Special Sediment-related Disaster Hazard Area Etc.

Case Study（Examples）

Contents

1. Setting condition

1.1 Setting condition (Topographic and geological survey)

Table-1.1 Setting condition

Items	Condition	Notes
Reference point	Set relevant point as reference point, considering topographic conditions such as the outlet of valley and changing point of gradient	
Gradient of torrent bed	θ =14.0 degrees	Average gradient of the point 200m upstream of reference point
Drainage area	A=0.10km^2	
Assumed debris flow runoff section length	L_1=550m, L_2=115m, L_3=90m, L_4=150m	
Torrent bed width	De_1～De_4=4.0m	
Erosion depth	Be_1=1.5m, Be_2=1.5m, Be_3=1.0m, Be_4=1.5m	
Planned amount of rainfall in 24 hours	R_{24}=260mm/hr	
Friction angle of sand	ϕ =35 °	
Density of flow water	ρ =11.77kN/m^3	1.2×10^{3}kg/m^3
Density of gravel	σ =25.50 kN/m^3	2.6×10^{3}kg/m^3
Density of a unit of sediment deposition	C_*=0.6	

※In the computing example, 10m contour topographic map is used.

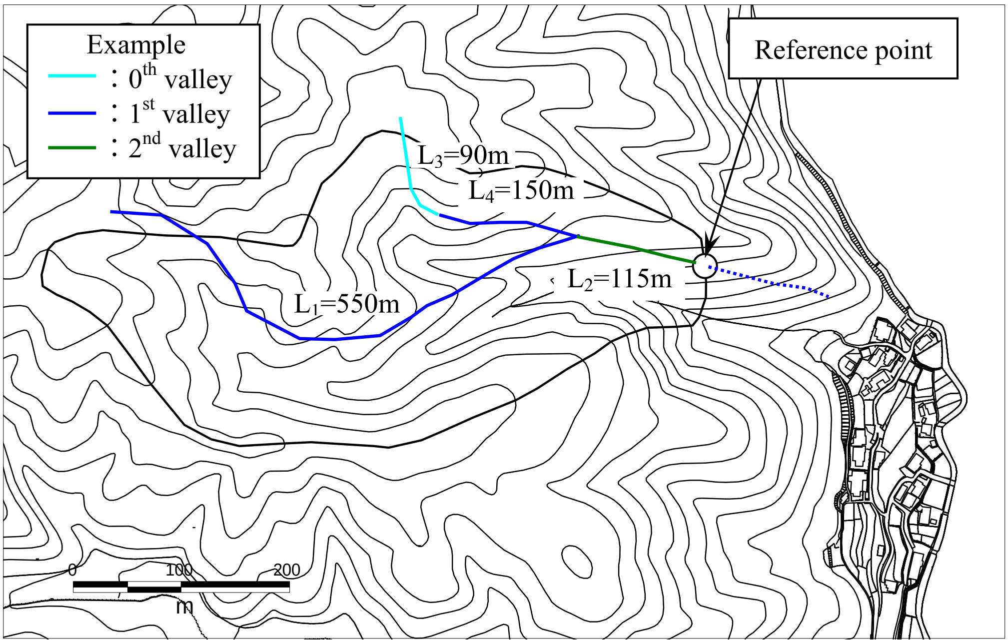

Figure-1.1 Plane figure of area river basin

※ Reference point should be set, considering outlet of valley, alluvial fan, hook, changing point of gradient, narrow pass outlet, debris flow flood record etc.

2. Setting Special Sediment-related Disaster Hazard Area

2.1 Computing quantity of earth and rock etc at reference point

2.1.1 The volume of deposition on the torrent bed (Ve')

Ve' is computed by the equation below and its maximum value is calculated as $Ve' = 3{,}900\mathrm{m}^3$. The torrent in this case is the flow along a line drawn upstream from the reference point.

$$Ve' \quad Ae \times Lme$$

$$Ae = B' \times De$$

$$Ve' = B' \times De \times Lme$$

Where: Ve'：sediment deposition volume on torrent bed [m^3], Ae：erosion possible sectional area of sediment deposition on torrent bed (m^2), Lme：assumed debris flow runoff section length [m], B'：erosion width [m], D_e：erosion depth [m].

$$V_{e1}' = 4.0\mathrm{m} \times 1.50\mathrm{m} \times 550\mathrm{m} = 3{,}900\mathrm{m}^3$$
$$V_{e2}' = 4.0\mathrm{m} \times 1.50\mathrm{m} \times 115\mathrm{m} = 690\mathrm{m}^3$$
$$V_{e3}' = 4.0\mathrm{m} \times 1.00\mathrm{m} \times 90\mathrm{m} = 360\mathrm{m}^3$$
$$V_{e4}' = 4.0\mathrm{m} \times 1.50\mathrm{m} \times 150\mathrm{m} = 900\mathrm{m}^3$$

