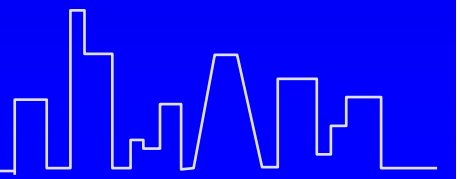
US Army Corps
of Engineers
Chicago District

Armor Stone Durability In the Great Lakes Environment

Joseph A. Kissane, P.G.
District Geologist
Geotechnical Branch
U.S. Army Corps of Engineers
Chicago District

CELRC-TS-DG
111 N. Canal St. Suite 600
Chicago, IL 60606
(312) 846-5453
joseph.a.kissane@usace.army.mil



US Army Corps
of Engineers
Chicago District

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

US Army Corps
of Engineers
Chicago District

Stone Types

A-Stone: Large Stone in Direct Contact with Water

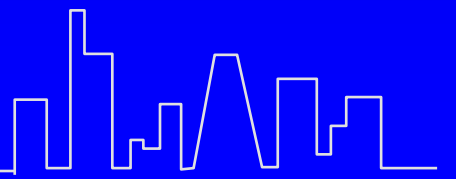
B-Stone: Underlayer Stone – Transitional Layer

C-Stone: Bedding Between Foundation and B-Stone

US Army Corps
of Engineers
Chicago District

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



US Army Corps
of Engineers
Chicago District

Cut Limestone Blocks

Used initially in "Laid Up" structures

Later used in rubble mound and as capstone

US Army Corps
of Engineers
Chicago District

Blasted Dolomite and Limestone

US Army Corps
of Engineers
Chicago District

Blasted Quartzite

US Army Corps
of Engineers
Chicago District

Blasted Granite

US Army Corps
of Engineers
Chicago District

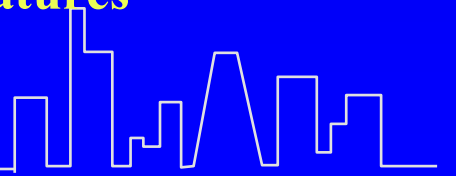
Drilled and Split Granite

US Army Corps
of Engineers
Chicago District

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**



US Army Corps
of Engineers
Chicago District

Laboratory Test Criteria

Test	Test Method	Acceptance Criteria
Specific Gravity[3/]	ASTM C 127	2.6 - 3.0
Absorption[1/2]	ASTM C 127	< 1 percent and > 3 percent
Los Angeles Abrasion	ASTM C 535	< 20 percent loss after 500 revolutions
Freeze-Thaw [1/2]	ASTM D 5312	< 2 percent loss after 35 cycles
Wetting-Drying [1/2]	ASTM D 5313	< 2 percent loss after 80 cycles
Petrographic Examination	ASTM C 295	No deleterious materials allowed
Field Examination	ASTM D 4992	No deleterious materials allowed

US Army Corps
of Engineers
Chicago District

Visually Identified Criteria

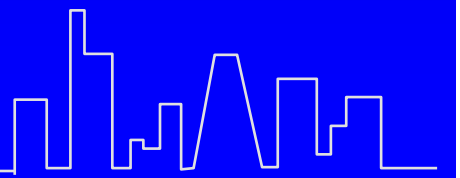
"…quality to insure permanence of structure in the climate in which it is to be used… …free of features which may tend to increase deterioration from natural causes or breakage during handling, transportation, or placement . "

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



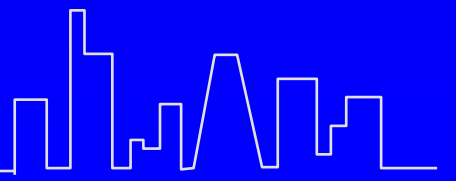
US Army Corps
of Engineers
Chicago District

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**



US Army Corps
of Engineers
Chicago District

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

US Army Corps
of Engineers
Chicago District

Factors That Impact Armor Stone Durability
Cont'd

Discontinuities, etc.

