Monitoring and Maintenance of Coastal Infrastructure

Materials in Coastal Design

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Materials in Coastal Design

Contents

• Material Requirements
• Earth and Sand
• Stone
• Portland Cement and Asphalt
• Steel and Other Metals
• Wood
• Geotextiles and Plastics

Based on CEM Chapter VI-4
Primary Material Requirements

- Material Properties and Strength
- Material Durability
- Material Adaptability
- Material Costs
- Material Availability
- Material Handling Requirements
- Maintenance Requirements
Material Properties and Strength

• **Specific Gravity.** Important where structure self-weight provides stability

• **Strength.** Determines size and shape of structure members to resist tension, compression, bending and shear

• **Resistance to Cyclic, Impact and Seismic Loads.** Achieved through structure deflection, differential settlement, or localized damage

(Continued)
Material Properties and Strength

(Concluded)

- **Flexibility.** Bending without breaking to help absorb impacts. Depends on material properties and shape of structure.

- **Compatibility.** Be aware of:
  - Physical and chemical differences
  - Galvanic reactions
  - Different expansion and flexibility
Material Durability

*Durability* includes resistance to abrasion, chemical attack, corrosion, biofouling, wet/dry and freeze/thaw cycles, and temperature change.

- **Earth and Sand.** Generally good. Soil may degrade to silt
- **Stone.** Igneous rock most durable, sedimentary rock may fail in shear. Stones with cracks vulnerable to freeze/thaw.
- **Concrete and Asphalt.** Concrete considered durable. Cracks can cause spalling. Asphalt is not very durable.

(Continued)
Material Durability

(Concluded)

- **Steel.** Very durable *if* protected from rust
- **Wood.** Durability depends on type, usage, exposure, and maintenance
- **Geotextiles and Plastics.** Resistant to chemicals but some synthetics may deteriorate in sunlight.
Material Requirements

Material Adaptability

- **Earth and Sand.** Variety of mound shapes, allows differential settlement, tolerates temperature extremes
- **Concrete.** Very adaptable for large gravity structures, vertical faces, deeper water
- **Steel.** Very adaptable for complex structures, support frameworks, movable parts, and floating structures
- **Wood.** Fairly adaptable for small structures and components
- **Geotextiles and Plastics.** Limited uses outside intended function
Material Requirements

Material Costs

Consider costs associated with:
• Large quantities
• Onsite storage
• Material transportation
• Future maintenance
• Fabrication
• Handling
Material Availability

• **Earth and Sand.** Earth is widely available. Beach-quality sand is less common. Avoid silts and deltaic soils.

• **Stone.** Widely available, but quality may be inadequate

• **Concrete and Asphalt.** Concrete components available in all US mainland coastal regions. Asphalt is generally available.

(Continued)
Material Requirements

Material Availability

(Concluded)

• **Steel.** Standard steel grades in common shapes and lengths are generally available. Special shapes and prefabricated parts usually not locally available.

• **Wood.** Hardwoods becoming less available. Softwoods more available, but not as good for some applications.

• **Geotextiles and Plastics.** Usually not locally available. Large quantities require good lead time.
Material Handling Requirements

- **Earth and Sand.** Easily handled with conventional equipment. Offshore sand requires dredging and transport.
- **Stone.** Problems arise with large stones. Adequate equipment (trucks/cranes) is critical. Road limits in transport. Heavy loads on site.
- **Concrete and Asphalt.** Some designs may require special equipment for mixing, transport, and placement. Air temperature and underwater placement are factors.

(Continued)
Material Handling Requirements (Concluded)

- **Steel.** Components easily transported. Assembly may require special equipment (e.g., heavy cranes). Very heavy fabrications may require special cranes.
- **Wood.** No difficulty in transport or assembly. Preservative treatment may require special equipment.
- **Geotextiles and Plastics.** Conventional transportation. Special equipment and techniques for placement. May need to weight fabric.
Material Requirements

Maintenance Requirements

• **Earth and Sand.** Replacement of eroded volume. Repair of protective layers.
• **Stone.** Replacement of broken and missing stones (*high mobilization costs!*)
• **Concrete and Asphalt.** Mend cracked and broken section. Apply protective coatings. Replace broken concrete armor units.

(Continued)
Maintenance Requirements

(Concluded)

• **Steel.** Remove rust and corrosion. Apply protective coatings. Replace members weakened by impacts or overstressing. Service cathodic protection.

