

# DEBRIS FLOW

TAMOTSU TAKAHASHI

*Disaster Prevention Research Institute, Kyoto University*



*Published for the International Association for Hydraulic Research by*  
A.A.BALKEMA / ROTTERDAM / BROOKFIELD / 1991



# Table of contents

PREFACE	IX
1 THE NATURE OF DEBRIS FLOW OBSERVED IN SOME MOUNTAIN TORRENTS	1
1.1 Observation at the gully Kamikamihorizawa of Mt. Yakedake, Japan	1
1.1.1 Process of generation of debris flow	2
(a) The situation of occurrence	2
(b) Rainfall condition for occurrence of debris flow	2
1.1.2 Process of flow	5
(a) Behavior of flow	5
(b) The translation velocity of the forefront	5
(c) The origin of the flow material	8
(d) Specific density and the pressure in the flow	10
1.1.3 Process of deposition	11
(a) Stoppage of the debris flow and the arrival distance	11
(b) Characteristics of the debris lobes and their distribution on the debris fan	12
(c) Topographical change on the debris fan	14
1.2 Observation at some other basins in Japan	15
1.2.1 Observation at the Name River	15
1.2.2 Observation in the gullies on the Sakurajima Volcano	17
1.2.3 Observation in the experimental basin of the Hodaka Sedimentation Observatory	19
1.3 Observation at Jiang-Jia Ravine, China	19
1.3.1 Process of occurrence of the debris flow	21
1.3.2 Particle size	23
1.4 Observation at Mt. Thomas, North Canterbury, New Zealand	23
2 MECHANICS OF FLOW	26
2.1 Momentum conservation equations	26
2.2 Constitutive relations	27

2.3	Debris flows in the inertial range	32
2.3.1	Stony debris flow	32
	(a) The first approximation	32
	(b) The second approximation	36
	(c) Comparison to the field data	40
2.3.2	Immature debris flow	41
	(a) Definition and thickness of particle flowing layer	41
	(b) Velocity distribution	43
	(c) Resistance formula	45
	(d) Sediment discharge	46
	(e) Cross-sectional mean solids concentration	47
2.3.3	Turbulent mud flow	48
	(a) Modeling of the flow	48
	(b) Resistance law	50
	(c) Kármán constant	51
2.3.4	A hybrid of stony and muddy debris flows	52
2.3.5	Existence criteria of various type flows	55
2.4	Debris flow in the macro-viscous range	57
2.4.1	Mechanics of flow	57
2.4.2	Existing criteria of the flow in the viscous range	59
2.4.3	Solids concentration	61
3	PROCESSES OF OCCURRENCE, DEVELOPMENT AND DECLINATION	63
3.1	Mechanism of occurrence	63
3.1.1	Debris flow produced by appearance of/increase in surface water flow on the gully bed	63
3.1.2	Liquefaction of landslide mass	70
3.1.3	Debris flow generation due to natural dam collapse	73
	(a) Erosive destruction due to overtopping	74
	(b) Abrupt sliding collapse	75
	(c) Progressive failure	75
3.2	Formation of hydrograph	75
3.2.1	Development of a debris flow on a varying slope bed	75
	(a) Description of the process	75
	(b) Fundamental equations	76
	(c) Comparison of experimental results with calculated ones	79
3.2.2	Debris flow due to landslide dam failure	83
	(a) Debris flow prediction model for the overtopping type failure	83
	(b) Debris flow prediction model for the instantaneous slip failure type	85
	(c) Debris flow prediction model for the progressive failure type	89

3.3	Deformation of hydrograph	90
3.3.1	Kinematic wave theory	90
3.3.2	The big mud flow in the Stava River, Italy	92
4	CHARACTERISTICS OF FULLY DEVELOPED FLOW	100
4.1	Model of quasi-steady flow and the shape of the snout	100
4.2	Roll waves	103
4.3	Mechanics of accumulation of boulders at front of debris flow	105
4.3.1	Mechanism of particle segregation in a stony debris flow	105
4.3.2	A numerical simulation of convergence of larger particles to the front	110
4.4	Transportation of huge stones	113
4.5	Debris flow around bend	116
5	PROCESSES OF DEPOSITION	121
5.1	Stoppage of inertial stony debris flow	121
5.2	Analysis of deposition in the channel of constant width	124
5.2.1	Surface slope on the deposit of a stony debris flow	124
5.2.2	Longitudinal profile of the deposit of stony debris flow	125
	(a) In the case of $\theta_d \leq \gamma$	125
	(b) In the case of $\gamma < \theta_d < \theta_c$	127
5.2.3	Numerical simulation of the depositing process of a stony debris flow	129
5.2.4	Analysis of deposition of turbulent muddy flow	132
5.3	The debris cone formation process	134
5.3.1	Description of the experimental results	134
5.3.2	Numerical simulation	136
	(a) Fundamental equations	136
	(b) Verification of the mathematical model by experiment	138
5.3.3	Particle size distribution in the debris cone	140
	(a) Field and experimental data	140
	(b) Mathematical model	141
5.3.4	Analyses of the actual debris flow/mud flow deposition	145
	(a) Horadani debris flow	145
	(b) Armero mud flow	147
	APPENDIX – NOTATIONS	155
	REFERENCES	161