

Technical Report

Inputs and Outputs of DLBreach
– A Simplified Physically-Based Dam/Levee Breach Model
(Version 2016.4)

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Disclaimer

The DLBreach model (Version 2016.4) was developed by Dr. Weiming Wu, Department of Civil and Environmental Engineering, Clarkson University, NY, USA. A user is required engineering expertise to use DLBreach correctly. The reliability and accuracy of any results obtained from DLBreach should be carefully examined by experienced engineers.

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Inputs and Outputs of DLBreach

– A Simplified Physically-Based Dam/Levee Breach Model

Weiming Wu

Introduction

DLBreach is a simplified physically-based Dam/Levee Breach model developed by Dr. Weiming Wu, Department of Civil and Environmental Engineering, Clarkson University, NY, USA. Details on model formulations and validations of DLBreach refer to Wu (2013, 2016). Described in this report are the inputs required to run DLBreach, the outputs generated by DLBreach, and how to run the model.

DLBreach requires only one input file, *casename.txt*, to run. All the model inputs are stored in *casename.txt*, and all the results are stored in a single result file, *casename.out*.

The file name *casename* is the case name and needs to be keyed in through screen when the executable *DLBreach.exe* is run through Command Prompt. The input file *casename.txt* should be placed together with the *DLBreach.exe* in the same directory. The result file *casename.out* will be also generated there.

The input and output files are in ASCII format. *casename.out* can be viewed by MicroSoft Excel or Notepad.

The parameters in the new version (2016.4) of DLBreach are input using advanced cards. The parameters and how to specify them are explained below.

Note that the SI (international) unit system is used in DLBreach.

Time Step and Simulation Time Period

Time_Step: This card specifies time step in **seconds**. It is a real type. Its value can be from 0.1 s to 5 s, varying case by case. This card does not have a default value and has to be given.

Example of this card:

Time_Step 0.5 ! in sec

Simulation_Period: This card includes two parameters: beginning and end times of the simulation period. Both are in **seconds**, and real type. The beginning time is usually given as zero, but can be any time from which the model starts. This card does not have default values and has to be given.

Example:

Simulation_Period 0.0, 1000000.0 ! in sec

Water Properties

Water_Density: This card specifies water density. The water density is in **kg/m³** (usually is about 1000 kg/m³). It is a real type. The default value is 1000 kg/m³. If the default value is used, this card is not needed.

Example:

Water_Density 1025.0 ! in kg/m^3

Water_Kinematic_Viscosity: This card is for kinematic viscosity of water. The kinematic viscosity of water is in m^2/s , and usually about $0.000001 \text{ m}^2/\text{s}$. It is a real type. The default value is $0.000001 \text{ m}^2/\text{s}$. If this value is used, this card is not needed.

Example:

Water_Kinematic_Viscosity 0.0000011 ! in m^2/s

Embankment Dimensions

DLBreach approximates the embankment body with a trapezoidal cross-section. The upstream and downstream toes have the same elevations. **All the elevations are referred locally to the embankment toe or base level, and positive values indicate above the base level.**

The following five cards are used to define the height (in **m, i.e., meters**), crest width (in **m**), upstream slope (**unitless**), downstream slope (**unitless**) and length (in **m**) of the dam, levee or barrier embankment. All these variables are real type. The upstream and downstream slopes are defined as **vertical/horizontal (V/H) ratio**. **The embankment length is the base length, which is the maximum breach bottom width.**

The cards and an example value of each card are given below:

Embankment_Height	10.0	! in m
Embankment_Crest_Width	10.0	! in m
Embankment_Upstream_Slope	0.4	! V/H
Embankment_Downstream_Slope	0.4	! V/H
Embankment_Length	100.0	! in m

Breach Mode

Breach_Mode: This card is used to define the breach mode. The entry is an integer type: =1 for overtopping, and 2 for piping.

The card is

Breach_Mode 1 ! for overtopping

or

Breach_Mode 2 ! for piping

For overtopping, there are three submodes, which are defined by the card **Overtopping_Mode**. The entry of this card is an integer type. The value is set as 1 for overtopping of homogeneous embankment with general surface erosion mode (i.e., non-cohesive or uncompacted cohesive embankment); =2 for overtopping of homogeneous embankment with headcut erosion mode (i.e. compacted cohesive embankment); and =3 for overtopping of composite embankment with clay core.

