iRIC Software

Changing River Science

Morpho2DH ver.2

Solver Manual

- Debris/Mud flow -

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Contents

I. Outline

I.1 Morpho2DH

Morpho2DH is a calculation solver that a debris/mud flow model is added to Morpho2D.
Morpho2D is the unsteady horizontal two dimensional bed deformation analysis solver of bed material load, which is developed by Hiroshi Takebayashi, Kyoto University. The governing equations are written in boundary fitted general coordinate system. In 2009, the solver was installed to RIC-Nays Version 1.0 which is the free software developed by RIC. Some functions are added to the original version and the improved version is installed into iRIC Version2.0 on March 2011. On March 2014, Morpho2D was unified with Nays2D and Nays2DH was developed.

Morpho2DH is the horizontal two dimensional debris/mud flow analysis solver which can reproduce the transport and deposition process of debris/mud flow due to the landslides. Structures (ex. sabo dam, weir, house and so on) and horizontal distribution of maximum erosion depth can be considered in the analysis.
The unsteady horizontal two dimensional bed deformation analysis of bed material load which can be performed as it used to be.

I.2 Characteristics of flow model

① TVD-MacCormack scheme (2nd order accuracy) is used for the convection term in the momentum equations as the difference method.

② Energy dissipation is calculated by the constitutive lows of two layers model. The laminar flow layer near the bed and the turbulence flow layer on the laminar flow are considered in the two layer model.

③ Movements of the mixtures of water and sediment due to landslides are used as the initial conditions of debris flow

④ The horizontal distribution of maximum erosion depth can be considered.

⑤ Structures (ex. sabo dam, weir and so on) can be considered by use of the height data of the fixed bed area.

⑥ Houses and buildings can be considered as fixed bed elevations as well as river structures, allowing for the calculation of sediment deposition on top of buildings and the transport of debris/mud flows. Very tall obstacles can also be considered by specifying the calculation cell where the obstacle exists as a polygon.

⑦ The time of occurrence of slope failure can be varied for each slope failure.

II. Governing equations

II.1 Governing equations

The relationship between the Cartesian coordinate system and the generalized curvilinear coordinate system is expressed as:

$$J = \frac{1}{\left(\frac{\partial x}{\partial \xi} \frac{\partial y}{\partial \eta} - \frac{\partial x}{\partial \eta} \frac{\partial y}{\partial \xi} \right)} \tag{1-1}$$

$$\frac{\partial \xi}{\partial x} = J \frac{\partial y}{\partial \eta} \tag{1-2}$$

$$\frac{\partial \eta}{\partial x} = -J \frac{\partial y}{\partial \xi} \tag{1-3}$$

$$\frac{\partial \xi}{\partial y} = -J \frac{\partial x}{\partial \eta} \tag{1-4}$$

$$\frac{\partial \eta}{\partial y} = J \frac{\partial x}{\partial \xi} \tag{1-5}$$

In Eqs. (1-1) – (1-5), ξ and η represent coordinates along the longitudinal and transverse directions in the generalized curvilinear coordinate system, respectively; x and y represent the coordinates in the Cartesian coordinate system.

Debris/mud flows comprise a mixture of flowing water and sediments; this mixture is treated as a single-phase continuum fluid body (Egashira and Itoh, 2004). The mass conservation equation for the water and sediment mixture is:

$$\frac{\partial}{\partial t}\left(\frac{h}{J}\right)+\frac{\partial}{\partial \xi}\left(\frac{hU}{J}\right)+\frac{\partial}{\partial \eta}\left(\frac{hV}{J}\right)=\frac{E}{c_* J} \tag{2}$$

where t, h, and U and V represent the time, flow depth, and contravariant depth-averaged flow velocities above the bed along the ξ and η coordinates, respectively. These velocities are defined as:

$$U=\frac{\partial \xi}{\partial x}u+\frac{\partial \xi}{\partial y}v \tag{3}$$

$$V=\frac{\partial \eta}{\partial x}u+\frac{\partial \eta}{\partial y}v \tag{4}$$

where u and v represent the depth-averaged flow velocities above the bed along the x and y coordinates, respectively. The term on the right-hand side of Eq. (2) indicates the sink and source of the mass and expresses the development and decrescence of a debris flow caused by the exchange of the mixture of water and sediment between the bed surface and debris flow, where c_* denotes the concentration of the sediment in the static deposition layer (bed layer) and E represents the erosion rate of the bed. When the cohesive characteristics of the bed layer on the bedrock can be neglected and the equilibrium bed condition wherein the bed erosion rate is the same as the sediment deposition rate, the bed erosion rate can be estimated using (Egashira and Ashida, 1992)

