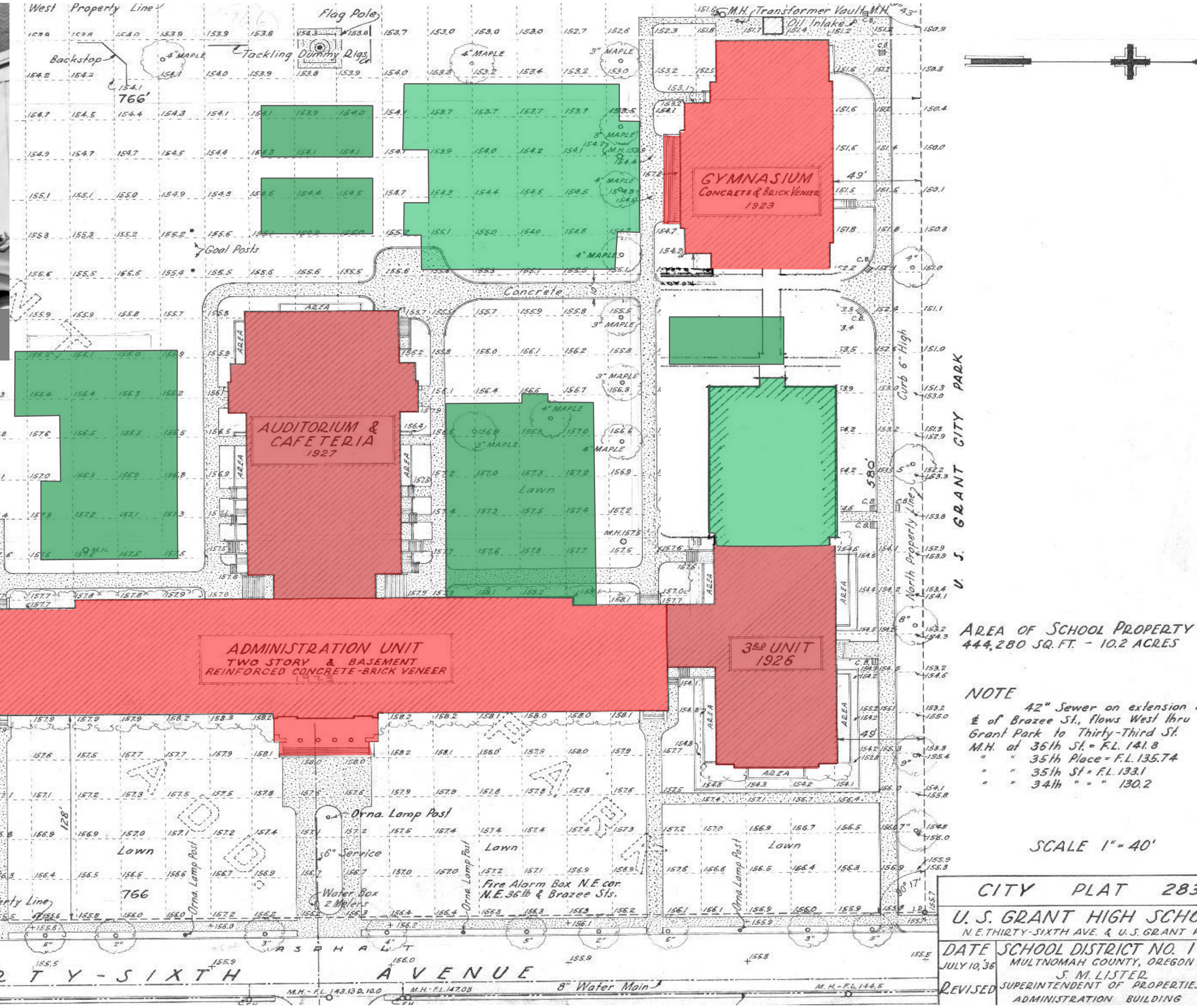


Alterations Over Time



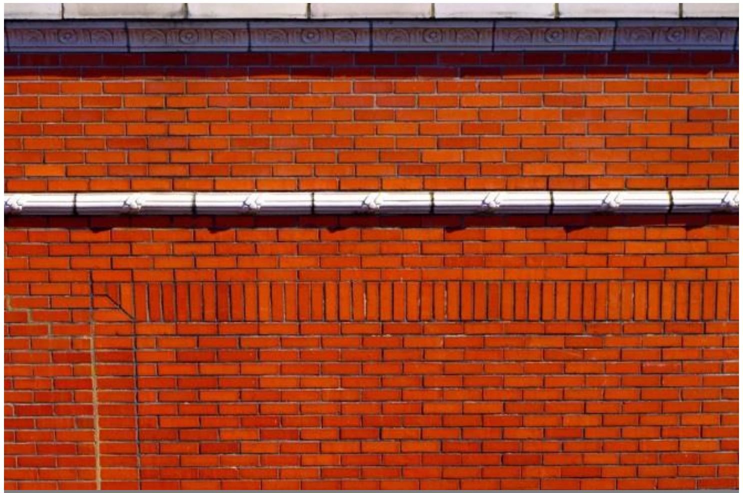
Alterations Over Time

Old Gym 1963-64

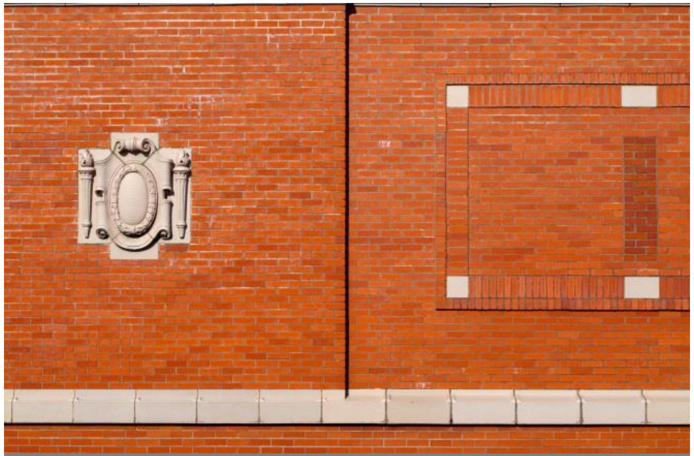


Alterations Over Time

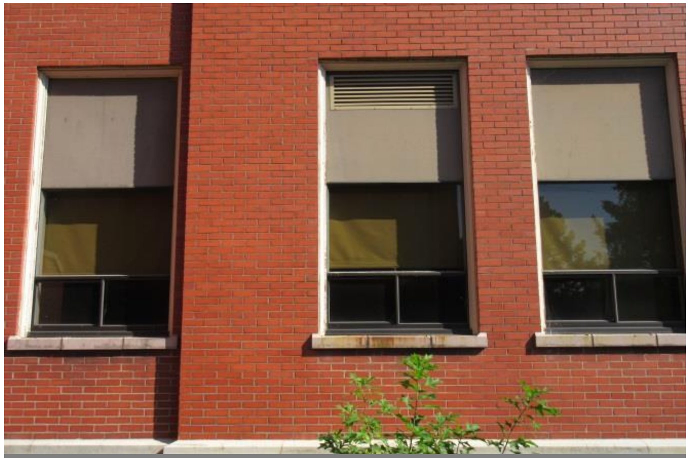
Multi-light wood windows



Terra cotta moldings



Brick details and blind windows



Original window size & proportion

Masonry Details

Visual Observations

Exterior Visible Damage

Exterior Visible Damage

Exterior Visible Damage

Exterior Visible Damage

Exterior Visible Damage

Brick Manufacturing

Western Clay Products - Montana

Brick Composition

1. Clay – chemical compound of silica, alumina and metallic oxides (color)
2. Water
3. Additives - sand

Brick Manufacturing

1. Mining
2. Preparation
3. Molding
4. Drying
5. Firing

Brick Composition

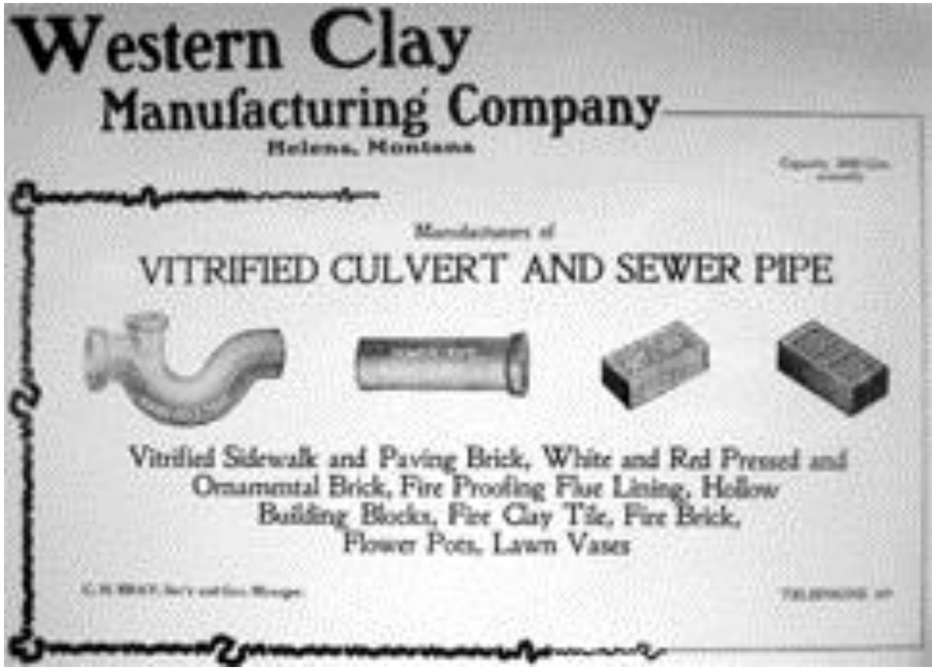
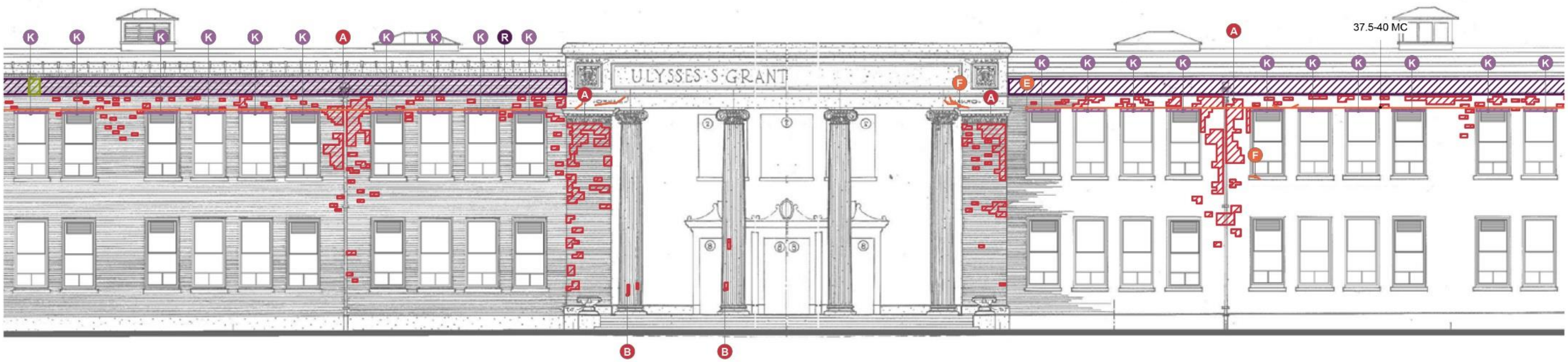