The card is

Overtopping_Mode	1	! for general surface erosion
Overtopping_Mode	2	! for headcut erosion

or



Overtopping_Mode 3 ! for composite embankment with clay core

Pilot Breach

Initial_Overtopping_Breach: This card is used to define the depth and width of the pilot breach channel. It has two entries, both real type and in **m**.

If the pilot breach depth and width are 0.2 and 1.0 m, respectively, this card is

Initial_Overtopping_Breach 0.2, 1.0 ! in m

Initial_Piping_Breach: This card defines the depth of the initial breach pipe measuring from the embankment top to the bottom of the initial breach pipe, and the width of the initial breach pipe. It has two entries, both real type and in **m**. Note that the model assumes a square cross-section for the initial breach pipe, so that the breach height is set to the specified width in the code.

If the pilot pipe breach bottom is located at 5 m below the embankment top and the initial breach width is 0.1 m, this card is

Initial_Piping_Breach 5.0, 0.1 ! in m

Breach Entrance Local Head Loss

Overtop_Entrance_Head_Loss_Coef: This card specifies the local head loss coefficient at the overtopping breach entrance. It is a real type and **unitless**. The default value is 1.0. Thus, if the default value is used, this card does not need to be included in the input file.

If the breach entrance head loss is 0.5, this card is

Overtop_Entrance_Head_Loss 0.5 ! unitless

Pipe_Entrance_Head_Loss_Coef: This card specifies the local head loss coefficient at the pipe entrance. It is a real type and **unitless**. The default value is 0.05. Thus, if the default value is used, this card does not need to be included in the input file.

If the pipe entrance head loss is 0.1, this card is

Pipe_Entrance_Head_Loss_Coef 0.1 ! unitless

Breach Side Slope

The DLBreach model has implemented two methods to determine the breach side slope. The default method uses the slope stability model to calculate the breach side slope. The user can overwrite this by specifying a constant side slope for the breach through the entire breaching process. For example, if the breach side slope is 1.0, the following card is

Breach_Side_Slope_Constant 1.0 ! V/H

Note that the side slope is defined as **vertical/horizontal (V/H)**.

Breach Location

This card specifies the location of the breach. The entry is a real type, specifying whether the breach is located in the middle (=2.0), or on one side (=1.0). The card is

Breach_Location 2.0 ! Two-sided breach
 or
 Breach_Location 1.0 ! One-sided breach

Hard Bottom Elevation

The card *Hard_Bottom_Elevation* specifies the elevation of hard bottom or base erosion limit with reference to the embankment base (a negative value indicating below the embankment base). It is a real type, in m.

For example, if the hard bottom is located at 5.0 m below the embankment base level, the card is

Hard_Bottom_Elevation -5.0 ! in m

Note that only the average elevation, not the lowest elevation, of hard bottom is used.

Manning’s Roughness Coefficient of Breach Channel

The breach is divided to three segments: upstream slope, flat top and downstream slope. If the three segments have the same Manning’s n value, the card *Breach_Manning_n* is used. The entry is a real type. For example, if the Manning’s n is 0.02, the card reads:

Breach_Manning_n 0.02

If the three segments have different values of Manning’s n, the card *Breach_Manning_n_Segments* is used. The three entries are real type. For example, if the Manning’s n is 0.02, 0.025 and 0.03 for the upstream slope, flat top and downstream slope, respectively, the card reads:

Breach_Manning_n_Segments 0.02, 0.025, 0.03

Embankment Sediment Properties

Noncohesive_or_Cohesive_Sediment: This card specifies the embankment sediment to be noncohesive or cohesive. The entry is an integer: =1 for noncohesive sediment; =2 for cohesive sediment.

Noncohesive_or_Cohesive_Sediment 1 !Noncohesive sediment
 or
 Noncohesive_or_Cohesive_Sediment 2 !Cohesive sediment

The following cards are used to specify the diameter (in meter), specific gravity (unitless), porosity (unitless), clay content (fraction between 0 and 1), cohesion (Pa), and internal friction coefficient ($\tan\phi$) of the embankment sediment.

Examples (the values may change case by case):

Sediment_Diameter 0.001 ! in m
 Sediment_Specific_Gravity 2.65 ! unitless

Sediment_Porosity	0.35	! unitless
Sediment_Clay_Content	0.2	! in fraction between 0.0-1.0
Sediment_Cohesion	20000.0	! in Pa
Sediment_Internal_Friction	0.75	! tan ϕ

If the sediment is noncohesive, the noncohesive sediment transport model is used. The nonequilibrium adaptation length is set as λ times the breach channel width at the water surface. The value of λ is specified using the card *Noncohesive_Sed_Adaptation_Lamda*. Entry of this card is a real type. The suggested value is 6.0 for field case and 3.0 for laboratory case.