$$\frac{E}{\sqrt{u^2+v^2}}=c_* \tan\left(\theta-\theta_e\right) \tag{5}$$

where θ denotes the bed slope in the flow direction and it is calculated using

$$\sin\theta=\frac{u\sin\theta_x+v\sin\theta_y}{\sqrt{u^2+v^2}} \tag{6}$$

where θ_x and θ_y denote the bed slope in the x-direction and bed slope in the y-direction, respectively. A laminar flow layer is dominant when the sediment size is large; therefore, the flow becomes a debris flow. When the sediment size is small, a turbulent flow layer is formed on the laminar flow layer near the bed, and this becomes a mud flow. Considering the formation of both laminar and turbulent flows and referring to the averaged depth and sediment concentration, the equilibrium bed slope θ_e in the flow direction can be obtained as:

$$\tan\theta_e=\frac{\left(\frac{\sigma}{\rho}-1\right)\bar{c}}{\left(\frac{\sigma}{\rho}-1\right)\bar{c}+1}\frac{h_s}{h}\tan\phi_s \tag{7}$$

where ϕs denotes the angle of repose. The mass conservation of sediments in the debris and the mud flow is

$$\frac{\partial}{\partial t}\left(\frac{\bar{c}h}{J}\right)+\frac{\partial}{\partial \xi}\left(\frac{\bar{c}hU}{J}\right)+\frac{\partial}{\partial \eta}\left(\frac{\bar{c}hV}{J}\right)=\frac{E}{J} \tag{8}$$

The momentum conservation equations are given as

$$\begin{aligned}
&\frac{\partial}{\partial t}\left(\frac{hU}{J}\right)+\frac{\partial}{\partial \xi}\left(U\frac{hU}{J}\right)+\frac{\partial}{\partial \eta}\left(V\frac{hU}{J}\right)\\
&\quad-\frac{hu}{J}\left(U\frac{\partial}{\partial \xi}\left(\frac{\partial \xi}{\partial x}\right)+V\frac{\partial}{\partial \eta}\left(\frac{\partial \xi}{\partial x}\right)\right)-\frac{hv}{J}\left(U\frac{\partial}{\partial \xi}\left(\frac{\partial \xi}{\partial y}\right)+V\frac{\partial}{\partial \eta}\left(\frac{\partial \xi}{\partial y}\right)\right)\\
&\quad=-gh\left(\frac{1}{J}\left(\left(\frac{\partial \xi}{\partial x}\right)^2+\left(\frac{\partial \xi}{\partial y}\right)^2\right)\frac{\partial z_b}{\partial \xi}+\frac{1}{J}\left(\frac{\partial \xi}{\partial x}\frac{\partial \eta}{\partial x}+\frac{\partial \xi}{\partial y}\frac{\partial \eta}{\partial y}\right)\frac{\partial z_b}{\partial \eta}\right)\\
&\quad-\frac{1}{\rho_m}\left(\frac{1}{J}\left(\left(\frac{\partial \xi}{\partial x}\right)^2+\left(\frac{\partial \xi}{\partial y}\right)^2\right)\frac{\partial P}{\partial \xi}+\frac{1}{J}\left(\frac{\partial \xi}{\partial x}\frac{\partial \eta}{\partial x}+\frac{\partial \xi}{\partial y}\frac{\partial \eta}{\partial y}\right)\frac{\partial P}{\partial \eta}\right)-\frac{\tau_{b\xi}}{\rho_m J}
\end{aligned} \tag{9}$$