Image: National Building Museum

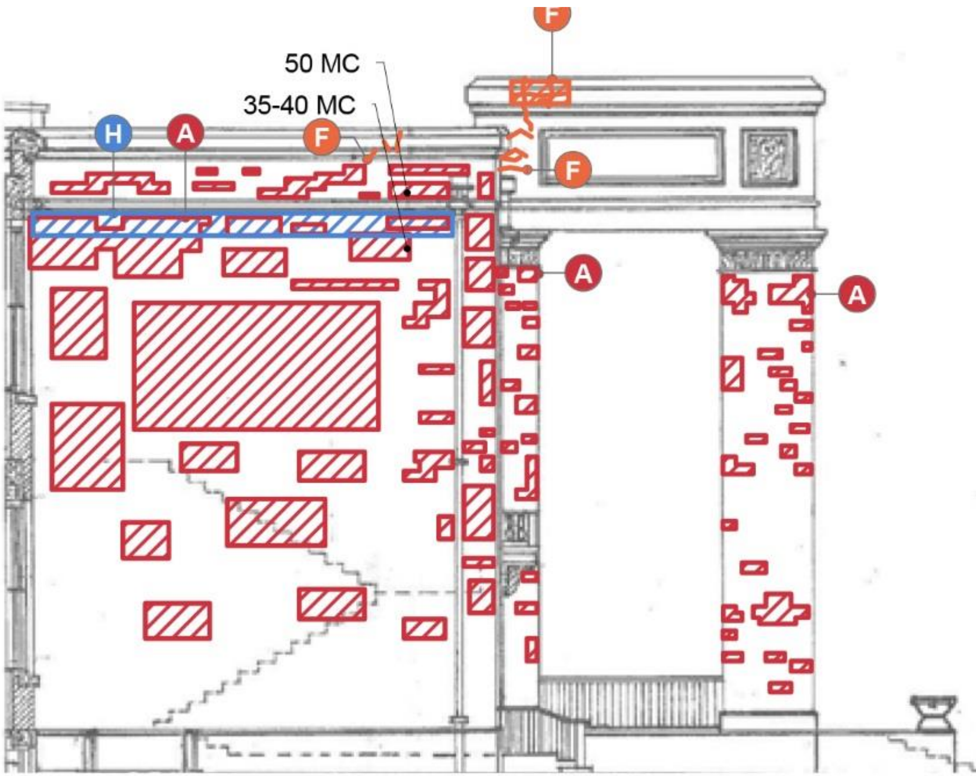
Brick Products

Mapping



Extent of Problem

Extent of Problem – Clear limit



Extent of Problem – protected area

East Elevation

West Elevation

Extent of Problem – Original Construction

New or “Historic” Deficiencies

Comparative Photographs

Comparative Photographs

Comparative Photographs

Comparative Photographs

Common Deficiencies

- Poor construction
- Material composition
- Weather
- Human intervention

Mercy Corps HQ, Portland Oregon – Historic wing

Common Deficiencies

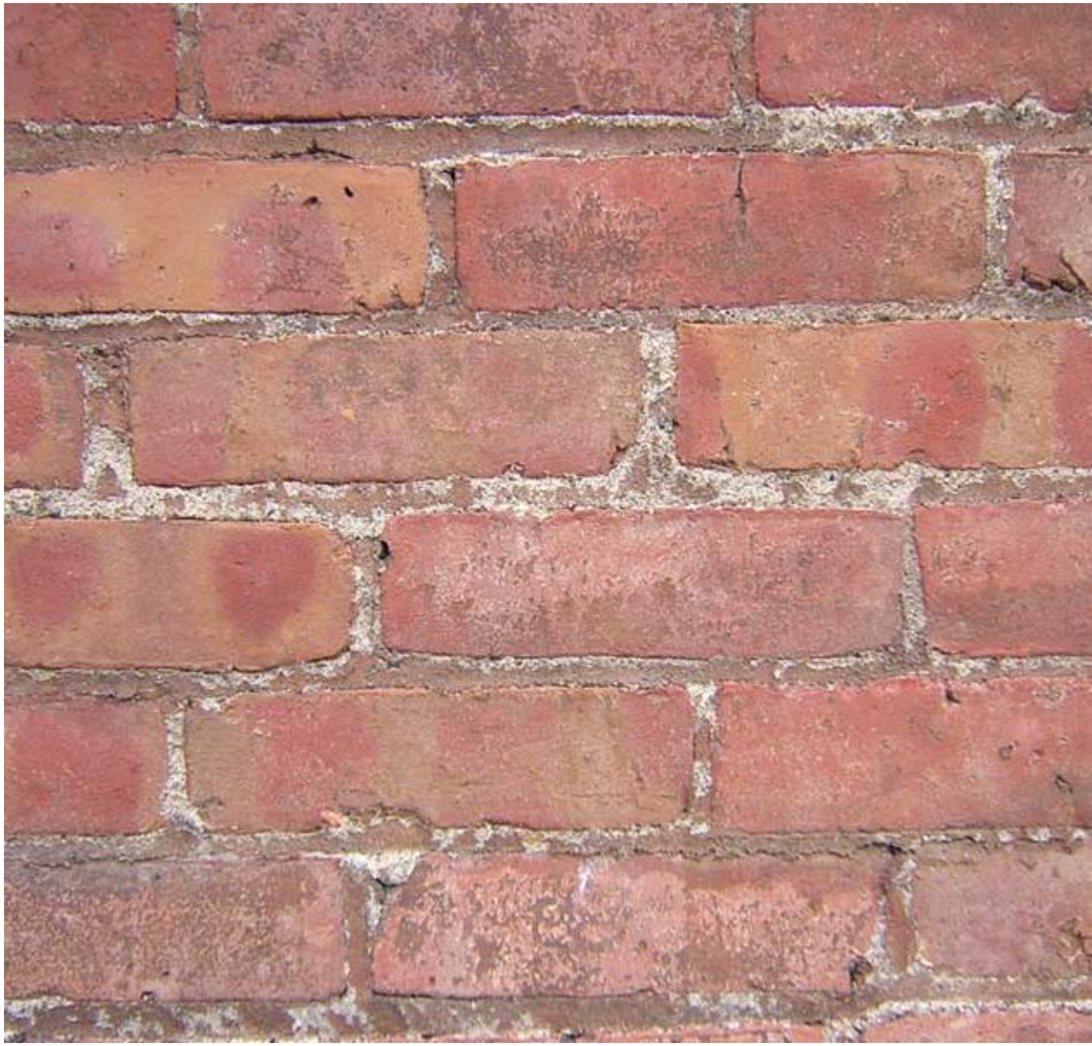
Cracking

Poor firing;
Fast cooling

Roosevelt Middle School, Medford Oregon

Common Deficiencies

Discoloring Impurities



WSU, Spokane Washington

Deformities Poor Firing

Private Residence, Irvington Neighborhood, Portland Oregon

Common Deficiencies

Salts

Efflorescence low firing

Source: Carbonates - mortar
Sulfates - brick
Chlorides - additives

Typical: Sodium (Na)
Potassium (K)
Calcium (Ca)

COMMON SOURCE OF EFFLORESCENCE

Principal Efflorescing Salt		Most Probable Source
Calcium sulfate	$CaSO_4 \bullet 2H_2O$	**Brick**
Sodium sulfate	$Na_2SO_4 \bullet 10H_2O$	Cement-brick reactions
Potassium sulfate	K_2SO_4	Cement-brick reactions
Calcium carbonate	$CaCO_3$	Mortar or concrete
Sodium carbonate	Na_2CO_3	Mortar
Potassium carbonate	K_2CO_3	Mortar
Potassium chloride	KCl	Acid Cleaning
Sodium chloride	NaCl	Sea Water
Vanadyl sulfate	$VOSO_4$	**Brick**
Vanadyl chloride	$VOCl_2$	Acid Cleaning
Manganese oxide	Mn_3O_4	**Brick**
Iron oxide	Fe_2O_3 or $Fe(OH)_3$	Iron in contact or brick w ith "black core" or black heart
Calcium hydroxide	$Ca(OH)_2$	Cement

