REVETMENTS

CE A676 Coastal Engineering

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Purposes and Operational Constraints

Purposes

- Erosion control
  - Embankment
  - Toe protection for a seawall, retaining wall or other rigid, impermeable structure
- Flood protection
- Slope stability
  - Retaining a fill or embankment
- Beach access

Constraints

- Construction materials and equipment on hand
- First cost
- Practicality of routine maintenance
- Maintenance cost
- Environmental effects
  - Marine and terrestrial habitats
  - Impacts on adjacent property
- Zoning
- Permits

CE A676 Coastal Erosion
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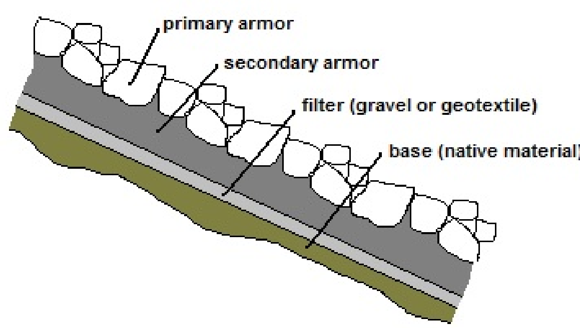
Site Conditions to consider

- Water levels
- Winds
- Waves
- Topography
- Bathymetry
- Natural bed materials
- Longshore transport
- Marine habitats
- Property ownership
- Beach uses (pedestrians, fishing…)

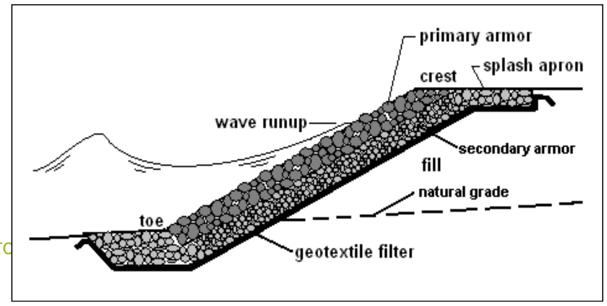
Revetment Layers

- Primary Armor
  - Sized to withstand wave action
  - Sized to withstand currents on streambanks
  - Rock, prefabricated interlocking concrete shapes, wire-mesh gabions filled with stones or sand bags
- Secondary Armor
  - Sized as filter between layers
  - Cushion over filter fabric
- Filter
  - Sized to contain native material
  - Gravel layer or
  - Geotextile
- Base
  - Native material graded as revetment foundation



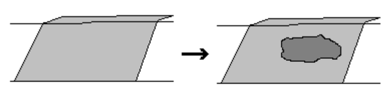
Design – good practice

- Steeper slope minimizes horizontal footprint
  - 1v:1.5h max slope
  - Requires larger armor
  - May require extensive fill
- Armor should rest on appropriate underlayer
  - Never on native material
    - Common error and cause of failure
- Crest may high enough to preclude overtopping or
  - Overtopping erosion may be prevented by splash apro
- Toe is critical
  - May be hard to build at or below waterline
- Structures (walls, building foundations,…) close behind revetment
  - May reduce permeability
  - May reflect wave energy



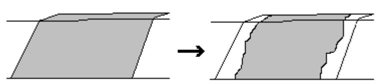
Common revetment failure modes

- Armor displacement: gaps or irregularities in slope



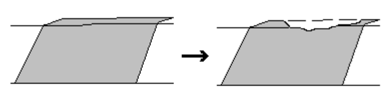
ARMOR DISPLACEMENT

- Flanking: scour at ends



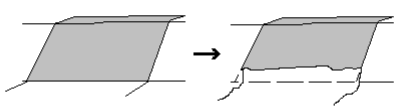
FLANKING

- Overtopping (scour behind crest)



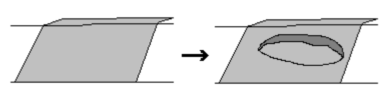
OVERTOPPING

- Toe Scour



TOE SCOUR

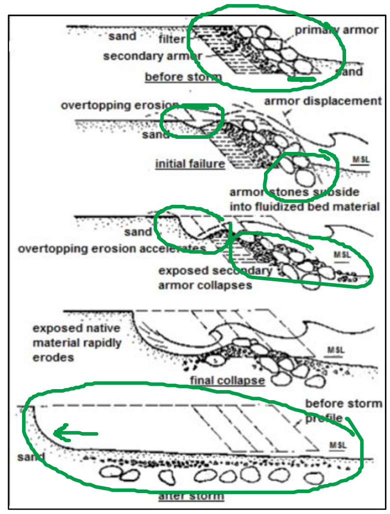
- Ineffective filter (slumping of slope)



INEFFECTIVE FILTER

Revetment failure due to common errors

- Design errors
  - Armor is too small
  - Toe armor rests on native sand
    - No secondary armor or filter beneath
  - Crest susceptible to overtopping
- Localized fluid accelerations around armor stones at toe fluidize sandy bed material
  - Armor stones sink into quick sand
- Overtopping erosion depletes revetment foundation



