

Table of contents

PREFACE.....	V
SUMMARY	VII
LIST OF FIGURES	XV
LIST OF TABLES	XIX
1 INTRODUCTION.....	1
1.1 BACKGROUND.....	1
1.2 PROBLEM DESCRIPTION.....	1
1.3 PREVIOUS RESEARCH	1
1.4 RESEARCH OBJECTIVE	1
1.5 RESEARCH QUESTIONS	2
1.6 STRUCTURE OF THE REPORT	2
PART 1: LITERATURE STUDY	
2 THE DESIGN OF THE CURRENT BARRIER	6
2.1 HISTORY	6
2.2 DELTA PLAN.....	6
2.3 CLOSABLE STORM SURGE BARRIER	7
2.4 DESIGN OF THE STORM SURGE BARRIER	8
2.4.1 <i>Boundary conditions</i>	8
2.4.2 <i>Overall design</i>	8
2.4.3 <i>Bottom consolidation</i>	8
2.4.4 <i>Piers</i>	10
2.4.5 <i>Construction of the other parts</i>	10
2.5 SETTLEMENTS AND MAINTENANCE	10
2.6 FUTURE OF THE BARRIER	11
2.6.1 <i>Future vision of the Delta committee</i>	11
2.6.2 <i>Sea level rise</i>	11
2.7 SUMMARIZED	12
3 STRUCTURAL DESIGNS FOR LIFTING SLIDES.....	13
3.1 OTHER WATER BARRIERS WITH LIFTING SLIDES	13
3.1.1 <i>Hartel barrier</i>	13
3.1.2 <i>Storm surge barrier Hollandse IJssel</i>	13
3.2 CONCEPTS FOR SLIDES IN THE EASTERN SCHELDT BARRIER	14
3.2.1 <i>Concepts Veraart</i>	14
3.2.2 <i>Concepts Van der Laken</i>	15
3.2.3 <i>Concepts concrete slides</i>	17
3.2.4 <i>Analysis of concepts</i>	18
3.3 HYDRAULIC DESIGN CONSIDERATIONS FOR LIFTING SLIDES	18
3.3.1 <i>Vibrations by flow</i>	18
3.3.2 <i>Wave impact loads</i>	19
3.4 SUMMARIZED	20
4 FIBRE REINFORCED POLYMERS	21

4.1	HISTORY	21
4.2	GENERAL	22
4.3	REINFORCEMENTS.....	22
4.3.1	<i>Glass fibres</i>	22
4.3.2	<i>Carbon fibres</i>	23
4.3.3	<i>Polyaramid fibres</i>	23
4.3.4	<i>Other reinforcements types</i>	23
4.3.5	<i>Reinforcement forms</i>	23
4.4	RESINS	24
4.4.1	<i>Unsaturated polyester resins</i>	25
4.4.2	<i>Vinyl ester resins</i>	25
4.4.3	<i>Epoxy resins</i>	25
4.4.4	<i>Other resin types</i>	25
4.5	CORES	25
4.5.1	<i>Foam</i>	25
4.5.2	<i>Honeycomb</i>	26
4.5.3	<i>Balsa wood</i>	26
4.6	MANUFACTURING PROCESSES	26
4.6.1	<i>Open mold processes</i>	27
4.6.2	<i>Closed mold processes</i>	28
4.6.3	<i>Continuous processes</i>	31
4.6.4	<i>Comparison manufacturing methods</i>	31
4.7	CHARACTERISTICS OF FIBRE REINFORCED POLYMERS	32
4.7.1	<i>Durability</i>	32
4.7.2	<i>Sustainability</i>	33
4.7.3	<i>Fire resistance</i>	33
4.7.4	<i>Mechanical properties</i>	33
4.7.5	<i>Costs</i>	34
4.8	DESIGN CODES	35
4.9	REFERENCE PROJECTS	35
4.9.1	<i>Kreekrak sluices</i>	36
4.9.2	<i>Spiering sluice</i>	36
4.9.3	<i>Minehunter ‘Alkmaarklasse’</i>	37
4.9.4	<i>FRP concept for lifting slide</i>	37
4.10	SUMMARIZED	37

PART 2: MAIN REPORT

5	THE DESIGN OF THE CURRENT SLIDES	40
5.1	THE CLOSURE STRUCTURE	40
5.2	BOUNDARY CONDITIONS	41
5.3	DESIGN CONSIDERATIONS	42
5.4	THE DESIGN	43
5.5	LOADS ON THE SLIDES	46
5.5.1	<i>Horizontal wave and water loads (closed position)</i>	46
5.5.2	<i>Vertical wave loads (during closure)</i>	47
5.5.3	<i>Dead load</i>	47
5.5.4	<i>Torsion</i>	48
5.5.5	<i>Longitudinal loads</i>	48