Common Deficiencies

High Porosity
volume relation

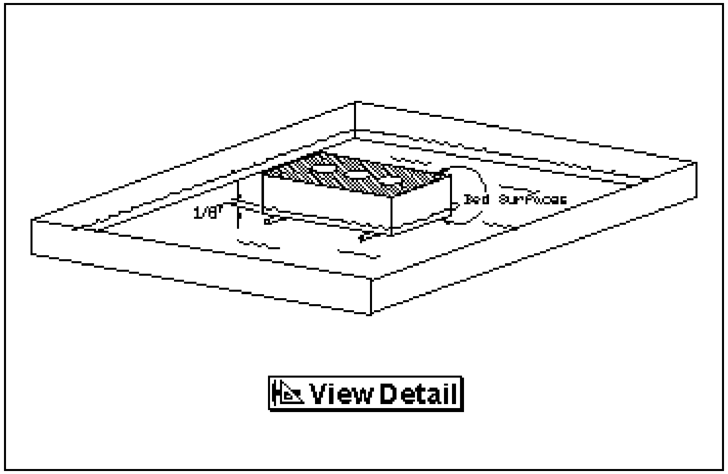
volume of voids : volume of the total

Affects **Permeability**

High Absorption
weight relation

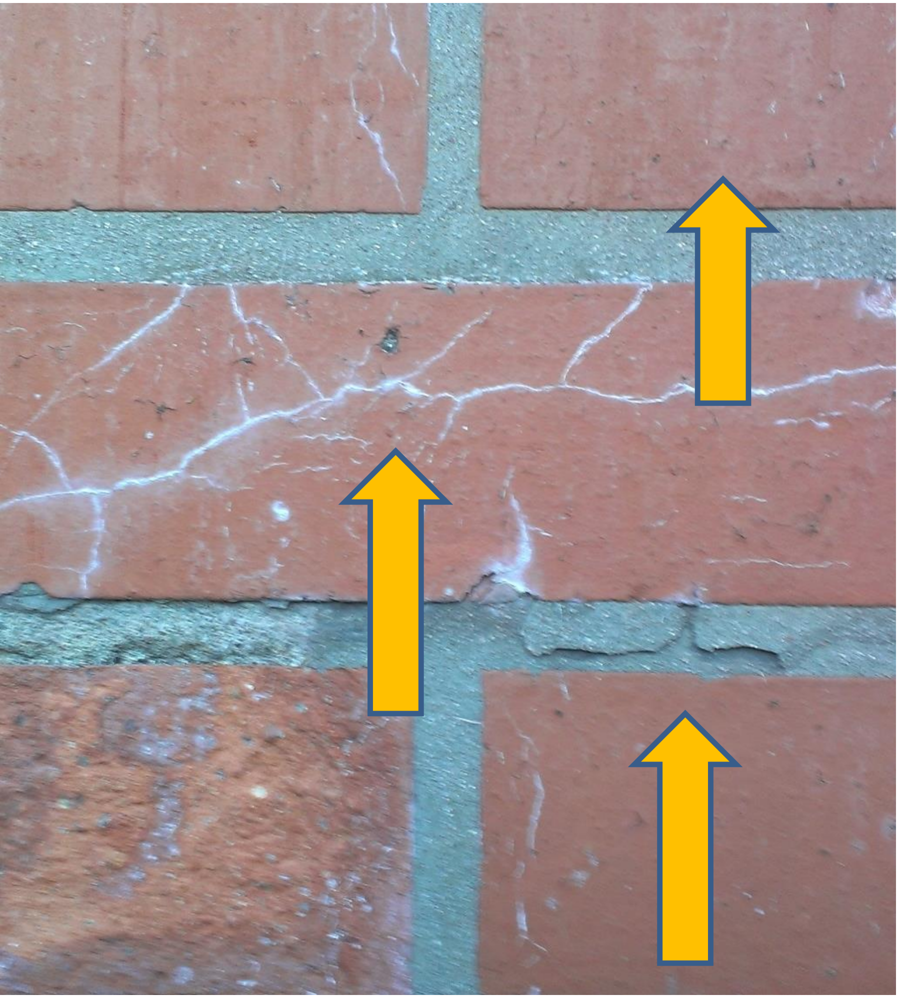
weight dry : weight wet

Affects **Capillary** suction

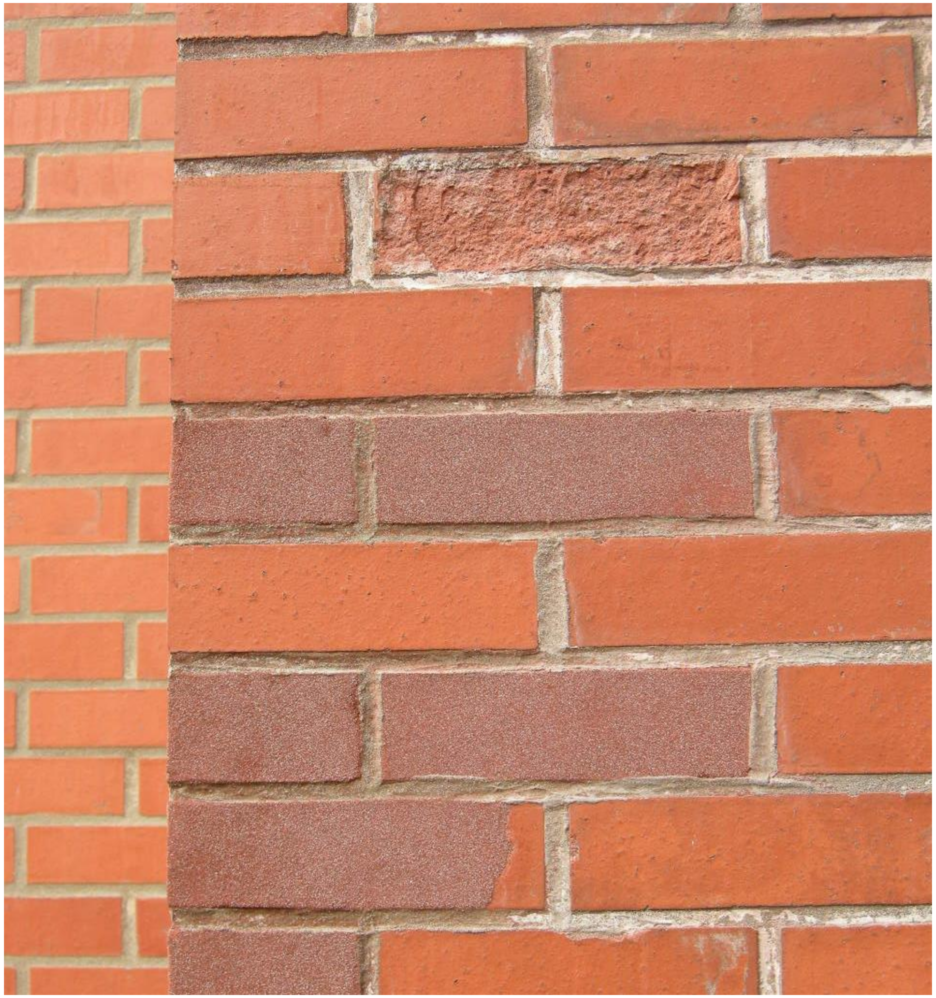


Common Deficiencies

Visual Observations

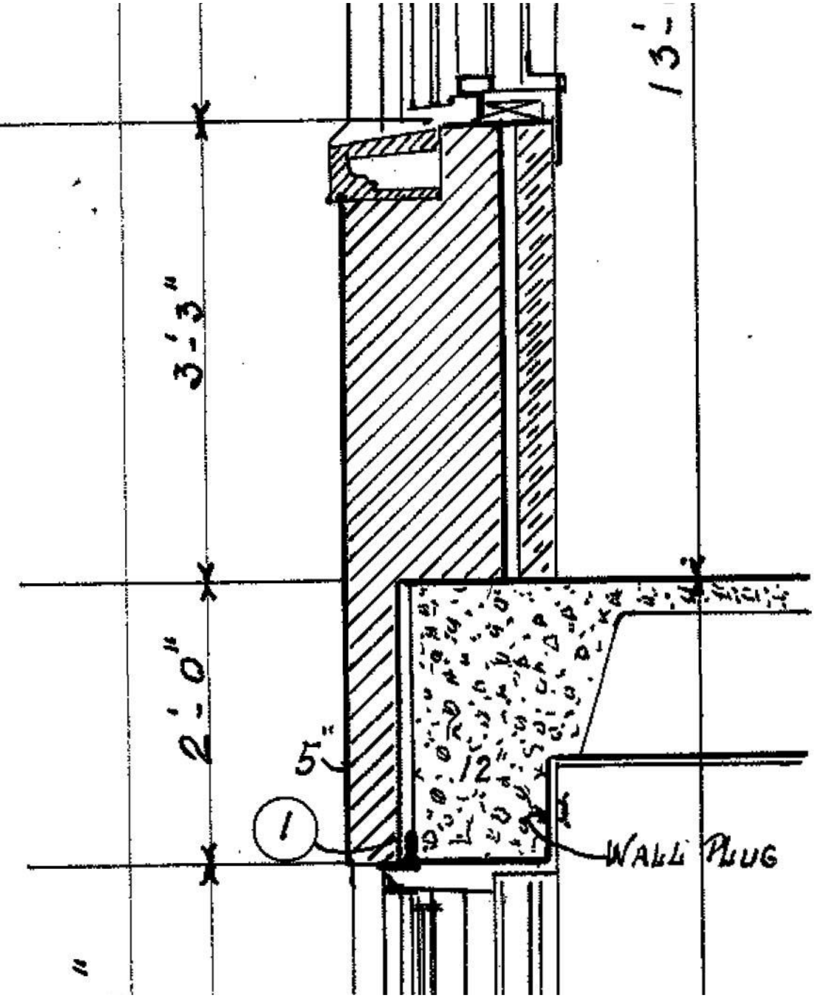


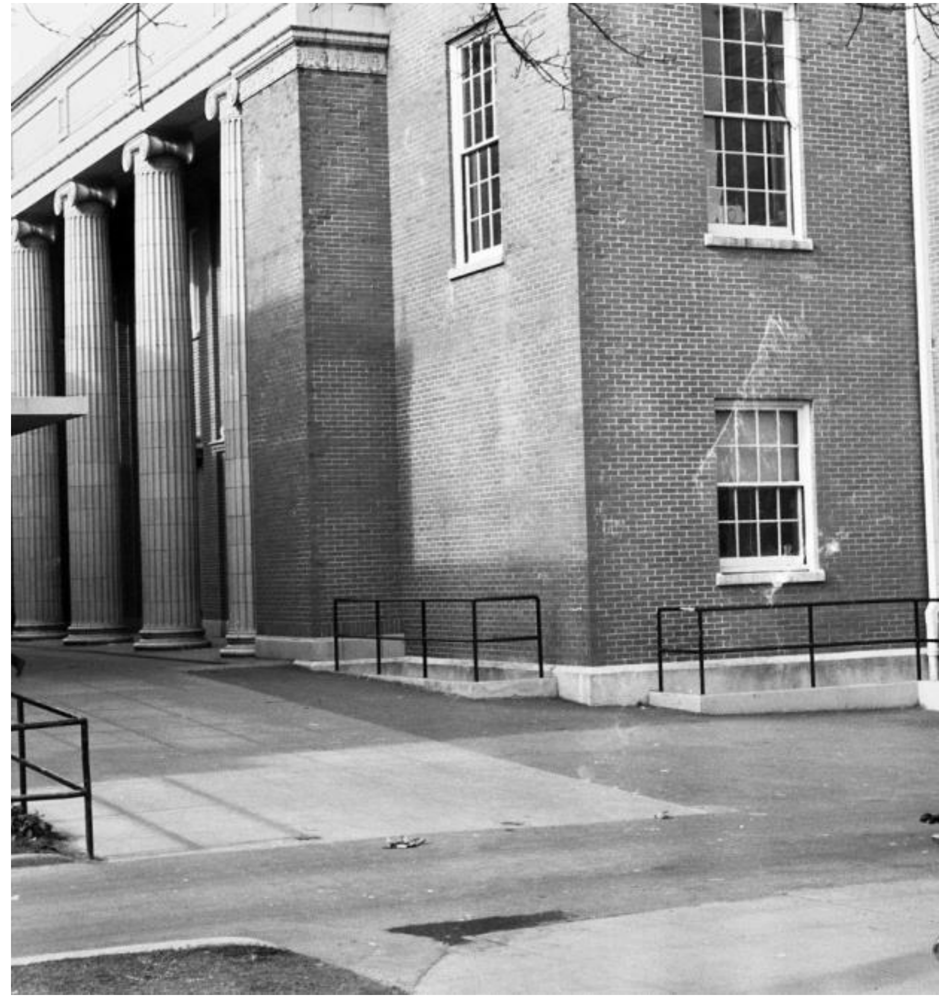
