## Contents

	Preface Variables	X
1	Introduction	
	1.1 Background	
	1.2 Contents of this book	
2	Surge overflow, wave overtopping, and combination	
	2.1 Surge overflow	
	2.1.1 Surge overflow discharge	
	2.1.2 Critical water depth and velocity	
	2.1.3 Shear stress of surge overflow	
	2.2 Wave overtopping	
	2.2.1 Processes of overtopping	
	2.2.2 Average overtopping discharge	
	2.2.3 Distribution of individual overtopping volumes	]
	2.2.4 Probability of overtopping	
	2.3 Combined wave and surge overtopping	1
	2.3.1 Combined wave and surge overtopping discharge	]
	2.3.2 Distribution of individual overtopping volumes	1
	2.3.3 Hydraulic parameters on the landward side slope of levees	1
	2.5.5 Tryulaute parameters on the randward-side slope of levees	-
	2.4 Turbulence measurement	
	2.4.2 Turbulent shear stress	
3	Three strengthening systems	1
	3.1 Background	
	3.2 Three innovative levee-overtonning protection methods	
	3.2.1 High-performance turf reinforcement mats (HPTRM)	-
	3.2.2 Articulated Concrete Block (ACB) system	
	3.2.3 Roller Compaction Concrete (RCC)	4
	3.2.4 Environmental impact of three levee-strengthening systems	,

	3.3 Material properties of the three strengthening systems	26		
	3.3.1 Testing methods and properties results of HPTRM	26		
	3.3.2 Testing methods and properties results of ACB	31		
	3.3.3 Testing methods and properties results of RCC	33		
4	Full-scale physical model testing of levee overtopping	38		
	4.1 Full-scale test model setup	38		
	4.1.1 Test facility	38		
	4.1.2 Levee embankment setup	38		
	4.1.3 Wave generator	40		
	4.1.4 Pump system	42		
	4.2 Installation of levee-strengthening layers	42		
	4.2.1 Installation of HPTRM test section and maintenance	42		
	4.2.2 Installation of ACB test section	44		
	4.2.3 Installation of RCC test section	48		
	4.3 Instrumentation and data collection	49		
	4.3.1 Hydraulic instrumentation	49		
	4.3.2 Data processing	51		
	4.4 Testing procedures	53		
	4.4.1 HPTRM test section	54		
	4.4.2 ACB test section	55		
	4.4.3 RCC test section	55		
	4.5 Erosion check method	57		
	4.5.1 HPTRM test section	57		
	4.5.2 ACB test section	58		
	4.5.3 RCC test section	59		
	4.6 Scale, model, and measurement effects	60		
5	Testing of erosion function apparatus			
	5.1 Erosion Function Apparatus (EFA)	61		
	5.2 EFA tests	62		
	5.3 Test results	62		
6	Hydraulic parameters of combined wave and surge overtopping	66		
	6.1 Distribution of incident wave	66		
	6.2 Wave overtopping patterns	68		
	6.3 Hydraulic parameters of surge-only overflow	71		
	6.3.1 Surge-only overflow discharge	71		
	6.3.2 Flow thickness on landward-side slope	72		
	6.3.3 Average flow velocity on landward-side slope	73		
	6.4 Combined wave and surge overtopping discharge	74		
	6.4.1 Combined wave and surge overtopping discharge	74		
	6.4.2 Distribution of individual overtopping volumes	75		
	6.4.3 Distribution of instantaneous overtopping discharge	80		

