River Embankment and Protection Works

Organization of Eastern Caribbean States

Regional Engineering Workshop

Kingstown, St. Vincent & the Grenadines

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Geotechnical Branch

SAJ District Office
Lecture Overview

- River Hydraulic Concepts – Unit Hydrograph
- Sediment and rock movement in rivers
- Scour
- Embankment protection options, e.g. riprap, gabions, reinforced concrete (rc) walls, green solutions
- Bridge abutment protection
- Riprap design example (determination of size, shape, thickness, slope, gradation, etc.)
Learning Outcomes

- Be able to appreciate river erosion process
- Have a better understanding of appropriate interventions to reduce river erosion
Design Manuals/Guidance

• The US Army Corps of Engineers Engineer Manual No. 1110-2-1601 “Hydraulic Design of Flood Control Channels”
Design Manuals/Guidance

- U.S. Federal Highway Administration (FHWA) (Hydraulic Engineering Circulars)
Design Manuals/Guidance

- US Department of Transportation (DOT) Design Publications

- AASHTO Design Publications
  (American Association of State Highway and Transportation Officials)

• Understand that USACE manual tends to be more robust and also concentrates more on flood control structures
Open Channel Hydraulics

- Per USACE Engineering Manual (EM) 1110-2-1601,
- The physical hydraulic elements concerned in hydraulic design of channels consist of
  - Invert slope (So),
  - Cross-sectional area (A),
  - Wetted perimeter (P), and
  - Equivalent boundary surface roughness (k).
- The hydraulic radius (R) used in resistance formulae is the ratio $A/P$. 
Unit Hydrographs

- A hydrograph is a graph showing the rate of flow versus time past a specific point in a river or channel.
- Rate of flow is typically expressed in cubic meters or cubic feet per second.
- A unit hydrograph is the hypothetical unit response of a watershed to a unit input of rainfall.
- Is a technique that provides a practical and relatively easy to apply tool for quantifying the effect of rainfall on a drainage basin.
Unit Hydrographs

- Multiple types of unit hydrographs
Sediment and Rock Movement in Rivers

• Natural process of erosion and deposition occurs in all river systems.

• Amount of sediment and rocks transported depends on several factors: water velocity and water flow, the nature of the sediments (i.e., cohesive vs non-cohesive, particle size, etc.), frequency of extreme events (floods, hurricanes, etc.), and channel geometry

• Generally, deposition will occur if the sediment supply is greater than the sediment discharge
Sediment and Rock Movement in Rivers

- Flood control channels typically have protected banks but unprotected inverted banks.
- Unprotected inverted banks require a determination of the depth of the bank protection below the invert in regions where bed scour may occur.
- Levee heights may depend on the amount of sediment that may deposit in the channel.
- The design of such channels requires estimates of sediment transport to predict channel conditions under given flow and sediment characteristics.
Sediment and Rock Movement in Rivers

• Methods of empirically correlating bed load discharge with mean channel velocity at various flow depths and median grain size diameters have been developed.

• This procedure provides rough estimates of bed-load movement in flood control channels.
Scour
Scour
Scour
Scour and Soil

• Clay and silt are fairly resistant to scour, especially if covered with vegetation.
• Non-cohesive soils (i.e., sands and gravel) are more susceptible to scour.
  – Sands with particle sizes of 0.1 mm through 50 mm, low particle weight, no cohesion between grains, and little vegetation.
  – This particle size range comprises the majority of the bed and suspended load in many streams.
Mitigation of Scour

- Stable channels require that the channel be in material or lined with material capable of resisting the scouring forces of flow.

- Channel armoring is required if these forces are greater than those that the bed and bank material can resist.
Mitigation of Scour

- Permissible velocity and shear

- Permissible velocities should be based on reliable field experience or laboratory test results

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### Table 2-5
Suggested Maximum Permissible Mean Channel Velocities

