October 10, 2017

ENGINEERING FIELD HANDBOOK (NEH PART 650)
210 - ENGINEERING
NOTICE WI-136


Purpose: Revision to Chapter 16, pages 89-112

Explanation of Changes: The existing section on Shoreline Riprap Protection Design Procedure is being replaced. Pages were renumbered for consistency.

Filing Instructions (EFH):

Remove:
Existing Tabulations Sheets
Page: 16-WI-89 to 16-WI-112 in Chapter 16

Insert:
New Tabulations Sheet
Pages: 16-WI-49 to 16-57 Chapter 16

Wisconsin supplements and transmittal notices for the EFH can be found on the Wisconsin NRCS web site at http://www.nrcs.usda.gov/wps/portal/nrcs/detail/wi/technical/engineering/.

ANGELA BIGGS
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ANGELA L. BIGGS
State Conservationist

Attachments
SHORELINE RIPRAP PROTECTION DESIGN PROCEDURE

This design procedure is based on deep water wave height development and wave height prediction developed by:


B) Young, 1997, “The growth rate of finite depth wind-generated waves”.


The design wave height (Ho) is based on wave height, wave length, setup, and run-up (See Figure 1) of waves caused by wind.

Note: The method currently used by the Wisconsin Department of Natural Resources uses only the wave height (Hs).

Figure 1: Wave Height and Length, Setup, Run-up, and Upper Limits of Riprap and Protection

CALCULATE DESIGN WAVE HEIGHT:

1. Using an aerial photograph, USGS quad map, or other planimetric view of the lake, locate the site needing protection. Draw the longest unobstructed straight-line across the open water of the lake from the design point until it intersects the opposite shoreline. The length of the line is the fetch.

2. Estimate the average depth of the lake along the fetch line by examining a lake map. Numerical average is used when stations are uniformly spaced to represent the site and weighted average is used when grade changes (high and low elevations) are used to represent the site.
   a. Using evenly spaced points along the fetch, sum the reported depths, and divide by the number of recorded values. (Numerical average)
   b. Using unevenly spaced points along the fetch, weight the average of adjacent depths by the distance along the fetch line. (Weighted average, using the average end area)
3. Calculate the significant wave height (H_s) by applying a storm wind speed of 35 miles per hour, with the measured fetch at the shore protection site and the average depth along that fetch, using the Young and Verhagen 1996 and Young 1997 equations.

Non-dimensional fetch  
\[ c = \frac{gF}{(U_a)^2} \]  
Young Section 2.1

Non-dimensional water depth  
\[ d = \frac{gd}{(U_a)^2} \]  
Young Section 2.2

Where  
\( g \) = gravitational acceleration 32.174 (ft./sec²)  
\( F \) = fetch (feet)  
\( U_a \) = storm wind speed 51.45 (ft./sec)  
\( d \) = average (numerical or weighted) depth of water along fetch line (ft.)

Non-dimensional energy  
\[ e = 3.64 \times 10^{-3} \left\{ \tanh A_1 \tanh \left[ B_1 \tanh \frac{1}{A_1} \right] \right\}^{1.74} \]  
Young-Verhagen Eq. 25

Where  
\( A_1 = 0.493d^{0.75} \)  
\( B_1 = 3.13 \times 10^{-3} c^{0.57} \)  
Young-Verhagen Eq. 26

Energy  
\[ E = e(U_a)^4/g^2 \]  
Young Section 2.1

Significant Wave Height  
\[ H_s = 4E^{0.5} \]  
Young-Verhagen Section 9.1.3

Table 1. Design Frequency Selection

<table>
<thead>
<tr>
<th>Description</th>
<th>Riprap Run-up &amp; WPH*</th>
<th>Precast Concrete Block or Gabion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Hazard: Failure of protective measure does not endanger anything of value; distance from shore to anything of value exceeds 40 feet. Raw bank height is less than 5 feet.</td>
<td>( H_{10} )</td>
<td>( H_{10} )</td>
</tr>
<tr>
<td>Moderate Hazard: Failure of measure increases threat to something valuable; distance from shore to anything of value exceeds 20 feet. Raw bank height is less than 10 feet.</td>
<td>( H_5 )</td>
<td>( H_5 )</td>
</tr>
<tr>
<td>High Hazard: Failure of measure would threaten existence of valuable structure or property; distance from shore to anything of value is less than 20 feet.</td>
<td>( H_1 )</td>
<td>( H_1 )</td>
</tr>
</tbody>
</table>