$$\begin{aligned}
&\frac{\partial}{\partial t}\left(\frac{hV}{J}\right)+\frac{\partial}{\partial \xi}\left(U\frac{hV}{J}\right)+\frac{\partial}{\partial \eta}\left(V\frac{hV}{J}\right)\\
&\quad-\frac{hu}{J}\left(U\frac{\partial}{\partial \xi}\left(\frac{\partial \eta}{\partial x}\right)+V\frac{\partial}{\partial \eta}\left(\frac{\partial \eta}{\partial x}\right)\right)-\frac{hv}{J}\left(U\frac{\partial}{\partial \xi}\left(\frac{\partial \eta}{\partial y}\right)+V\frac{\partial}{\partial \eta}\left(\frac{\partial \eta}{\partial y}\right)\right)\\
&\quad=-gh\left(\frac{1}{J}\left(\frac{\partial \xi}{\partial x}\frac{\partial \eta}{\partial x}+\frac{\partial \xi}{\partial y}\frac{\partial \eta}{\partial y}\right)\frac{\partial z_b}{\partial \xi}+\frac{1}{J}\left(\left(\frac{\partial \eta}{\partial x}\right)^2+\left(\frac{\partial \eta}{\partial y}\right)^2\right)\frac{\partial z_b}{\partial \eta}\right)\\
&\quad-\frac{1}{\rho_m}\left(\frac{1}{J}\left(\frac{\partial \xi}{\partial x}\frac{\partial \eta}{\partial x}+\frac{\partial \xi}{\partial y}\frac{\partial \eta}{\partial y}\right)\frac{\partial P}{\partial \xi}+\frac{1}{J}\left(\left(\frac{\partial \eta}{\partial x}\right)^2+\left(\frac{\partial \eta}{\partial y}\right)^2\right)\frac{\partial P}{\partial \eta}\right)-\frac{\tau_{b\eta}}{\rho_m J}
\end{aligned} \tag{10}$$

where g and z_b represent the gravitational acceleration and bed elevation, respectively. Pressure P is assumed to be static pressure, which is given as

$$P=\int_0^h \rho_m g\left(h-z\right)\cos\theta dz \tag{11}$$

where z represents the vertical coordinate. The density of the debris flow ρ_m is

$$\rho_m=\left(\sigma-\rho\right)\bar{c}+\rho \tag{12}$$

where ρ and σ represent the water density and sediment density, respectively. $\tau_{b\xi}$ and $\tau_{b\eta}$ in Eqs. (9) and (10) represent the contravariant shear stresses in the ξ and η directions, respectively. These shear stresses are defined as

$$\tau_{b\xi}=\frac{\partial \xi}{\partial x}\tau_{bx}+\frac{\partial \xi}{\partial y}\tau_{by} \tag{13}$$

$$\tau_{b\eta}=\frac{\partial \eta}{\partial x}\tau_{bx}+\frac{\partial \eta}{\partial y}\tau_{by} \tag{14}$$

where τ_{bx} and τ_{by} represent the shear stresses in the x- and y-directions, respectively, as

$$\tau_{bx} = \left\{ \tau_y + \rho f_b \left(u^2 + v^2 \right) \right\} \frac{u}{\sqrt{u^2 + v^2}} \tag{15}$$

$$\tau_{by} = \left\{ \tau_y + \rho f_b \left(u^2 + v^2 \right) \right\} \frac{v}{\sqrt{u^2 + v^2}} \tag{16}$$

The energy dissipation of both the solid and fluid motion bases was considered to estimate the shear stress. τ_{ys} denotes the yield stress, which uses the following relation for non-cohesive materials.

$$\tau_y = \left(\frac{\bar{c}}{c_*} \right)^{\frac{1}{n}} \left(\sigma - \rho \right) \bar{c} g h \cos\theta \tan\phi_s \tag{17}$$

where n is a constant, and it is set to 5 here. Further, f_b in Eqs. (20) and (21) denotes the resistance coefficient, for which the following relation is used.

$$f_b = 72\alpha^2, \quad \alpha = \frac{\kappa}{6} \qquad \text{(Turbulence flow layer)} \tag{18}$$

$$f_b = \frac{25}{4} \left\{ k_f \frac{\left(1 - \bar{c}\right)^{\frac{5}{3}}}{\bar{c}^{\frac{2}{3}}} + k_d \frac{\sigma}{\rho} \left(1 - e^2\right) \bar{c}^{\frac{1}{3}} \right\} \left(\frac{h}{d} \right)^{-2} \qquad \text{(Laminar flow layer)}^{2)} \tag{19}$$

The second term is from the inelastic collisions of sediment particles, where $k_f = 0.16$, $k_d = 0.0828$, and e represents the inelastic coefficients of the particles herein; dm represents the mean particle size of the sediment in the debris flow. The bed elevation equation is

$$\frac{\partial}{\partial t} \left(\frac{z_b}{J} \right) = -\frac{E}{c_* J} \tag{20}$$

where, z_b is the bed elevation.

<References>

Egashira, S., Ashida, K., 1992. Unified view of the mechanics of debris flow and bed-load, in: Stud. Appl. Mech. Elsevier 31, 391–400.

Egashira, S., Itoh, T., 2004. Numerical simulation of debris flow. J. Jap. Soc. Comput. Fluid Dyn. 12, 33–43.