2.1.2 The transportable volume of sediment（Vec）

Outflow correction coefficient（fr）is, based on the past debris flow record, function of the area river basin and within the range of $0.1 \leqq fr \leqq 0.50$. When computed in the equation below it is fr = 0.50.

$$\begin{aligned} fr &= 0.05(\log A - 2.0)^2 + 0.05 \\ &= 0.05(\log 0.10 - 2.0)^2 + 0.05 \\ &= 0.50 \end{aligned}$$

fr ：outflow correction factor

A ：Area river basin [$0.10\mathrm{km}^2$]

Sediment concentration of the debris flow at the reference point (C_{d0}) is computed with Takahashi formula. Sediment concentration is computed as $C_{d0} = 0.4740$ according to the equation below. Maximum value is $C_{d0} = 0.9C_* = 0.54$.

$$C_{d0} = \frac{\rho \cdot \tan\theta_0}{(\sigma - \rho)(\tan\varphi - \tan\theta_0)}$$

ρ ：density of flowing water [11.77kN/m^3]

σ ：density of gravel [25.50kN/m^3]

θ_0 ：gradient of the ground at the reference point [14 degrees]

φ ：angle of internal friction of gravel [35 degrees]

$$C_{d0} = \frac{11.77 \cdot \tan 14^\circ}{(25.50 - 11.77)(\tan 35^\circ - \tan 14^\circ)}$$
$$= 0.4740$$

The transportable volume of sediment (Vec) is computed based on the total amount of rainfall of planned scale. The transportable volume of sediment (Vec) is computed as $Vec = 19{,}600m^3$ by the equation below.

$$Vec = \frac{10^3 \cdot R_T \cdot A}{1-\lambda}\left[\frac{Cd_0}{1-Cd_0}\right]fr$$

$$= \frac{10^3 \cdot 260 \cdot 0.10}{1-0.40}\left[\frac{0.4740}{1-0.4740}\right] \cdot 0.50$$

$$= 19{,}600m^3$$

R_T : amount of rainfall in 24 hours [260mm/24hrs.]

λ : void ratio of deposition (0.4)

A : Area river basin [0.10km^2]

C_{d0} : sediment concentration of debris flow at the reference point [0.4740]

V_0 is the smaller of the volume of deposition on the torrent bed (Ve') and the volume of sediment that can be transported by object rainfall (Vec) : $Ve' = 3{,}900m^3$.

$$Ve'(= 3{,}900m^3) < Vec\ (= 19{,}600m^3)$$

2.2 Setting the direction of debris flow

Direction of debris flow is set upon consideration of current watercourse, torrent bed plane configuration, straight movement of debris flow and the result of site investigation. In the example, the direction of debris is set on consideration of watercourse upstream of the reference point and the straight movement of debris flow.

