Modelling sea dike toe erosion during storms

Thieu Quang Tuan[1]**, Nguyen Quang Luong**[1]**, Le Ngoc Anh**[1]

Abstract: Toe erosion, especially in stormy conditions, is one of the common mechanism causing the failure and instability of the sea dikes and revetments. The erosion intensity becomes more serious at the beaches which is under the impacts of typhoons. Reliable forecasts about the intensity of toe erosion of sea dikes in stormy conditions have important ecnomomic and technical meaning in the design and construction of sea dikes. This study considers and evaluate the extent of the scour in front of the dike toe during the typhoon using the numerical model WADIBE-TC. The protective structures for dike toes consist of buried toes, cylinders and coarse rock apron.

Keywords: sea dike, toe erosion, storm, numerical model, WADIBE

1. Introduction

In the North and Central provinces of Vietnam, toe erosion or foreshore loss is a dangerous and common mechanism causing the failure of the sea dikes, especially when the dikes are constructed in the area having strong erosion development. During storms, the cross-shore sediment transport due to the impacts of waves and storm surges are main causes of the formation of scours in front of the toes and foreshore sink. There are differences with respect to the phenomena, process as well as the training solution between erosion occurring in stormy conditions (due to cross-shore sediment transport processes) and erosion cause by the deficiency of supplementary sediment for the longshore sediment transport. The latter process causes the chronic erosion and it is very expensive to control while the first process is the cause of acute erosion occuring only during stormy conditions. Up to now, in the design of sea dikes, toe erosion calculations all have been based on the empirical formulas set up for vertical walls. Field observations have shown that these formulas have not taken all the influence of the parameter into consideration, and they often produce overestimated results when applied to sea dikes.

For the reasons above, this study considers and evaluate the extent of the scour in front of the dike toe during the typhoon using the numerical model WADIBE-TC developed by Faculty of Marine and Coastal Engineering, Water Resources University, which simulates the time-dependent development of the scour in front of the toes of the structures based on the cross-shore sediment transport modelling. The model is calibrated using the measured data from the wave flume experiment belonging to the Sea Dike Research Project No.3 carried out by Marine and Coastal Engineering Faculty. It is also applied to compute and verify a case study of erosion of Thinh Long dike in Hai Hau, Nam Dinh in Damrey typhoon in 2005.

2. Simulations of some typical toe erosion structures with WADIBE-TC

2.1. Main scenarios

The model simulates 3 types of common toe protection structures: buried toes, cylinders and combination of cylinders and coarse rock apron. Detailed simulation cases are shown in Table 1.

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Table 1. Different scenarios executed in the model

Type of protection	SWL	Wave		Dimension			Duration
	(m)	Hs (m)	Tp (s)	S (m)	L(m)	Crown wall	(hour)
1. Buried toe	0.65	0.3	3	0			2.0- 3.0-4.0-6.0-8.0
	0.65	0.25	3			0.25	2.0- 3.0-4.0-6.0-8.0
	0.65	0.25	3			0.15	2.0- 3.0-4.0-6.0-8.0
	0.65	0.25	3	0			2.0- 3.0-4.0-6.0-8.0
	0.65	0.25	2.5	0			2.0- 3.0-4.0-6.0-8.0
	0.65	0.25	2.5	0.1			2.0- 3.0-4.0-6.0-8.0
	0.65	0.25	2.2	0			2.0- 3.0-4.0-6.0-8.0
	0.65	0.25	2.2	0.1			2.0- 3.0-4.0-6.0-8.0
	0.65	0.25	2.2			0.25	2.0- 3.0-4.0-6.0-8.0
	0.65	0.25	2.5	0		0.15	2.0- 3.0-4.0-6.0-8.0
	0.65	0.25	2.5	0		0.25	2.0- 3.0-4.0-6.0-8.0
	0.65	0.25	2.2	0.1		0.25	2.0- 3.0-4.0-6.0-8.0
	0.65	0.25	2.5	0.1		0.25	2.0- 3.0-4.0-6.0-8.0
2. Cylinder	0.65	0.25	2.5	0			2.0- 3.0-4.0-6.0-8.0
	0.65	0.25	2.5	0.1			2.0- 3.0-4.0-6.0-8.0
	0.65	0.25	2.2	0			2.0- 3.0-4.0-6.0-8.0
	0.65	0.25	2.2	0.1			2.0- 3.0-4.0-6.0-8.0
	0.65	0.25	2.5			0.25	2.0- 3.0-4.0-6.0-8.0
	0.65	0.25	2.2			0.25	2.0- 3.0-4.0-6.0-8.0
	0.65	0.25	2.5			0.3	2.0- 3.0-4.0-6.0-8.0
	0.65	0.25	2.2	0.1		0.3	2.0- 3.0-4.0-6.0-8.0
	0.65	0.25	2.5	0.1		0.3	2.0- 3.0-4.0-6.0-8.0
	0.65	0.25	2.2			0.3	2.0- 3.0-4.0-6.0-8.0
3. Apron	0.65	0.25	2.5	0.1		0.3	2.0- 3.0-4.0-6.0-8.0
	0.65	0.25	2.2	0.1		0.3	2.0- 3.0-4.0-6.0-8.0
	0.65	0.25	2.5		1		2.0- 3.0-4.0-6.0-8.0
	0.65	0.25	2.2		1		2.0- 3.0-4.0-6.0-8.0
	0.65	0.25	2.5		1	0.3	2.0- 3.0-4.0-6.0-8.0
	0.65	0.25	2.2		1	0.3	2.0- 3.0-4.0-6.0-8.0
	0.65	0.25	2.5				2.0- 3.0-4.0-6.0-8.0
	0.65	0.25	2.2				2.0- 3.0-4.0-6.0-8.0