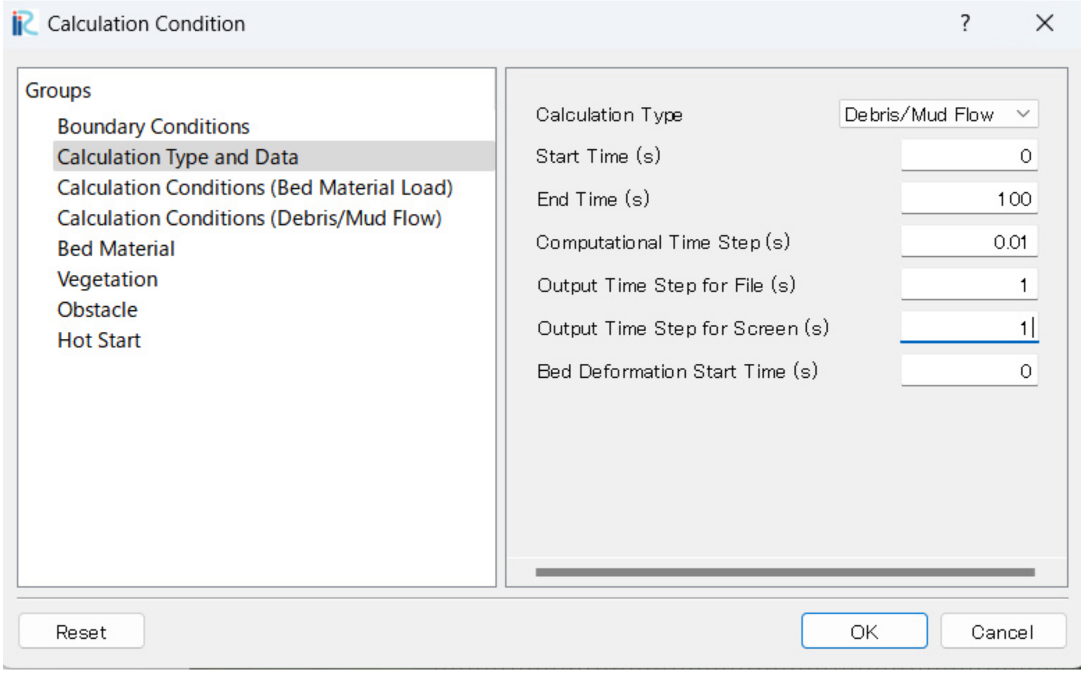
Takebayashi, H., Fujita, M., Ohgushi K.: Numerical modeling of debris flows using basic equations in generalized curvilinear coordinate system and its application to debris flows in Kinryu River Basin in Saga City, Japan, Journal of Hydrology, 615, Part A, 128636, 2022.

III. Calculation condition

In this chapter, calculation condition of Morpho2DH is described by use of the setting dialog boxes of iRIC.

III.1 Setting of calculation parameters

Calculation type and data (ex. calculation time and so on) are set.



Calculation Type: Debris/Mud Flow
Start Time (s): 0
End Time (s): 100
Computational Time Step (s): 0.01
Output Time Step for File (s): 1
Output Time Step for Screen (s): 1
Bed Deformation Start Time (s): 0