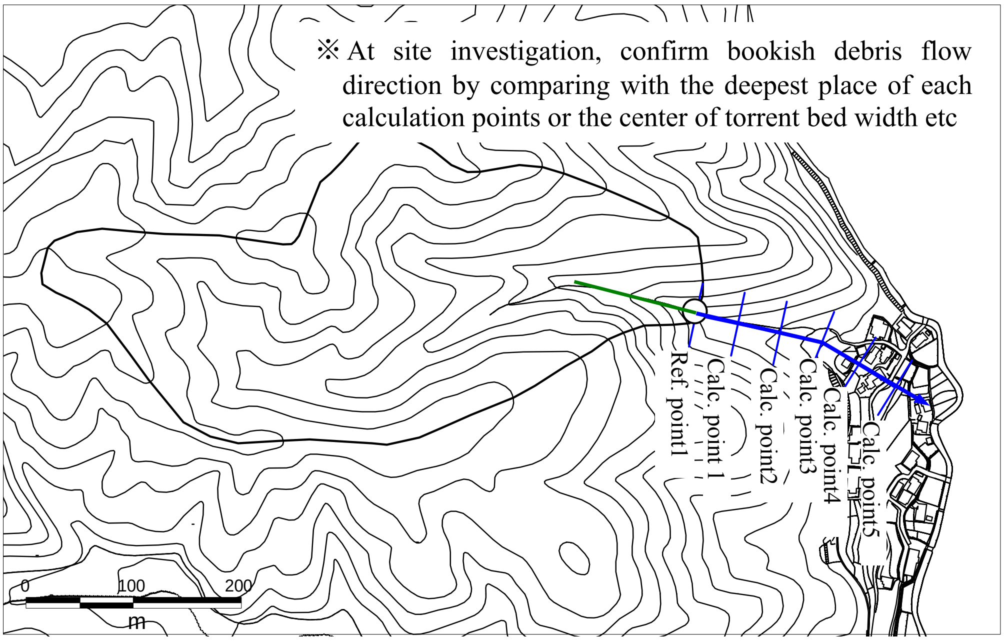

Figure-2.2 Example of debris flow watercourse setting

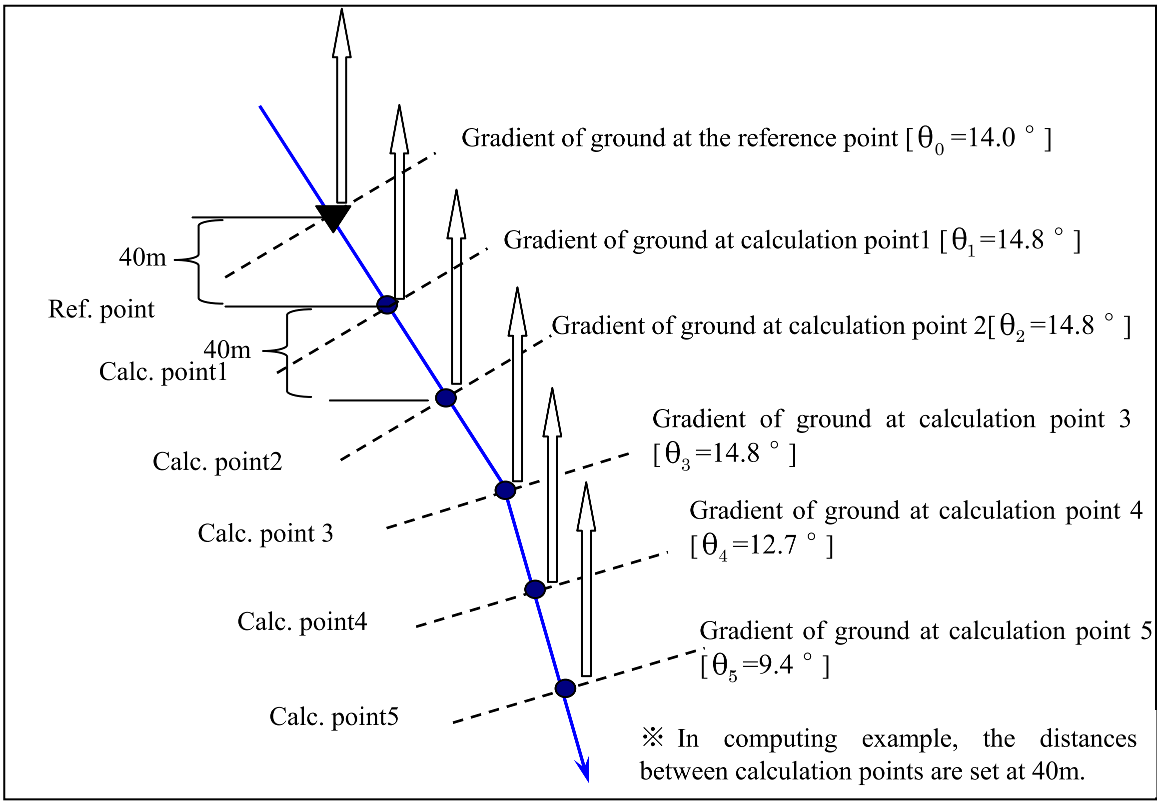

Figure-2.3 Image of longitudinal slope setting

2.3 Estimation of the peak discharge of debris flow

The peak discharge of debris flow at the reference point is computed by equation below, using Q_{sp0} =50.0 m^3/s.

$$Q_{sp0} = \frac{0.01}{C_{d0}} C_* \cdot V_0$$

Q_{sp0} : peak discharge of debris flow at the reference point ［m^3/s］

V_0 : volume of deposition in the debris flow at the reference point（including void）［3,900m^3］

C_* : density of a unit of sediment deposition [0.60]

C_{d0} : sediment concentration of debris in the flow [0.4740]

$$Q_{sp0} = \frac{0.01}{C_{d0}} C_* \cdot V_0$$

$$Q_{sp0} = \frac{0.01}{0.4740} 0.60 \cdot 3900$$

$$= 50.0 m^3/s$$

2.4 Computing hydrodynamic force of debris flow acting on buildings and strength of normal buildings

At first, compute " debris flow cross-sectional area A " by trial-and-error method so that the peak discharges of debris flow. Q_{sp0} (which was computed in Section 2.3)= Q.