Noncohesive_Sed_Adaptation_Lamda	6.0	! unitless
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If the sediment is cohesive, the erodibility coefficient (k_d) and critical shear stress for erosion (τ_c) are needed. They are specified by the following two cards. The units of k_d and τ_c are $\text{cm}^3/\text{N}\cdot\text{s}$ and Pa, respectively. In the case of $k_d = 10.0 \text{ cm}^3/\text{N}\cdot\text{s}$ and $\tau_c = 0.15 \text{ Pa}$, these two cards are

Cohesive_Soil_Erosion_kd	10.0	! $\text{cm}^3/\text{N}\cdot\text{s}$
Cohesive_Soil_Erosion_Tauc	0.15	! Pa

Headcut Erosion Model

If headcut is considered (the card *Overtopping_Mode* is set as 2), the headcut erosion model needs to be specified through the card *Headcut_Model*. Three headcut migration models are available in the code. One is the formula $dx/dt=C_1[(qH)^{1/3}-A_0]$, in which the coefficient C_1 and A_0 are given as functions of the erodibility index defined in the USDA SITE program (USDA-NRCS, 1997). The second one is the formula $dx/dt=C_t q^{1/3} H^{1/2}$, in which the coefficient C_t is a coefficient depending on the embankment material. The third one is the formula $dx/dt=C_2 (qH)^{1/3}$, in which C_2 is a coefficient. C_2 is linearly related to the erodibility coefficient k_d (Hanson et al. 2011) that can be measured using the submerged jet test device (Hanson and Cook 2004). [The second option has been better tested in DLBreach, and suggested as the default. \$C_t\$ is around 0.0025-0.0049.](#)

The card *Headcut_Model* has two entries. The first entry is an integer: =1 for the formula $dx/dt=C_1[(qH)^{1/3}-A_0]$; =2 for the formula $dx/dt=C_t q^{1/3} H^{1/2}$; and =3 for the formula $dx/dt=C_2 (qH)^{1/3}$. The second entry is a real type. If the first entry is 1, the second entry is for the erodibility index. If the first entry is 2, the second entry is the coefficient C_t . If the first entry is 3, the second entry is the coefficient C_2 . The default values of this card are 2 and 0.0049. The example of this card is given as

Headcut_Model 2, 0.0049

If the above default headcut model parameters are used, this card does not need to be provided in the input file.

Clay Core Parameters

If clay core is considered (the card *Overtopping_Mode* is set as 3), the following clay core geometry and soil properties are specified by the corresponding cards:

Core_Height: core height, in **m**;
Core_Crest_Width: core crest width, in **m**;
Core_Upstream_Slope = core upstream slope (**V/H**);
Core_Downstream_Slope = core downstream slope (**V/H**);
Core_Center_Location = distance of core crest center to the embankment crest center
 (positive for downstream), in **m**;
Core_Manning_n = Manning's *n* when core is exposed to the flow;
Core_Sediment_Diameter = core soil diameter, in **meter**;
Core_Sediment_Specific_Gravity = core soil specific gravity;
Core_Sediment_Porosity = core soil porosity;
Core_Sediment_Clay_Content = core soil clay content, in **fraction** (in the scale of 1);
Core_Sediment_Cohesion = core soil cohesion, in **Pa**;
Core_Sediment_Internal_Friction = core soil internal friction coefficient (**tan ϕ**);
Core_Cohesive_Erosion_kd = core soil erodibility coefficient k_d , in **cm³/N-s**.
Core_Cohesive_Erosion_Tauc = critical shear stress for core soil erosion, in **Pa**.
Core_Noncohesive_or_Cohesive = sediment transport model for core (=1, non-cohesive;
 =2, cohesive sediment)

The above clay core cards have the same formats as the cards of embankment body soil properties.

Clay Cover Parameters

The DLBreach model requires the information on whether there is a clay cover on the upstream slope, flat top and/or downstream slope segments. The default option is no clay cover. If any of the three segments has clay cover, the corresponding card *Clay_Cover_at_Breach_Top*, *Clay_Cover_at_Upstream_Slope*, or *Clay_Cover_at_Downstream_Slope* is used.

