

PRINCIPLES OF SEDIMENT TRANSPORT
IN
RIVERS, ESTUARIES AND COASTAL SEAS

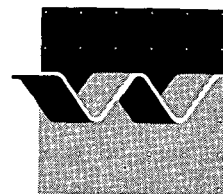
INSTITUT FÜR WASSERBAU
UND WASSERWIRTSCHAFT
TECHNISCHE HOCHSCHULE DARMSTADT
PETERSENSTR. 13, 64287 DARMSTADT
Tel. 0 61 51/16 21 43 • Fax: 16 32 43

Juv. - Nr. : 2773

Book 2



University of Utrecht
Department of Physical Geography



Delft Hydraulics

Bibliothek Wasser und Umwelt
(TU Darmstadt)



61520210

CONTENTS

1	INTRODUCTION	1.1
1.1	Definitions	1.1
1.2	History	1.3
1.3	Symbols and units	1.4
1.4	Characteristic parameters	1.5
2	FLUID VELOCITIES AND BED SHEAR STRESSES	2.1
2.1	Introduction	2.1
2.2	Currents	2.1
2.2.1	Current boundary layer	2.1
2.2.2	Hydraulic regimes	2.2
2.2.3	Velocity distribution over the depth	2.4
2.2.4	Fluid mixing coefficient	2.4
2.2.5	Bed-shear stress and bed friction	2.5
2.3	Waves	2.7
2.3.1	Near-bed orbital velocities	2.7
2.3.2	Wave-boundary layer	2.9
2.3.3	Hydraulic regimes in waves	2.10
2.3.4	Velocity distribution in wave boundary layer	2.11
2.3.5	Bed-shear stress and bed friction	2.15
2.3.6	Breaking waves	2.18
2.3.7	Mass transport in non-breaking waves	2.20
2.3.8	Mass transport by breaking waves	2.28
2.4	Combined current and waves	2.28
2.4.1	Introduction	2.28
2.4.2	Wave characteristics	2.29
2.4.3	Current velocities and bed-shear stresses	2.29
	References	2.48
3	FLUID AND SEDIMENT PROPERTIES	3.1
3.1	Fluid properties	3.1
3.1.1	Introduction	3.1
3.1.2	Fluid density	3.1
3.1.3	Fluid viscosity	3.1
3.2	Sediment properties	3.3
3.2.1	Introduction	3.3
3.2.2	Density and porosity	3.5
3.2.3	Shape	3.7
3.2.4	Size	3.9
3.2.5	Particle fall velocity	3.11
3.2.6	Angle of (natural) repose	3.17
	References	3.19
4	INITIATION OF MOTION	4.1
4.1	Initiation of motion in currents	4.1
4.1.1	Introduction	4.1
4.1.2	Critical bed-shear stress	4.1
4.1.3	Critical depth-averaged velocity	4.14
4.1.4	Design of stable channels	4.16
4.1.5	Examples and problems	4.19

CONTENTS (continued)

4.2	Initiation of motion in waves	4.23
4.2.1	Critical velocity	4.23
4.2.2	Critical bed-shear stress	4.23
4.2.3	Examples and problems	4.25
4.3	Initiation of motion for combined currents and waves	4.27
4.3.1	Critical bed-shear stress	4.27
4.3.2	Examples and problems	4.29
4.4	Initiation of suspension in currents	4.31
4.4.1	Critical bed-shear stress	4.31
4.4.2	Critical depth-averaged velocity	4.32
4.4.3	Examples and problems	4.32
	References	4.34
5	BED FORMS	5.1
5.1	Introduction	5.1
5.2	Bed forms in unidirectional currents	5.1
5.2.1	Classification	5.1
5.2.2	Shape and dimensions of bed forms	5.7
5.2.3	Examples and problems	5.22
5.3	Bed forms in non-steady currents	5.24
5.3.1	Non-steady river flow	5.24
5.3.2	Tidal flow	5.28
5.3.3	Examples and problems	5.32
5.4	Bed forms in waves	5.32
5.4.1	Classification	5.32
5.4.2	Shape and dimensions of bed forms	5.33
5.4.3	Examples and problems	5.42
5.5	Bed forms in currents and waves	5.43
5.5.1	Classification	5.43
5.5.2	Shape and dimensions of bed forms	5.46
5.5.3	Examples and problems	5.51
	References	5.53
6	EFFECTIVE BED ROUGHNESS	6.1
6.1	Introduction	6.1
6.2	Current-related bed roughness	6.1
6.2.1	Introduction	6.1
6.2.2	Available methods	6.1
6.2.3	Methods based on bed-form parameters	6.1
6.2.4	Methods based on integral parameters	6.11
6.2.5	Comparison of methods	6.15
6.2.6	Examples and problems	6.16
6.3	Wave-related bed roughness	6.18
6.3.1	Available method	6.18
6.3.2	Examples and problems	6.21
6.4	Bed roughness in combined currents and waves	6.23
6.4.1	Available method	6.23
6.4.2	Examples and problems	6.24
	References	6.26