Then compute "flow width of the debris flow B" at reference point, using value A.

$$U = \frac{Q}{A} = \frac{1}{n} R^{\frac{2}{3}} I_b^{\frac{1}{2}}$$

$$Q = \frac{1}{n} \cdot \left(\frac{A}{S}\right)^{\frac{2}{3}} (\sin\theta)^{\frac{1}{2}} \cdot A$$

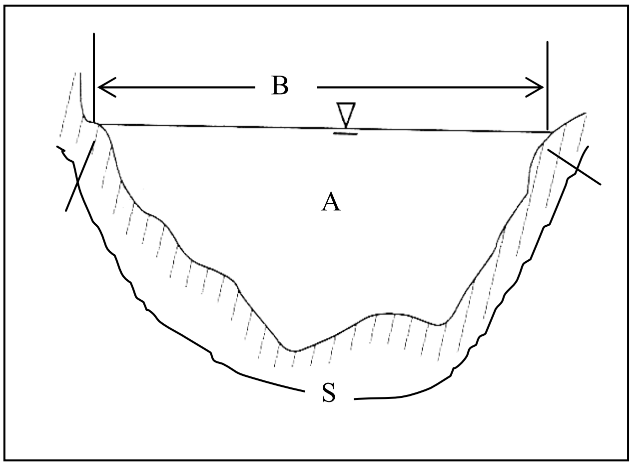

Figure-2.4 Calculation of debris flow width by cross-section flow capacity

Q : Discharge [m^3/s]

A : Cross-sectional area of flow [m^2]

n : roughness coefficient [natural channel : 0.10]

S : wetted perimeter (S＝A/R, R : hydraulic radius)

θ_0 : gradient of the ground [14.0 °]

When assuming $A=11.7m^2$, $R=0.80m$

$$Q = \frac{1}{n} \cdot \left(\frac{A}{S}\right)^{\frac{2}{3}} (\sin\theta)^{\frac{1}{2}} \cdot A$$

$$= \frac{1}{0.10} \cdot \left(\frac{11.7}{14.7}\right)^{\frac{2}{3}} (\sin 14.0°)^{\frac{1}{2}} \cdot 11.7$$

$$= 50.0 m^3/s = Q_{sp0}$$

Therefore, when $A=11.7m^2$, $R=0.80m$ it is computed that B=14.4m.

Since both banks are predicted to be fairly distant at the calculation points on the alluvial fan, assume maximum value for B. The relationship between B and Q_{spi} can be described in regime formula below and as a result B=28.3m.

$$B = \alpha \cdot Q_{sp0}{}^{\beta}$$

α ：4.0

β ：0.50

$$B = 4.0 \cdot 50.0^{0.50}$$

$$= 28.3m$$

When comparing debris flow width by cross-section flow capacity（B=14.4m）and the flow width computed by regime formula（B=28.3m）, debris flow width by cross-section flow capacity is smaller than the maximum value. Therefore, debris flow width at the reference point adopts B=14.4m. And even at the calculation points, debris flow width computed by regime formula, which was calculated at the reference point, is used as the maximum value.

Flow depth of the debris flow at the reference point is computed in the equation below: h_0=0.9m.

$$h_0 = \left(\frac{n \times Q_{sp0}}{B_0 \cdot (\sin\theta_0)^{0.5}}\right)^{\frac{3}{5}}$$

h_0 ：flow depth of the debris flow at the reference point [m]

n ：roughness coefficient [natural channel：0.10]

Q_{sp0}：peak discharge of debris flow at the reference point [$50.0m^3/s$]）

θ_0 ：the gradient of the land at the reference point [14.0 °]

$$h_0 = \left(\frac{0.10 \times 50.0}{14.4 \cdot (\sin 14.0°)^{0.5}}\right)^{\frac{3}{5}}$$

$$= 0.9m$$

Debris flow velocity at the reference point is computed by the equation below: U_0=4.6m/s

$$U_0 = \frac{R_0^{2/3}(\sin\theta_0)^{1/2}}{n}$$

U_0 : flow velocity of the debris flow at the reference point[m/s]

n : roughness coefficient [natural channel : 0.10]

R_0 : hydraulic radius (h_0 =debris flow depth[m])

θ_0 : gradient of ground at reference point [14.0 °]

$$U_0 = \frac{0.9^{2/3}(\sin 14.0°)^{1/2}}{0.10}$$
$$= 4.6\text{m/s}$$

Density of debris flow is computed by the equation below: ρ_{d0} =18.28kN/m^3.

$$\rho_{d0} = \frac{\rho\tan\varphi}{\tan\varphi - \tan\theta_0} = \sigma \cdot C_{d0} + \rho(1 - C_{d0})$$