Each card has three entries: The first entry indicates whether a clay cover exists on that segment (=1 for yes), the second entry is the Manning's *n* on that segment, and the third entry is the thickness of the clay cover on that segment (in meter).

For example, if the downstream slope has a clay cover of 0.3 m in thickness and a Manning's *n* of 0.016, the following card is used:

Clay_Cover_at_Downstream_Slope 1, 0.016, 0.3

If no clay cover exists on a segment, the corresponding card is not needed. The code already set the default as no clay cover.

The current version of the model assumes that the clay covers on all the three segments have the same soil properties, which are specified using the following cards:

Clay_Cover_Sediment_Diameter = cover soil diameter, in **m**;
Clay_Cover_Soil_Specific_Gravity = cover soil specific gravity, **unitless**;
Clay_Cover_Soil_Porosity = cover soil porosity, **unitless**;
Clay_Cover_Soil_Clay_Content = cover soil clay content, in **fraction** (in the scale of 1).

Clay_Cover_Soil_Erosion_kd = cover soil erodibility coefficient k_d , in $\text{cm}^3/\text{N}\cdot\text{s}$.

Clay_Cover_Soil_Erosion_Tauc = critical shear stress for cover soil erosion, in Pa.

These cards have the same formats as the cards of embankment soil properties. **These cards are needed only if any segment has clay cover.**

Initial Water Levels at Upstream and Downstream Sides

The card *Initial_Up&Downstream_WSL* specifies the initial water levels at the upstream and downstream of the breach. Two entries of this card are real type, in m. If the initial water levels are 5.0 and 0.01 m on the upstream and downstream sides, respectively, this card is

Initial_Up&Downstream_WSL 5.0, 0.01 ! in m

Upstream Water Level Routing

Because the DLBreach model considers a two-way breach, the definition of upstream and downstream sides is quite flexible. Any side of the breach can be set as upstream, and the other side is downstream. However, as a tradition in inland dam or levee breach modeling, the reservoir or river side is set as the upstream.

DLBreach has three options to provide or calculate the upstream water level. The first option uses the reservoir water balance equation to determine the reservoir water level. This option couples the reservoir routing and breach models. The second option uses the time series of water level, which can be measured or calculated using a hydrodynamic model. The third option sets the upstream as an open channel flowing out.

The first option is often used for dam breach, and the second option is often used for levee and barrier breach. The third option is just in case that the “upstream” is actually downstream, where the breach flow goes to an open channel.

Reservoir routing

In this case, the curve of reservoir surface area or volume versus water level (above the embankment base), i.e. A_s - z curve or V - z curve is needed. There are five methods to specify the A_s - z or V - z curve. The card *Upstream_Reservoir* is used to define the method.

In method 0, the V - z curve is specified as pairs of z and V . The z and V values are in m and m^3 , respectively. The model uses the piecewise linear interpolation to calculate the reservoir volume for a given z . The card consists of method counter, number of the pair values, and pairs of z and V . For example, if there are N pairs of z and V , the card for method 0 reads:

Upstream_Reservoir 0, N,
 z_1 , V_1
 z_2 , V_2
 ...
 z_N , V_N

Note that because the above entries are read through a single statement, no notation “!” or any text appears between 0, N , and the pairs of data.

In method 1, the $A_s - z$ curve is specified as pairs of z and A_s . The z and A_s values are in **m** and **m²**, respectively. The card consists of method counter, number of the pair values, and pairs of z and A_s . For example, if there are N pairs of z and A_s , the card for method 1 reads:

```
Upstream_Reservoir      1, N,
                        z1, A_s1
                        z2, A_s2
                        ...
                        zN, A_sN
```

Note that because the above entries are read through a single statement, no notation “!” or any text appears between 1, N , and the pairs of data.

In method 2, the reservoir storage volume (denoted as V_H) and surface area (denoted as A_H) for a given water level such as normal pool level or embankment height (denoted as H) are known. The model uses the power function $A_s = \alpha z^m$ as the $A_s - z$ curve. The coefficient α and m are determined using the known reservoir volume and surface area at the given water level, as described in Wu (2013, 2016). In this case, the card reads

```
Upstream_Reservoir      2, V_H, A_H, H
```