Design guidance

- Coastal Engineering Manual, Part VI, Chapter 5
  - Also various other CEM Parts and Chapters, by reference
- FHWA, 2008. "Highways in the Coastal Environment, " HEC-25, 2nd ed.
  - Includes overview of coastal processes
- Various PIANC (International Navigation Assn.) publications


Homer Spit, Alaska

Rock revetment armor

- For waves: **Hudson Formula**
  - Point of incipient motion
  - M_{50} = mass of armor unit
  - ρ_r = density of rock
    - use γ_r (specific weight to compute W_r (weight of armor unit)
  - H = design wave height
    - Guidance varies: use $H_{10} = 1.27 H_s$ per FHWA HEC-25
  - K_d = stability coefficient = 2.2 for riprap (HEC-25)
    - assumes waves breaking on the slope; 2 layers of primary armor
    - See CEM VI-5 for extended discussion of K_d for revetments, breakwaters, and jetties, and of Hudson formula alternatives
  - $\Delta = \frac{\rho_r - \rho}{\rho} = S_r - 1$ = reduced gravity (buoyancy) factor
    - ρ = density of ambient water; S_r = specific gravity of rock
  - $\cot\theta$ = cotangent of revetment slope

$$M_{50} = \frac{\rho_r H^3}{K_d \Delta^3 \cot\theta}$$

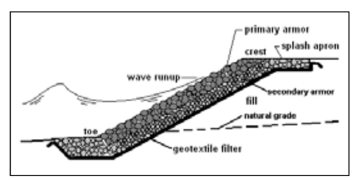
Filtering

- Filter size: $\mathbf{D_{15(filter,\ above)} \leq 5D_{85(underlayer)}}$
  - assumes effective pore diameter = $D_{15}/5$
  - For improved drainage: $\mathbf{D_{15(filter,\ above)} \leq 5D_{15(underlayer)}}$
    - assumes permeability varies as square of grain size
- Riprap weight gradation: $0.125W_{50} < W < 4W_{50}$
  - Related to Hudson formula and to filtering criteria above
  - Porosity: P = 37-40 %

Layer Geometry

- Layer thickness: $r = nk_{\Delta}\left(\frac{M}{\rho_r}\right)^{1/3} = nk_{\Delta}\left(\frac{W}{\gamma_r}\right)^{1/3}$; edge of equivalent cube for $k_{\Delta} = 1$
  - $k_{\Delta} = 1$ for rough angular randomly placed quarrystone
  - n = number of layers; n = 2, best practice for primary and secondary armor
  - n = 2 assumed for $K_d = 2.2$
  - For riprap: $2.0\left(\frac{W_{50}}{\gamma_r}\right)^{1/3}$ or $1.25\left(\frac{W_{max}}{\gamma_r}\right)^{1/3}$
- Number of armor pieces per unit slope area: $\frac{N}{A} = nk_{\Delta}\left(1 - \frac{P}{100}\right)\left(\frac{\gamma_r}{W}\right)^{2/3}$

Revetment crest elevation



- Reduce or prevent overtopping during storms
  - Cost reduction, if some overtopping is accommodated
  - Erosion-resistant "splash apron" behind crest is good practice
- HEC-25 runup (riprap revetments): $R_{2\%} = 1.6r\varepsilon H_s$
  - Runup exceeded by 2% of waves in design sea state
  - H_s = significant wave height near revetment toe
  - r = roughness coefficient; r = 0.55 for riprap
  - Surf similarity parameter: $\varepsilon = \frac{\tan\theta}{\sqrt{\frac{2\pi H_s}{g T_p^2}}}$
  - θ = revetment slope angle from horizontal
  - T_p = peak period associated with H_s

Alternatives to quarrystone armor

- Prefabricated concrete shapes
  - Shapes designed to enhance interlocking
    - Increased stability coefficient, K_d
    - Refer to detailed guidance of CEM VI-5
  - May be connected to form a "mattress"
    - No 2nd layer of primary armor
    - Quick installation


Unalaska, Alaska


Northstar Island, Alaska – with permission from BP

Coastal revetment design checklist

1. Determine site water level ranges (tides and storm surge)
   - extreme high and extreme low levels
2. Determine the wave climate for the site
   - Consider 50-year to 100-year return period for armor design
   - Choice of a less severe condition increases risk of future damage
3. Identify optimum armor configuration to resist the design wave conditions
4. Determine potential wave runup to select the crest elevation and volume of wave overtopping
5. Provide for local surface and overtopping runoff
   - Provide for other drainage, such as from nearby culverts and ditches
6. Consider end conditions to avoid flanking failure
7. Design the toe protection
8. Design the filter
9. Provide for firm compaction of fill material
10. Consider environmental impacts of
    - materials supply (*e.g.*, quarry and borrow pit operations),
    - effects on shoreline habitat and migrating species, and
    - changes of sediment supply to neighboring property that may be induced by revetment


Endicott, Prudhoe Bay, Alaska
Photo by Orson Smith