σ : density of gravel [25.50kN/m^3]

ρ : density of flowing water [11.77kN/m^3]

C_{d0} : sediment concentration of debris in the flow [0.4740]

$$= 25.50 \cdot 0.4740 + 11.77(1 - 0.4740)$$
$$= 18.28\text{kN/m}^3$$

Debris flow force acting on buildings is computed by the equation below: F_{d0} =39.5kN/m^2.

$$F_{d0} = \rho_{d0} \cdot U_0^{\,2}/g$$

F_{d0} : debris flow force acting on buildings at the reference point [kN/m^2]

ρ_{d0} : density of debris flow at the reference point [18.28kN/m^3]

U_{d0} : flow velocity of debris flow at the reference point [4.6m /s]

g : gravitational acceleration (9.807)

$$F_{d0} = 18.28 \cdot 4.6^2/9.807$$
$$= 39.5\text{kN/m}^2$$

Strength of buildings is computed by the equation below: P_0=39.5kN/m^2. However, the maximum flow depth of the debris flow is 2.8m and even if it is greater than that it is set on 2.8m.

$$P_0 = \frac{35.3}{h_0 \cdot (5.6 - h_0)}$$

P_0 : strength of buildings [kN/m^2]

h_0 : flow depth of debris flow [0.9m]

$$P_0 = \frac{35.3}{0.9 \cdot (5.6 - 0.9)}$$
$$= 8.3\text{kN/m}^2$$

The watercourse of the debris flow, which is the object of the calculation, is a deposition section, so it is unnatural for Q_{spi} to become larger as it proceeds downstream. To prevent Q_{spi} from becoming larger as it proceeds downstream, if, at (and only at) the time of calculation, the gradient of the land θ_a at a certain point a is greater than the gradient of the land θ_b at a calculation point b which is upstream from the concerned point（$\theta_a > \theta_b$）, then we take $\theta_a = \theta_b$.
Since the gradient of ground at the calculation point 1 is: $\theta_0 = 14.0\text{degree} < \theta_1 = 14.6\ \text{degree}$, the gradient of ground used at the calculation point 1 is 14.0°.
Sediment concentration of debris flow is computed by the equation below: C_{d1}=0.4740.

$$C_{d1} = \frac{\rho \cdot \tan\theta_1}{(\sigma - \rho)(\tan\varphi - \tan\theta_1)}$$

ρ ：density of flowing water [11.77kN/m^3]
σ ：density of gravel [25.50kN/m^3]
θ_0 ：gradient of ground at the reference point [14.0°]
θ_1 ：gradient of ground at the reference point [14.6°]
φ ：angle of internal friction of gravel [35°]

$$C_{d1} = \frac{11.77 \cdot \tan 14.0°}{(25.50 - 11.77)(\tan 35° - \tan 14.0°)}$$
$$= 0.4740$$

As for quantity of earth and rock etc at calculation point 1, V_i should be computed upon consideration of sediment deposition. Assuming that the debris flow has sediment concentration C_{di} and that sediments are deposited with the density of a unit C_*, and simplifying the expression, we obtain the below equation and the result V_i=3,900m^3 is computed.

$$V_i = \frac{C_* - C_{d0}}{C_* - C_{di}} \cdot \frac{C_{di}}{C_{d0}} V_0$$

V_i ：quantity of earth and rock etc at calculation point [m^3]
V_0 ：quantity of earth and rock etc at reference point [m^3]
C_* ：density of a unit of sediment deposition [0.60]
C_{d1} ：sediment concentration of debris flow at the calculation points [0.4740]

$$V_1 = \frac{0.60 - 0.4740}{0.60 - 0.4740} \cdot \frac{0.4740}{0.4740} \cdot 3{,}900$$
$$= 3{,}900\text{m}^3$$

Peak discharge of debris flow at the calculation point 1 is computed by the equation below: Q_{sp}= m^3/s.

$$Q_{spi} = \frac{0.01}{C_{di}} C_* \cdot V_i$$

Q_{sp1} : peak discharge of debris flow at the calculation point 1 [m^3/s]

V_1 : amount of sediment that can be transported by the debris flow at the calculation point 1 (include void) [3,900m^3]

C_* : density of a unit of sediment deposition [0.60]

C_{d1} : sediment concentration of debris in the flow [0.4740]

$$Q_{sp1} = \frac{0.01}{0.4740} 0.60 \cdot 3{,}900$$
$$= 50.0 m^3/s$$

The flow width of the debris flow at the calculation point 1 is computed as the flow width of debris flow at the reference point (refer to page 5, section 2.4).

$$Q = \frac{1}{n} \cdot \left(\frac{A}{S}\right)^{\frac{2}{3}} (\sin\theta)^{\frac{1}{2}} \cdot A$$

Q : Discharge[m^3/s]

A : Cross-sectional area of flow[m^2]

n : roughness coefficient[natural channel : 0.10]

S : wetted perimeter（S＝A/R, R : hydraulic radius）

θ_0 : gradient of the ground[14.6 °].