Exterior Visible Damage



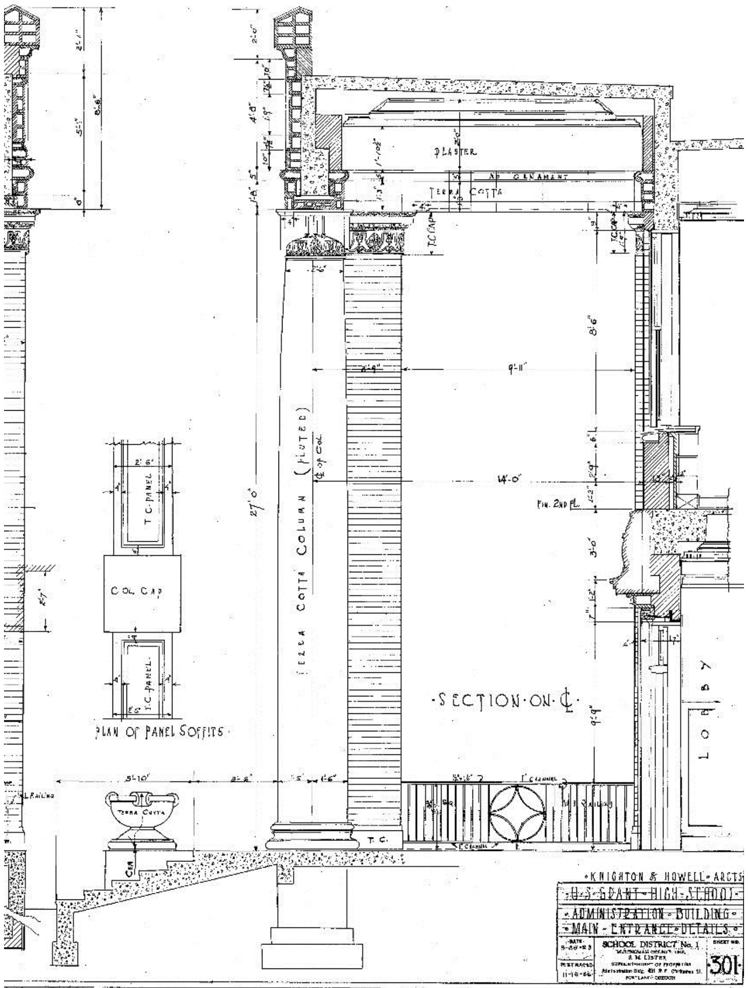
Exterior Visible Damage

Historic Document Review: Wall Construction

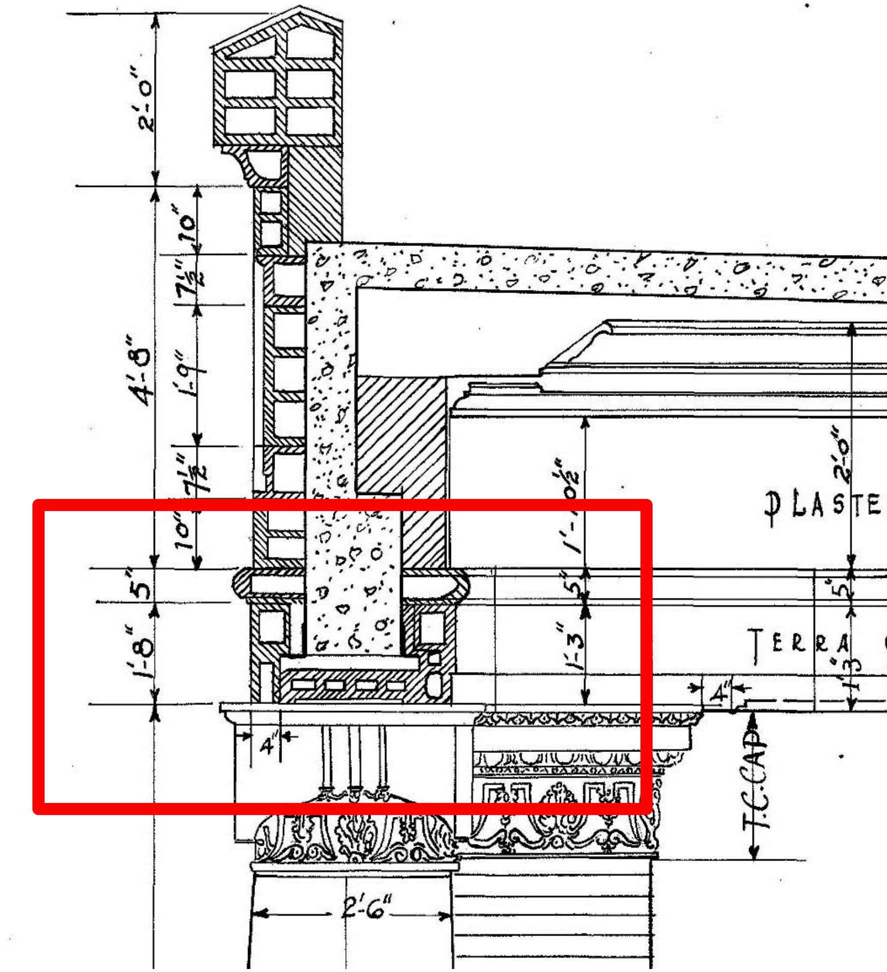




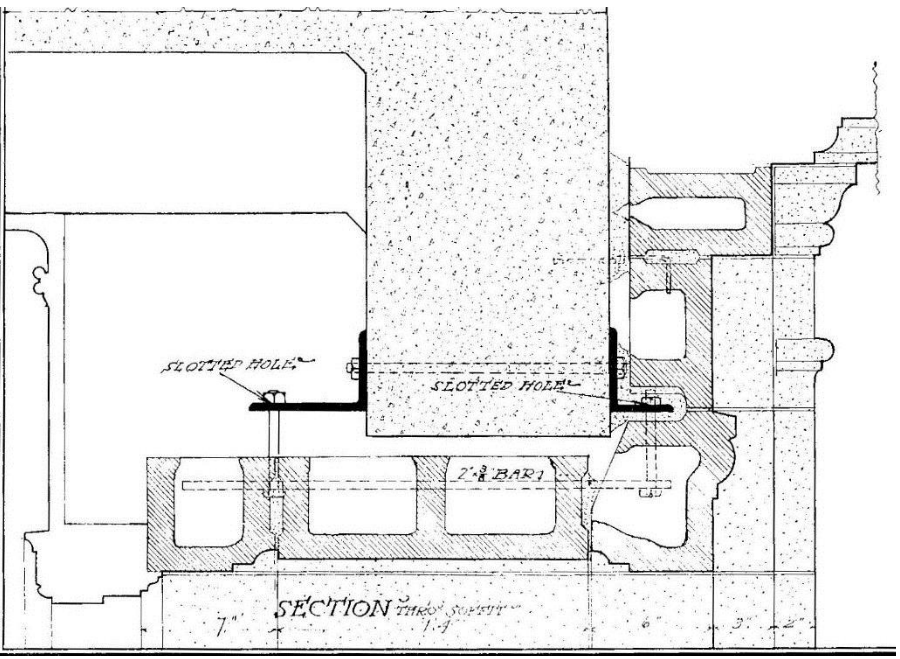
Wall Construction



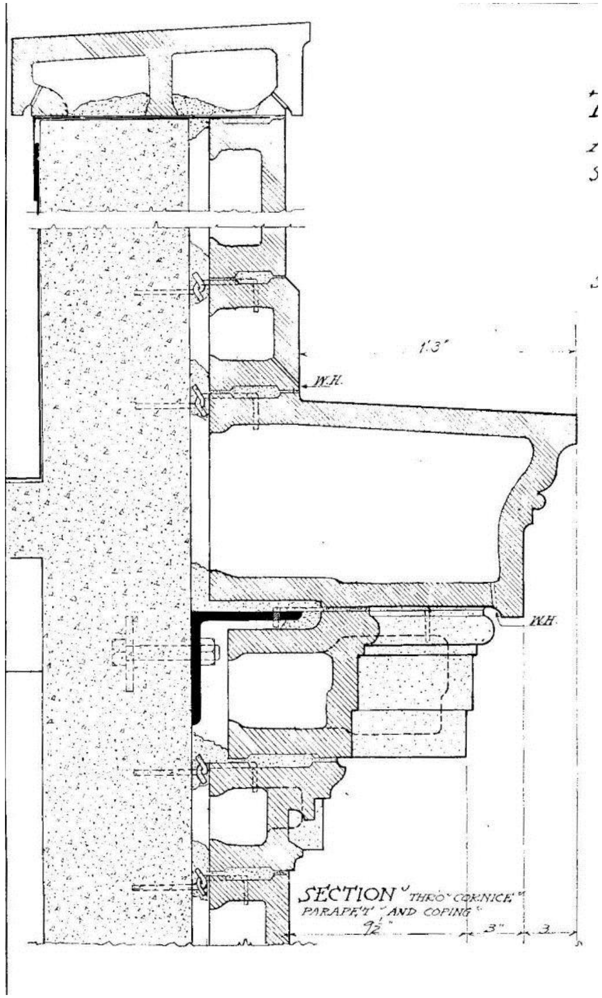
Wall Construction



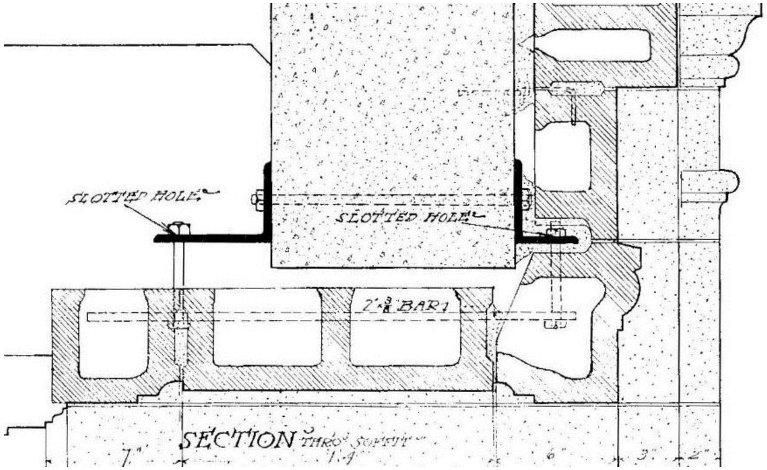
Wall Construction



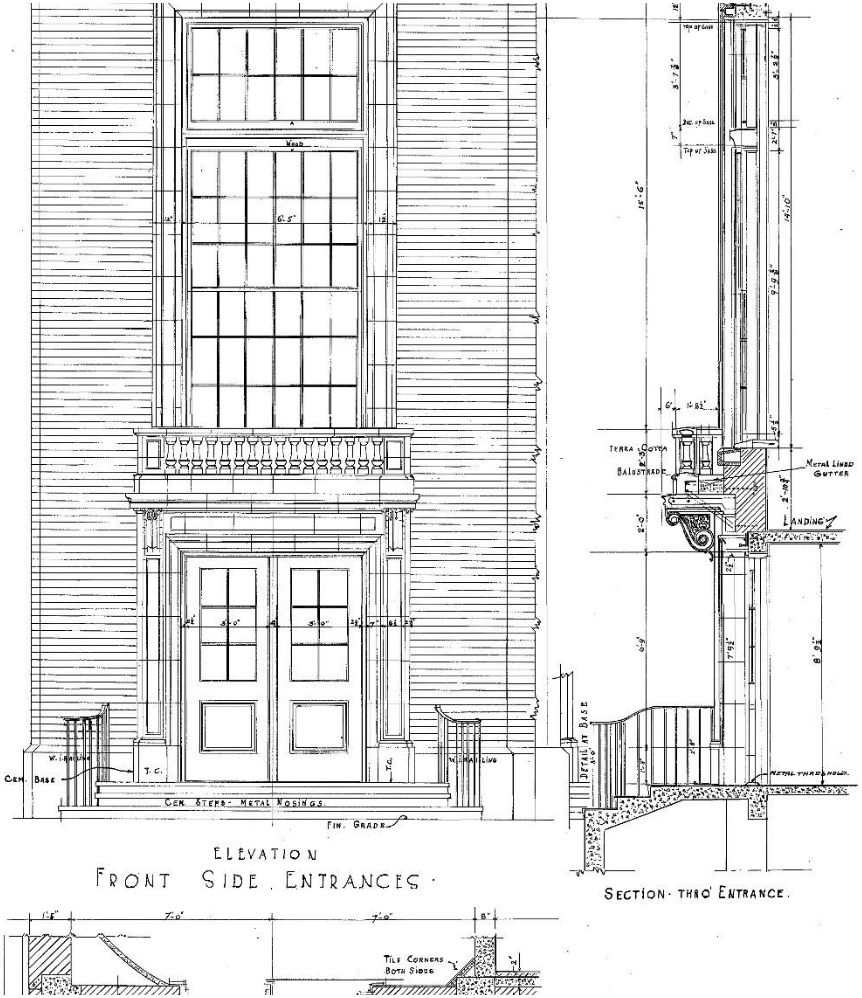
National Terra Cotta Society,
Terra Cotta Standard Construction, 1927