5.5.6	<i>Ice loads</i>	48
5.5.7	<i>Wind loads</i>	48
5.5.8	<i>Water flows and leakage gaps vibrations</i>	48
5.5.9	<i>Collision</i>	48
5.5.10	<i>Terrorist attack</i>	48
6	DESIGN REQUIREMENTS AND ASSUMPTIONS	49
6.1	GENERAL REQUIREMENTS.....	49
6.2	GEOMETRICAL BOUNDARY CONDITIONS.....	49
6.3	LOADS ON THE SLIDES.....	50
6.4	ASSUMPTIONS.....	51
7	MATERIAL SELECTION	52
7.1	MANUFACTURING METHOD.....	52
7.2	REINFORCEMENT.....	53
7.3	RESIN.....	53
7.4	CORE.....	53
7.5	LAMELLA PROPERTIES.....	54
7.6	SAFETY FACTORS.....	54
7.6.1	<i>Material safety factor</i>	55
7.6.2	<i>Conversion safety factor</i>	55
7.7	FRACTURE CRITERION.....	56
7.8	MATERIAL PROPERTIES (INITIAL DESIGN STAGE).....	57
8	STRUCTURAL CONCEPTS	59
8.1	DESIGN PHILOSOPHY.....	59
8.2	EVALUATION OF PREVIOUS CONCEPTS.....	59
8.3	SANDWICH.....	60
8.3.1	<i>Hand calculation</i>	60
8.3.2	<i>Finite element analysis</i>	61
8.3.3	<i>Conclusion</i>	63
8.4	HORIZONTALLY CURVED SHELL.....	63
8.5	BOX GIRDER.....	64
8.5.1	<i>Straight box girder</i>	65
8.5.2	<i>Varying thickness</i>	69
8.5.3	<i>Manufacturability</i>	75
8.5.4	<i>Hydraulic adjustments</i>	76
8.5.5	<i>Conclusion</i>	76
9	DEFLECTION REQUIREMENT	78
9.1	LESS STRICT REQUIREMENT.....	78
9.2	RIGOROUSLY SOLUTION.....	78
9.2.1	<i>Overall idea</i>	79
9.2.2	<i>Checking the feasibility of the adjustments</i>	80
9.2.3	<i>Concluding</i>	84
9.3	OTHER SOLUTIONS.....	84
9.4	EVALUATION.....	85
9.4.1	<i>Simple comparison of costs</i>	85
9.4.2	<i>Comparison of costs with alternatives on the long term</i>	86
9.4.3	<i>Choice of elaborating short and medium term or long term solution</i>	86

10	FINAL DESIGN.....	88
10.1	ADJUSTMENTS ON MATERIAL PROPERTIES.....	88
10.1.1	<i>Safety factors</i>	88
10.1.2	<i>Lamella properties</i>	88
10.1.3	<i>Strain criterion</i>	88
10.1.4	<i>Core properties</i>	89
10.2	STRUCTURE IN GENERAL.....	89
10.3	STRUCTURAL IMPROVEMENTS.....	90
10.3.1	<i>Decreasing the peaks in the strains</i>	90
10.3.2	<i>Addition of gaps in horizontal plates</i>	92
10.3.3	<i>Optimizing the laminates</i>	93
10.3.4	<i>Adding some additional load cases</i>	94
10.4	FINAL FEA MODEL.....	96
10.4.1	<i>Dimensions</i>	96
10.4.2	<i>Constraints</i>	98
10.4.3	<i>Load cases</i>	98
10.4.4	<i>Load combinations</i>	100
10.4.5	<i>Laminate surfaces</i>	101
10.5	FEA ANALYSIS.....	101
10.5.1	<i>Force distribution</i>	101
10.5.2	<i>Deformations</i>	106
10.5.3	<i>Strains</i>	107
10.6	BUCKLING OF HORIZONTAL PLATES.....	115
10.7	MANUFACTURABILITY.....	116
11	COST COMPARISON.....	117
11.1	COSTS OF VARIANTS.....	117
11.1.1	<i>Raising dikes</i>	117
11.1.2	<i>Dam</i>	118
11.1.3	<i>Rigorously solution</i>	118
11.2	COMPARISON OF VARIANTS.....	119
11.3	LIFE CYCLE ANALYSIS.....	120
12	CONCLUSIONS AND RECOMMENDATIONS.....	122
12.1	CONCLUSIONS OF LITERATURE STUDY.....	122
12.2	CONCLUSIONS OF THE MAIN RESEARCH.....	123
12.3	FINAL CONCLUSION.....	124
12.4	RECOMMENDATIONS.....	124
	REFERENCES.....	126
 APPENDICES		
APENDIX A:	CALCULATION OF LAMELLA PROPERTIES.....	132
APENDIX B:	CALCULATION OF SANDWICH VARIANT.....	134
APENDIX C:	COMPARISON LAMINATE STIFFNESS MATRIX.....	136
APENDIX D:	DISTRIBUTION OF SUPPORT REACTIONS.....	138
APENDIX E:	LOADS SPECIFICATION.....	139

APENDIX F: FINAL DESIGN DLUBAL RFEM..... 166
APENDIX G: EXTRA COSTS RIGOROUSLY SOLUTION 299
APENDIX H: INFORMATION PROVIDED ON DVD 302