Note: When \( H_s \) is used, some damage may result to the shoreline in extreme events. Where this is unacceptable, or maintenance may be poor, increase the design frequency. Raw bank height may be only the lower portion of the total bank height. Use the two terms with caution.  
*WPH = Wave Protection Height
4. Choose a design frequency for the site from Table 1 and note the corresponding safety design factor (DF\text{wph}) from Table 2. Multiply the wave height (H_s) determined in step 3 by the DF\text{wph}, to obtain the design wave height (H_o). Note that these are minimum design factors that may need to be increased for local circumstances.

Design Wave Height \[ H_o = DF_{wph} \cdot H_s \]

Table 2. Safety Design Factors for Waves (DF\text{wph}) and Riprap (DF\text{riprap})

<table>
<thead>
<tr>
<th>Definition</th>
<th>Notation</th>
<th>Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average of highest 1/3 of all waves</td>
<td>H_s</td>
<td>1.00</td>
</tr>
<tr>
<td>Average of highest 10% of all waves</td>
<td>H_{10}</td>
<td>1.27</td>
</tr>
<tr>
<td>Average of highest 5% of all waves</td>
<td>H_5</td>
<td>1.37</td>
</tr>
<tr>
<td>Average of highest 1% of all waves</td>
<td>H_1</td>
<td>1.67</td>
</tr>
</tbody>
</table>

CALCULATE PROTECTION LIMITS:

5. Calculate \( H_o/L \) (design wave height/wave length).

Where Wave Period (T) = \( 0.559(U_{RF})^{1/3} \)

\[
\text{Wave Length (L)} = 5.12T^2
\]

ACOE Shore Protection Manual TR69 EQ. A20

6. Design the revetment slope ratio (i.e. 2:1, 3:1, etc).

7. Using the revetment slope and using the calculated \( H_o/L \), select the appropriate relative run-up ratio, \( R/H_o \), in Table 3.

Table 3. Relative Run-up Ratio (R/H_o)

<table>
<thead>
<tr>
<th>( z )</th>
<th>( 0.02 )</th>
<th>( 0.03 )</th>
<th>( 0.04 )</th>
<th>( 0.05 )</th>
<th>( 0.06 )</th>
<th>( 0.07 )</th>
<th>( 0.08 )</th>
<th>( 0.09 )</th>
<th>( 0.10 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5</td>
<td>2.01</td>
<td>1.94</td>
<td>1.86</td>
<td>1.81</td>
<td>1.75</td>
<td>1.71</td>
<td>1.67</td>
<td>1.62</td>
<td>1.55</td>
</tr>
<tr>
<td>2</td>
<td>2.00</td>
<td>1.91</td>
<td>1.82</td>
<td>1.74</td>
<td>1.66</td>
<td>1.58</td>
<td>1.50</td>
<td>1.45</td>
<td>1.39</td>
</tr>
<tr>
<td>3</td>
<td>1.87</td>
<td>1.73</td>
<td>1.59</td>
<td>1.47</td>
<td>1.35</td>
<td>1.27</td>
<td>1.19</td>
<td>1.13</td>
<td>1.06</td>
</tr>
<tr>
<td>4</td>
<td>1.60</td>
<td>1.46</td>
<td>1.32</td>
<td>1.21</td>
<td>1.10</td>
<td>1.01</td>
<td>0.93</td>
<td>0.87</td>
<td>0.82</td>
</tr>
<tr>
<td>5</td>
<td>1.33</td>
<td>1.20</td>
<td>1.07</td>
<td>0.98</td>
<td>0.89</td>
<td>0.82</td>
<td>0.75</td>
<td>0.69</td>
<td>0.64</td>
</tr>
<tr>
<td>6</td>
<td>1.10</td>
<td>1.00</td>
<td>0.90</td>
<td>0.81</td>
<td>0.73</td>
<td>0.68</td>
<td>0.62</td>
<td>0.58</td>
<td>0.53</td>
</tr>
<tr>
<td>10</td>
<td>0.64</td>
<td>0.60</td>
<td>0.56</td>
<td>0.53</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
</tr>
</tbody>
</table>

