Sources of Stone Recently Used in Chicago District

- **Valders and Hayton, WI - dolomite**
- **Wausau, WI - blasted and drilled/split granite**
- **Little Current, Ont. - quartzite**
- **Waterloo, WI - quartzite**
- **Bloomington area, IN - cut limestone**
- **Ste. Genevieve, MO - blasted limestone**
Stone Types

A-Stone: Large Stone in Direct Contact with Water

B-Stone: Underlayer Stone – Transitional Layer

C-Stone: Bedding Between Foundation and B-Stone
Stone / Rock Types Used in the Chicago District

- Cut Limestone Blocks – Early 1900s to present
- Blasted Limestone and Dolomite – 1960s to present
- Blasted Quartzite – Early 1990s to present
- Blasted Granite – Late 1990s to present
- Drilled and split granite – 2005
Cut Limestone Blocks

Used initially in “Laid Up” structures

Later used in rubble mound and as capstone
Drilled and Split Granite
Stone Materials Specifications

Great Lakes Stone Team in late 1990s to address inconsistencies

Representatives of 3 Districts, Local Sponsors and Industry

Developed Great Lakes Armor Stone Guide Specification

Included Combination of Visually-verified and Laboratory Criteria

Laboratory Criteria Based on Concrete Aggregate Tests

Visual Criteria Subject to Some Discretion

On-Site Meetings at Sources to Establish Mutual Understanding

Use of Reference/Index Stones at Quarry to Display Features
# Laboratory Test Criteria

<table>
<thead>
<tr>
<th>Test</th>
<th>Test Method</th>
<th>Acceptance Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific Gravity&lt;sup&gt;3/&lt;/sup&gt;</td>
<td>ASTM C 127</td>
<td>2.6 – 3.0</td>
</tr>
<tr>
<td>Absorption&lt;sup&gt;1/2&lt;/sup&gt;</td>
<td>ASTM C 127</td>
<td>&lt; 1 percent and &gt; 3 percent</td>
</tr>
<tr>
<td>Los Angeles Abrasion</td>
<td>ASTM C 535</td>
<td>&lt; 20 percent loss after 500 revolutions</td>
</tr>
<tr>
<td>Freeze-Thaw&lt;sup&gt;1/2&lt;/sup&gt;</td>
<td>ASTM D 5312</td>
<td>&lt; 2 percent loss after 35 cycles</td>
</tr>
<tr>
<td>Wetting-Drying&lt;sup&gt;1/2&lt;/sup&gt;</td>
<td>ASTM D 5313</td>
<td>&lt; 2 percent loss after 80 cycles</td>
</tr>
<tr>
<td>Petrographic Examination</td>
<td>ASTM C 295</td>
<td>No deleterious materials allowed</td>
</tr>
<tr>
<td>Field Examination</td>
<td>ASTM D 4992</td>
<td>No deleterious materials allowed</td>
</tr>
</tbody>
</table>
Visually Identified Criteria

“...quality to insure permanence of structure in the climate in which it is to be used... ...free of features which may tend to increase deterioration from natural causes or breakage during handling, transportation, or placement. ”

Vugs: Less than 5% of exposed surface area exhibiting vugs, and vugs shall not be aligned along bedding planes. No vugs greater than 4-inches in diameter.

Stylolites shall not exhibit gaps, separation or clay mineralization or appear likely to separate.

Dimensional aspect ratio 3:1 based on measurements of 3 mutually perpendicular axes when represented within a rectangular “box” orientation.

No fractures or bedding planes that appear likely to cause failure
Factors That Impact Armor Stone Durability

- **Environment and Climate – Nature of Project**

- **Above or Below Water Placement**
  - Prefer no distinction in acceptance criteria to avoid confusion in field
  - Contractors unlikely to charge less for lower quality, so why lower standards?

- **Production Methods**
  - Cut Stone – Oolitic Limestone and Sandstone
  - Drilled and Split Stone
  - Blasted Stone
  - Curing and Aging
Factors That Impact Armor Stone Durability

Cont’d

• Rock Type

- Sedimentary rock has inherent anisotropy

- Carbonates (and any sedimentary rock) vary based on depositional environment. Carbonates are often most readily available

- Meta-quartzite has uniform mineralogy and crystalline intergrowth

- Granite includes variation in mineralogy and crystalline intergrowth
Factors That Impact Armor Stone Durability

Cont’d

Discontinuities, etc.

Fractures – mechanically caused by excavation methods

Joints – naturally occurring as a consequence of lithification and stresses

Bedding – separation planes and clay or oxidized minerals along bedding

Stylolites – suture-like features formed in conjunction with pressure dissolution

Micaceous or mineralized zones – biotite, sericite and clay minerals are weaker than surrounding rock

Vugs – discontinuous voids or bubbles in rock mass
Small fractures require careful inspection to detect

May require wetting stone to aid visibility

Discontinuous fractures of no consequence
Joints

Often detected during quarrying

May worsen with exposure
Stylolites

- May or may not be a problem
- May represent failure surfaces
- May be more durable than surrounding rock
Micaceous / Mineralized Zones

Clay along joints or bedding planes

Disseminated softer minerals may cause fracturing during handling and placement
Vugs

May or may not be a problem
Act as havens for vegetation
If aligned form plane of weakness
Factors That Impact Armor Stone Durability

Cont’d

Transportation, Handling and Placement
Quality Control and Quality Assurance

- Shift from intensive Government Inspection (QA) to Contractor QC
- Training and qualifications of Contractor QC personnel
- Training and technical support (Design and A/E) for Government QA personnel
- Quarry visit to establish acceptance criteria
- QC oversight during quarrying, selection and transportation
- QA oversight throughout
Quarry Visits to Establish Acceptance Criteria

- Resolve misunderstandings early
- Document agreements
Ongoing Investigations

Monitoring of Completed Coastal Projects – MCCP

- 1994-1998 study of armor stone in Great Lakes region
- Included investigations in laboratory, quarries and project performance
- 4 Structures in Lake Michigan and one in Lake Erie (Chicago Harbor, Calumet Harbor, Burns Harbor, Calumet Harbor CDF, and Cleveland Harbor)

Monitoring Report produced in 2004-2005 summarizing results
Ongoing Investigations

Monitoring of Completed Navigation Projects – MCNP

• 2005 – 2010 study of armor stone durability

• Includes investigations in laboratory, quarries and project performance

• 3 Structures in Great Lakes – Lake Michigan, Lake Erie and Lake Superior
  (Burns Harbor, IN; Cleveland Harbor, OH and Keweenaw Harbor, MI)

Study of factors in durability, effects of scale on laboratory tests, develop guidelines for selection criteria, possibly develop testing protocols and guidance documents
Questions, Comments, Feedback???
(please don’t throw stones)

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