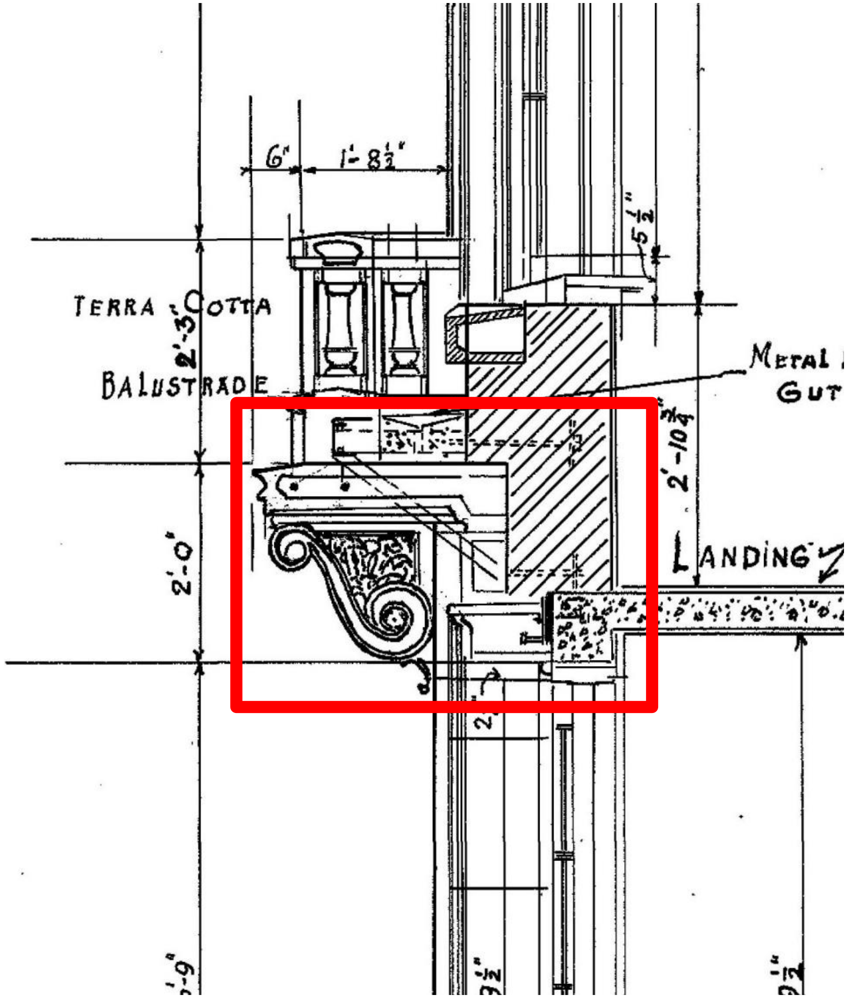
Wall Construction

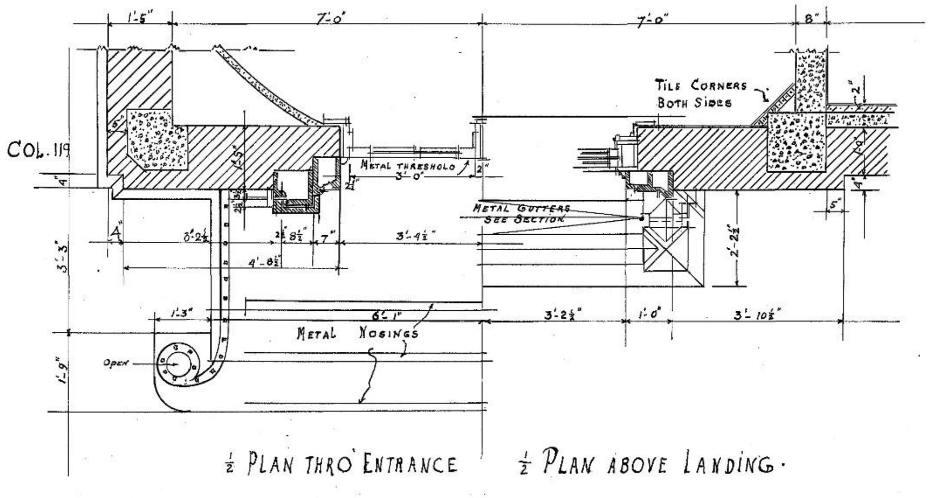


Wall Construction



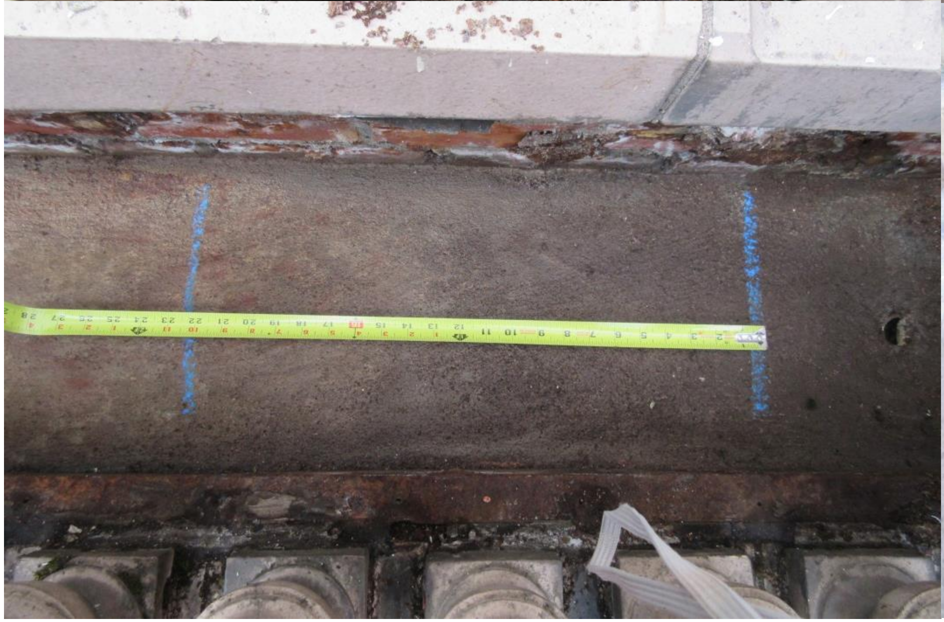
Wall Construction





Wall Construction

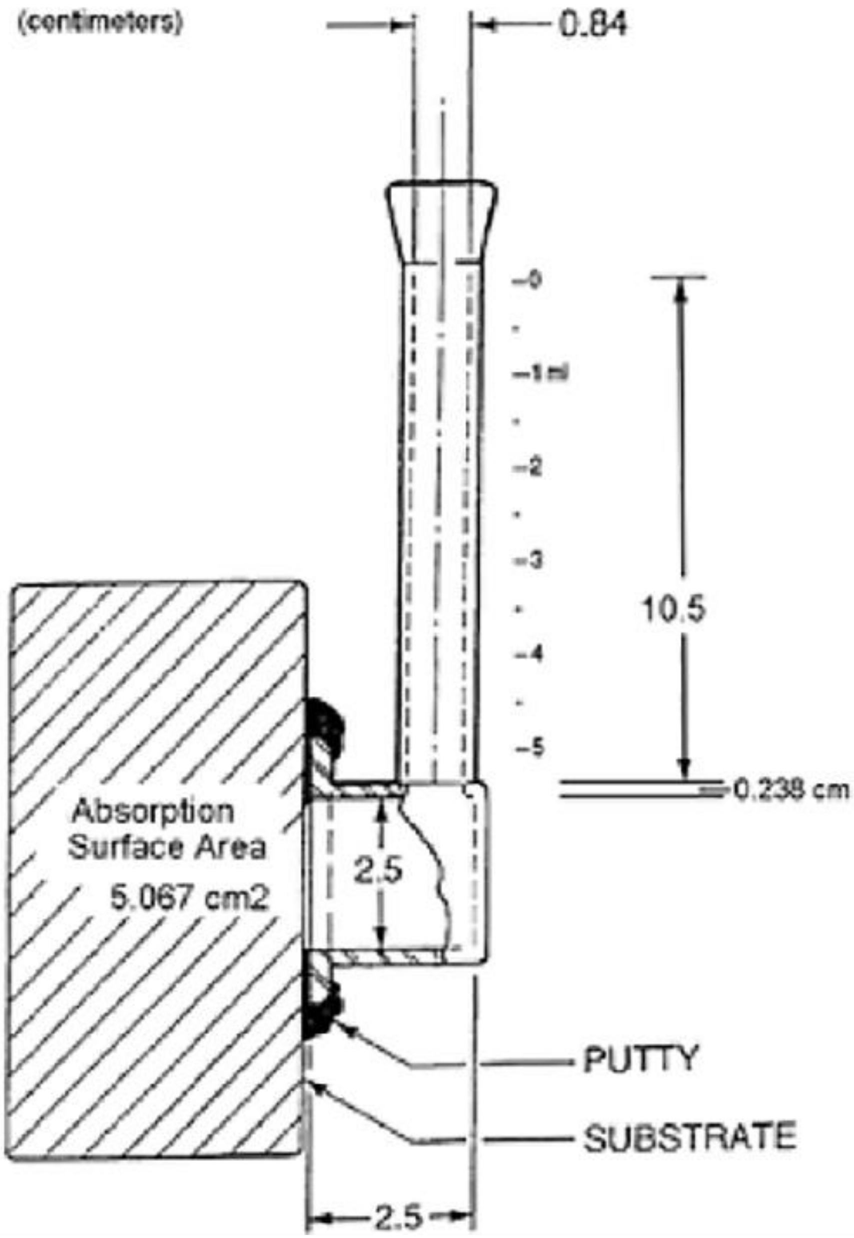





Wall Construction

Field Testing

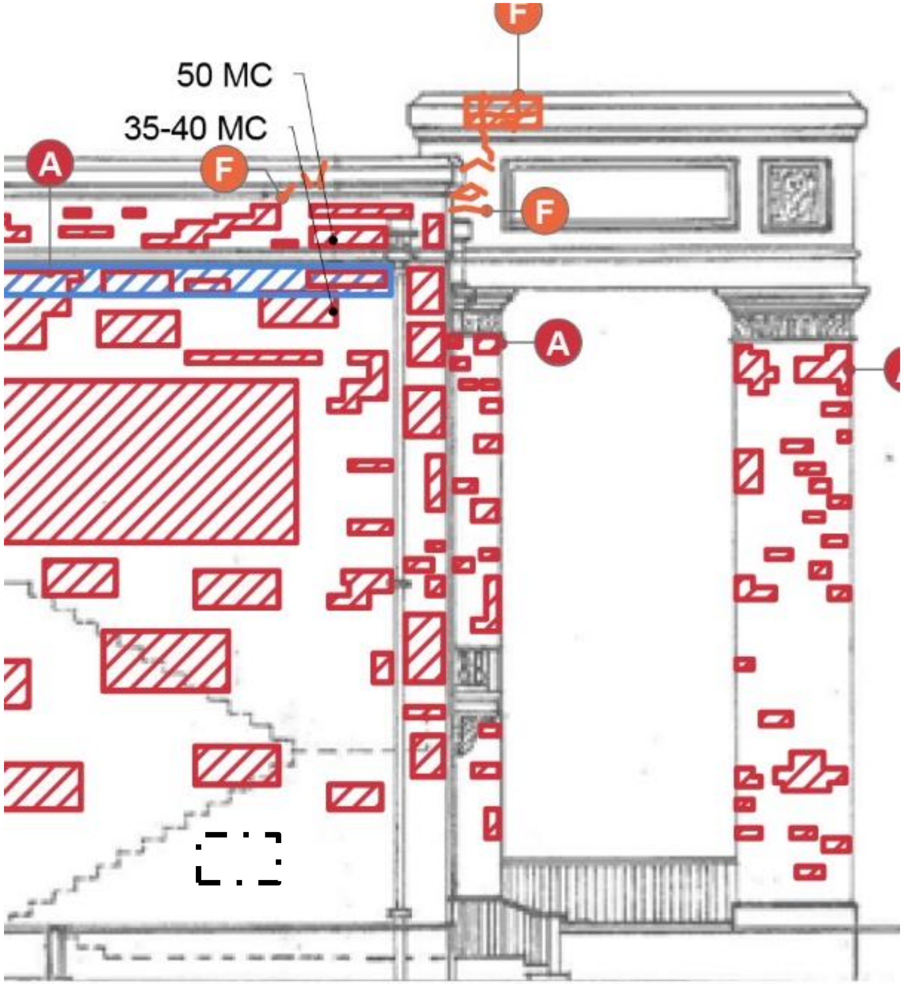
Rilem Test Method No. 11.4
Vertical Application