Figure III—1　Setting dialog box of Calculation type and data

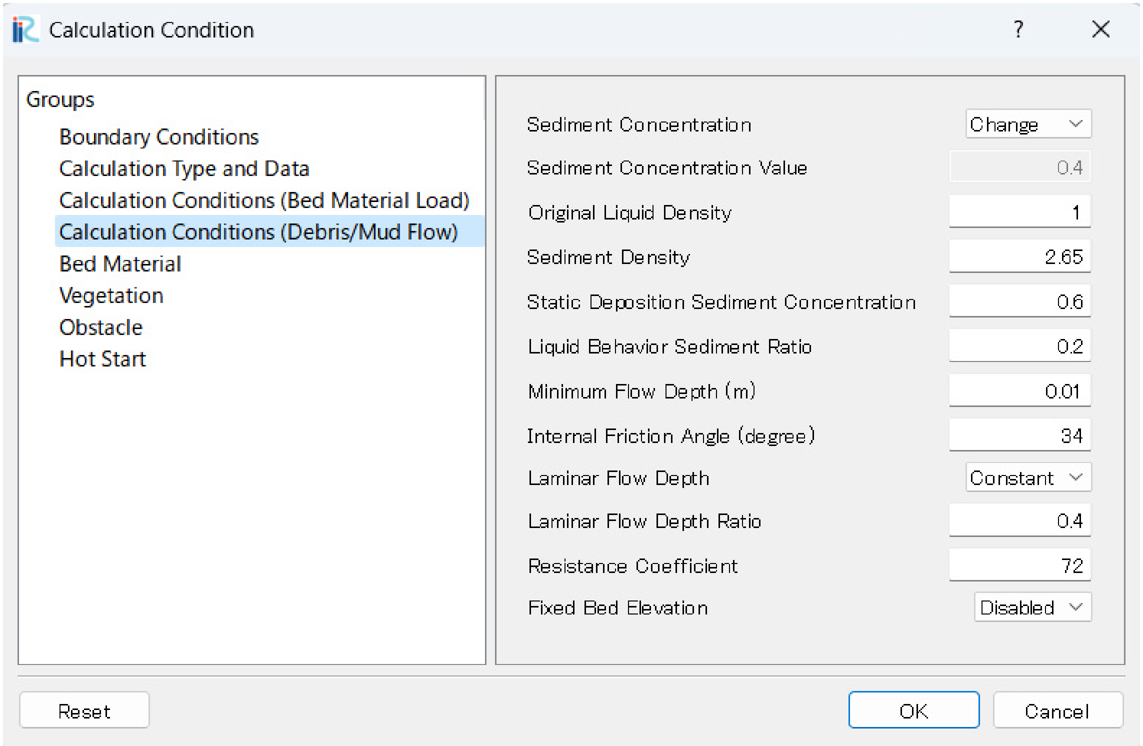
Table III—1　Explanation of setting of calculation parameters

#	Items	Setting method	Else
1	Calculation Type	Select [Debris/Mud flow] for bed deformation analysis by debris/mud flow. [Flow only] is for flow calculation. [Bed material load] is for bed deformation analysis by bed material load.	
2	Start Time (s)	Start time of the calculation is set.	Unit is second.
3	End Time (s)	End time of the calculation is set.	Unit is second.
4	Calculation Time Step (s)	Time step Δt is set.	Unit is second. The time step is decided considering CFL condition.
5	Output Time Step for File (s)	Output time step for file is set.	Unit is second. Short time step

			makes a smooth animation. Unit is second.
6	Output Time Step for Screen (s)	Output Time Step of calculation condition for Screen is set.	Unit is second.
7	Bed Deformation Start Time (s)	When the debris/mud flow calculation is performed, please input 0.	Unit is second.

III.2 Setting of calculation conditions

Calculation conditions are set.



Sediment Concentration: Change
Sediment Concentration Value: 0.4
Original Liquid Density: 1
Sediment Density: 2.65
Static Deposition Sediment Concentration: 0.6
Liquid Behavior Sediment Ratio: 0.2
Minimum Flow Depth (m): 0.01
Internal Friction Angle (degree): 34
Laminar Flow Depth: Constant
Laminar Flow Depth Ratio: 0.4
Resistance Coefficient: 72
Fixed Bed Elevation: Disabled

Figure III—2 Setting dialog box of calculation conditions

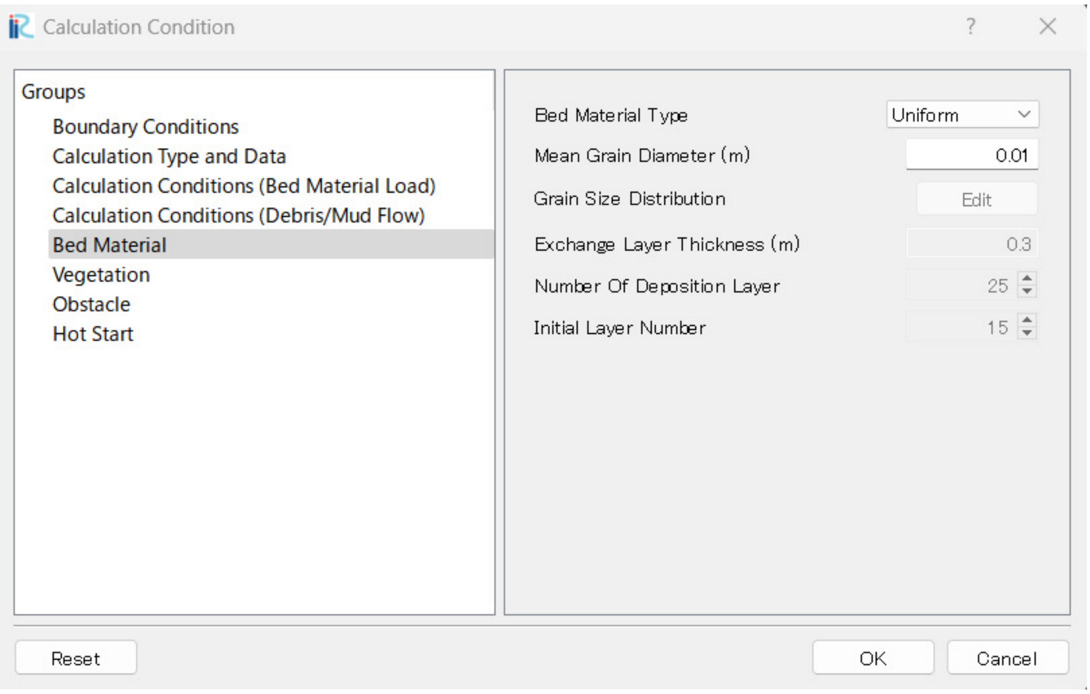
Table III—2 Explanation of setting of calculation conditions

