Monitoring and Maintenance of Coastal Infrastructure

Repair and Rehabilitation of Coastal Structures

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Repair and Rehabilitation of Coastal Structures

Contents

• General Aspects of Repair and Rehabilitation
• Rubble-Mound Structures
• Other Types of Coastal Structures

Based on: CEM Chapter VI-8 (Author: Steven A. Hughes)
Definitions

**Repair:** Fixing portions of a structure that have been damaged by waves, winds, currents, surges, impacts, or seismic activity.

**Rehabilitation:** *Renovation* of deteriorated structure components to original condition or *upgrading* the structure to withstand greater design loads.
When is Repair Needed?

- After damaging storms or other damaging events
- When periodic condition inspections indicate progressive deterioration
- If performance monitoring indicates the project is not functioning as planned
- When there is chronic damage from underestimating design loads
- When structure function is modified
General Aspects of Repair and Rehabilitation

Should Project be Repaired?

Depends Upon...

- What functions are served by the project
  - Are other commerce activities affected?
  - Has risk of injury increased?
- How critical is the project relative to other projects in need of repair
  - Economic Considerations
  - Possibility of imminent failure or collapse
Differences From New Design

Design Environment Considerations:

• In general, no difference in actual design parameters (waves, water levels, etc.)
• May have better estimates of design parameters
• Regulatory/environmental restrictions probably changed
• Can draw on past performance and monitoring data
General Aspects of Repair and Rehabilitation

Components for Preparing Design

General Design Steps

1. Review original design criteria
2. Determine the cause of the problems
3. Investigate the present structure relative to the as-built plans
4. Devise a solution to the problem
5. Design a repair that fixes problem without extensive modifications

It helps if you have:

- Original plans and specs
- As-built plans
- Corporate memory
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Rubble-Mound Structures

- Relatively flexible with tolerance to slight movement of armor
- Damage is usually
  - Armor unit breakage
  - Dislocation of armor
  - Removal of a section of armor
Rubble-Mound Structures
Options for Rubble-Mound Structures

**Slope and Crest Repair**
- Chinking, resurfacing
- Addition of dissimilar armor
- Layer reconstruction
- Crest raising
- Burial

**Toe and Foundation Repair**
- Toe reconstruction
- Scour apron
- Addition of a berm

**Core Repair or Void Sealing**
- Precast concrete blocks
- Filter cloth
- Grout

**Replace Original Structure**
Repair and Rehabilitation of Rubble-Mound Structures

Repair Considerations:

• Availability of construction materials
• Equipment and site access
• Rubble mound already exists
• Armor mixed with underlayer
• Difficult to change structure slope
• Difficult to secure embedded toe
• Transition into existing structure
• Mixing of armor types and sizes
• Difficult to remove broken and/or embedded armor
• Difficult to repair spot damage on slopes
## Repair and Rehabilitation of Rubble-Mound Structures

<table>
<thead>
<tr>
<th>Method</th>
<th>Handling Attachment</th>
<th>Comment</th>
<th>Access</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tracked hydraulic excavator</td>
<td>Bucket</td>
<td>Positive pick-up and placement. Limited placement and movement. Drops stone.</td>
<td>Suitable for beaches, over crest stones</td>
</tr>
<tr>
<td></td>
<td>Fixed-arm</td>
<td>Positive pick-up and placement.</td>
<td>As above</td>
</tr>
<tr>
<td></td>
<td>Orange peel grab</td>
<td>Non-positive pick-up and placement. Difficult to pick up individual stones from face.</td>
<td>As above</td>
</tr>
<tr>
<td>Wheeled hydraulic excavator</td>
<td>Bucket grapple grab</td>
<td>As above</td>
<td>Only suitable for hard smooth traffic surfaces, small stones, and limited reach</td>
</tr>
<tr>
<td>Crawler crane</td>
<td>Orange peel grab</td>
<td>As above, slower than excavator because of attachment</td>
<td>Suitable for remote areas of structure where hard traffic surface available adjacent to damage</td>
</tr>
<tr>
<td>Jack-up pontoon with crane or excavator</td>
<td>Bucket grapple grab</td>
<td>As above</td>
<td>Suitable for non-drying sites without access from the structure.</td>
</tr>
<tr>
<td>Cranes and excavator for reinforcing failed sections by other means</td>
<td>Buckets and skips</td>
<td>Applicable to areas where importing large stones is difficult.</td>
<td>Need good access close to structure to reinforce sections with concrete or asphalt grout</td>
</tr>
<tr>
<td>Block and tackle</td>
<td>Chains and lifting eyes</td>
<td>Suitable where rock does not have to be moved far distances.</td>
<td>Access for large plant materials difficult.</td>
</tr>
</tbody>
</table>