When assuming A=10.8m^2, R=0.87m

$$Q = \frac{1}{n} \cdot \left(\frac{A}{S}\right)^{\frac{2}{3}} (\sin\theta)^{\frac{1}{2}} \cdot A$$
$$= \frac{1}{0.10} \cdot \left(\frac{11.7}{12.4}\right)^{\frac{2}{3}} (\sin 14.6°)^{\frac{1}{2}} \cdot 10.8$$
$$= 50.0 m^3/s = Q_{sp0}$$

Therefore, when A=10.8m^2, R=0.87m it is computed that B=11.7m.

When comparing debris flow width by cross-section flow capacity（B=14.4m）and the flow width computed by regime formula（B=28.3m）, debris flow width by cross-section flow capacity is smaller than the maximum value. Therefore, debris flow width at the reference point adopts B=11.7m

Flow depth of the debris flow at the calculation point 1 is computed by the equation below: h_1 =1.0m.

$$h_1 = \left(\frac{n \times Q_{sp1}}{B_1 \cdot (\sin\theta_1)^{0.5}} \right)^{\frac{3}{5}}$$

h_1 : flow depth of the debris flow at the calculation point 1 [m]

n : roughness coefficient [natural channel : 0.10]

Q_{sp1} : peak discharge of debris flow at the reference point [50.0m^3/s])

θ_1 : gradient of the land at the calculation point 1 [14.6 °]

$$h_1 = \left(\frac{0.10 \times 50.0}{11.7 \cdot (\sin 14.8°)^{0.5}} \right)^{\frac{3}{5}}$$

$$= 1.0\text{m}$$

Flow velocity of the debris flow at the calculation point 1 is computed by the equation below: U_1=4.6m/s

$$U_1 = \frac{R_1^{2/3} (\sin\theta_1)^{1/2}}{n}$$

U_1 : Flow velocity of the debris flow at the calculation point 1 [m/s]

n : roughness coefficient [natural channel : 0.10]

R_1 : hydraulic radius （h_0 = debris flow depth[m]）

θ_1 : gradient of ground at the calculation point 1 [14.6 °]

$$U_1 = \frac{1.0^{2/3} (\sin 14.8°)^{1/2}}{0.10}$$

$$= 5.1\text{m/s}$$

Density of debris flow at the calculation point 1 is computed by the equation below: ρ_{d1} =18.28kN/m^3.

$$\rho_{d1} = \frac{\rho \tan\varphi}{\tan\varphi - \tan\theta_1} = \sigma \cdot C_{d1} + \rho(1 - C_{d1})$$

σ : density of gravel [25.50kN/m^3]

ρ : density of flowing water [11.77kN/m^3]

C_{d1} : sediment concentration of debris in the flow [0.4740]

$$= 25.50 \cdot 0.4740 + 11.77(1 - 0.4740)$$

$$= 18.28\text{kN/m}^3$$

Hydrodynamic force of debris flow acting on buildings is computed by the equation below: F_{d1} =48.5kN/m[2.]

$$F_{d1} = \rho_{d1} \cdot U_1^2/g$$

F_{d1} : hydrodynamic force of debris flow acting on buildings at the calculation point 1 [kN/m^2]

ρ_{d1} : density of debris flow at the calculation point 1 [18.28kN/m^3]

U_{d1} : flow velocity of debris flow at the calculation point1 [5.1m /s]

g : gravitational acceleration (9.807)

$$F_{d1} = 18.28 \cdot 5.1^2/9.807$$
$$= 48.5\text{kN/m}^2$$

Strength of buildings is computed by the equation below: P_1=39.5kN/m^2 However, the maximum flow depth of the debris flow is 2.8m and even if it is greater than that it is set on 2.8m.

$$P_1 = \frac{35.3}{h_1 \cdot (5.6 - h_1)}$$

P_1 : strength of building [kN/m^2]

h_1 : flow depth of debris flow [1.0m]

$$P_1 = \frac{35.3}{1.0 \cdot (5.6 - 1.0)}$$
$$= 7.7\text{kN/m}^2$$

For calculation points 2 to 5, make same calculations as calculation point 1.

