VERMONT
VTrans

Hydraulics Engineering Instructions (HEI)

Distribution: Structures, Bureau Chiefs, Chief of Contract Admin., Consultants

Approved: DocuSigned by: Jeff DeGraff 73B6C56D867447F... **Date:** 10/24/2024
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Subject: **Permissible Shear Stress Approach & Design Manning's n: E-Stone and Stone Fill**

Administrative Information:

Effective Date: This HEI shall be considered effective for the Structures & Hydraulics Section from the date of approval.

Superseded HEI: None.

Exceptions: None.

Disposition of HEI Content: The technical information transmitted by this HEI will be incorporated into the next revision of the VTrans Hydraulics Manual.

Purpose:

This HEI will update guidance and equations for estimating manning's n and sizing channel E-Stone and/or Stone Fill found in section 5.3.2 of the VTrans Hydraulics Manual.

Technical Information:

References:

"Culvert Design for Aquatic Organism Passage", Hydraulic Engineering Circular No. 26 (HEC 26), First Edition, FHWA-HIF-11-008, Federal Highway Administration

Vermont Agency of Transportation, 2024 Standard Specifications for Construction

Froehlich, D.C. (2012), "Resistance to Shallow Uniform Flow in Small, Riprap-Lined Drainage Channels", Journal of Irrigation and Drainage Engineering, Volume 138, Issue 2

Manual Updates:

Tables 5-2a and 5-2b will supersede Table 5-2 found in the VTrans Hydraulics Manual. The mean particle diameters have been updated to reflect the gradations found in SECTION 706 – STONE FOR MASONRY, RIPRAP, AND OTHER PURPOSES of the 2024 Standard Specifications for Construction. In addition to sizing E-Stone and Stone Fill with the use of the Ishbash Equation (Table 5-1), the Permissible Shear Stress approach is implemented to determine the permissible shear stress of (channel) E-Stone and Stone fill. Design manning's equations were reviewed by FHWA and are recommended when determining bed shear stresses.

Environmental Stone (E-Stone)

The purpose of E-Stone is to provide a stable channel bottom through the culvert while providing stream simulation for fish and other aquatic organism passage. E-Stone can be used to regrade the channel and/or banks upstream and downstream of the crossing typically below Ordinary High Water (OHW). E-Stone consists of coarse material and fine material (a gap graded material). The coarse material provides a stable bottom, while the fine material's primary function is to fill the voids to maintain surface water flow, as well as to allow for some sediment transport through the crossing. E-Stone Coarse material gradation is shown below for reference. Figure 1 can be used to determine the general shape of the E-Stone.

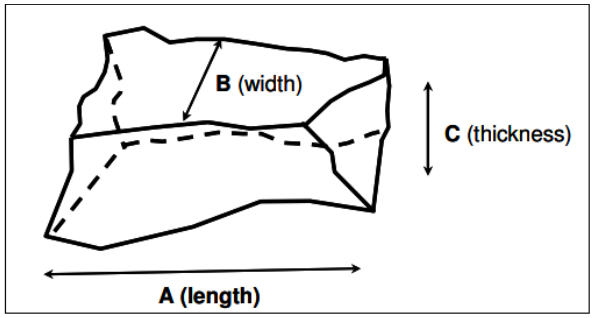

Figure 1: General Stone shape described

Table 5-2a: E-Stone Fill Coarse Material Gradation (50% of Volume) *

E-Stone Type	Least Dimension (in) (C axis)	D50 (in) (B axis)	Longest Dimension (in) (A axis)	Length to Thickness Ratio, A/C	Embedment/ Thickness (in)
I	12	**12**	18	1.5	18
II	18	**18**	24	1.3	24
III	24	**24**	36	1.5	36
IV	36	**36**	48	1.3	48

*at least 25 percent of the particles shall have a maximum dimension of 2 inches and be well graded material (or streambed material)

Sand Borrow and/or fines may be added to seal the bed and maintain surface water flow

Stone Fill

The main purpose of stone fill is primarily for bank armoring above OHW. For a slope stability project along a river or stream, stone fill type III and IV can also be used as a counterweight/berm to provide resistance to a rotating/sliding mass of material. Stone Fill mostly consists of coarse material that is not well graded and should not be used for any in channel work as there are not any fines to prevent seepage/subterranean flow. Stone Fill Coarse material gradation is shown below for reference. Figure 1 can be used to determine the general shape of the Stone Fill Coarse material.

Table 5-2b: Stone Fill Coarse Material Gradation (50% of Volume) **

Stone Fill Type	Least Dimension (in) (C axis)	D50 (in) (B axis)	Longest Dimension (in) (A axis)	Remaining 50% shall have longest dimension (in) vary from**:	Embedment/ Thickness (in)
I	4	**6**	12	1 to 12	12
II	12	**12**	36	2 to 36	24
III	16	**18**	48	3 to 48	36
IV	20	**24**	60	3 to 60	48

**Maximum length to thickness ratio, A/C, equal to 3

<u>Permissible Shear Stress Approach (Sheilds)</u>

Bed material is considered stable if the boundaries are in static equilibrium (immobile). A fundamental methodology for assessing static equilibrium is the permissible shear stress approach. The permissible shear stress is the maximum bed shear stress that will not cause erosion of the channel bed material.