CHL: Steven Hughes, PhD
General Categories of Armor Layer Repair

- Spot replacement of broken or dislodged units
- Overlaying existing armor layers
- Replacing armor layers
- Rebuilding the structure

Design guidance is sparse…mostly common sense rules-of-thumb
Spot Replacement of Units

When to Use Spot Replacement Repair

- Damage consists of individual displaced armor units
- No large sections of armor displaced
- No evidence of general slope failure
- Percentage of displaced units is 5% or less
Spot Replacement of Units

Repair Method

- Replace dislodged armor units with units of similar type and size
- Reuse displaced units **IF** sound and not broken into smaller pieces
- Supplement with new units
Repair of Armor and Underlayers

Spot Replacement of Units

Rock Armor Repair Technique

• Repair underlayer if necessary
• Achieve good interlocking of armor units
  • If undamaged armor interlocking is good, replace dislodged units with good contact with neighbors
  • If undamaged matrix is loose, rehandle armor as necessary so repair section has interlocking
Repair of Armor and Underlayers

Spot Replacement of Units

Concrete Armor Repair Technique

Good interlocking is **essential** for stability

- Remove and replace undamaged armor layer from the damage location all the way up the slope
- Repair section should resemble a “V”
- Assure good interlocking with undisturbed portions
Repair of Armor and Underlayers

Spot Replacement of Units

Advantages

• Least expensive
• Shorter time on site
• Less new material costs
• Less rehandling of existing armor

Caveat

Important to establish damage caused by design event and not by a lesser storm event
Repair of Armor and Underlayers

Overlaying Damaged Armor Layers

When to Use Armor Overlays

- Armor layer damage is wide-spread
- Large sections are displaced or slumped
- Damage was caused by the design storm or a more severe condition (but not always)

Often damaged structure has lower crest and milder slopes than originally built
Repair of Armor and Underlayers

Overlaying Damaged Armor Layers

Repair Methods

• Single-layer stone overlays
  • Uses less material
  • No design guidance, must test in physical model

• Two-layer stone overlays
  • Use new construction guidance
  • Model test large projects

• Overlays using dissimilar armor units
  • Usually concrete armor units over stone
  • Design guidance available
  • Model test large projects
# Stability Coefficients for Dissimilar Armor Layer Overlays

<table>
<thead>
<tr>
<th>Overlay Type</th>
<th>Stability Coef. $K_d$</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dolos over stone (trunk)</td>
<td>12</td>
<td>Randomly placed. Minimum stability for long waves in shallow water.</td>
</tr>
<tr>
<td>Dolos over stone (head)</td>
<td>8</td>
<td>Slope 1:1.5</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>Slopes 1:2 thru 1:3.5</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>Slopes 1:4 thru 1:5</td>
</tr>
<tr>
<td>Tribar over stone (trunk)</td>
<td>9</td>
<td>Randomly placed on slopes no steeper than 1:2</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>Uniformly placed on slopes as steep as 1:1.5</td>
</tr>
<tr>
<td>Dolos over dolos (trunk)</td>
<td>15.6</td>
<td>Randomly placed. Minimum stability for long waves in shallow water.</td>
</tr>
<tr>
<td>Dolos over tribars (Trunk and head)</td>
<td>15</td>
<td>Randomly placed. Exceeds stability of new construction.</td>
</tr>
</tbody>
</table>
Repair of Armor and Underlayers