<table>
<thead>
<tr>
<th>Channel Material</th>
<th>Mean Channel Velocity, fps</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fine Sand</td>
<td>2.0</td>
</tr>
<tr>
<td>Coarse Sand</td>
<td>4.0</td>
</tr>
<tr>
<td>Fine Gravel</td>
<td>6.0</td>
</tr>
<tr>
<td>Earth</td>
<td></td>
</tr>
<tr>
<td>Sandy Silt</td>
<td>2.0</td>
</tr>
<tr>
<td>Silt Clay</td>
<td>3.5</td>
</tr>
<tr>
<td>Clay</td>
<td>6.0</td>
</tr>
<tr>
<td>Grass-lined Earth (slopes less than 5%)†</td>
<td></td>
</tr>
<tr>
<td>Bermuda Grass</td>
<td></td>
</tr>
<tr>
<td>Sandy Silt</td>
<td>6.0</td>
</tr>
<tr>
<td>Silt Clay</td>
<td>6.0</td>
</tr>
<tr>
<td>Kentucky Blue Grass</td>
<td></td>
</tr>
<tr>
<td>Sandy Silt</td>
<td>5.0</td>
</tr>
<tr>
<td>Silt Clay</td>
<td>7.0</td>
</tr>
<tr>
<td>Poor Rock (usually sedimentary)</td>
<td>10.0</td>
</tr>
<tr>
<td>Soft Sandstone</td>
<td>8.0</td>
</tr>
<tr>
<td>Soft Shale</td>
<td>3.5</td>
</tr>
<tr>
<td>Good Rock (usually igneous or hard metamorphic)</td>
<td>20.0</td>
</tr>
</tbody>
</table>

Notes:
1. For particles larger than fine gravel (about 20 millimetres (mm) = 3/4 in.), see Plates 29 and 30.
2. Keep velocities less than 5.0 fps unless good cover and proper maintenance can be obtained.
Embankment Protection Options

- Riprap
- Gabions
- RC Walls
- Green solutions
Embankment Protection Options

Riprap
Embankment Protection Options

Riprap

- Advantages
  - Can tolerate moderate subsidence
  - Can conform to irregularities in bank slopes
  - Local damage can be repaired by the placement of more rock
  - Riprap is recoverable and can be stockpiled for future use
  - Effective in areas of high velocity
Embankment Protection Options

Riprap

- Disadvantages
  - More sensitive to local economic factors
  - Is highly dependent on QC and skill of placement
  - Restrictions on placement for steep slopes
Riprap Considerations

- Effectiveness
  - Stone shape, size, weight, durability, gradation, and layer thickness
  - Channel alignment, cross-section, slope, and velocity distribution
  - Selection of appropriate filter
  - Bank material and groundwater conditions
  - Construction QC for both stone production and placement is critical
Riprap Characteristics

**Shape**
- Riprap should be blocky in shape
- Should have sharp, angular, clean edges at the intersections of relatively flat faces
- Rounded stones interlock less than angular, and have less of a drag force to resist movement
Riprap Characteristics

- Relation between stone size and weight
  - Riprap resistance to erosion is related to the size and weight of the stones
  - Design guidance is often expressed in terms of D%, where % denotes the percentage of the total weight of the graded material that contains stones of less weight.
Riprap Characteristics

- Relation between stone size and weight
  - The relation between size and weight is described using a spherical shape by the equation

\[
D_{se} = \left( \frac{6W_{se}}{\pi \gamma_s} \right)^{1/3}
\]

- Or the relation can be a shape midway between a sphere and cube

\[
W = \frac{1}{2} \left( 1 + \frac{\pi}{6} \right) D^3 G_s \gamma_{h2o}
\]

For the bulk specific gravity \( G_s \), and the unit weight of water \( \gamma_{h2o} \)
Riprap Characteristics
Riprap Characteristics

- **Unit weight of stone**
  - Unit weight of stone is typically between 135 to 175 pcf
  - Riprap sizing relations are sensitive to unit weight
    - Small differences in unit weight can drastically alter the required size of the stones
    - The larger the unit weight the smaller the stone dimension
  - Need to be determined as accurately as possible
Riprap Characteristics

- **Durability**
  - Durability effects service life
  - Softer rock is less durable and will begin to erode
  - Eroded stones become less angular and hence less interlocking occurs
  - Stone with weak planes may shear and fracture
  - Petrographic analysis of stone should be performed
  - Initial savings often trumped by life cycle costs for O&M and more frequent replacement
Riprap Characteristics

- Gradation
  - Gradation effects the ability to resist erosion
  - Stone needs to be well graded throughout the in-place thickness
  - Gradation limits should not be so restrictive that production costs are excessive
  - Cost can be reduced by selecting standardized gradations that are already in production or stockpiled
  - Also dependent on the bank soils and filter requirements
Riprap Characteristics

- Gradation Continued...
  - Optimum gradations are also an economics problem that includes many factors:
    - Rock quality
    - Cost per ton at the quarry
    - Number of tons required
    - Miles transported (fuel costs)
    - Cost of transportation per ton-mile
    - Cost per ton for placement
    - Need for and cost of filter
    - QC during construction and number of gradations required
Riprap Characteristics

- **Layer thickness**
  - The layer thickness should not be less than the spherical diameter of the upper limit W100 stone or less than 1.5 times the spherical diameter of the upper limit W50 stone, whichever is greater.
  - For underwater placement the above should be increased by 50% to provide for uncertainties, unless divers or soundings are used, in which case it can be reduced to 25%.
Riprap Characteristics

Layer thickness continued...