• **Wood.** Reapply protective coatings. Replace deteriorated members and portions damaged by impacts and fire.

• **Geotextiles and Plastics.** Replace fabric damaged by sun exposure. Repair and replace damaged or vandalized geobags.
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Earth and Sand

Uses in Coastal Construction

Earth and/or Sand:

- Caissons (used as filler material)
- Bulkheads and vertical-front structures (foundations and backfills)
- Dikes (sand and clay)
- Land Reclamation (need load bearing capacity)
- Construction Roads (temporary or permanent)

(Continued)
Earth and Sand

Uses in Coastal Construction

(Concluded)

Sand:

• Beach and Dune Reconstruction (beach-quality sand)
• Rubble-Mound Breakwaters (not common practice, must be protected with geotextile)
• Concrete Aggregate (sand and gravel)
Earth and Sand

General Classification

• **Boulders.** Bulky, hard rock with $D > 300$ mm
• **Cobbles.** Usually more rounded with $75 < D < 300$ mm
• **Gravels.** Hard, rounded to angular particles with $4.8 < D < 75$ mm
• **Sands.** Hard rock particles with $0.074 < D < 4.8$ mm
• **Silts and Clays.** Soil particles with $D < 0.074$ mm. Silts are unstable and difficult to compact. Clays have cohesive strength and low drainage.
## Important Properties

**Soil Density.** Density of soil mixture including voids (see various definitions in the table)

<table>
<thead>
<tr>
<th>Name</th>
<th>Symbol</th>
<th>Defining Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Basic Parameters</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight of solids</td>
<td>$W_s$</td>
<td></td>
</tr>
<tr>
<td>Weight of water</td>
<td>$W_w$</td>
<td></td>
</tr>
<tr>
<td>Volume of solids</td>
<td>$V_s$</td>
<td></td>
</tr>
<tr>
<td>Volume of voids</td>
<td>$V_v$</td>
<td>$V_s + V_v$</td>
</tr>
<tr>
<td>Total volume</td>
<td>$V$</td>
<td></td>
</tr>
<tr>
<td>Water unit weight</td>
<td>$Y_w$</td>
<td></td>
</tr>
<tr>
<td><strong>Derived Parameters</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dry soil</td>
<td>$Y_d$</td>
<td>$\frac{W_s}{V}$</td>
</tr>
<tr>
<td>Unit weight</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moist soil</td>
<td>$Y_m$</td>
<td>$\frac{W_s + W_w}{V}$</td>
</tr>
<tr>
<td>Unit weight</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Saturated soil</td>
<td>$Y_{sat}$</td>
<td>$\frac{W_s - V_s Y_w}{V}$</td>
</tr>
<tr>
<td>Unit weight</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Immersed soil</td>
<td>$Y_{imm}$</td>
<td>$\frac{W_s - V_s Y_w}{V}$</td>
</tr>
<tr>
<td>Unit weight</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Specific gravity</td>
<td>$G$</td>
<td>$\frac{V_s}{Y_w}$</td>
</tr>
<tr>
<td>Void ratio</td>
<td>$e$</td>
<td>$\frac{V_v}{V_s}$ or $\frac{n}{100 - n}$</td>
</tr>
<tr>
<td>Porosity</td>
<td>$n$</td>
<td>$\frac{V_v}{V} \times 100%$ or $\frac{e}{1-e} \times 100%$</td>
</tr>
</tbody>
</table>
Earth and Sand

Important Properties

• **Relative Density.** Ratio of in-situ density to range of possible densities for noncohesive soils (sands)

\[ D_r = \frac{e_{\text{max}} - e}{e_{\text{max}} - e_{\text{min}}} \times 100\% \]

(Continued)
Earth and Sand

Important Properties

- **Relative Compaction.** Ratio of unit dry weight of *compacted* soil to maximum possible unit dry weight

\[ R_c = \frac{\gamma_d}{\gamma_{d\text{max}}} \times 100\% \]

(Continued)
Earth and Sand

Important Properties

- **Shear Strength.** Strength at which in-situ soil fails by shear
- **Compressibility.** Settlement that occurs under loading.
  
  Three phases are: immediate settlement, primary consolidation, secondary consolidation.

(Continued)
Earth and Sand

Important Properties

• **Permeability.** Parameter related to viscous flow of water through soil. Best determined by field tests.