	6.5	Hydraulic parameters of landward-side slope	83
		0.5.1 Average now thickness and now velocity on	01
		6.5.2 Characteristic wave heights on landward side slope	04 85
		6.5.2 Characteristic wave heights on landward-side slope	80
		$6.5.5$ Estimation of $m_{rms}$ on randward-side slope	89
	6.6	Standardized analysis of hydraulic narameters of combined and	07
	0.0	Surge evertenning	00
		6.6.1 Surge-only overflow and combined wave and surge	90
		overtonning discharge	91
		6.6.2 Average flow thickness on landward-side slope	92
		6.6.3 Average flow velocity on landward-side slope	93
	67	Shear stress	93 04
	0.7	671 Shear stress calculation	94
		672 Shear stress analysis	95
		673 Estimation of shear stresses on landward-side slope	97
		5.7.5 Estimation of shear stresses on fundward side stope	21
7	Tur	bulent analysis	99
	7.1	Measurement setup	99
		7.1.1 Model setup and instrumentation	99
		7.1.2 Data collection and initial analyses	103
	7.2	Overtopping discharge	104
	7.3	Turbulent intensity of overtopping flow	108
		7.3.1 Turbulence velocity fluctuations	108
		7.3.2 New formula for turbulent intensity on the crest and	
		the land-side slope	110
	7.4	Turbulent shear stress	112
		7.4.1 Log profile method	113
		7.4.2 Reynolds stress and turbulent kinetic energy methods	114
		7.4.3 Nadal and Hughes' method	118
		7.4.4 New formulas for shear stress estimation on the crest and	
		on the land-side slope	119
8	Hv	draulic erosion on landward-side slone of levees and concentual	
0	mo	del of soil loss from levee surface	122
	8 1	Hydraulic grosion on landward side slone of levees	122
	0.1	8.1.1. Hydraulic erosion on the RCC test section	122
		8.1.2 Hydraulic erosion on the ACB test section	122
		813 Hydraulic erosion on the HPTRM test section	120
	8 2	Concentual model of soil loss from love surface	125
	0.2	8 2 1 Definition	135
		8.2.2 Soil eradibility of HPTPM	133
		8.2.2 Son croutonity of the riking	13/
		8.2.4 Early remodes of HDTP M strengthand lava	130
		0.2.+ ranule modes of fir i Kivi-strengthened levee	140

x Conten	ts
----------	----

9	Nu	merical s	study of combined wave overtopping and storm surge		
	ove	rflow of	strengthened levee	142	
	9.1	Princet	on Ocean Model (POM) method	142	
		9.1.1 N	umerical methodology	143	
		9.1.2 S	ensitivity analyses	146	
		9.1.3 N	Iodel calibration	148	
		9.1.4 St	torm surge overflow discharge	149	
		9.1.5 C	ombined wave and storm surge overtopping discharge	150	
		9.1.6 F	low parameters on the HPTRM-strengthened levee slope	154	
		9.1.7 A	verage flow thickness at the landward-side slope toe	155	
		9.1.8 T	ime series upcrossing analysis	156	
		9.1.9 E	stimation of wavefront velocity on the landward-side slope	159	
	9.2	Smooth	ned Particle Hydrodynamic (SPH) method	160	
		9.2.1 N	Jumerical methodology	161	
		9.2.2 N	Jumerical wave generator	164	
		9.2.3 S	ensitivity analysis	164	
		9.2.4 A	verage overtopping discharge for combined wave and		
		SI	arge overtopping	165	
		9.2.5 F	low parameters on the landward levee slope	171	
10	Nu	merical	study of turbulence overtopping and erosion	176	
	10.	1 Nume	rical methodology	177	
		10.1.1	Governing equations	177	
		10.1.2	Boundary condition	178	
		10.1.3	Model setup	180	
		10.1.4	Numerical scheme	181	
		10.1.5	Random wave generation	181	
	10.2 Model calibration				
	10	3 Storm	surge overflow erosion	185	
	10.4	4 Comb	ined wavelsurge overtopping shear stress, turbulence, and erosion	185	
		10.4.1	Turbulent shear stress	186	
		10.4.2	Turbulent kinetic energy	188	
		10.4.3	Prediction of erosion rate at the toe of landward-side slope	190	
	10	5 Erodil	bility and failure of HPTRM-strengthened levee under		
		differe	ent overtonning conditions	194	
		10.5.1	Turf-element model and HPTR M-element model	194	
		10.5.2	Characterization of HPTRM-element model	195	
		10.5.3	Failure process of HPTRM-strengthened levee against		
			steady overtopping	195	
		10.5.4	Failure process of HPTRM-strengthened levee against		
			combined overtopping	196	
		10.5.5	Discussion on validation of the proposed analytic equation	200	
		10.5.6	Discussion on linear relationship for HPTRM-strengthened clay	204	
	D4	Contractor		207	
	кеј	erences		207	

Rejerences			
Index			