CONTENTS (continued)

7	BED MATERIAL SUSPENSION AND TRANSPORT IN STEADY UNIFORM CURRENTS	7.1
7.1	Introduction	7.1
7.2	Bed-load transport	7.2
7.2.1	Introduction and definitions	7.2
7.2.2	Characteristics of moving bed-load particles	7.4
7.2.3	Particle pick-up from the bed	7.13
7.2.4	Deterministic bed-load transport formulae	7.20
7.2.5	Bed-load transport at low shear stress	7.29
7.2.6	Bed-load transport at steep slopes	7.29
7.2.7	Bed-load transport of non-uniform material	7.33
7.2.8	Comparison of bed-load transport formulae	7.38
7.2.9	Stochastic bed-load transport formulae	7.38
7.2.10	Examples and problems	7.43
7.3	Suspended load transport	7.49
7.3.1	Introduction	7.49
7.3.2	Mass balance equation suspended sediment	7.51
7.3.3	Fluid and sediment mixing coefficient	7.53
7.3.4	Concentration profiles	7.55
7.3.5	Velocity profiles in lower regime	7.59
7.3.6	Reference concentration and reference level	7.61
7.3.7	Suspended sediment size in case of non-uniform bed material	7.65
7.3.8	Suspended load transport rates	7.67
7.3.9	Stratification effects in high-concentration suspensions	7.75
7.4	Total load transport	7.91
7.4.1	Prediction methods	7.91
7.4.2	Comparison of methods	7.95
7.4.3	Examples and problems	7.98
	References	7.105
8	BED MATERIAL SUSPENSION AND TRANSPORT IN WAVES	8.1
8.1	Introduction	8.1
8.2	Identification of transport processes	8.2
8.2.1	Non-breaking waves	8.2
8.2.2	Breaking waves	8.8
8.2.3	Vector presentation of fluxes	8.10
8.3	Analysis of measured concentration profiles and transport rates	8.11
8.3.1	Instantaneous concentrations	8.11
8.3.2	Time-averaged concentrations	8.15
8.3.3	Sediment load and transport rate	8.27
8.4	Computation of time-averaged concentration profiles	8.35
8.4.1	Introduction	8.35
8.4.2	Time-averaged convection-diffusion equation	8.36
8.4.3	Particle size of suspended sediment	8.38
8.4.4	Sediment mixing coefficient for non-breaking waves	8.38
8.4.5	Sediment mixing coefficient for breaking waves	8.46
8.4.6	Reference concentration in near-bed region	8.48
8.4.7	Methods for computation of time-averaged concentration profiles	8.51

CONTENTS (continued)

8.5	Computation of sediment transport rates	8.58
8.5.1	Introduction	8.58
8.5.2	Sediment transport models	8.58
8.5.3	Sediment transport formulae	8.59
8.5.4	Influence of bed slope on bed-load transport	8.67
8.6	Examples and problems	8.68
	References	8.73
9	BED MATERIAL SUSPENSION AND TRANSPORT IN COMBINED WAVES AND CURRENTS	9.1
9.1	Introduction	9.1
9.2	Analysis of measured concentration profiles and transport rates	9.1
9.2.1	Time-averaged concentration profiles	9.1
9.2.2	Sediment transport rates	9.9
9.3	Computation of time-averaged concentration profiles	9.16
9.3.1	Methods	9.16
9.3.2	Comparison of measured and computed concentration profiles	9.17
9.4	Computation of sediment transport in non-breaking waves	9.24
9.4.1	Methods	9.24
9.4.2	Comparison of measured and computed transport rates	9.27
9.5	Computation of sediment transport in breaking waves	9.29
9.5.1	Methods	9.29
9.5.2	Comparison of measured and computed transport rates	9.33
9.6	Examples and problems	9.34
	References	9.37
10	BED MATERIAL TRANSPORT, EROSION AND DEPOSITION IN NON-STEADY AND NON-UNIFORM FLOW	10.1
10.1	Introduction	10.1
10.2	Sediment transport in non-steady flow	10.1
10.2.1	River flow	10.1
10.2.2	Tidal flow	10.1
10.3	Sediment transport in non-uniform conditions	10.10
10.3.1	General	10.10
10.3.2	Erosion and scour near structures	10.14
10.3.3	Deposition in channels	10.19
	References	10.29
11	TRANSPORT OF COHESIVE MATERIALS	11.1
11.1	Introduction	11.1
11.2	Cohesion, plasticity, viscosity and yield stress	11.2
11.3	Flocculation	11.7
11.4	Settling	11.9
11.4.1	Influence of salinity	11.9
11.4.2	Influence of concentration	11.9
11.4.3	Influence of water depth and flow velocity	11.11
11.4.4	Influence of measuring instrument	11.12