**Darcy Equation for Steady Flow**

\[ Q = K A \frac{\Delta h}{L} \]

where

\( Q \) = discharge

\( A \) = flow cross-sectional area

\( L \) = length of flow path

\( \Delta h \) = head difference over the flow length

(Continued)
# Earth and Sand

## Important Properties (Concluded)

### Typical Soil Permeability Coefficients

<table>
<thead>
<tr>
<th>Soil Types</th>
<th>Particle Size Range, cm</th>
<th>Permeability Coefficient, k</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$D_{\text{max}}$</td>
<td>$D_{\text{min}}$</td>
</tr>
<tr>
<td>Uniform, coarse sand</td>
<td>0.2</td>
<td>0.05</td>
</tr>
<tr>
<td>Uniform, medium sand</td>
<td>0.05</td>
<td>0.025</td>
</tr>
<tr>
<td>Clean, well-graded sand and gravel</td>
<td>1.0</td>
<td>0.0005</td>
</tr>
<tr>
<td>Uniform, fine sand</td>
<td>0.025</td>
<td>0.005</td>
</tr>
<tr>
<td>Well-graded, silty sand and gravel</td>
<td>0.5</td>
<td>0.001</td>
</tr>
<tr>
<td>Silty sand</td>
<td>0.2</td>
<td>0.0005</td>
</tr>
<tr>
<td>Uniform silt</td>
<td>0.005</td>
<td>0.0005</td>
</tr>
<tr>
<td>Sandy clay</td>
<td>0.10</td>
<td>0.0001</td>
</tr>
<tr>
<td>Silty clay</td>
<td>0.005</td>
<td>0.0001</td>
</tr>
<tr>
<td>Clay (30 to 50 percent clay sizes)</td>
<td>0.005</td>
<td>0.00005</td>
</tr>
</tbody>
</table>
Earth and Sand

Placement Considerations

• **Dumped Placement.** Onshore placement includes backfill, foundations, beachfills, structure cores. Opportunity to compact placed material. Offshore placement by dumping or dragline will settle, sorting may occur during fall, and turbidity may occur.

• **Hydraulic Placement.** Transported via pipeline and paced as a slurry mixture. Greater accuracy and less segregation under water. Land-placement give large runoff.

• **Compaction.** Above water compaction by usual mechanical methods to achieve specified parameters. Underwater compaction is limited to cyclic wave loading.
Earth and Sand

Environmental Considerations

• Effects of Soils on the Environment.
  • Polluted soils should not be used
  • Limit use of dredged soils to good quality materials
  • Examine recent environmental regulations

• Effects of the Environment on Soils.
  • Soil particles are generally unaffected
  • Erosion and decrease of fill volume by water, wind, burrowing animals, or human activities
  • Possible liquefaction of submerged loose sand in seismic regions
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Based on CEM Chapter VI-4
Stone

Uses in Coastal Construction

• **Laid-Up Structures.** Steep or vertical fronts of laid-up cut stone masonry (rarely used today)

• **Rubble-Mound Structures.** Armor units, underlayers, cores (quarryrun), and cap stones

• **Rip-Rap Structures.** Shore and bank protection structures under mild waves and currents

(Continued)
Stone

Uses in Coastal Construction

(Concluded)

- **Toe Protection.** Graded stone to protect structures from scour and undermining
- **Scour Blankets.** Stone protection of areas susceptible to scour such as bridge piers
- **Stone Fill.** Stones used as filler for caissons, cribs, and gabions
- **Filter Layers.** Smaller stones and gravel used as filter layers over soil or sand
Stone

Types of Rock

- **Granite.** Medium- and coarse-grained igneous rocks (feldspar and quartz). Hard, dense, strong, low porosity. Good for riprap and armor stones.
- **Basalt.** Dense, fine-grained volcanic rocks. Very dense, hard, tough, and durable. Good for aggregates, riprap, and armor stone.

(Continued)
Stone

Types of Rock

(Concluded)

- **Carbonate.** Fine- to coarse-grained rocks containing varying amounts of calcite (limestone, dolomite, marble). Generally sound, dense, tough, and strong. Suitable for aggregates, riprap, and armor stone, but varies widely.

- **Sandstone.** Sedimentary rock made of small particles cemented together. Strength varies widely depending on cementing material. Generally porous and weathers poorly. May be suitable as crushed stone.
Stone

Important Properties

• **Specific Weight.** Most important for armor stones. Less important for underlayers.