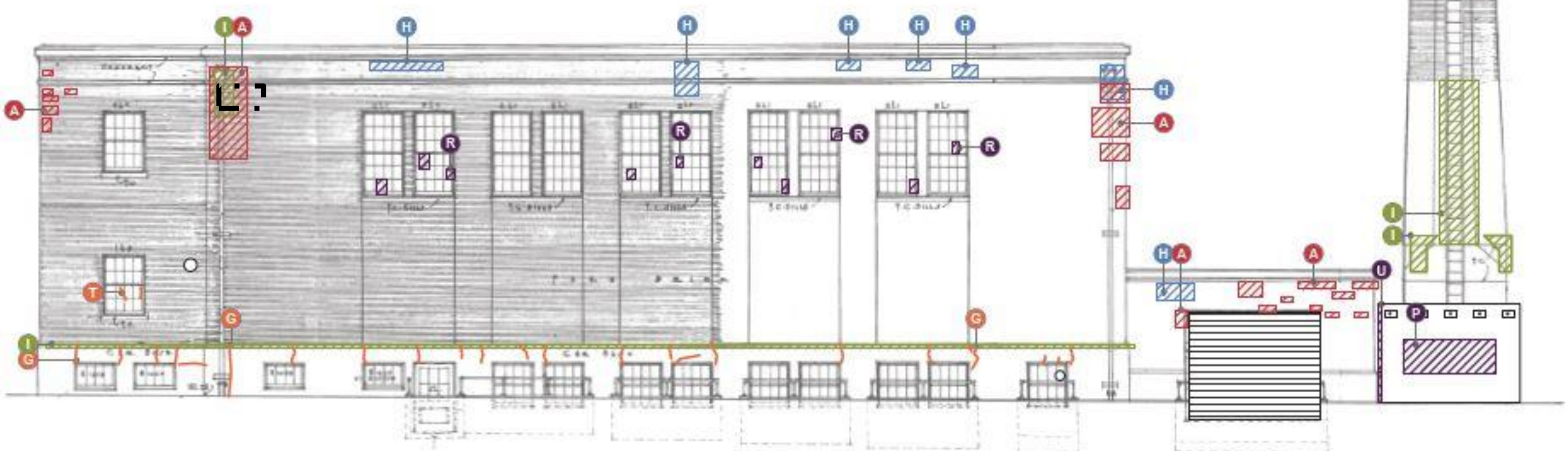
Field Testing – RILEM tube

Field Testing

Wall ties

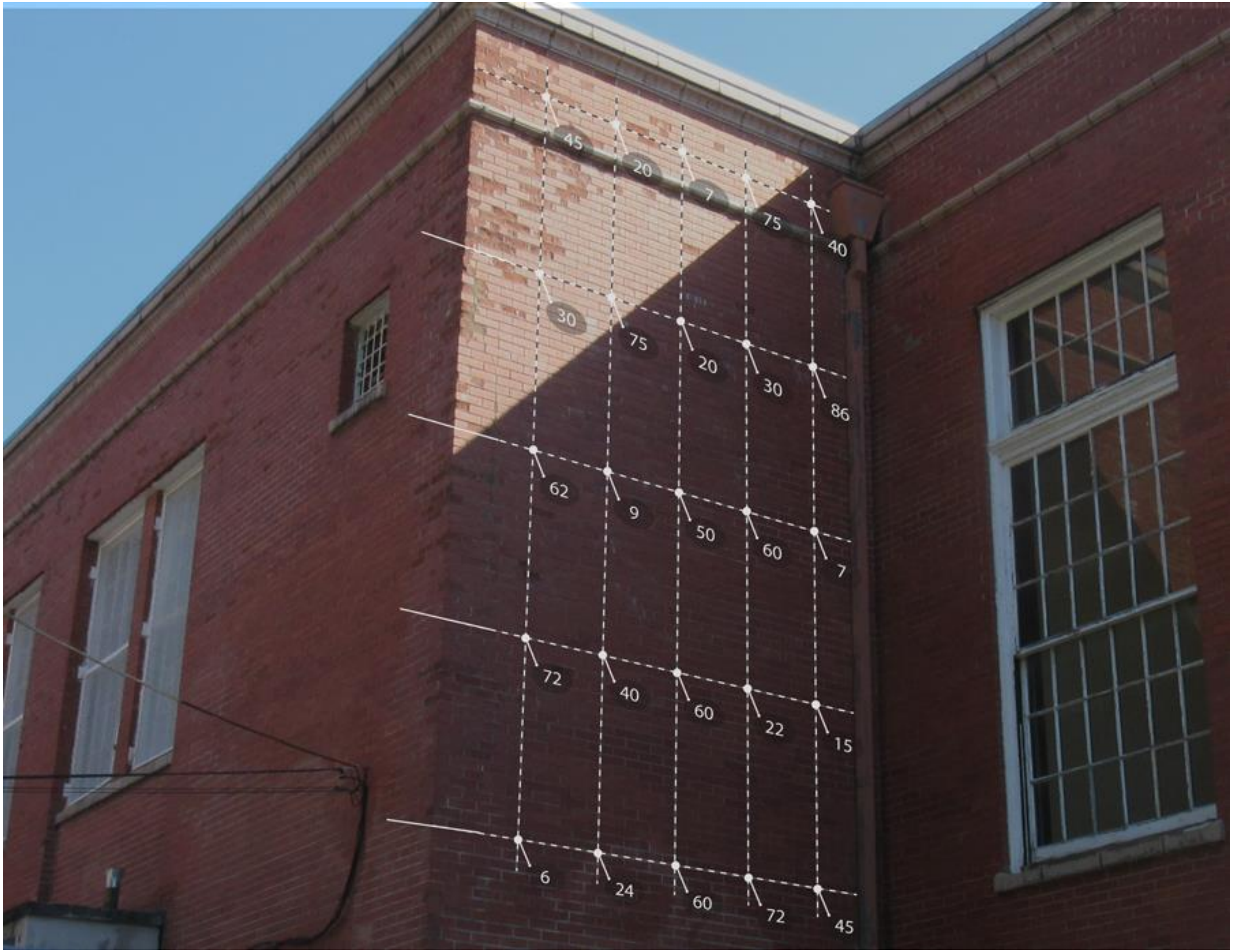


Wall lets



Wall lets

Old Gym Moisture Readings Location 1



Old Gym Moisture Readings Location 2

Old Gym Roof Investigation

Old Gym Interior – During Construction

Lab Testing

BIA TABLE 4

Physical Properties in Brick Specifications

		Maximum Cold Water Absorption, %		Maximum Five-Hour Boiling Absorption, %		Maximum Saturation Coefficient	
		Average of 5 brick	Individual	Average of 5 brick	Individual	Average of 5 brick	Individual
C 62 Grade	SW	—	—	17.0	20.0	0.78	0.80
	MW	—	—	22.0	25.0	0.88	0.90
	NW	—	—	No limit	No limit	No limit	No limit

ASTM C 67 – Physical Analysis of Clay Face Brick

ABSORPTION*

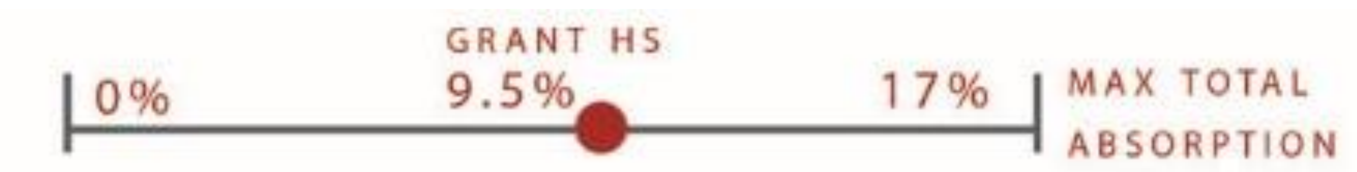
Unit No.	1A	2A	3A	4A	5A	**AVG**
Dimensions (as tested)						
Length (inches)	3.9	3.9	3.9	3.9	3.9	**3.9**
Width (inches)	3.9	3.8	4.0	3.9	3.9	**3.9**
Height (inches)	2.3	2.3	2.3	2.3	2.3	**2.3**
24-Hour Immersion (%)	7.9	6.9	8.4	5.7	8.2	**7.5**
5-Hour Boil (%)	9.8	9.0	10.6	7.6	9.4	**9.5**
Saturation Coefficient	0.81	0.77	0.80	0.76	0.79	**0.79**

FREEZE-THAW*

Unit No.	1B	2B	3B	4B	5B	**AVG**
Dimensions (as tested)						
Length (inches)	3.9	3.9	3.9	3.9	3.9	**3.9**
Width (inches)	3.9	3.8	4.0	3.9	3.9	**3.9**
Height (inches)	2.3	2.3	2.3	2.3	2.3	**2.3**
Freeze-Thaw Durability @ 50 cycles (% loss)	0.15	0.11	0.11	0.08	0.10	**0.11**

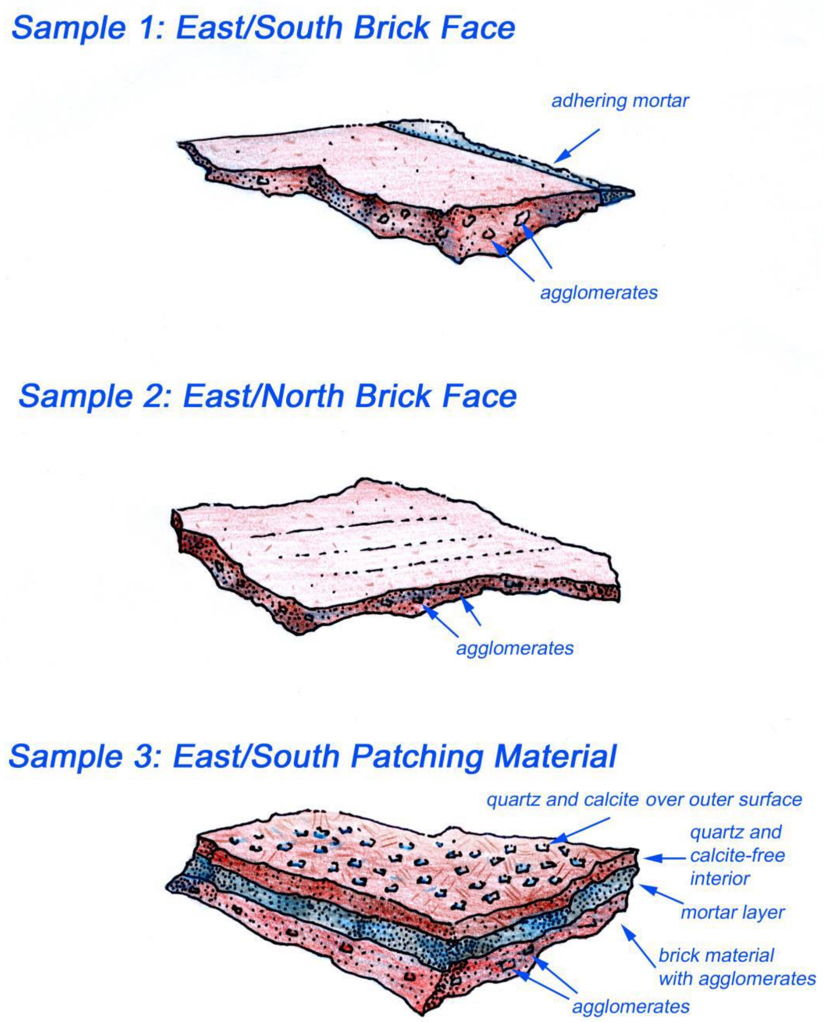
Observations: Specimens showed no signs of cracking or breakage after testing.

