MMC Levee Breaching Erosion Rate Methodology

Dana Moree, Modeling Technical Lead, USACE, Vicksburg, Mississippi,
Dana.M.Foxworth@usace.army.mil

Abstract

The simplified physical breach method within the Hydrologic Engineering Center-River Analysis System (HEC-RAS) allows for the calculation of breach parameters based on the physical conditions at the breach location. The simplified physical method can be applied to any breach of an embankment of less than 30 feet and is recommended for Modeling, Mapping, and Consequences (MMC) Levee Breach studies. The method requires an input of a breach widening rate versus velocity and down-cutting rate versus velocity relationships (erosion rates). The HEC-RAS breach editor window is shown below in figure 1. Although there are currently no widely accepted erosion rates for use with this method, the U.S. Army Corps of Engineers (USACE) is making progress toward this goal.

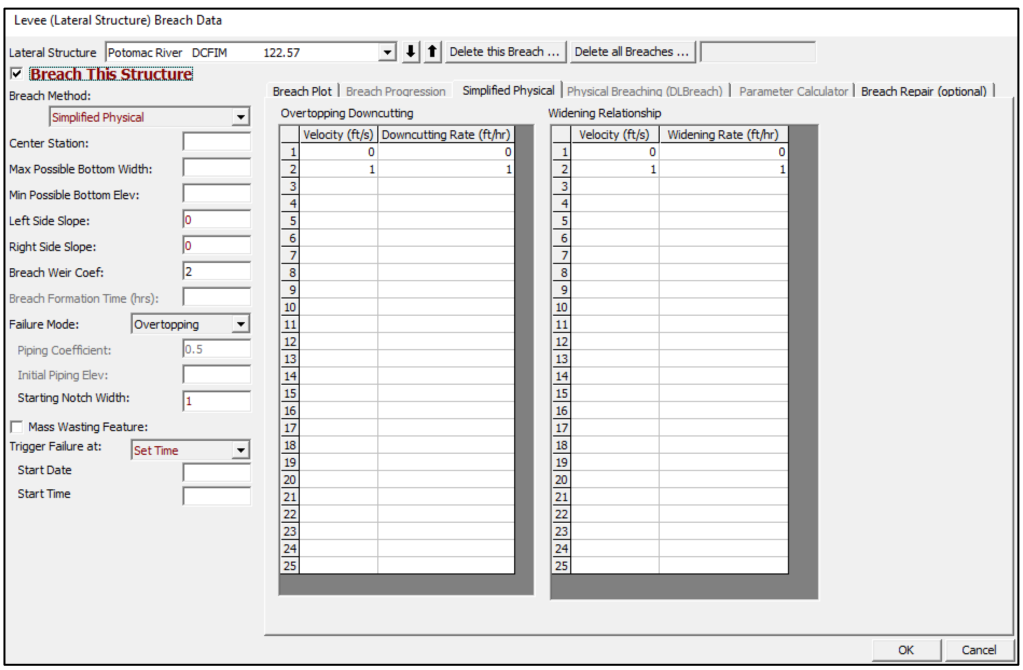

Figure 1. HEC-RAS Breach Editor Window

Research

The paper Calculation of Levee-Breach Widening Rates, April 2022, written by Bryant Robbins and Maureen Corcoran, is primarily used to support the MMC application of the simplified physical breach method. This paper builds upon the USACE Engineering and Research and Development Center (ERDC) Report written by Johannes Wibowo (2016).

The equation in the Robbins and Corcoran paper used by the MMC is shown below in Equation 1, with the only difference being that variables simplified into the 0.0132 constant in the 2022

ERDC paper are individually calculated. The equation is used to develop a single relationship for each breach location analyzed. Thought the relationship was developed for widening, it is applied to both the widening and downcutting parameters. A calculator spreadsheet was developed to standardize this procedure.

$$\frac{dW}{dt} = 2k_d(\gamma_w R_h^{-\frac{1}{3}}(\frac{n}{k})V^2 - \tau_c)$$

(1)

Where $\frac{dW}{dt}$ *is the erosion rate in feet per hour,* k_d *is an erodibility parameter with units of (ft/hr)/psf,* γ_w *is the unit weight of water in pounds per cubic foot, R is hydraulic radius (assumed to be height of the levee in feet), n is the Manning's roughness coefficient, k is the unitless conversion between English and SI units, V is velocity in feet per second, and* τ_c *is critical shear stress with units of pounds per square foot.*

Application

The MMC calculator spreadsheet has the option to adjust four parameters, k_d, τ_c, Manning's N, and Levee Height. This equation was developed in English Units, however many of the inputs are provided in SI Units. The SI units for k_d are typically found as (mm/hr)/Pa and for τ_c as pascals. For the purposes of the MMC Levee Breach Erosion Rate Calculator Spreadsheet, these values are first converted to English Units, then entered into the equation. Additional information for each of these parameters is included in the sections below.