From TR69 Figure 12

8. Determine the run-up (R) of the waves by multiplying the relative run-up ratio, \( R/H_o \), by the design wave height, \( H_o \). For revetments other than angular riprap, multiply R by 1.2. This accounts for the smoother surface and the lower weight.

Run-up \[ R = H_o \cdot (R/H_o) \]

ACOE Shore Protection Manual Vol. 2 Ch. 2
9. Determine the setup ($S$). Setup is the lesser of $0.1$ times the wave height ($H_s$) or $0.5$ feet.

\[
S = \begin{cases} 
0.1H_s & \text{if } 0.1H_s \leq 0.5 \text{ feet} \\
0.5 & \text{if } 0.1H_s > 0.5 \text{ feet}
\end{cases}
\]

10. Calculate Lower Limit:

The lower limit for the riprap shall be $1.5$ times the Wave Height ($H_s$), below the normal low lake elevation for the year for deep water and the lake bottom for shallower water. TR69 II.D.1

11. Determine Upper Limit of Protection:

Use the highest of the following:

- Ordinary High Water Mark (OHWM) elevation plus the design storm wave height.
- Seep lines in the bank if not controlled in some other fashion.
- Boat-generated waves
- OHWM elevation plus the wave setup and run-up.

See Standard 580 Streambank and Shoreline Protection for minimum Criteria and treatment measures. (i.e. Vegetative Treatments, Soil Bioengineering Treatments, and Structural Treatments)

Note: The maximum upper limit for riprap for a NR-328 General Permit is Ordinary High Water elevation plus the Wave Height, ($H_s$). The designer may choose a higher elevation and a DNR Individual Permit if vegetated practices are not stable between the Upper Limit of Protection elevation and the General Permit maximum riprap elevation.

ROCK SELECTION:

12. Rock Size Wave Height: Choose a design frequency for the site from Table 1 and note the corresponding safety design factor ($DF_{riprap}$) from Table 2. Multiply the $H_s$ determined in step 3 by the $DF_{riprap}$ to obtain a rock size wave height ($H_{rock}$).

Note:
- These are minimum design factors that may be increased for local circumstances.
- The design factor is different for determining run-up and wave protection height (WPH) and for determining rock size wave height ($H_{rock}$)

\[
H_{rock} = H_s * DF_{riprap}
\]

The size of rock is determined from relationships of wave heights, wave velocities, and drag on the rock relative to the stable size of the rock needed to resist these forces for a given bank slope.

Rock Size Weight (lbs.)

\[
W_{50} = \frac{(Factor_{rock} * G_s * H_{rock}^3)}{(G_s - 1)^3 * z)
\]

Where
- \(Factor_{rock} = 19.5\) for cubical rock
- \(Factor_{rock} = 31.2\) for spherical rock
- \(G_s =\) rock specific gravity (typically 2.65)
- \(z =\) revetment slope ratio (i.e. 2 for a 2:1 bank slope)

Note: Rock Factor ($Factor_{rock}$) is specific weight of water divided by a rock stability factor. Dumped rock riprap value of 3.2 is recommended for the rock stability factor. ($62.4/3.2=19.5$) A stability factor of 2.0 was used for the less stable spherical rock.