In method 3 or 4, the reservoir storage volume or surface area for a given water level is known. The model still uses the power function $A_s = \alpha z^m$ as the $A_s - z$ curve. In these two methods, the user needs to specify the exponent m , which is about 2.0 (i.e., 1.0-3.0). The coefficient α is determined in the model using the method described in Wu (2013, 2016). The card reads:

```
Upstream_Reservoir      3, V_H, H, m
```

or

```
Upstream_Reservoir      4, A_H, H, m
```

Specifying upstream water level

In this option, the time series of water surface level (WSL) consists of pairs of values of time (denoted as t in **hours**) and water level (z_s in **m**). The model uses the piecewise linear interpolation to calculate the upstream water level for a given time. If the number of the pair values is N , this card reads

```
Upstream_WSL_Time_Series  N,
                        t1, z_s1
                        t2, z_s2
                        ...
                        tN, z_sN
```

Note that the water level is referred to the embankment base and has positive value above the embankment base level. Because the above entries are read through a single statement, no notation “!” or any text appears between N and the pairs of data.

If the time series of WSL is too long, the user can arrange the WSL time series in a file and use the following card to specify the WSL file name:

Upstream_WSL_File *WSL_file_name*

The data format in the file *WSL_file_name* is arranged as

N
t₁, z_{s1}
t₂, z_{s2}
...
t_N, z_{sN}

Open channel flowing out

In this option, the “upstream” is set as an open channel through which flows out. The channel is assumed to be wide and has a rectangular cross-section. The water depth in the channel is determined using the uniform flow assumption. The channel width, longitudinal slope, and Manning’s n are specified using the following card:

Upstream_Channel_Flow_Out *Channel width, slope, Manning’s n*

Downstream Water Level Routing

Like the upstream water level, the downstream water level is also provided or determined using three options. The first option uses the storage basin (like bay, lake or reservoir) water balance equation to determine the basin water level. This option couples the basin routing and breach models. The second option uses the time series of water level, which can be measured or calculated using a hydrodynamic model. The third option sets the downstream as an open channel flowing out.

Storage basin routing

In this case, the curve of storage basin surface area or volume versus elevation (above the embankment base), i.e. $A_s - z$ or $V - z$ curve is needed. There are five methods to specify the $A_s - z$ or $V - z$ curve. The card *Downstream_Storage_Basin* is used to define the method. This card is very similar to the reservoir card.

In method 0, the $V - z$ curve is specified as pairs of z and V . The z and V values are in m and m³, respectively. For example, if there are N pairs of z and V , the card for method 0 reads:

Downstream_Storage_Basin 1, N,
 z₁, V₁
 z₂, V₂
 ...
 z_N, V_N

Note that because the above entries are read through a single statement, no notation “!” or any text appears between 1, N, and the pairs of data.

In method 1, the $A_s - z$ curve is specified as pairs of z and A_s . The z and A_s values are in m and m², respectively. For example, if there are N pairs of z and A_s , the card for method 1 reads:

Downstream_Storage_Basin 1, N,
 z₁, A_{s1}

z_2, A_{s2}
 \dots
 z_N, A_{sN}

In method 2, the basin storage volume (denoted as V_H) and surface area (denoted as A_H) for a given water level (denoted as H) are known. DLBreach uses the power function $A_s = \alpha z^m$ as the $A_s - z$ curve, like the reservoir case. The card for method 2 reads

Downstream_Storage_Basin 2, V_H, A_H, H

In method 3 or 4, the basin storage volume or surface area for a given water level is known. The model uses the power function $A_s = \alpha z^m$ as the $A_s - z$ curve. In these two methods, the user needs to specify the exponent m , which is about 2.0 (i.e., 1.0-3.0). The card reads:

Downstream_Storage_Basin 3, V_H, H, m

or

Downstream_Storage_Basin 4, A_H, H, m

Specifying downstream water level

In this option, the time series of water surface level (WSL) is defined as pairs of values of time (denoted as t in hours) and water level (z_s in m). If the number of the pair values is N , this card reads

Downstream_WSL_Time_Series N,
 t_1, z_{s1}
 t_2, z_{s2}
 \dots
 t_N, z_{sN}

Note that because the above entries are read through a single statement, no notation “!” or any text appears between N and the pairs of data.

If the time series of WSL is too long, the WSL time series can be arranged in a file, whose name can be specified using the following card:

Downstream_WSL_File *WSL_file_name*

The data format in the file *WSL_file_name* follows:

N
 t_1, z_{s1}
 t_2, z_{s2}
 \dots
 t_N, z_{sN}

Open channel flowing out

In this option, the downstream is set as an open channel which flows out. The channel is assumed to be wide and has a rectangular cross-section. The water depth in the channel is

determined by assuming uniform flow and using the Manning equation. The channel width, longitudinal slope, and Manning's n are specified using the following card:

Downstream_Channel_Flow_Out *Channel width, slope, Manning's n*

Additional Inputs for Flow Routing

In addition to determination of the upstream and downstream water levels described above, if needed, the user may specify the inflow to and outflow from the reservoir or storage basin, as well as sluice gate and spillways using the following cards.