CONTENTS (continued)

11.5	Deposition	11.15
11.5.1	Introduction	11.15
11.5.2	Concentrations larger than 10 kg/m^3	11.15
11.5.3	Concentrations from 0.3 to 10 kg/m^3	11.15
11.5.4	Concentrations smaller than 0.3 kg/m^3	11.19
11.5.5	Critical bed-shear stress for deposition	11.21
11.5.6	Deposition rates	11.22
11.6	Consolidation	11.22
11.7	Erosion	11.28
11.7.1	Introduction	11.28
11.7.2	Consolidated hard deposits	11.29
11.7.3	Consolidated soft deposits	11.31
11.7.4	Erosion rates	11.34
11.7.5	Bed forms and roughness	11.34
11.8	Transport of mud by currents	11.35
11.8.1	(Quasi) steady flow	11.35
11.8.2	Non-steady (tidal) flow	11.36
11.9	Transport of mud by waves	11.42
	References	11.46
12	MATHEMATICAL MODELS OF SEDIMENT TRANSPORT	12.1
12.1	Introduction	12.1
12.2	Flow models	12.2
12.2.1	Introduction	12.2
12.2.2	Three-dimensional flow models	12.3
12.2.3	Two-dimensional horizontal flow model for estuaries and seas	12.8
12.2.4	Two-dimensional vertical flow model	12.10
12.2.5	One-dimensional flow model for rivers or estuaries	12.11
12.3	Wave models	12.14
12.3.1	Introduction	12.14
12.3.2	Basic equations	12.14
12.3.3	Two-dimensional horizontal models for combined refraction, diffraction, shoaling and dissipation	12.16
12.3.4	Two-dimensional models for combined refraction, shoaling and dissipation	12.21
12.4	Sediment transport and morphological models	12.26
12.4.1	Introduction	12.26
12.4.2	Basic equations of sediment transport	12.26
12.4.3	Three-dimensional models	12.38
12.4.4	Two-dimensional vertical models	12.42
12.4.5	Two-dimensional horizontal models	12.50
12.4.6	One-dimensional models	12.55
	References	12.58

CONTENTS (continued)

13	MEASURING INSTRUMENTS FOR SEDIMENT TRANSPORT, SETTLING VELOCITY AND WET BULK DENSITY	13.1
13.1	Introduction	13.1
13.2	Measuring facilities	13.1
13.3	Measuring principles	13.3
13.3.1	Suspended load transport	13.3
13.3.2	Bed-load transport	13.4
13.4	Measuring statistics	13.6
13.4.1	General aspects	13.6
13.4.2	Sampling site	13.6
13.4.3	Number of measurements for suspended load transport	13.6
13.4.4	Number of measurements for bed-load transport	13.15
13.4.5	Sampling frequency	13.16
13.5	Computation of sediment transport	13.17
13.5.1	Suspended load transport per unit width	13.17
13.5.2	Total load transport per unit width	13.22
13.5.3	Total load transport in cross-section	13.22
13.5.4	Tide-integrated total load	13.24
13.6	Instruments for bed-load transport	13.25
13.6.1	Introduction	13.25
13.6.2	Trap sampling	13.25
13.6.3	Bed-form tracking	13.32
13.7	Instruments for suspended load transport	13.33
13.7.1	Introduction	13.33
13.7.2	Bottle and trap samplers	13.34
13.7.3	Pump samplers	13.48
13.7.4	Optical and acoustical samplers	13.53
13.7.5	Comparison of suspended load samplers	13.60
13.7.6	Selection of suspended load sampler	13.63
13.8	Instruments for particle size and settling velocity	13.65
13.8.1	General aspects	13.65
13.8.2	Sieve instruments	13.66
13.8.3	Sedimentation methods	13.67
13.8.4	Coulter Counter	13.72
13.8.5	In-situ Laser diffraction	13.72
13.8.6	In-situ video camera	13.73
13.8.7	Selection of instruments	13.73
13.9	Instruments for bed material sampling	13.74
13.9.1	Introduction	13.74
13.9.2	Grab, dredge and scoop samplers	13.75
13.9.3	Core samplers	13.75
13.10	Instruments for in-situ measurement of wet bulk density	13.76
13.10.1	General aspects	13.76
13.10.2	Mechanical core sampler	13.76
13.10.3	Acoustic probe	13.77
13.10.4	Nuclear radiation probe	13.77
	References	13.81

- APPENDICES**
- A:** TRANSPOR-program; Computation of sediment transport in current and in wave direction
 - B:** Sand transport in closed conduits
 - C:** Side-wall roughness correction method of Vanoni-Brooks
 - D:** Pollution aspects of sediments