Lab Testing



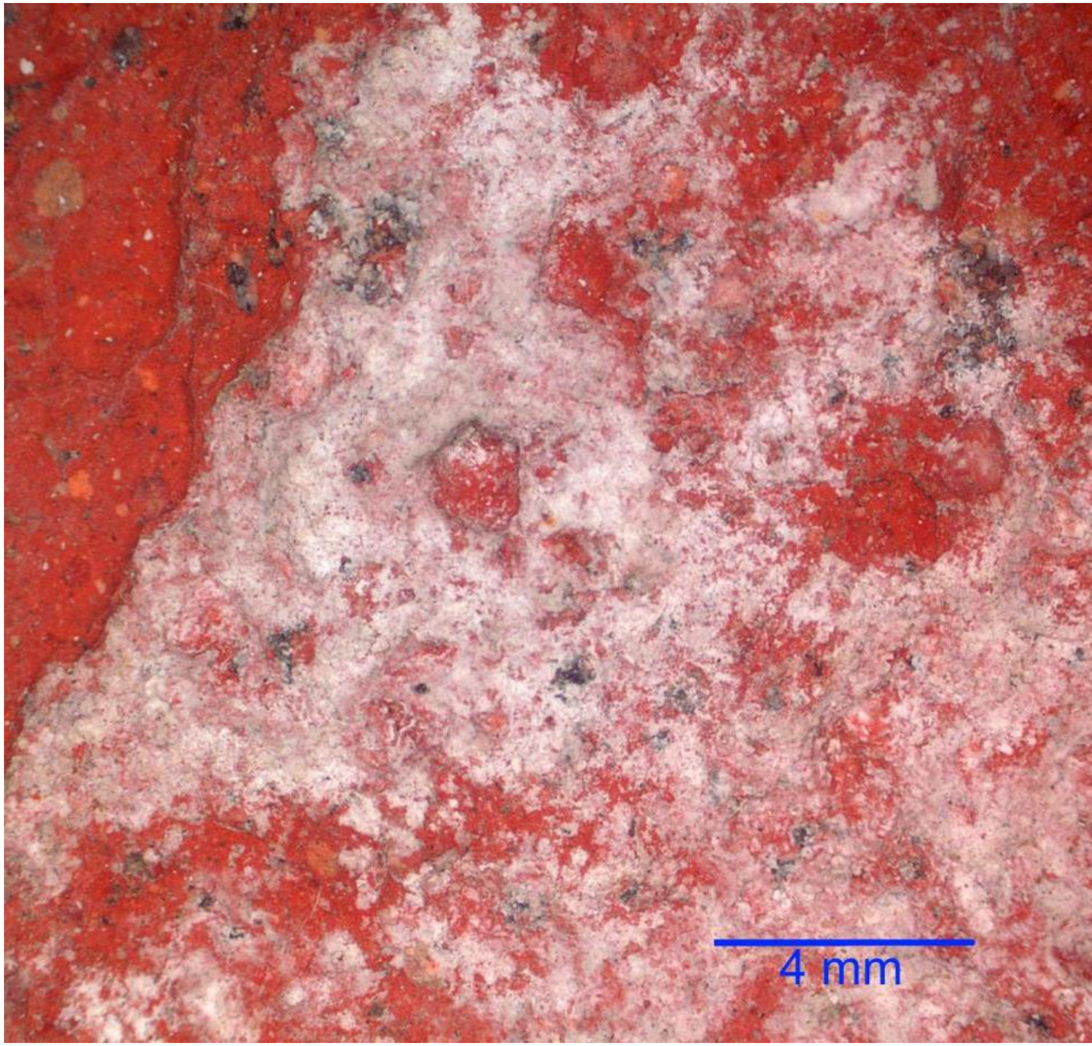
Lab Testing - IRA

All three samples showed silica as the binding mechanism, thus do not appear to have had an applied coating. The sampling fracture planes, following the surfaces in these samples, suggests the silica may have been recrystallized and hardened by subsequent atmospheric exposure



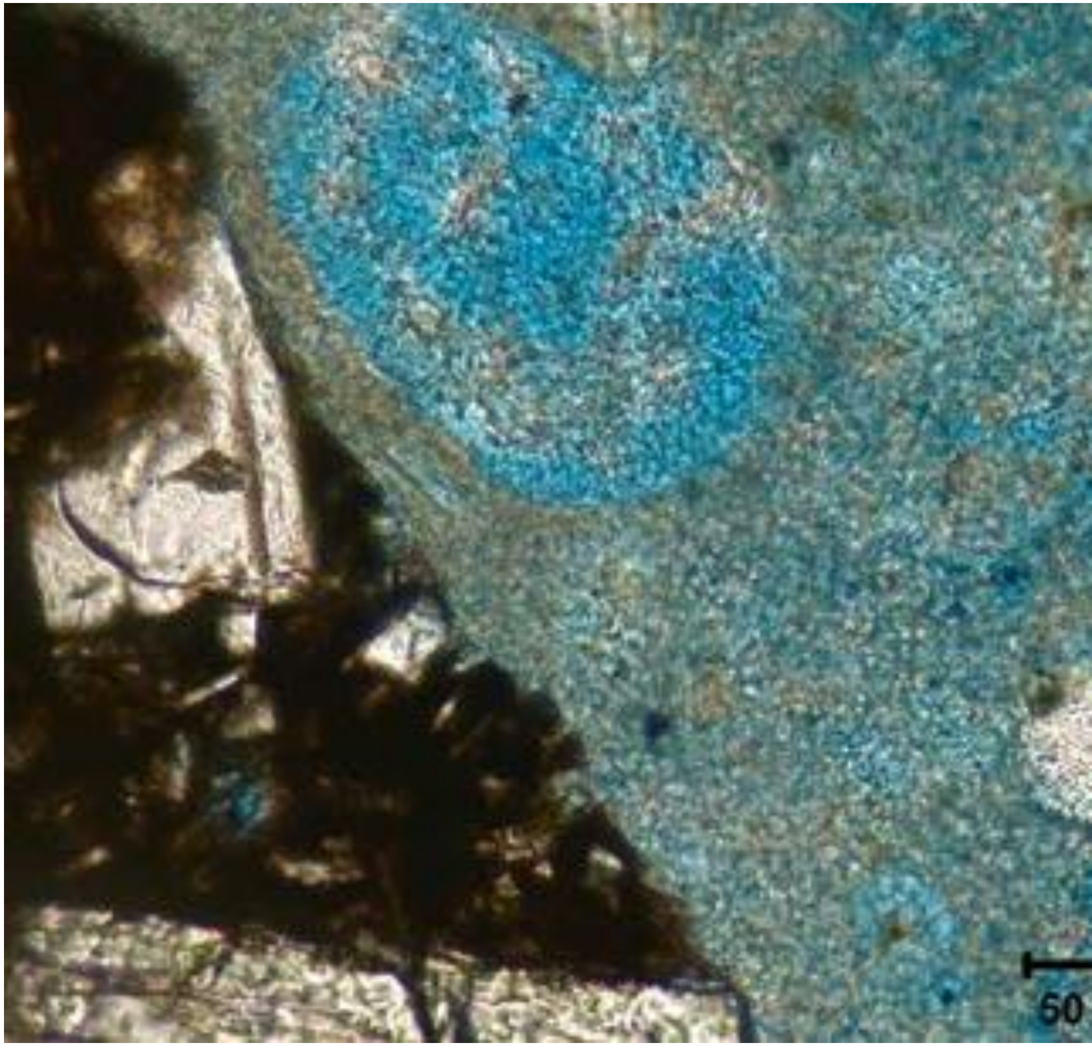
Lab Testing: Surface Salt Deposition

…. precipitated calcium carbonate (probably calcite) and opal-hydrous silica Clay minerals were not observed. A few encapsulated frustules (shells) of diatoms and fibers from fabrics were also recovered within the deposit in a manner suggesting rain and/or service water allowed dissolved calcium and silica from the mortar to seep laterally onto this surface and mineralize.



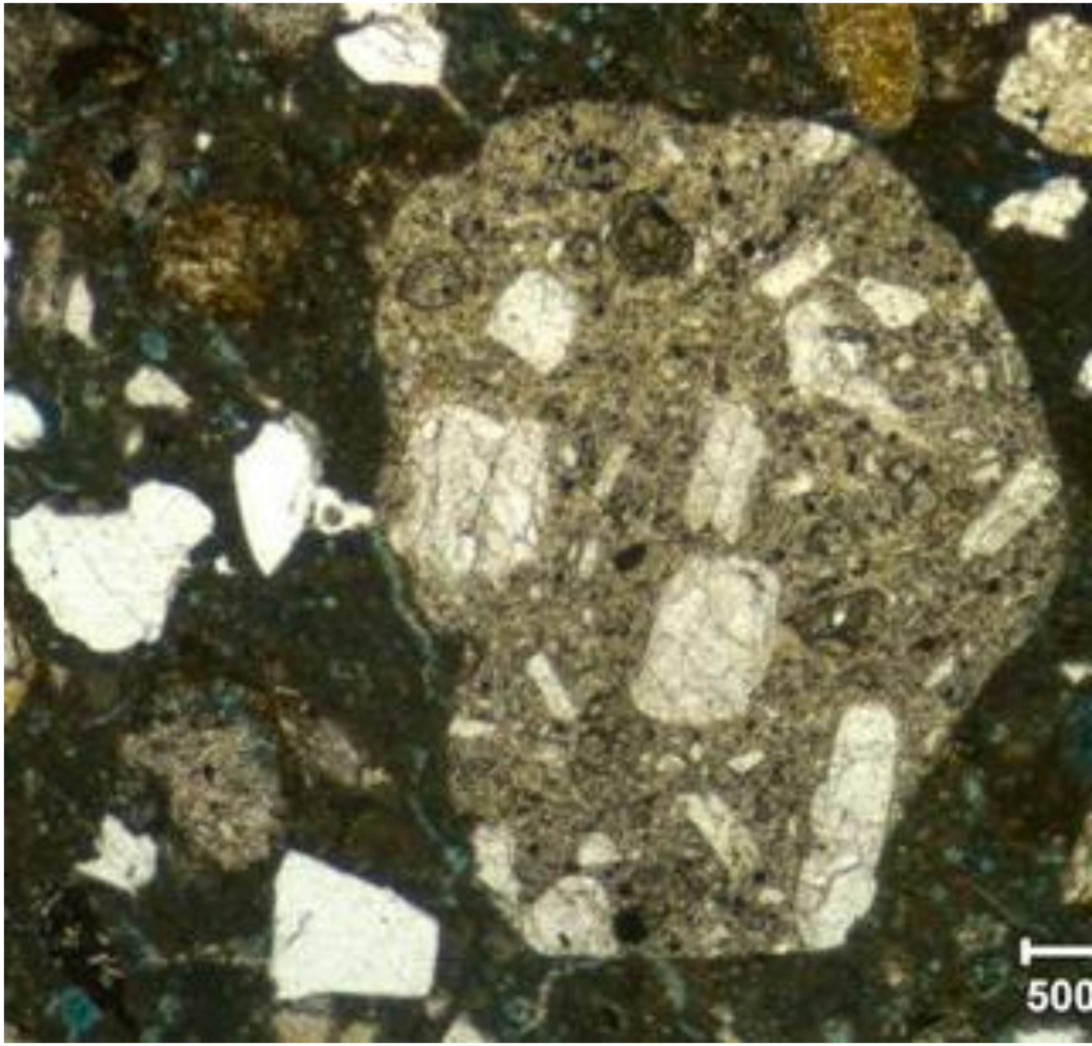
Mortar Sample

High magnification photo shows more detail on the porosity within the cementing matrix. This type of porosity looks as though it formed after formulation of the mortar and could be due to dissolution of unstable granular components. If so, then the increased porosity of the interior of the mortar may be related to water movement through the mortar .