Armor Layer Overlay Concerns

- Armor interface with existing underlying armor
  - Extra effort to achieve interlocking between armor layers
  - Underwater portion is very difficult...uneven slope
- Leeside crest armor units
  - Key into existing structure (overtopping stability)
- Overlay toe
  - Must be secured and protected (may need new toe berm)
  - Dislodged armor stones may litter the bottom
- Construction methods
  - Begin at toe and work upslope
  - May need to build up uneven underlayer
Repair of Armor and Underlayers

LAKE SIDE

DOLOSSE (2 TONS EACH)
(2 LAYERS RANDOMLY PLACED)

+0.0 LWD (EL 568.6 FT)

13.0'

+10.3'

HARBOR SIDE

EXISTING EAST BREAKWATER
(TYPICAL)

THEORETICAL LIMITS OF EXISTING BREAKWATER

UNDERLAYER STONE, TYPE 'C' (600# TO 1300#)

UNDERLAYER STONE, TYPE 'B' (0.65 TON TO 2.0 TON)

EXISTING LAKE BOTTOM
(VARIES -30.0' TO -35.0' LWD)

BEDDING STONE, TYPE 'D' (60# TO CHIPS)

SECTION OF BREAKWATER TRUNK

CONCRETE ARMOR UNIT DESIGN,
BREAKWATER TRUNK
(CLEVELAND HARBOR EAST BREAKWATER
1980 REHABILITATION)

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Repair of Armor and Underlayers

Overlaying Damaged Armor Layers

**Advantages**

- Less expensive than replacing armor layer
- Can be used to raise crest and reduce slope
- Larger armor stones can be used

**Disadvantages**

- Large quantities of new materials required
- Interfacing overlay with existing degraded structure
- Lack of design guidance!
Repair of Armor and Underlayers

Replacing Armor Layers

When to Replace Armor Layers

• Original armor layer is inadequate structurally
  • Excessive broken armor units
  • Undersized armor units

• Original armor layer is inadequate functionally
  • Excessive wave overtopping
  • Excessive wave transmission

• Damage NOT caused by armor instability
Repair of Armor and Underlayers

Replacing Armor Layers

Repair Method

- Remove existing armor layer on a section
- May need to adjust or replace existing first underlayer
  - Increase underlayer size to accommodate larger replacement armor
  - Assure proper thickness and compaction
- Build from the toe and proceed upslope
- Plan construction sequence to minimize rehandling of old and new armor unit
Repair of Armor and Underlayers

Replacing Armor Layers

**Advantages**

- Provides a more stable structure with less future maintenance cost
- Provides intended (or enhanced) functionality
- Use new construction design guidance

**Disadvantages**

- Very expensive!
- Long construction times which may impact activities at the project site
- Site stockpiling of construction materials
Rebuilding the Structure

When to Rebuild

- Structure sustains catastrophic damage
  - Structure integrity has been lost
  - Repair requires a major redesign
- Original structure fails to fulfill its intended function
- New functionality requirements
Rebuilding the Structure

Repair Method

• **Rebuild at the same location**
  - May need to bury or completely remove existing structure
  - Prepare relic structure to serve as base for new structure
    – Remove material (major expense)
    – Prepare new toe
    – Lay down bedding material
  - Probably will result in larger cross section
  - Reuse materials or cost will be greater than new construction

• **Rebuild adjacent to old abandoned structure**
  - Requires functional needs are met
  - Regulatory requirements may be more stringent
Repair of Armor and Underlayers

Rebuilding the Structure

Advantages

• More robust structure
• Less long-term maintenance costs
• Improved (or new) functionality

Disadvantages

• Very expensive to remove existing structure
• Very expensive to build new structure
• Disruption to project activities
Repair and Rehabilitation of Rubble-Mound Structures

Repairing Caps and Crown Walls

• Damage occurs when…
  • Concrete sections are dislodged by wave action
  • Underlying support stones are lost
  • Differential settlement

• Concrete sections may remain intact or they may break because of loading, movement or inadequate support
Repairing Caps and Crown Walls

Repair Methods

• Correct minor displacements with hydraulic jacks or cranes
• Remove cap sections and replace missing underlying armor units; replace cap section
• Replace broken sections with new elements
• Remove damaged cast-in-place sections and cast new sections
Other Aspects of Repair