$$\tau_p = \frac{F_*(\gamma_s - \gamma_w)D_{50}}{FS}$$

$$R_{ep} = \frac{U_* D_{50}}{\nu}$$

$$U_* = \sqrt{\tau_b/\rho_w} = \sqrt{\gamma_w y S/\rho_w}$$

Table 5-2c Shield's Parameter, F_*

Particle Reynolds Number	F_*
$R_{ep} \leq 4x10^4$	0.047
$4x10^4 < R_{ep} \leq 2x10^5$	Linear Interpolation
$R_{ep} \geq 2x10^5$	0.10

τ_b = bed shear stress, psf
τ_p = permissible shear stress, psf
F_* = Shield's parameter
FS = Factor of Safety (1.5)
R_{ep} = particle Reynolds number
U_* = shear velocity, fps
g = gravitational acceleration, $32.2 \frac{ft}{s^2}$
y = design flow depth, ft
S = design slope (energy or channel), ft/ft
ν = kinematic viscosity $(1.217x10^{-5}\ ft^2/_s\ @\ 60^0 F)$
D_{50} = stone size for which 50% by weight of the bed material is smaller
γ_w = specific weight of water $(62.4 \frac{lb}{ft^3})$
γ_s = specific weight of stone $(165.36 \frac{lb}{ft^3})$
ρ_w = water density $(1.94 \frac{slugs}{ft^3})$

E-Stone Fill Design Example 1 – Channel Bed Shear Stress Known

Givens:
Max bed shear was extrapolated from a hydraulic model such as SRH-2D, RAS2D, HEC-RAS, or HY-8.

$\tau_b = 3\,psf$

Check:
Will E-Stone Type I be stable?
D50 = 1-ft

$$U_* = \sqrt{\tau_b/\rho_w} = \sqrt{3psf \Big/ 1.94\,\frac{slugs}{ft^3}} = 1.24\,psf$$

$$R_{ep} = \frac{U_* D_{50}}{\nu} = \frac{1.24psf * 1ft}{1.217x10^{-5}\ ft^2/s} = 102180.77$$

$$F_* = 0.047 + \frac{(102180.77 - 4x10^4)(0.1 - 0.047)}{2x10^5 - 4x10^4}$$

$$F_* = 0.068$$

$$\tau_p = \frac{F_*(\gamma_s - \gamma_w)D_{50}}{FS} = \frac{0.068 * (165.36 - 62.4) * 1}{1.5}$$

$$\tau_p = 4.64\,psf$$

$$\tau_p > \tau_b, Stable$$

E-Stone Fill Design Example 2 – Max Flow Depth and Channel Slope Known

Givens:
Max flow depth was determined using Manning's equation, SRH-2D, HEC-RAS, HY-8, etc.
y = 4ft
S = 0.03 ft/ft

Check:
Will E-Stone Type I be stable?
D50 = 1-ft

$$\tau_b = \gamma_w y S = 62.4 * 4 * 0.03 = 7.49\, psf$$

$$U_* = \sqrt{\tau_b / \rho_w} = \sqrt{7.49psf \Big/ 1.94 \frac{slugs}{ft^3}} = 1.96\, psf$$

$$R_{ep} = \frac{U_* D_{50}}{\nu} = \frac{1.96psf * 1ft}{1.217x10^{-5}\ ft^2/s} = 161432.69$$

$$F_* = 0.047 + \frac{(161432.69 - 4x10^4)(0.1 - 0.047)}{2x10^5 - 4x10^4}$$

$$F_* = 0.087$$

$$\tau_p = \frac{F_*(\gamma_s - \gamma_w) D_{50}}{FS} = \frac{0.087 * (165.36 - 62.4) * 1}{1.5}$$

$$\tau_p = 5.97\, psf$$

$$\tau_p < \tau_b, Unstable$$

<u>E-Stone/Stone Fill Design Manning's n values</u>

Manning's n is a function of flow depth and can be determined using the following set of equations. In place of the bed hydraulic radius, R_b, flow depth may be substituted to determine design manning's n values. When applying the equations, the minimum R_b/D_{50} ratio to be used is 0.5; corresponds to a minimum flow depth equal to $0.5D_{50}$. Design manning's n values for selected depths are shown in Table 5.2d.

$$C_* = 5.62\ x\ log_{10}\left(\frac{R_b}{1.7D_{50}}\right) + 6.25$$

$$n = \frac{K_u R_b^{1/6}}{C_* \sqrt{g}}$$

Where:

C_* = dimensionless Chezy coefficient
K_u = manning formula conversion factor (1.0 for SI, 1.486 for US)
R_b = portion of hydraulic radius that applies to the channel bed, ft
D_{50} = stone size for which 50% by weight of the bed material is smaller
g = gravitational acceleration, $32.2\frac{ft}{s^2}$
n = manning's roughness coefficient

Table 5-2d E-Stone/Stone Fill Design Manning's n values

D50 (ft)	Depth ≤ 1ft	Depth = 4ft	Depth ≥10ft
0.5	0.039	0.033	0.031
1.0	0.053	0.040	0.036
1.5	0.066	0.045	0.040
2.0	0.080	0.050	0.043
3.0	0.086	0.058	0.049

Implementation:

The content of this HEI will be implemented immediately on all projects.

Transmitted Materials:

No supplemental materials are transmitted with this HEI.