#	Items	Setting method	Else
1	Sediment Concentration	Please select [Change] when you want to consider the spatiotemporal change of sediment concentration.	
2	Sediment Concentration Value	When [Constant] is selected in [Sediment Concentration], please input value to sediment concentration.	
3	Original Liquid Density	The original liquid here is water and 1 is used.	
4	Sediment Density	Please input sediment density.	The density of granite is about 2.65.
5	Static Deposition Sediment Concentration	Static deposition sediment concentration is between 0.54 and 0.8.	
6	Liquid Behavior Sediment Ratio	Fine material behaves as liquid phase. Content rate of 0.2mm and finer diameter is rough standard to decide the value.	

7	Minimum Flow Depth	Minimum flow depth must be set to get stable calculation results. Smaller value is recommended.	The unit is m.
8	Internal Friction Angle	Input measured internal friction angle of the sediment.	The unit is degree.
9	Laminar Flow Depth	When the temporal change of laminar flow depth is considered, please select [Change].	
10	Laminar Flow Depth Ratio	When the flow characteristics are debris flow, the laminar flow depth ratio is about 1. When the flow characteristics are mud flow, the laminar flow depth ratio must be smaller than 1.	
11	Resistance Coefficient	Value of resistance coefficient must be set to reproduce flow depth.	
12	Fixed Bed Elevation	When some parts of the bed composed of rock or sabo dams is set in the calculation area, please select [Enable] in [Fixed Bed Elevation]. When [Fixed Bed Elevation] is [Enable], the fixed bed area must be set using polygons.	

III.3 Setting of bed material conditions

Bed material conditions are set.



Bed Material Type: Uniform
Mean Grain Diameter (m): 0.01
Grain Size Distribution
Exchange Layer Thickness (m): 0.3
Number Of Deposition Layer: 25
Initial Layer Number: 15

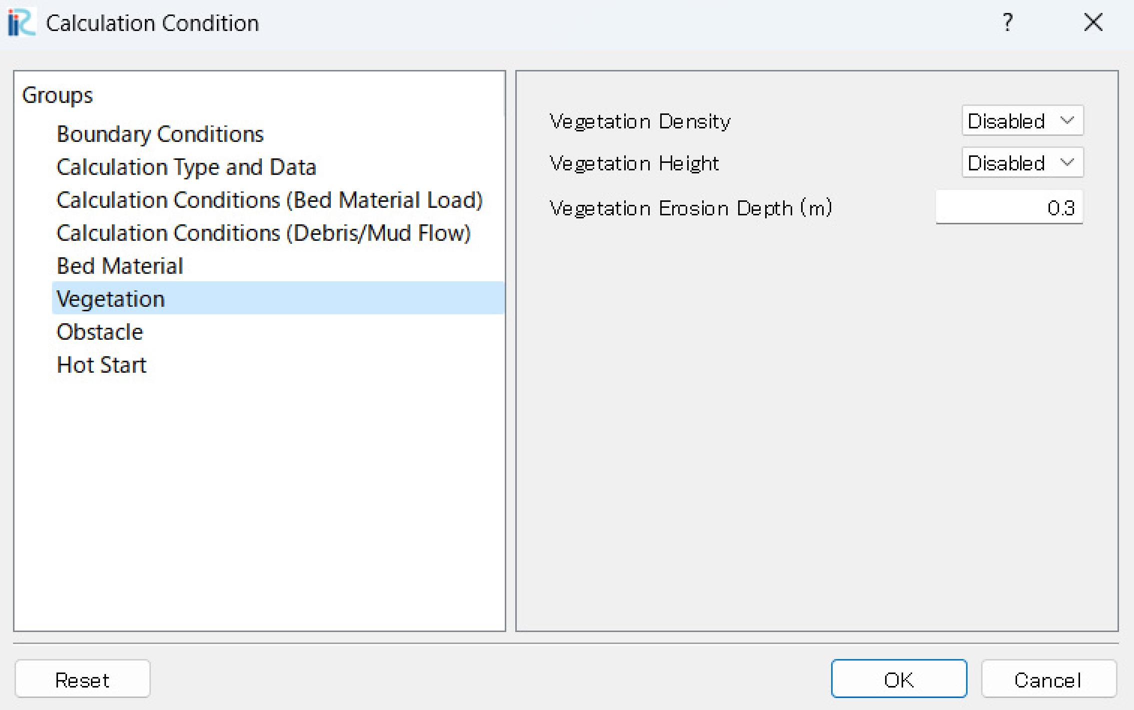
Figure III—3 Setting dialog box of bed material conditions