For the purposes of MMC modeling efforts, and at the recommendation of RMC (USACE's Risk Management Center) and MMC leadership, it is recommended that shear stress (τ_c) be set to 0. This assumption is a conservative estimate selected in order to ensure erosion breach initiation and breach progression in areas of low velocity gradients. The lack of a modeled breach initiation has been a reoccuring breach modeling issue for levees that have a soil makeup, compaction, and/or protection that would align with the less erodible erosion rates.

It is recommended that the Manning's value in the direction of the breach be set at 0.034 and not be adjusted unless site specific data for the roughness condition during a breach is readily available. The Robbin's paper selected this value as an appropriate value for a relatively rough earthen channel. This parameter could be assessed with considerations to soil type and turbulence impacts during a higher-level risk assessment.

It is recommended that the levee height be estimated to the nearest foot at the levee breach initiation location. If the height at the breach location varies greatly, care should be taken to ensure the levee height is representative of the breach area.

It is expected in most cases a single k_d value will be appropriate for the whole levee system. Some level of conservatism is introduced with the shear stress assumption, therefore it is recommended that the best estimate, instead of a conservative k_d value be chosen. There are three options for selecting a k_d value, shown below in order of preference.

1. The local LSPM (Levee Safety Program Manager) or Geotechnical Lead provides a $k_d$value from direct testing done on Levee.

2. The local LSPM or Geotechnical Lead provides an estimated k_d value from known soil and compaction properties. This can be a specific value or a selection from the preselected MMC values.

3. The modeler may estimate a k_d value from the preselected MMC values based on known soil and compaction properties.

Erodibility Parameter Estimation

The preselected values are shown below (Table 1) and are based off an evaluation of values found in the Texas A&M university (TAMU) database developed by Briaud, Shafii, Chen and Medina-Cetina (2019) This evaluation was completed by RMC Technical Leads.

Table 1. Recommended Base Erodibility Parameters

Recommended k_d Values, if district information is not available		
k_d (mm/hr)/Pa	k_d (ft/hr)/psf	Descriptor
1	0.16	Moderately Resistant
25	3.93	Erodible
100	15.7	Very Erodible
500	78.5	Extremely Erodible

A summary of the selection rationale for erodibility parameter (k_d) are presented below. These values were selected though a review of the Briaud database by RMC Technical Leads (Table 2). These selections are generally based on lumped measured erodibility of various soil types as described with the USCS, or Unified Soil Classification System.

An erodibility parameter of 500 (mm/hr)/Pa was selected to represent an extremely erodible erosion-velocity relationship. This value was selected as it is slightly higher than the mean of all coarse-grained samples within the TAMU database. The coarse-grained samples of all types are also slightly higher than the coarse-grained samples of compacted embankments, such as dams or levees. This value is likely lowered by samples with appreciable fines. However, it is slightly more conservative than using the median erodibility parameter of all of the poorly-graded sand (SP) samples where all values with a k_d less than 5 (mm/hr)/Pa were excluded. This erodibility parameter produces results very similar to the upper end of the very erodible curve (as defined by the 2016 Wibowo paper) identified in previous versions of this appendix and is intended to be an infrequently used upper bound.

An erodibility parameter of 100 (mm/hr)/Pa was selected to represent a very erodible erosion-velocity relationship. This value was selected because it represents a number that is slightly higher than the median erodibility of all silty sand (SM) samples in the database with k_d less than 5 (mm/hr)/Pa excluded and is similar to the mean erodibility value for Silt (ML). This erodibility parameter produces results very similar to the upper end of the erodible curve recommended by previous versions of the MMC Technical Manual for Levees and this appendix and as defined by the 2016 ERDC paper.

An erodibility parameter of 25 (mm/hr)/Pa was selected to represent an erodible erosion-velocity relationship. This value was selected as it is slightly less than the median k_d of all silty sand (SM) and silt (ML), where any value with a k_d less than 5 (mm/hr)/Pa is neglected. This curve agrees with the mean k_d values for clayey sand (SC), clayey sand with silty sand (SC-SM), and well-graded sand with silty sand (SW-SM) embankment materials in the database. This erodibility parameter produces results between the 2022 very erodible and moderately resistant curves that is slightly higher than the upper bounds of the moderately resistant curve recommended by prior versions of the MMC SOP as defined by the 2016 ERDC paper.