Table-2.1 Result of calculation of peak discharge of debris flow etc

	Ref. Point	Calc. Point1	Calc. Point2	Calc. Point 3	Calc. Point 4	Calc. Point 5
Gradient of ground θ_i [degree]	14.0	14.6	14.8	14.8	12.7	9.4
Gradient of ground, considering gradient of ground upstream θ_i [degree]	14.0	14.0	14.0	14.0	12.7	9.4
Quantity of earth and rock etc V_i[degree]	14.0	14.0	14.0	14.0	12.7	9.4
Density of debris flow ρ_{di} [degree]	1.864	1.864	1.864	1.864	1.770	1.572
Peak discharge of debris flow Q_{spi} [degree]	50.0	50.0	50.0	50.0	33.0	19.0
Debris flow width computed by cross-section flow calculation B_i [degree]	14.4	11.7	12.4	22.5	14.4	47.3
Debris flow width computed by regime formula B_i [degree]	28.3	28.3	28.3	28.3	28.3	28.3
Flow width of adopted debris flow B_i [degree]	14.4	11.7	12.4	22.5	14.4	28.3
Flow depth of debris flow h_i[m]	0.9	1.0	0.9	0.7	0.7	0.4
Flow velocity of debris flow U_i[m/s]	4.6	5.1	4.8	4.0	3.7	2.2
Hydrodynamic force of debris force acting on buildings F_{di}[kN/m^2]	39.5	48.5	43.0	29.9	24.3	7.7
Strength of normal buildings P_i[kN/m^2]	8.3	7.7	8.3	10.3	10.3	17.0

2.5 Method of illustration of special sediment-related disaster hazard area

For special sediment-related disaster hazard area, compare F_{di} and P_i, which were computed in Section 2.4 and obtain the calculation point which satisfy the equation below. On the relevant torrents, up to calculation points 4 are considered special sediment-related disaster hazard area.

$$F_{di} > P_{di}$$

Table-2.2 Result of judgment of special sediment-related disaster hazard area

	Ref. Point	Calc. Point1	Calc. Point2	Calc. Point3	Calc. Point4	Calc. Point5
Hydrodynamic force of debris flow acting on buildings F_{di} [kN/m^2]	39.5	48.5	43.0	29.9	24.3	7.7
Strength of normal buildings P_i [kN/m^2]	8.3	7.7	8.3	10.3	10.3	17.0
A point which exceeds the strength of normal buildings	○	○	○	○	○	×

Illustrate the flow width of debris flow, which was calculated in Section 2.5, on the plane figure.