13. Rock Gradation and Thickness: The size, gradation and thickness of rock depends on the rock available. Tables 4 and 5 describe two gradations that may be used.
Table 5 gradation consists of a well-graded mixture of smaller and larger rock. Table 4 gradation is a less well-graded mixture (does not contain smaller rock and tends to be more uniform in size). Well graded riprap is more effective in preventing leaching of the underlying material. All rock used shall be of a hard and sound material meeting Wisconsin Construction Specification 9. Rock Riprap.

| Rock Size Diameter $D_{50}$ (inches) | $D_{50} = 1.10 \left( \frac{W_{50}}{Gs \cdot 62.4 \, \text{lb/ft.}^3} \right)^{1/3} \cdot 12 \, \text{(in./ft.)} $ TR-69 Figure 9 |

### Table 4. Riprap Gradation (Rock Chute method)

<table>
<thead>
<tr>
<th>Percent Passing</th>
<th>Size $^1$ (in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>$1.5 \times D_{50} - 2.0 \times D_{50}$</td>
</tr>
<tr>
<td>85</td>
<td>$1.3 \times D_{50} - 1.8 \times D_{50}$</td>
</tr>
<tr>
<td>50</td>
<td>$1.0 \times D_{50} - 1.5 \times D_{50}$</td>
</tr>
<tr>
<td>10</td>
<td>$0.8 \times D_{50} - 1.3 \times D_{50}$</td>
</tr>
</tbody>
</table>

$^1$Round up to nearest inch.

### Table 5. Riprap Gradation (EFH 17 method)

<table>
<thead>
<tr>
<th>% Passing</th>
<th>Size of Stone (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>$2 \times d_{50}$</td>
</tr>
<tr>
<td>60 - 85</td>
<td>$1.5 \times d_{50}$</td>
</tr>
<tr>
<td>25 - 50</td>
<td>$d_{50}$</td>
</tr>
<tr>
<td>5 - 20</td>
<td>$0.5 \times d_{50}$</td>
</tr>
<tr>
<td>0 - 5</td>
<td>$0.2 \times d_{50}$</td>
</tr>
</tbody>
</table>

The minimum thickness of the rock shall be 2 times the $D_{50}$ size of the rock, but not less than 12 inches.

**TOE PROTECTION:**

A critical part of the design of shoreline revetments is protection of the toe. The breaking waves will "scrape along the bottom" causing a scour that may undermine the revetment. Four alternative toe protection designs are described below and where it is best suited. Figure 2 depicts three forms of toe protection for riprap with geotextile and riprap.

The geotextile will act as a filter. The geotextile material shall meet the requirements of NRCS Wisconsin Construction Specification (WCS) 13. Geotextiles, as directed by pages 17-WI-61 through 17-WI-70, Guide for the Use of WCS 13. Geotextiles. The ends of the geotextile shall be buried at least 12 inches on the top and ends of construction. The Corps of Engineers recommends the use of a Dutch Toe (wrapping the end of the geotextile into the riprap) as illustrated in Figure 2. A 4 to 6 inch layer of sand protection may be desirable between the geotextile and riprap to prevent tearing of the cloth during installation of the rock.

**Type A** is meant for lakeshores with shallow water (less than $18'' + 2*d_{50}$) at the shore and a flat lakebed slope. This type can be used where the riprap "lower limit" calculated in step 9 goes below the existing lake bottom. A toe as shown may replace the need to extend the riprap below the lake bottom elevation.

**Type B** is meant for lakeshores with deep water (greater than lower limit + 48") at the shore. This type of toe protection stabilizes the bank through a region where the scour is likely to occur. The thickened section of riprap is to be centered at the elevation calculated for the lower limit of the riprap. This type of toe should be used where drop-off occurs within 50 feet of the shore. This may result in the toe being beneath the lake bottom to limit movement of the drop-off.
**Type C** is intended for lakes with an intermediate depth (greater than $18^\circ + 2d_{50}$) at the shore. For safety reasons, there must be at least $18^\circ$ of water depth at the shore after the riprap is installed. This type also replaces the need to go below the lake bottom elevation as in Type A. This toe may also be easier to install than the Type A toe.