Reservoir or Storage Basin Inflow: this card is used to specify the inflow discharge to the upstream reservoir or downstream storage basin through pairs of values of time (denoted as t , in **hours**) and discharge (denoted as Q_r , in m^3/s). The model uses the piecewise linear interpolation to calculate the inflow discharge for a given time. If the number of the pair values is N , this card reads:

Upstream_Reservoir_Inflow N ,
 t_1, Q_{r1}
 t_2, Q_{r2}
 ...
 t_N, Q_{rN}

or

Downstream_Storage_Basin_Inflow N ,
 t_1, Q_{r1}
 t_2, Q_{r2}
 ...
 t_N, Q_{rN}

Note that because the above entries are read through a single statement, no notation “!” or any text appears between N and the pairs of data.

Spillways and Sluice Gates on Embankment: if there are spillways and/or sluice gates on the embankment where breach occurs, the flows through these structures **are accounted** in the water balance equation in the upstream reservoir and downstream storage basin. The flow through a spillway is calculated as

$$Q_{spill} = \alpha_{sm} C_{spill} B_{spill} (z_s - z_{b,spill})^{1.5} \quad (1)$$

where Q_{spill} is the discharge through the spillway, α_{sm} is the downstream submergence coefficient, C_{spill} is the discharge coefficient, B_{spill} is the spillway flow width, z_s is the water level in the reservoir or basin, and $z_{b,spill}$ is the elevation of the spillway crest.

The flow through a sluice gate is calculated as

$$Q_{sluice} = C_{sluice} A_{sluic} [z_{s,up} - \max(z_{b,sluice}, z_{s,down})]^{0.5} \quad (2)$$

where Q_{sluice} is the discharge through the sluice gate, C_{sluice} is discharge coefficient, A_{sluice} is the cross-sectional area of sluice gate opening, $z_{s,up}$ and $z_{s,down}$ are the water levels in the upstream and downstream, and $z_{b,sluice}$ is the elevation of the sluice gate bottom.

DLBreach allows the user to specify any number of spillways and/or sluice gates. For each spillway, the crest elevation, flow width and discharge coefficient need to be given. For each sluice gate, the gate bottom elevation, opening cross-sectional area and discharge coefficient need to be given. If the number of spillways is N , the following card is used:

Spillways_on_Embankment N ,
 $z_{b,spill}, B_{spill}, C_{spill}$ of spillway No. 1
 $z_{b,spill}, B_{spill}, C_{spill}$ of spillway No. 2
 ...
 $z_{b,spill}, B_{spill}, C_{spill}$ of spillway No. N

Note that because the above entries are read through a single statement, no notation “!” or any text appears between N and the pairs of data.

Similarly, the following card is used for sluice gates (total number of sluice gates as N):

Sluice_Gates_on_Embankment N ,
 $z_b, sluice, A_{sluice}, C_{sluice}$ of sluice gate No. 1
 $z_b, sluice, A_{sluice}, C_{sluice}$ of sluice gate No. 2
 ...
 $z_b, sluice, A_{sluice}, C_{sluice}$ of sluice gate No. N

Note that because the above entries are read through a single statement, no notation “!” or any text appears between N and the pairs of data.

Offsite Spillways and Sluice Gates: Occasionally, reservoir or storage basin may have spillways or sluice gates which are not built on the embankment where breach occurs. Flows through these offsite structures do not go to the downstream water body, so they **are not included** in the water balance calculation for the downstream water body. However, the flows through these structures are accounted in the water balance calculation for the corresponding water body, either upstream reservoir or downstream storage basin. The following four cards are used for these offsite structures. The format of each card is similar to the above spillway or sluice gate card, and thus is not repeated here.