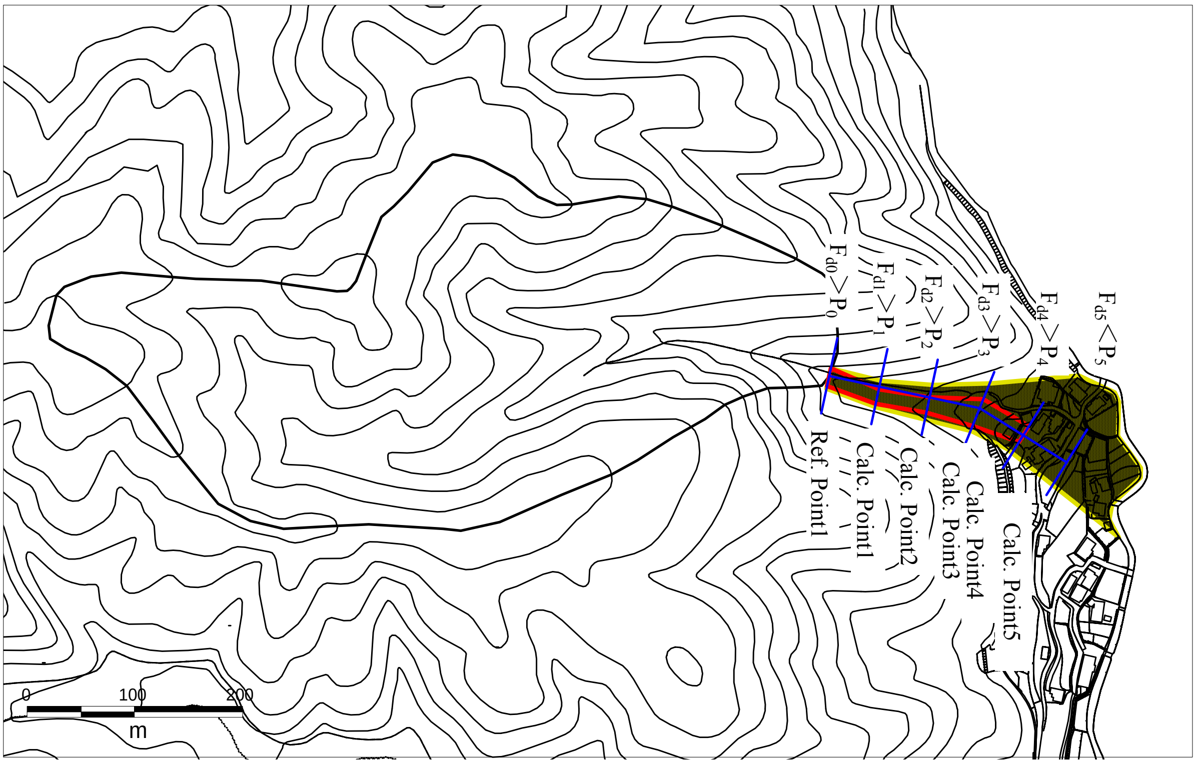

Figure-2.5 Example of setting special sediment-related disaster hazard area

3. Setting sediment-related disaster warning area

Sediment-related disaster warning area is set on the area where gradient of ground is greater than 2 ° in the range from reference point (top of alluvial fan) to downstream, where the torrent area river basin is smaller than 5km^{2}. The area where it is obvious that the debris flow will not reach due to the topographic features is excluded.

Set debris flow dispersion angle based on the topography of the outlet of valley, and determine the expanse of debris flow in cross-section direction. Debris flow dispersion angle should be in the range of 10～60 ° . However, the maximum expanse of debris flow in cross-section direction is 30 times of flow width of debris flow at the reference point.

Gradient of ground 2 degrees is, for example, at the point where the relative height difference from the point which is separated 200m by horizontal distance upstream is smaller than 7.0m and the lower point can be set as the bottom of the sediment-related disaster warning area.

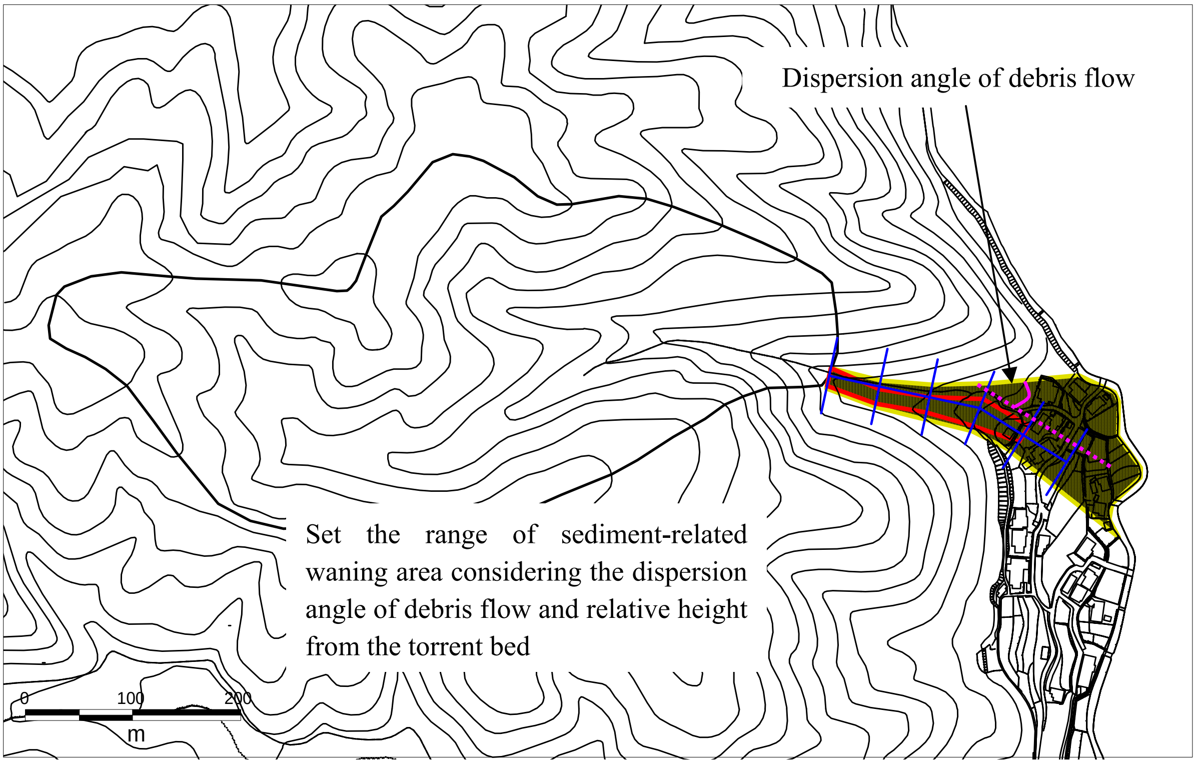

Figure-3.1 Example of setting of sediment-related disaster warning area etc.