- All stones should be contained within the layer thickness
- Oversized stones, even in isolated spots, may result in riprap failure by precluding mutual support and interlock, or by creating turbulence
- Small amounts of oversized rock should be removed individually and replaced with proper sized stones
Riprap Characteristics

- **Channel side slopes**
  - Riprap stability is greatly affected by channel side slopes
  - Side slopes should ordinarily not be steeper than 1V on 1.5H
  - For steeper slopes stability analyses should properly address soil characteristics, groundwater and river conditions, and also probable failure mechanisms
  - Size of stone increases when the slope angle approaches the angle of repose of the riprap
Riprap Characteristics

- **Filter Criteria**
  - The proper design of granular and fabric filters is critical to the stability of riprap.
    - If the openings are too large, excessive flow through the filter can cause erosion and failure of the bank material.
    - If the openings in the filter are too small, the build-up of hydrostatic pressures behind the filter can cause a slip plan to form causing a slide failure.
    - If riprap required is large enough than use of a bedding stone may be required if filter fabric is used to protect against damage during placement of stone.
Riprap Design Elements

- **Erosive Forces**
  - Design Storm Stage, velocity, depth of flow, channel geometry

- **Riprap Properties**
  - Density, shape, slope, gradation, thickness

- **Other Considerations**
  - Channel geometry, Depth of Scour, Availability, Vandalism
    - Vandalism and/or theft of the stones is a serious problem in urban areas where small riprap has been placed. A $W_{50}(\text{min})$ of 80 lb should help prevent theft and vandalism.
Design Method

Embankment Protection Options

Gabions
Gabions
**Gabions**

- **Advantages**
  - Can be used on slopes too steep for riprap
  - The ability to use smaller, lower quality, and less dense stone
  - Can conform to minimal shifts in the soil and even span minor pockets of subsidence without failure
  - Ease of construction
    - Typically can be constructed without the use of heavy construction equipment
Gabions

- Advantages continued…
  - Standardized designs
  - Suppliers can assist in designs
  - Roughness of the gabion structure is more similar to natural stream banks
  - Can be designed to function for different applications
    - Gravity retaining walls for earth retention
    - Drop structures and weirs to control water velocity
Gabions

- Disadvantages
  - Less durable than riprap or rc walls
  - Less flexibility than riprap
  - Susceptible to damage during flooding if debris collides or lodges in the wire
  - Also susceptible to abrasion in systems with large sediment transport
  - More difficult and expensive to repair than riprap
Gabions
Gabions

- **Design considerations**
  - Foundation materials
    - Adequate support of the weight of the gabions
  - Scour undermining the gabions
    - Rule of thumb is to embed the gabions a depth that is 2 times the anticipated depth of scour
    - This can be reduced by use of a scour apron
  - Free draining backfill materials
    - Reduces hydrostatic pressure on wall
Gabions

- Design considerations continued...
  - Use of filter
    - This can be either well graded granular material or fabric
  - Gabion configuration
    - If the gabions will function as a retaining wall a slope stability analysis should be performed
      - If additional stability is determined to be required the wall can be battered back into the slopes for added stability or slope stabilization features such as geogrids can be used
Reinforced Concrete
**Embankment Protection Options**

**Reinforced Concrete**

**Advantages**

- Require the least amount of right of way
- If designed correctly they fully contain the flow within the channel width
- Can tolerate the largest flow velocities
- Smooth surface allows for hydraulic efficiency
- Structural integrity makes them resistant to damage from debris
Reinforced Concrete

- Disadvantages
  - Typically going to be your most expensive option, sometimes your only option
  - Rigid revetment that will not conform to changes in bank geometry
  - Susceptible to failure due to settlement, undermining, outward displacement, slide action, and erosion at the ends of the wall
  - Typically requires a straightening of your channel
  - Smoothness of concrete increases velocities in the channel
Reinforced Concrete