Upstream_Offsite_Spillways
 Upstream_Offsite_Sluice_Gates
 Downstream_Offsite_Spillways
 Downstream_Offsite_Sluice_Gates

Auxiliary Flow over or through the Embankment: If some flow over or through the embankment does not go through the breach and the above-mentioned spillways or sluice gates but still contributes to the downstream basin water budget, the DLBreach model uses the card Auxiliary_Overflow_Time_Series to specify this part of flow. The time series includes pairs of values of time (denoted as t , **in hours**) and flow discharge (denoted as Q_o in m^3/s). If the number of pair values is N , this card reads:

Auxiliary_Overflow_Time_Series N ,
 t_1, Q_{o1}

t_2, Q_{o2}
 \dots
 t_N, Q_{oN}

Note that if such auxiliary flow does not contribute to the downstream basin water budget, it cannot be included in this card, but can be considered by deducting from the reservoir or basin inflow. Because the above entries are read through a single statement, no notation “!” or any text appears between N and the pairs of data.

Wave Information

Normally waves exist significantly on only one side of the breach. The model allows it can be either upstream or downstream side. The card *Waves* is used to specify which side waves exist. This card has two entries, which are integer: =1 if waves exist; =0 if waves do not exist. If waves exist on the upstream side, this card reads:

Waves 1, 0

If waves exist on the downstream side, this card is

Waves 0, 1

Note that if no waves exist on either side, this *Waves* card is not needed. Neither are the other cards for waves described below.

The wave conditions are represented by time series of wave characteristics. The time series includes pairs of values of time (denoted as t , in hours), significant wave height (H_s , in m), peak wave period (T_p , in sec), and wave angle with respect to shore normal direction (θ_w in degree). If the number of pair values is N , this card reads:

Wave_Time_Series $N,$
 $t_1, H_{s1}, T_{p1}, \theta_{w1}$
 $t_2, H_{s2}, T_{p2}, \theta_{w2}$
 \dots
 $t_N, H_{sN}, T_{pN}, \theta_{wN}$

Note that because the above entries are read through a single statement, no notation “!” or any text appears between N and the pairs of data.

If the time series is too long, the user can arrange the wave data in a file and use the following card to specify the wave data file name:

Wave_Data_File *wave_data_file_name*

The data format in the file *wave_data_file_name* should be

N
 $t_1, H_{s1}, T_{p1}, \theta_{w1}$
 $t_2, H_{s2}, T_{p2}, \theta_{w2}$
 \dots
 $t_N, H_{sN}, T_{pN}, \theta_{wN}$

The wave setup is set as $\eta = \alpha_w H_s$, in which H_s is the significant wave height and α_w is the wave setup coefficient, commonly between 0.15-0.5. The coefficient α_w is specified through the card *Wave_Setup_Coefficient*. For example, if α_w is specified as 0.4, this card reads:

Wave_Setup_Coefficient 0.4 ! unitless

The longshore sediment transport is calculated using one of the two formulas: CERC (1984) and Kamphuis (1991, 2002). The card *Longshore_SedTransport_Formula* is used to specify which formula is used. This card has one entry, which is an integer: =1 for the CERC formula; and =2 for the Kamphuis formula. For example, if the Kamphuis formula is used, this card reads:

Longshore_SedTransport_Formula 2

Because the longshore sediment transport formula is empirical, a scaling factor is used to multiply the formula to obtain accurate estimate of the longshore sediment transport rate. The default value of this scaling factor is 1. If another value is used, this factor is specified by the following card. For example, if 1.2 is given to the scaling factor, the card reads

Longshore_SedTran_Scaling_Factor 1.2 ! unitless

Wind Information

Wind can affect the breaching process by wind setup or setdown and wind driving force in the Keulegan equation. The wind setup is calculated using the following formula revised from McCartney (1976):

$$S = 2 \times 10^{-7} \frac{U_{win}^2 \lambda_w F_{win}}{D} \cos \theta_{win} \quad (3)$$

where S is the wind setup, in **meter**; U_{win} is the wind speed at 10 m above the ground, in **m/s**; F_{win} is the wind setup fetch, in **meter**; D is the average depth over the wind setup fetch, in meter; λ_w is a correction factor to consider the geometry convergence for the site of study; and θ_{win} is the angle of wind with respect to the breach axis pointing from the upstream to the downstream side.

The wind setup fetch measures the distance from the water level gauge station to the toe of the embankment. It is not the length or diameter of the water body. Usually the water level gage in the bay and sea is quite close to embankment. If the water level represents the average water level of a water body, the wind fetch may be the distance from the center of the water body to the embankment.