Mortar Sample

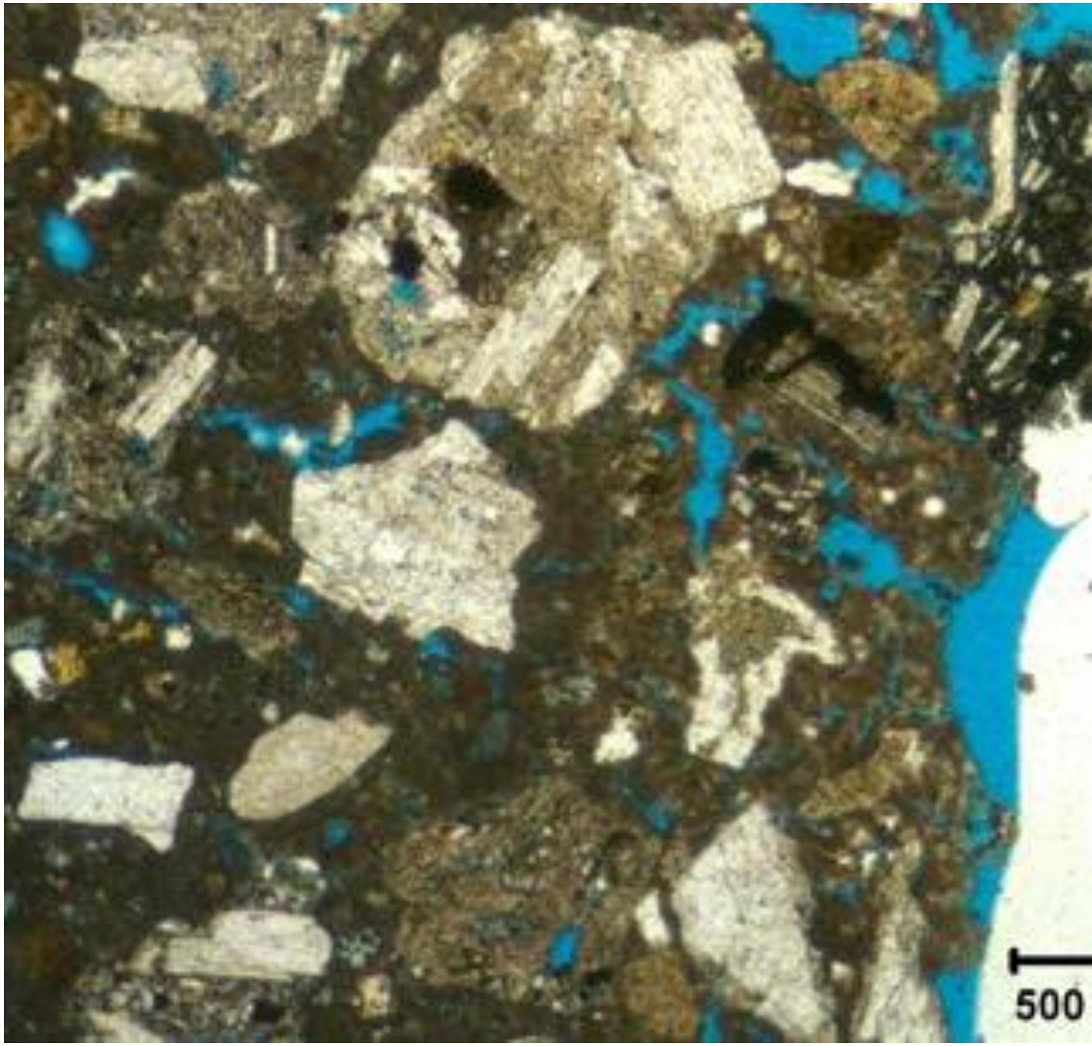
the total porosity of the interior of this mortar sample is about 3X that of the outer edge of the sample. The reduced porosity of the outer edge of the mortar could be a function of smearing of the exposed joint during finishing of the mortar. External pressure on the mortar surface would probably reduce the porosity of a thin zone.



Mortar Sample

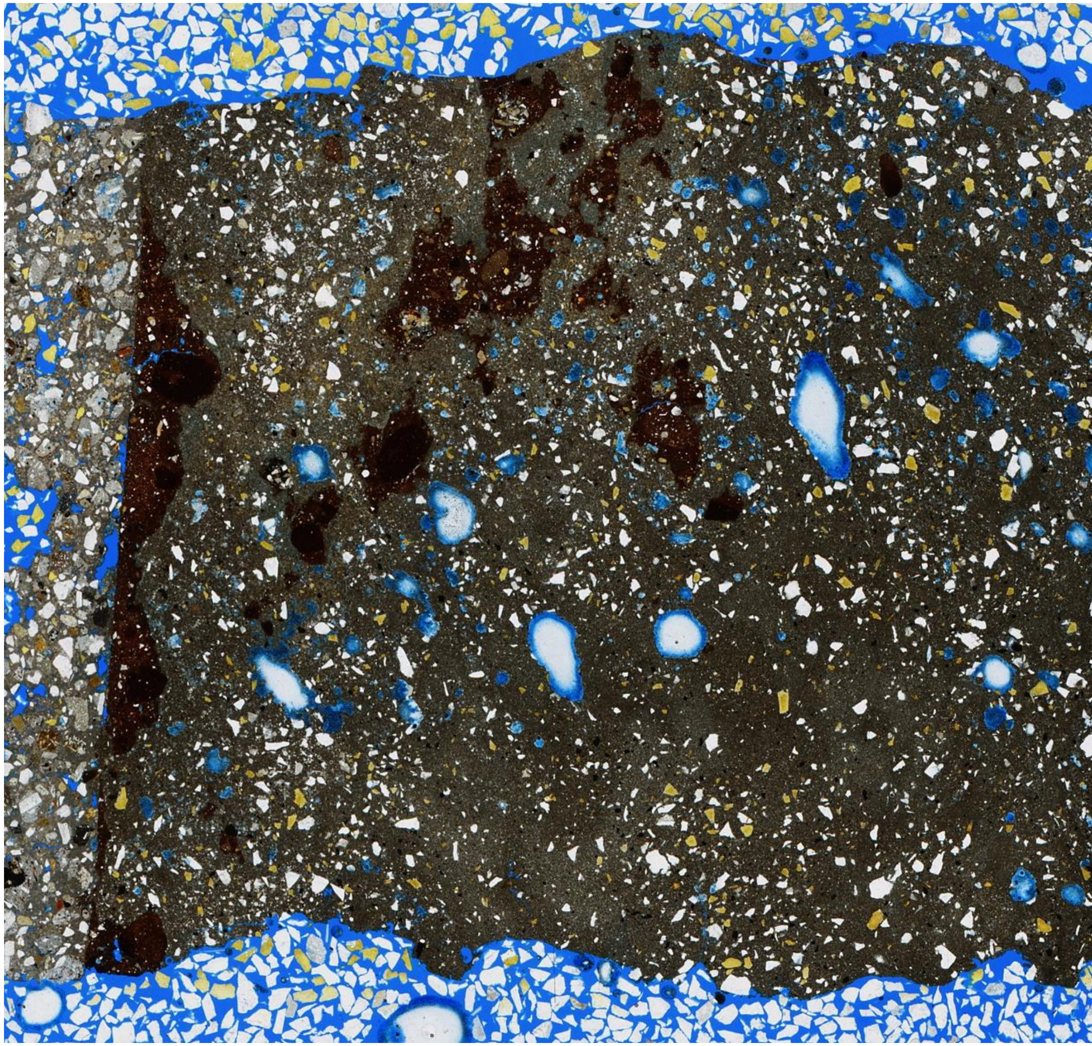
The primary difference between the edge mortar and the internal mortar is related to the amount of porosity in the cement matrix. The edge mortar shows only about 3% porosity, whereas the interior cement has nearly 8% porosity

The lime : aggregate ratio of this sample is about 48:52, or nearly 1:1, after removing minor amounts of porosity .



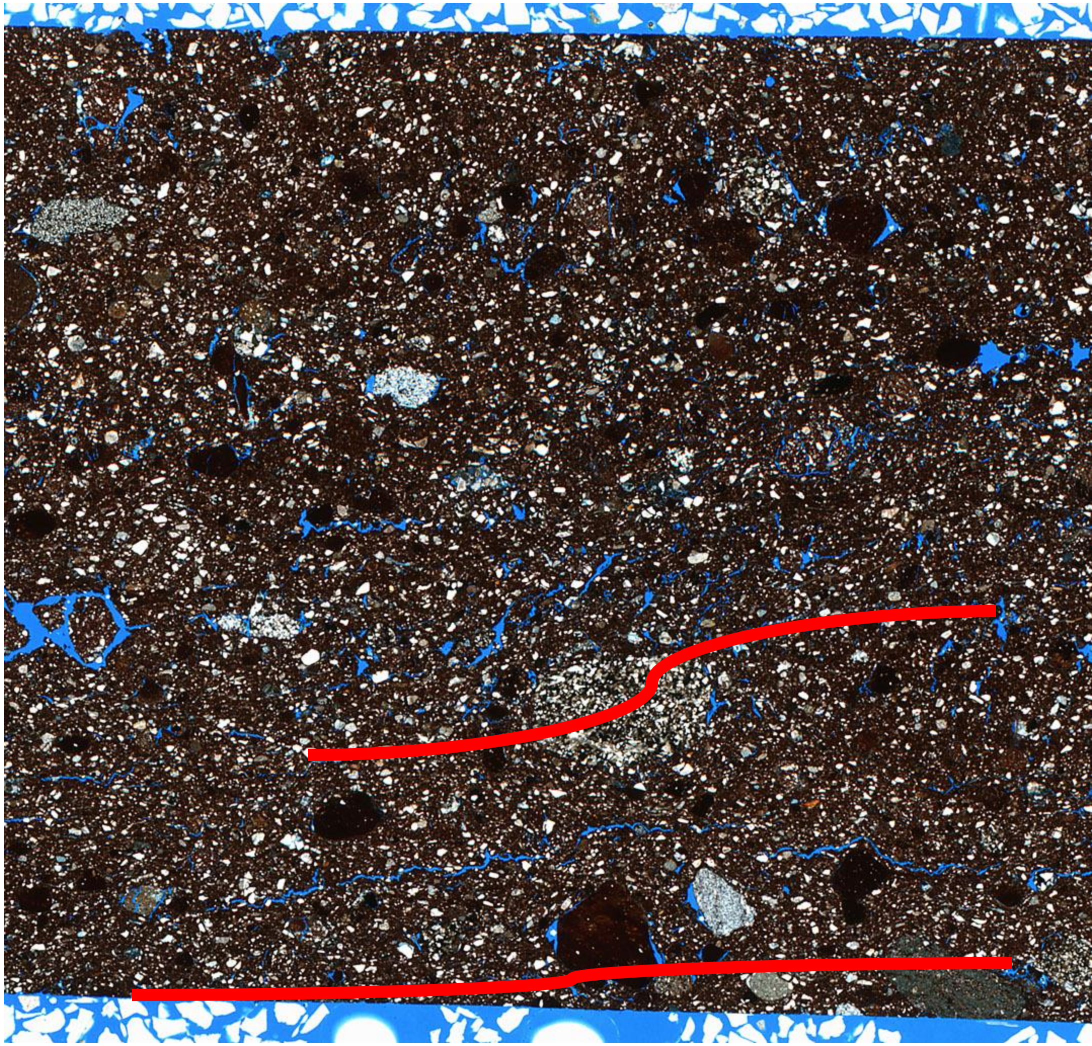
Brick Sample #2

Yellow-stained K-feldspar represents remnants of patching material that entered irregularities in the brick failure surface. The brick shows scattered large voids and planar void traces that often connect larger voids. The dark spots are areas of enhanced oxidation. The sandy material at the left edge of the brick represents lime mortar, rich in volcanic sand, that fills joints between the bricks.



Brick sample #3

The brick is transected by numerous planar and irregular voids that are often interconnected and provide pathways for water percolation through the brick, as well as possible locations for freeze/thaw damage. The center of the thin section shows a zone with complex interconnected porosity (blue areas) that may have developed during firing of the clay (shrinkage cracks). The common occurrence of large planar voids contributes to an increased risk of brick failure along these surfaces.



1. Failure mechanism inherent in manufacturing process. Likely due to poor bonding of clay during extrusion.
2. Low IRA is good and due to small diameter capillaries within brick. However, there is a correlation between small diameter capillary and susceptibility to expansion failures.
3. Salts in cement based mortars are leaching into the masonry over long periods of time. Upon drying, expansion of the salts within capillaries causing excessive force.
4. Some micro-climate freeze thaw may be occurring but is not the initial cause of failure

Conclusions

Next Steps

1. Control **water**
2. 100% repointing with lime based mortar
3. Replace all failed brick units
4. No sealers – need a way for any remaining capillary water containing mortar salts to exit the masonry.

Thank You!

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