- Disadvantages
  - Difficult to construct
  - Often requires additional structures to control velocities in the channel and at the terminus of the channel
    - Weirs, sediment or debris basins, and drop structures
Reinforced Concrete

- Design considerations
- Channel linings
  - Channel lining requirements are dependent upon the maximum velocity of flows and the resistance of the in situ materials to erosion.
  - Channel linings are affected by the quality of the contained waters
    - Presence of salts, sulfates, industrial wastes, and other abrasive or scouring materials requires thicker linings
    - Mix design revisions using admixtures can be used as an alternative to increasing the lining thickness
Reinforced Concrete

- Design considerations
- Wall backfill
  - For rectangular walls earth pressures should be determined in order to ensure stability
  - Free-draining granular materials should be used for backfill behind walls
    - They reduce lateral earth pressures
    - Minimize pressure increases from in situ materials having expansive characteristics
    - Increase the effectiveness of the drainage system
Reinforced Concrete

- Design considerations
  - Pilot channels
    - Constructed in the bottom of flat bottom channels to carry low flows and confine them thereby maintaining higher velocities which decreases the amount of sediment and debris that is deposited in the channel.
Reinforced Concrete

- **Design considerations**
  - Hydrostatic pressures
    - Both horizontal pressure behind walls and uplift pressures under liners should be determined
    - The magnitude of hydrostatic pressures can be reduced by installing proper drainage systems
  - Earthquake forces
    - Seismic forces on vertical walls may be significant and should be designed for
  - Surcharge
    - Loads from construction, maintenance equipment, vehicles, or other loads must be design for
Reinforced Concrete

- Design considerations
- Drainage
  - Drainage systems should be provided to control excessive hydrostatic pressures acting on the RC walls and liners, especially when the permanent water table is above the channel invert
Design considerations continued…

- Typical designs include
  - Open-drains with no backflow prevention.
    - More susceptible to clogging
    - Should only be used in non-critical and small channels (less than 3 m or 10 ft in bottom width)
  - Closed-drains provided with check valves to prevent backflow
    - Should be used for critical and large channels or where continuous relief of hydrostatic pressures is critical
  - These systems require routine maintenance
Reinforced Concrete

- Design Guidance
    - Structural Design on Concrete Lined Flood Control Channels
Embarkment Protection Options

Green Solutions
Green Solutions

- **Advantages**
  - Aesthetically closer to natural conditions
  - Ease of installation
  - Inexpensive
  - Ability to self-heal unless scour is severe
  - Can be used in conjunction with pilot channels to convey normal base flows

- **Disadvantages**
  - Can be labor intensive
  - Depending on technique can be more maintenance
Green Solutions

- Vegetation
  - Grass, ground cover, live staking can effectively protect against scour provided the slopes are not steeper than 3H to 1V and the water velocities are below 5 feet per second.
  - However, the vegetation must be compatible with the habitat in the project area and must be able to survive periods of inundation during flooding.
  - In steeper slopes geotextiles can be placed prior to plantings to increase the stability of the slopes and vegetation.
Embarkment Protection Options

Green Solutions
Green Solutions

- **Wattles**
  - Also called live fascines, entails using bundles of branch cuttings secured in shallow trenches.
  - These are backfilled until only the top of the wattle is exposed and serves to protect the slope and also as a point for vegetation to grow which further protects the embankment from moving water.
Green Solutions

- **Brush layering**
  - Placing live branches into excavated terraces, covered with soil, and compacted to form a series of reinforced benches
  - As the branches grow the roots further reinforce the slopes and the branches capture debris and reduce surface runoff and erosion

- **Brush mattressing**
  - A mattress-like branch layer is placed on the slope and is secured
  - Typically used with live staking and wattles
Green Solutions

- Brush mattressing
Green Solutions

- **Live cribwalls**
  - Simply combining a structural element of logs (or timbers) with live branch cuttings to form a reinforced wall
  - Used for slope stabilization, usually at the toe of slopes, or for stream bank protection
  - Vegetation improves the strength of the wall and improves the overall aesthetics by screening the structural components
Green Solutions

- Live cribwalls
Green Solutions

Stream Restoration

- Effort to restore systems altered by man back to their natural state
  - Enhancement of habitat, water quality
  - Returns the streams hydraulic response
- In urban settings may not be possible or may still require some need for erosion protection or the need to establish appropriate setbacks
Bridge Abutment Protection