• **Size and Distribution.** Designs specify $W_{50}$ and distribution. Armor stones are most uniform.

• **Stone Shape.** Angular, blocky stones best for armor units. Angularity in underlayers improves bonding between layers.

• **Durability.** Note past performance on projects supplied by quarry.

(Continued)
Stone

Important Properties

(Concluded)

• **Strength.** Generally not an issue. Must withstand weight of overlying stones.

• **Porosity and Absorption.** Stone durability decreases with increasing water absorption. Critical in freeze/thaw regions.

• **Abrasion and Soundness.** Abrasion resistance is important for stone handled in bulk. Soundness depends on fissures, laminations, blasting fractures, etc.
# Engineering Characteristics of Unweathered Rock

## Stone

<table>
<thead>
<tr>
<th>Rock Group Name</th>
<th>Rock Specific Weight (kN/m³)</th>
<th>Unconfined Compressive Strength (MPa) x 10⁶</th>
<th>Water Absorption (%)</th>
<th>Porosity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Igneous</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Granite</td>
<td>24.5-27.5</td>
<td>160-280</td>
<td>0.2-2.0</td>
<td>0.4-2.4</td>
</tr>
<tr>
<td>Diorite</td>
<td>25.5-30.4</td>
<td>160-280</td>
<td>---</td>
<td>0.3-2.7</td>
</tr>
<tr>
<td>Gabbro</td>
<td>27.5-31.4</td>
<td>180-280</td>
<td>0.2-2.5</td>
<td>0.3-2.7</td>
</tr>
<tr>
<td>Rhyolite</td>
<td>22.6-27.5</td>
<td>100-260</td>
<td>0.2-5.0</td>
<td>0.4-6.0</td>
</tr>
<tr>
<td>Andesite</td>
<td>23.5-29.4</td>
<td>160-280</td>
<td>0.2-10</td>
<td>0.1-10</td>
</tr>
<tr>
<td>Basalt</td>
<td>24.5-30.4</td>
<td>160-280</td>
<td>0.1-1.0</td>
<td>0.1-1.0</td>
</tr>
<tr>
<td><strong>Sedimentary</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quartzite</td>
<td>25.5-27.5</td>
<td>220-280</td>
<td>0.1-0.5</td>
<td>0.1-0.5</td>
</tr>
<tr>
<td>Sandstone</td>
<td>22.6-27.5</td>
<td>15-220</td>
<td>1.0-15</td>
<td>5-20</td>
</tr>
<tr>
<td>Siltstone</td>
<td>22.6-27.5</td>
<td>60-100</td>
<td>1.0-10</td>
<td>5-10</td>
</tr>
<tr>
<td>Shale</td>
<td>22.6-26.5</td>
<td>15-60</td>
<td>1.0-10</td>
<td>5-30</td>
</tr>
<tr>
<td>Limestone</td>
<td>22.6-26.5</td>
<td>30-120</td>
<td>0.2-5.0</td>
<td>0.5-20</td>
</tr>
<tr>
<td>Chalks</td>
<td>14.7-22.6</td>
<td>5-30</td>
<td>2.0-30</td>
<td>20-30</td>
</tr>
<tr>
<td><strong>Metamorphic</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phyllite</td>
<td>22.6-26.5</td>
<td>60-90</td>
<td>0.5-6.0</td>
<td>5-10</td>
</tr>
<tr>
<td>Schist</td>
<td>26.5-31.4</td>
<td>70-120</td>
<td>0.4-5.0</td>
<td>5-10</td>
</tr>
<tr>
<td>Gneiss</td>
<td>25.5-27.5</td>
<td>150-280</td>
<td>0.5-1.5</td>
<td>0.5-1.5</td>
</tr>
<tr>
<td>Marble</td>
<td>26.5-27.5</td>
<td>130-240</td>
<td>0.5-2.0</td>
<td>0.5-2.0</td>
</tr>
<tr>
<td>Slate</td>
<td>26.5-27.5</td>
<td>70-120</td>
<td>0.5-5.0</td>
<td>0.5-5.0</td>
</tr>
</tbody>
</table>
Durability Ranking for Common Stone

(Most Durable to Least Durable)