Table III—3 Explanation of setting of bed material conditions

#	Items	Setting method	Else
1	Bed Material Type	When debris/mud flow calculation is performed, please select [Uniform].	
2	Mean Grain Diameter (m)	Input mean grain diameter of the sediment that does not change phase into liquid.	Unit is m.

III.4 Setting of vegetation conditions

Set calculation conditions for vegetation. Note that this function is currently only available for flow only calculations and for bed deformation analysis with bed load and suspended load.



Vegetation Density: Disabled

Vegetation Height: Disabled

Vegetation Erosion Depth (m): 0.3

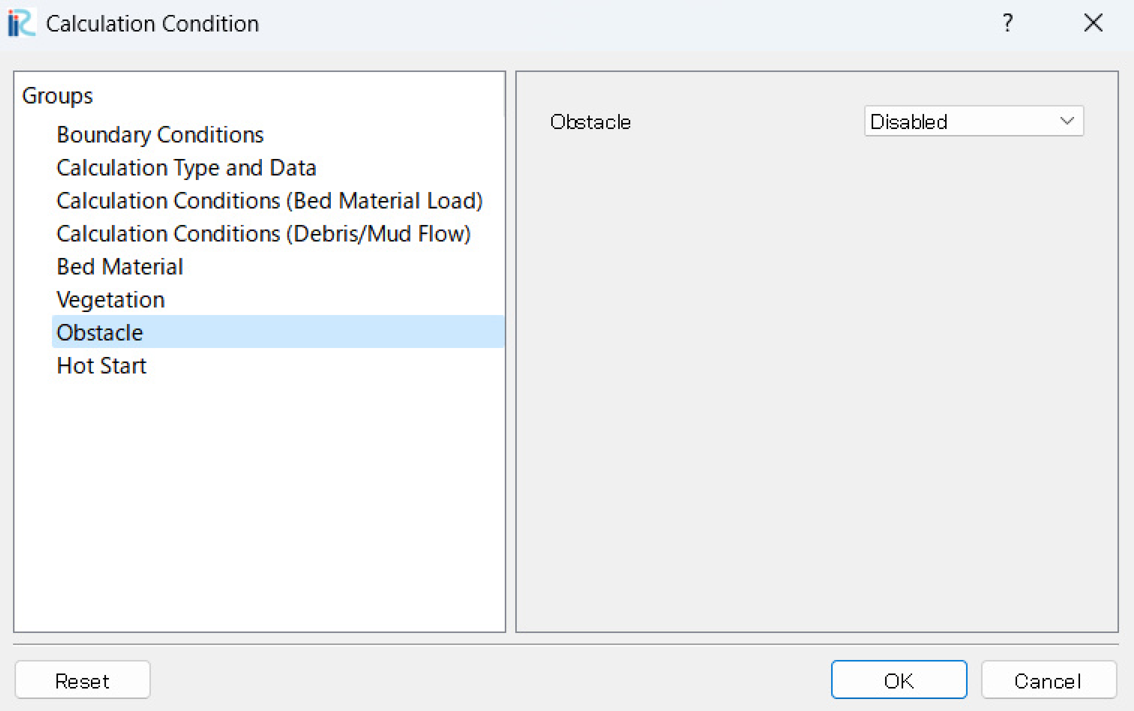
Figure III—4 Setting dialog box of vegetation conditions