- Schoharie Creek Bridge Collapse
Bridge Abutment Protection

- Schohaire Creek Bridge Collapse
  - New York State
  - Collapsed on April 5, 1987
  - The collapse killed 10 people

- Causes of failure
  - Investigation determined that failure was the result of extensive scour at one of the piers
    - Scour estimated at nearly 10 ft at the pier location
    - Investigation also determined that scour had begun shortly after bridge construction
    - Riprap design was inadequate
Bridge Abutment Protection

- How do we manage bridge scour?
  - Have accurate H&H information
    - Field data collection
    - Hydraulic analysis
  - Design countermeasures
    - Training structures
    - Riprap (or other armoring) of bridge piers and abutments
  - Proper O&M
    - Includes inspections of the bridge foundations
    - Developing a monitoring program, if required
Riprap Design Example

- Explanation of design example
  - Description:
    - Riprap design for the outer bank of a natural channel bend, bend radius of 620 ft and water-surface width is 200 ft
    - Depth at the toe of the outer bank is 15 ft
    - Local depth averaged velocity, \( V = 7.8 \) fps
    - Bank side slope is 2H:1V
    - The flow has low turbulence
    - Theft/vandalism is not considered a factor at this location, so the W50(min) of 80 lbs criteria was not considered in selection of riprap
    - Riprap will be placed in the wet
    - Local quarry has stone with a unit weight of 165 pcf
Riprap Design Example

- Explanation of design example

\[ D_{30} = S_f C_s C_v C_T d \left[ \left( \frac{\gamma_w}{\gamma_s - \gamma_w} \right)^{1/2} \frac{V}{\sqrt{K_1 g d}} \right]^{2.5} \]

- \( S_f = 1.3 \), Safety Factor, must be at least 1.1
  - This is to compensate for small inaccuracies in velocity, unit weight of rock, and depth, as well as pockets of undersized rock or impact forces

- \( C_s = 0.3 \), Stability Coefficient for Incipient Failure

\( C_s = \) stability coefficient for incipient failure,
\( D_{35}/D_{15} = 1.7 \) to 5.2

- = 0.30 for angular rock
- = 0.375 for rounded rock
Riprap Design Example

- Explanation of design example
  - \( C_v = 1.2 \)
  - \( C_t = 1.0 \)

- \( C_v \): vertical velocity distribution coefficient
  - \( = 1.0 \) for straight channels, inside of bends
  - \( = 1.283 - 0.2 \log (R/W) \), outside of bends (1 for \( R/W > 26 \))
  - \( = 1.25 \), downstream of concrete channels
  - \( = 1.25 \), ends of dikes

- \( C_t \): thickness coefficient (see d(1) below)
  - \( = 1.0 \) for thickness = \( 1D_{100}(\text{max}) \) or \( 1.5D_{50}(\text{max}) \), whichever is greater
Riprap Design Example

- Explanation of design example
  - $d \text{ (ft)} = \text{ location must be determined}$

  $d = \text{local depth of flow, length (same location as } V)\$

  $\gamma_w = \text{unit weight of water, weight/volume}\$

  $V = \text{local depth-averaged velocity, } V_{55} \text{ for side slope riprap, length/time}\$

  **NOTE:** $V_{55}$ is depth-averaged velocity at 50 percent of slope length up from toe, maximum value in bend

  - Should be determined through a hydraulic analysis
  - $d$ from analysis is 10 ft
Riprap Design Example

- Explanation of design example
  - $V_{ss} = 11.6$ fps

- Parameters:
  - $d$ = local depth of flow, length (same location as $V$)
  - $\gamma_w$ = unit weight of water, weight/volume
  - $V$ = local depth-averaged velocity, $V_{ss}$ for side slope riprap, length/time

- Graph:
  - $\frac{V_{ss}}{V_{avg}} = 1.74 - 0.32 \log (R/W)$

- Graph shows the relationship between $V_{ss}$ and $V_{avg}$ for different values of $R/W$. The graph is a decreasing line.
Riprap Design Example

- Explanation of design example

- $K_1 = 0.7$, bank angle correction factor

$$K_1 = \sqrt{1 - \frac{\sin^2 \theta}{\sin^2 \phi}}$$

where

- $\theta$ = angle of side slope with horizontal
- $\phi$ = angle of repose of riprap material (normally 40 deg)
Riprap Design Example

- $D_{30} = 0.68$ ft

\[
D_{30} = S_f C_s C_v C_t d \left[ \left( \frac{\gamma_w}{\gamma_s - \gamma_w} \right)^{1/2} \frac{V}{\sqrt{K_1 g d}} \right]^{2.5}
\]