1. Granite
2. Quartzite
3. Basalt
4. Limestone and Dolomite
5. Rhyolite and Dacite
6. Andesite
7. Sandstone
8. Breccia and Conglomerate
# Approximate Criteria for Evaluating Stone

<table>
<thead>
<tr>
<th>Test</th>
<th>Approximate Criterion for Suitability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Petrography</td>
<td>Fresh, interlocking crystalline, with few pores, no clay minerals, and no soluble minerals</td>
</tr>
<tr>
<td>Bulk specific gravity</td>
<td>Greater than 2.60</td>
</tr>
<tr>
<td>(saturated, surface dry)</td>
<td></td>
</tr>
<tr>
<td>Absorption</td>
<td>Less than 1.2 percent</td>
</tr>
<tr>
<td>MgSO$_4$ soundness</td>
<td>Less than 2 percent loss in five cycles$^1$</td>
</tr>
<tr>
<td>Glycol soundness</td>
<td>No deterioration except minor crumbs from surface</td>
</tr>
<tr>
<td>Abrasion</td>
<td>Less than 25 percent loss in 1,000 revolutions$^2$</td>
</tr>
<tr>
<td>Freezing-thawing</td>
<td>Largely unaffected in 20 cycles</td>
</tr>
<tr>
<td>Wetting-drying</td>
<td>No major progressive cracking in 35 cycles</td>
</tr>
<tr>
<td>Field visual</td>
<td>Distinctions based on color, massiveness, and other visual characteristics</td>
</tr>
<tr>
<td>Field index</td>
<td>Distinctions based on scratch, ring, and other physical characteristics</td>
</tr>
<tr>
<td>Field drop test</td>
<td>No breakage or cracking</td>
</tr>
<tr>
<td>Field set-aside</td>
<td>No loss or cracking in 12-month exposure</td>
</tr>
</tbody>
</table>

$^1$ Criteria are broad generalizations useful for preliminary judgment only rather than being reflective of any official standard.

$^2$ Coarse aggregate sizes.
Quarrystone Procurement and Inspection

- Review bids to assure no “underbidding”
- Resolve all environmental, historic preservation, and biologic constraints on quarrying by obtaining relevant permits
- Quarry inspection during production to ensure adequate stone quality and gradation
- Avoid over-blasting which may lead to fracturing of armor stone

(Continued)
Quarrystone Procurement and Inspection

• Employ well-trained inspectors familiar with blasting procedures
• Maintain records of stone quality from acceptable quarries. Disqualify unacceptable quarries up front.
• Identify unacceptable areas of in-situ stone within the quarry

(Continued)
Quarrystone Procurement and Inspection

(Concluded)

- Set aside approved stones in different sizes for visual reference by inspector and contractor
- Spread out stones in quarry for inspection prior to loading. Rotate armor stones.
- Periodically check armor stone weights at delivery
- Maintain adequate supply of stone at site
General Placement Considerations

• **On Slopes.** Begin at toe, proceed upslope. Maximum interlocking and minimum voids. Orient armor stone long axis outward from slope.

• **Cores, Bedding, Filters.** Attempt to minimize size segregation. **No drops > 0.6 m.** Achieve total coverage and avoid "hot spots."

• **Underlayers.** Achieve even distribution to full design thickness with minimum voids. **No drops > 0.6 m.** Mate to underlying layer.

• **Riprap.** Avoid segregation. Placement should not disturb underlayer. Build to full thickness (no multiple layers). Correct obvious weak spots. No pushing material downslope.
Stone

Armor Stone Placement Methods

• **Uniform Placement.** Cut and dressed uniform stones placed in orderly pattern. Most expensive.

• **Random Placement.** Careful placement of individual stones. Placed stones should contact neighbors. **No drops > 0.3 m.** No pushing stones downslope. Stability above water better than underwater.

• **Selective Placement.** Careful selection and placement to achieve better interlocking, i.e., "careful random placement."

• **Special Placement.** Parallelepiped stones carefully placed with long axis perpendicular to slope and heavier end closer to the underlayer.
Stone

Uniform Placement
Stone

Random Placement
Stone

Selective Placement
Stone

Special Placement
Environmental Considerations

• Wave Action. Can cause movements and impacts that chip or break armor stones

• Temperature and Fire. Most stone has reasonable tolerance to normal temperature change

• Freeze/Thaw. Can cause cracking

• Chemical Attack. Calcareous stones are subject to decomposition by acids.