An erodibility parameter of 1 (mm/hr)/Pa was selected to represent a moderately resistant erosion-velocity relationship. This value was selected because it represents a number that is slightly higher than the median k_d of all lean clay (CL), elastic silt (MH), and fat clay (CH) samples in the database. The curve allows for less erosion than the previous moderately resistant curve recommended by prior versions of the MMC SOPs as defined by Wibowo paper (2016). However, as this curve provides very limited erodibility, this curve is intended to be an infrequently used lower bound for MMC production simulations. Higher level studies may consider use of this or a similar erodibility parameter after thoroughly assessing soil type and construction methods for possible flaws. Consideration should be given on the likelihood of swaying the risk calculation using consequences from a breach that is not fully developed combined with a low probability of failure.

Table 2. Soil Sample Statistics—Preselected Modeling, Mapping, and Consequences Production Center Values

All Soil Samples–k_d ((mmh/hr)/Pa)					
Soil Type (USCS)	**Sample Count**	**Mean k_d**	**Median k_d**	**Minimum k_d**	**Maximum k_d**
CH	127	9.09	0.59	0.00	496.8
MH	12	11.93	0.76	0.10	111
CL	348	12.12	0.63	0.00	1,362.31
CL-ML	25	2.90	1.57	0.07	13.32
SC	76	26.08	2.58	0.02	486.17
SW	1	19.45	19.45	——	——
ML	40	90.14	4.55	0.02	1,718.02
SM	106	277.50	27.70	0.10	5,802.96
SP	26	1,176.04	306.15	0.11	6,690.26
All Embankment Samples with Reasonable* Results–k_d ((mmh/hr)/Pa)					
Soil Type (USCS)	**Sample Count**	**Mean k_d**	**Median k_d**	**Minimum k_d**	**Maximum k_d**
CH	14	0.84	0.28	0.02	3.39
MH	1	0.09	0.09	——	——
CL	16	0.17	0.09	0.03	0.84
CL-ML	8	4.52	4.33	1.57	7.38
SC	3	0.37	0.05	0.02	1.05
ML	2	0.63	0.63	0.62	0.63
SM	20	95.89	15.14	0.41	623.64

SP	2	210.43	210.43	133.71	287.16
All Natural (non-pre-processed) Embankment Samples with Reasonable Results–k_d ((mmh/hr)/Pa)**					
Soil Type (USCS)	**Sample Count**	**Mean k_d**	**Median k_d**	**Minimum k_d**	**Maximum k_d**
CH	14	0.84	0.28	0.02	3.39
MH	1	0.09	0.09	——	——
CL	15	0.14	0.09	0.03	0.84
CL-ML	0	——	——	——	——
SC	3	0.37	0.05	0.02	1.05
ML	2	0.63	0.63	0.62	0.63
SM	12	137.24	39.21	0.41	623.64
SP	2	210.43	210.43	133.71	287.16

*Reasonable results are defined as all values not unreasonably low per soil type as defined by the RMC Lead.

**Pre-processed refers to the fact that sample is disturbed prior to the testing methodology. An example includes drying and recompression.

References

ASTM International. *D2487-17e1 Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)*. West Conshohocken, PA; ASTM International, 2017. doi: https://doi.org/10.1520/D2487-17E01

Briaud, Jean, Shafii, I., Chen, H.-C., Medina-Cetina, Z 2019. *Relationship between Erodibility and Properties of Soils*. National Cooperative Highway Transportation Board Report 915. Washington, DC: Transportation Research Board.

Hydrologic Engineering Center–USACE .2022. HEC-RAS User's Manual. https://www.hec.usace.army.mil/confluence/rasdocs/rasum/latest.

Robbins and Corcoran 2020. Calculation of Levee-Breach Widening Rates. Engineering Research and Development Center–USACE. http://dx.doi.org/10.21079/11681/44163.

Wibowo 2016. Estimating Levee Erosion Widening Rates (Draft). Engineering Research and Development Center–USA

U.S. Army Corps of Engineers, MMC Appendix 3.1.4 Application of Simplified Physical Breach Method, 2022.

U.S. Army Corps of Engineers, MMC Levee Breach Modeling SOP, 2022.