- $S_f = 1.3$
- $C_s = 0.3$
- $C_v = 1.2$
- $C_t = 1.0$
- $d = 10$ ft
- $\gamma_w = 62.4$ pcf
- $\gamma_s = 165$ pcf
- $V (V_{ss}) = 7.8$ (11.6) fps
- $K_1 = 0.7$
Riprap Design Example

- $D_{30} = 0.68$ ft

| Table 3-1 |
| Gradations for Riprap Placement in the Dry, Low-Turbulence Zones |
| Limits of Stone Weight, lb$^1$, for Percent Lighter by Weight |

<table>
<thead>
<tr>
<th>$D_{100/\text{max}}$ (in.)</th>
<th>Max</th>
<th>Min</th>
<th>Max$^2$</th>
<th>Min</th>
<th>Max$^2$</th>
<th>Min</th>
<th>$D_{30}(\text{min})$ (ft)</th>
<th>$D_{90}(\text{min})$ (ft)</th>
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<td>10</td>
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<td>1,188</td>
<td>492</td>
<td>2.19</td>
<td>3.17</td>
</tr>
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Specific Weight = 165 pcf
## Riprap Design Example

- Selection of Specified vs. Design Gradation

### Standard Practice for Specifying Standard Sizes of Stone for Erosion Control

<table>
<thead>
<tr>
<th>R-700 SG = 2.65</th>
<th>% Finer</th>
<th>Upper (in)*</th>
<th>Lower (in)*</th>
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<th>Lower (lb)</th>
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<td>700</td>
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<tr>
<td>50</td>
<td>21.3</td>
<td>16.4</td>
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<td>300</td>
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<tr>
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<td>16.4</td>
<td>9.6</td>
<td>300</td>
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<th>% Finer</th>
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<th>Lower (in)*</th>
<th>Upper (lb)</th>
<th>Lower (lb)</th>
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<tbody>
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<td>16.4</td>
<td>700</td>
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<th>% Finer</th>
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<th>Lower (in)*</th>
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</tr>
</thead>
<tbody>
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<td>300</td>
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<tr>
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<table>
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<th>R-50 SG = 2.65</th>
<th>% Finer</th>
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<th>Lower (in)*</th>
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</tbody>
</table>

* Stone size depends on shape, the stone size reported assumes stone shape midway between a sphere and a cube.

** Equation used for weight to diameter conversions:

\[
W = \frac{1}{2} \left( 1 + \frac{\pi}{6} \right) D^2 \sqrt{G_s \gamma_{w_{20}}} \]

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Riprap Design Example

- **Layer Thickness**
  - The layer thickness should not be less than the spherical diameter of the upper limit \( W_{100} \) stone or less than 1.5 times the spherical diameter of the upper limit \( W_{50} \) stone, whichever is greater

\[
W = \frac{1}{2} \left(1 + \frac{\pi}{6}\right) D^3 G_s \gamma_h \alpha_o
\]

- \( W_{100} = 16.4 \) in
- \( W_{50} = 13 \) in, \( 1.5 \times 13 = 26 \) inches
Riprap Design Example

- **Layer Thickness**
  
  - However, riprap will be placed in the wet, therefore the layer thickness should be increased by 50% to take into account uncertainties in placement

  \[ 26 \times 1.5 = 39 \text{ inch riprap layer thickness} \]
Riprap Design Example

- **Filter Criteria**
  - The proper design of granular and fabric filters is critical to the stability of riprap.
    - To complete a design that can be used the filter media must be specified.
    - General rule of thumb is that for stones smaller than 300 lbs the use of filter fabric alone is recommended.
    - For larger stones the use of a gravel on top of the fabric to protect it during stone placement is recommended.
Design References

- The US Army Corps of Engineers Engineer Manual No. 1110-2-1601 “Hydraulic Design of Flood Control Channels”
- The US Army Corps of Engineers Engineer Manual No. 1110-2-1100 “Coastal Engineering”
- The US Army Corps of Engineers Engineer Manual No. 1110-2-2007 “Structural Design of Concrete Lined Flood Control Channels”
- FHWA (Hydraulic Engineering Circulars)
- AASHTO Design Publications
  - http://design.transportation.org/Pages/AASHTODesignPublications.aspx
Conclusion

- Multiple considerations for each situation
- Multiple solutions depending on your circumstances
- Questions?