The correction factor λ_w is about 1.0-1.5. It is combined with the fetch F_{win} as the effective fetch $F_{win,e}$:

$$F_{win,e} = \lambda_w F_{win} \quad (4)$$

The model assumes the water depth D as the water level above the embankment base. The model requires $F_{win,e}$ on both upstream and downstream sides. If wind blows from the upstream to the downstream, the wind setup is positive and raises the water level on the upstream side, whereas the wind setup is negative (i.e. setdown) and reduces the water level on the downstream side. The card *Wind_Time_Series* is used to specify the wind information. The time series

includes pairs of values of time (t , in **hour**), wind speed (U_{win} , in **m/s**), and wind blowing angle (θ_{win} , in degree). If the number of pair values is N , this card reads:

```
Wind_Time_Series      Upstream  $F_{win,e}$ , downstream  $F_{win,e}$ ,
                      N,
                       $t_1, U_{win1}, \theta_{win1}$ 
                       $t_2, U_{win2}, \theta_{win2}$ 
                      ...
                       $t_N, U_{winN}, \theta_{winN}$ 
```

Note that because the above entries are read through a single statement, no notation “!” or any text appears between *the first line* and the pairs of data.

If the time series of wind data is too long, the user can arrange the data in a file and use the following card to specify the wind data file name:

```
Wind_Data_File      wind_data_file_name
```

The data format in the file *wind_data_file_name* is arranged as

```
Upstream  $F_{win,e}$ , downstream  $F_{win,e}$ ,
N,
 $t_1, U_{win1}, \theta_{win1}$ 
 $t_2, U_{win2}, \theta_{win2}$ 
...
 $t_N, U_{winN}, \theta_{winN}$ 
```

If no wind effect exists, the above wind cards are not needed. The mode will automatically assume no wind.

Breach Phase Time

For coastal barrier/levee breach, DLBreach divides the simulation period into two phases: Intensive breaching phase and general breach (inlet) evolution phase. In the intensive breaching phase, the breach flow is modeled with the broad-crest weir flow equation or orifice flow equation in the cases of overtopping and piping breach, respectively. In the general evolution phase, the flow through the breach or inlet is modeled using the Keulegan equation. This treatment can also be used in the case of inland levee breach with a long evolution period. The breach flow in the intensive breaching phase are typically supercritical and upstream control, whereas the breach flow in the general evolution phase is subcritical or mixed sub-/supercritical and experiences significant downstream tailwater effect.

The intensive breaching phase period is specified using three options in DLBreach. The first option sets the intensive breaching period equal to the simulation period. This means no general evolution phase. This is the default option, often used for dam breach, or levee breach with short evolution period.

The second option sets the intensive breaching period as the time when the following conditions have met: (1) breach erosion reaches the embankment base (i.e. broad-crested weir disappear); (2) both the upstream and downstream water levels are higher than the breach bottom

elevation; and (3) the difference between the upstream and downstream water levels is less than 30% of the upstream super-elevation above the breach bottom. This option can be used in the case of levee and barrier breach.

The third option allows the user to specify the intensive breaching phase time according to the specific conditions of the study case.

The card *Breach_Phase_Time* is used to select one from the above three options. For the first option, the card reads:

Breach_Phase_Time 1

For the second option, the card is

Breach_Phase_Time 2

For the third option, the card is

Breach_Phase_Time 3, *breachphasetime*

The variable *breachphasetime* in the above card represents the intensive breaching phase time, whose unit is *hour*.

Note that if the default option (first option) is used, the card *Breach_Phase_Time* does not need to be included in the input file.

Model Outputs

During the model run, the following information is shown on screen:

Time step number, elapsed time (in minutes), breach flow (in m^3/s), upstream water level (in m), downstream water level (in m)

The model generates one result file, *casename.out*, in ASCII format, consisting of the following columns for parameters:

Time (in hours), breach flow discharge (m^3/s), flow discharge through spillways/gates on embankment (m^3/s), upstream water level with reference to embankment base (m), downstream water level (m), breach bottom elevation (m), breach bottom width (m), breach top width (m), flow area at the breach (m^2), breach side slope (V/H), cumulative water volume from breach and spillway/gate (m^3), sediment discharge at upstream (m^3/s), sediment discharge at downstream (m^3/s).

References

Wu, W. (2013). “Simplified physically-based model of earthen embankment breaching”, *Journal of Hydraulic Engineering*, ASCE, 139(8), 837–851.

Wu, W. (2016). “Introduction to DLBreach – A Simplified Physically-Based Dam/Levee Breach Model, version 2016.4.” Technical Report, Department of Civil and Environmental Engineering, Clarkson University, NY.