**Type D** is for sites where ice damage is a concern, larger rock can be placed in the toe area as shown in Figure 3. The rocks shall have a minimum weight of 425 pounds or a minimum diameter of 18 inches but should be approximately 2 times the $D_{50}$ or larger. They will be placed beginning at the shoreline and continue into the lake for a distance equal to three boulder diameters. The top of the boulders shall be set at an elevation no more than 1 foot above the Ordinary High Water elevation, which means that the boulders will have to be trenched into the lakebed in most instances. The boulders shall be placed over geotextile covered with a sand cushion a minimum of 6 inches thick.
TOP AND END PROTECTION:

Top Protection includes an overflow apron (Lo). Use an overflow apron when the computed wave protection height reaches an elevation higher than the top of the existing bank. The overflow apron length should be 6 feet horizontally for every foot of wave protection height above the existing top of bank, but not less than 3 feet in any case. The top protection can be riprap or bioengineering practices. See Figure 4.

End Protection is needed to resist attack when the Structural Treatment is terminated at a point that is unstable. Method A should be used for stable end points. Stable points include items such as a controlling structure, natural rock outcropping, etc. Method B should be used for unstable endpoints. See Figure 5.

![Figure 4. Top Protection (for Overtopping Waves)](image)

![Figure 5. End Protection](image)
OTHER PROTECTIVE MEASURES:

1. Gabions
   Gabions can also provide acceptable shoreline protection. The designer is encouraged to
   follow steps 1 through 11 of the riprap design procedure for determining the extent of the
   gabion protection. Design of the gabions themselves should follow manufacturer’s
   recommendations and NRCS Wisconsin Construction Specification (WCS) 17. Wire Mesh
   Gabions and Mattresses. The wave run-up should be increased by a factor of 1.2 as noted in
   step 8 of the design procedure for riprap. Geotextile should be used as a filter, just as stated
   for riprap. Banks shall be sloped at 1½ horizontal to 1 vertical or flatter.

2. Beaching Slope
   Shore protection with beaching slopes utilize the movement of semi-fluid sands up the beach
   with breaking waves, and off the beach with the receding waves to dissipate energy. For any
   given wave size, a beach will stabilize with a particular relationship between beach slope and
   the median grain size of the beach material. This method of protection shall only be used for
   slopes in the range of 10 to 4 horizontal to 1 vertical.

Requirements for the design of beaching slopes are:

<table>
<thead>
<tr>
<th>Slope</th>
<th>*D_{50} size of protective layer</th>
<th>Filter layer needed?</th>
<th>Minimum Layer Thickness (in)</th>
<th>Minimum Layer Thickness (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10:1</td>
<td>0.5 mm - 1.0 mm</td>
<td>No</td>
<td>None</td>
<td>12</td>
</tr>
<tr>
<td>8:1</td>
<td>1.0 mm - 5.0 mm</td>
<td>No</td>
<td>None</td>
<td>12</td>
</tr>
<tr>
<td>6:1</td>
<td>5.0 mm - 1.0 in.</td>
<td>Yes</td>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td>4:1</td>
<td>1.0 in. - 3.0 in.</td>
<td>Yes</td>
<td>6</td>
<td>12</td>
</tr>
</tbody>
</table>

*D_{50} size is percent of material passing by weight

A. Only material larger than 0.17 mm is to be used for obtaining the *D_{50} size of the material
   for the protective layer. The minimum *D_{50} size allowed shall be 0.5 mm.
B. Extend the slope protection below the normal low lake elevation for the year a distance of
   2 design wave heights, 2 x H_o
C. Extend slope protection above the Ordinary High Water elevation a distance equal to the
   computed wave run-up plus 1 ft.
D. Wave height and run-up can be calculated using the method for designing rock riprap.
E. Gradation for the protective layer shall be based on the *D_{50} size and limits described in
   the rock riprap section in Table 4 or 5.
F. Material for the protective layer that is outside the design particle size range (>2.5 x *D_{50})
   may be used if the layer thickness is increased by the percentage of the material outside
   the range.
G. The filter layer below the protective layer shall be designed using Chapter 26 of Part 633
   of the National Engineering Handbook.