Fractures – mechanically caused by excavation methods

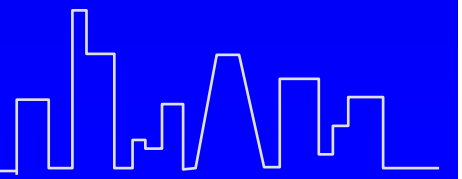
Joints – naturally occurring as a consequence of lithification and stresses

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



US Army Corps
of Engineers
Chicago District

Fractures

Small fractures require careful inspection to detect

May require wetting stone to aid visibility

Discontinuous fractures of no consequence

US Army Corps
of Engineers
Chicago District

Joints

Often detected during quarrying

May worsen with exposure

US Army Corps
of Engineers
Chicago District

Bedding

US Army Corps
of Engineers
Chicago District

Stylolites

May or may not be a problem

May represent failure surfaces

May be more durable than surrounding rock

US Army Corps
of Engineers
Chicago District

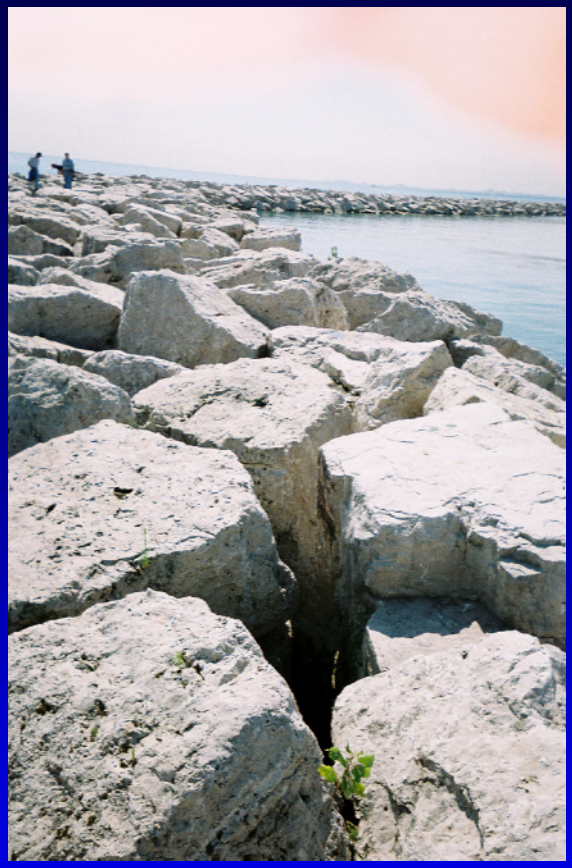
Micaceous / Mineralized Zones

Clay along joints or bedding planes

Diseminated softer minerals may cause fracturing during handling and placement

US Army Corps
of Engineers
Chicago District

Vugs



May or may not be a problem

Act as havens for vegetation

If aligned form plane of weakness

US Army Corps
of Engineers
Chicago District

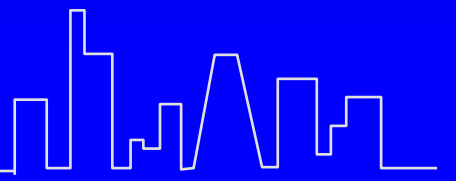
Factors That Impact Armor Stone Durability
Cont'd

Transportation, Handling and Placement

US Army Corps
of Engineers
Chicago District

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**



US Army Corps
of Engineers
Chicago District

Quarry Visits to Establish Acceptance Criteria

- **Resolve misunderstandings early**
- **Document agreements**

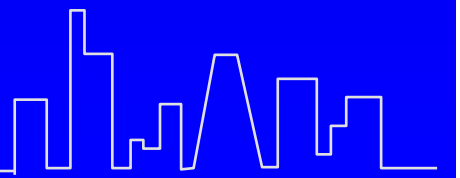
US Army Corps
of Engineers
Chicago District

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



US Army Corps
of Engineers
Chicago District

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

US Army Corps
of Engineers
Chicago District

Questions, Comments, Feedback???
(please don't throw stones)

Joseph A. Kissane, P.G.
CELRC-TS-DG
111 N. Canal St. Suite 600
Chicago, IL 60606
(312) 846-5453
joseph.a.kissane@usace.army.mil