- **Toes and Berms**
  - For minor damage add new material of same size as needed
  - For major damage redesign berm

- **Scour holes and bedding**
  - Fill and protect scour areas according to guidance

- **Void sealing**
  - Reduces wave and sand transmission
  - Corps guidance available
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Caissons

- Not very tolerant to movement or settlement
- Damage is usually
  - Differential settlement
  - Dislocation of sections
  - Breakage of sections or components
  - Concrete spalling
  - Component deterioration
Caissons

- **Dislocation**: Lift and reseat sections for small structures, remove and replace large sections
- **Settlement**: Add to top of caisson to achieve crest elevation
- **Localized damage**: Patch, repair and replace according to circumstances
Types of Concrete Repair

- **Concrete Replacement**
  - Replace defective concrete with machine-mixed concrete of proper type
  - Best for large repairs where damage is beyond reinforcement

- **Dry Pack**
  - Stiff mixture rammed into place in thin layers
  - Narrow slots and cavities

- **Shotcrete**
  - Bonds well with new or old concrete
  - Good for shallow repairs and vertical or overhead surfaces
Categories of Repair

• **Class 1: Deterioration Barrier Systems**
  • Acts as a barrier to prevent or delay further deterioration
  • Completed as maintenance item
  • Repair is non-load bearing

• **Class 2: Structural Reinforcing**
  • Strengthens existing, weakened load-bear members
  • Part of rehabilitation

• **Class 3: Structural Replacement**
  • Partial or complete replacement of structural member
Repair and Rehabilitation of Other Types of Coastal Structures

- **Class 1:** Deterioration Barrier Systems

- **Class 2:** Structural Reinforcing

- **Class 3:** Structural Replacement
## Repair and Rehabilitation of Other Types of Coastal Structures

<table>
<thead>
<tr>
<th>Construction Material</th>
<th>Class I</th>
<th>Class II</th>
<th>Class III</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Steel</strong></td>
<td><img src="image" alt="Coatings or Cathodic Protection" /></td>
<td><img src="image" alt="Concrete Jacket" /></td>
<td><img src="image" alt="Insert Section Concrete Jacket" /></td>
</tr>
<tr>
<td><strong>Concrete</strong></td>
<td><img src="image" alt="Coatings or Sealants" /></td>
<td><img src="image" alt="Concrete Jacket" /></td>
<td><img src="image" alt="Pipe Jack Concrete Jacket" /></td>
</tr>
<tr>
<td><strong>Timber</strong></td>
<td><img src="image" alt="Preservation Treatment or PVC Encasement" /></td>
<td><img src="image" alt="Concrete Jacket" /></td>
<td><img src="image" alt="Drift Pin" /></td>
</tr>
</tbody>
</table>

**Repair of Pilings**
Repair and Rehabilitation of Other Types of Coastal Structures

- **CONSTRUCTION MATERIAL**
  - **CLASS I**
    - **STEEL**
      - Coating or Other Preservation System
    - **CONCRETE**
      - Coating or Other Preservation System
    - **TIMBER**
      - Preservation Systems
  - **CLASS II**
    - **STEEL**
      - Structural Stiffening with Additional Members
    - **CONCRETE**
      - Pneumatically Applied Concrete Patches
    - **TIMBER**
      - Stiffening with Additional Members
  - **CLASS III**
    - **STEEL**
      - Member Replacement
    - **CONCRETE**
      - Major Reconstruction
    - **TIMBER**
      - Replacement of Members

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### Repair and Rehabilitation of Other Types of Coastal Structures

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<thead>
<tr>
<th>CONSTRUCTION MATERIAL</th>
<th>REPAIR TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CLASS I</td>
</tr>
<tr>
<td>STEEL</td>
<td>Coating Systems</td>
</tr>
<tr>
<td>CONCRETE</td>
<td>Preservation Systems</td>
</tr>
<tr>
<td>TIMBER</td>
<td>Preservation Systems</td>
</tr>
</tbody>
</table>

**Repair of Bulkheads**
Conclusions

• Important to know when repair or rehabilitation is needed
• Understand differences between R&R and new design
• Base decisions on structure functionality and consequences of lost functionality