Table III—4 Explanation of setting of vegetation conditions

#	Items	Setting method	Else
1	Vegetation Density	If vegetation is considered, [Enabled] is always selected in [Vegetation Density]. Polygons of vegetation regions must be set and the vegetation density values must be inputted.	
2	Vegetation Height	If vegetation height is considered, [Enabled] is selected in [Vegetation Height]. Polygons of vegetation regions must be set and the vegetation height values must be inputted. If [Disabled] is selected in [Vegetation Height], the vegetation height becomes infinity.	
3	Vegetation Erosion Depth	Calculation conditions for vegetation loss due to land erosion. If the land erodes more than this value from the initial land surface, the vegetation is considered to have flowed out and the vegetation density is zero.	

III.5 Setting of Obstacle condition

Sets calculation conditions related to obstacles.



Obstacle: Disabled

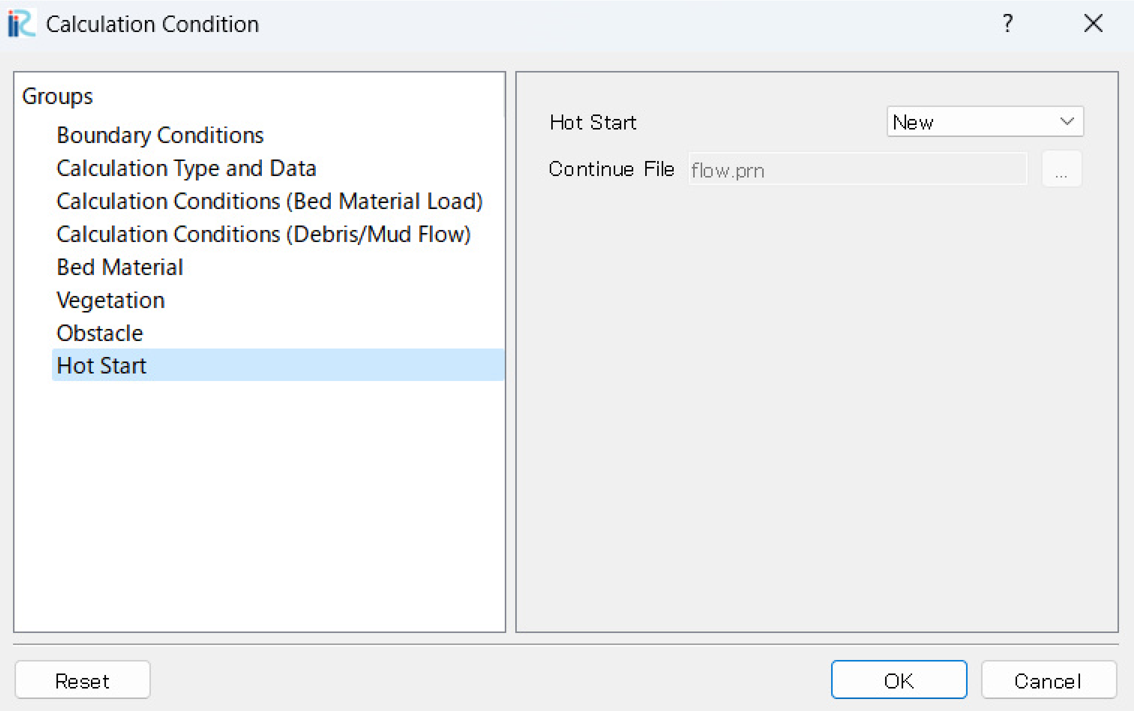
Figure III—5　Setting dialog box of obstacle conditions

Table III—5　Explanation of setting of obstacle conditions

#	Items	Setting method	Else
1	Obstacle	If obstacles are considered, [Enabled] is selected in [Obstacle] and polygons of obstacle regions must be set.	

III.6 Setting of Hot start function

Set hot start function. Note that this function is currently only available for flow only calculations and for bed deformation analysis with bed load and suspended load.



Hot Start: New

Continue File: flow.prn

Figure III―6 Setting dialog box of Hot start function

Table III―6 Explanation of setting of Hot start function

#	Items	Setting method	Else
1	Hot start	When users perform new calculation, please select [New]. When users want to start the calculation from the end of the previous calculation, please select [Continue].	
2	Continue File	In case of continue calculation, please load files in the previous calculation.	