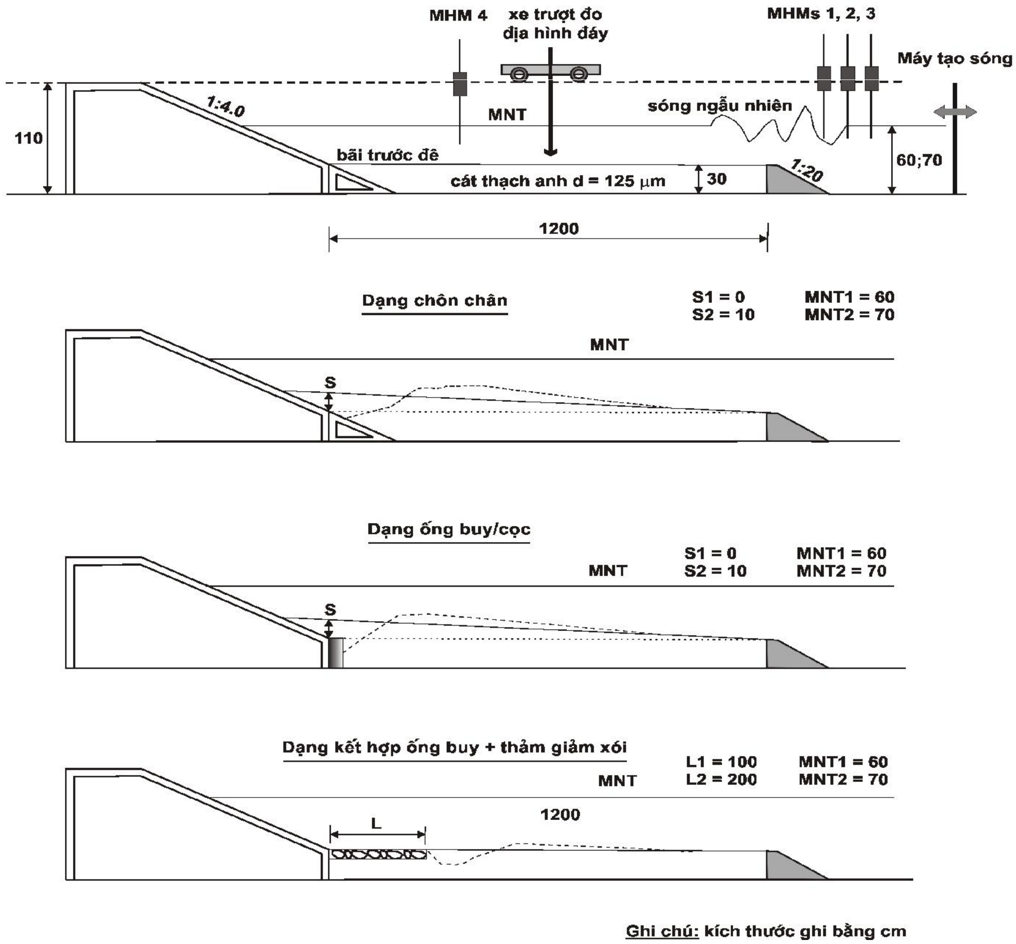
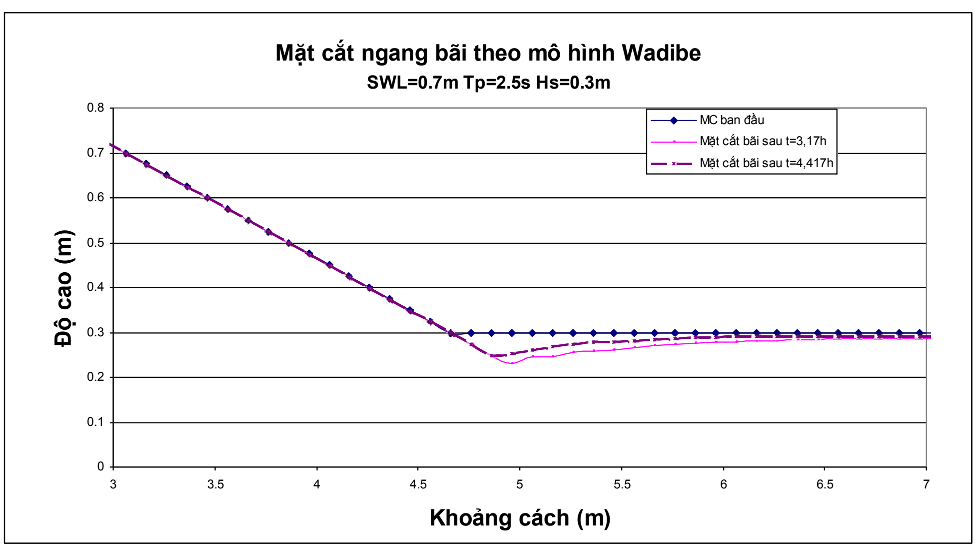


Figure 1. Different toe erosion test cases carried out in the wave flume

2.2. Model calibration



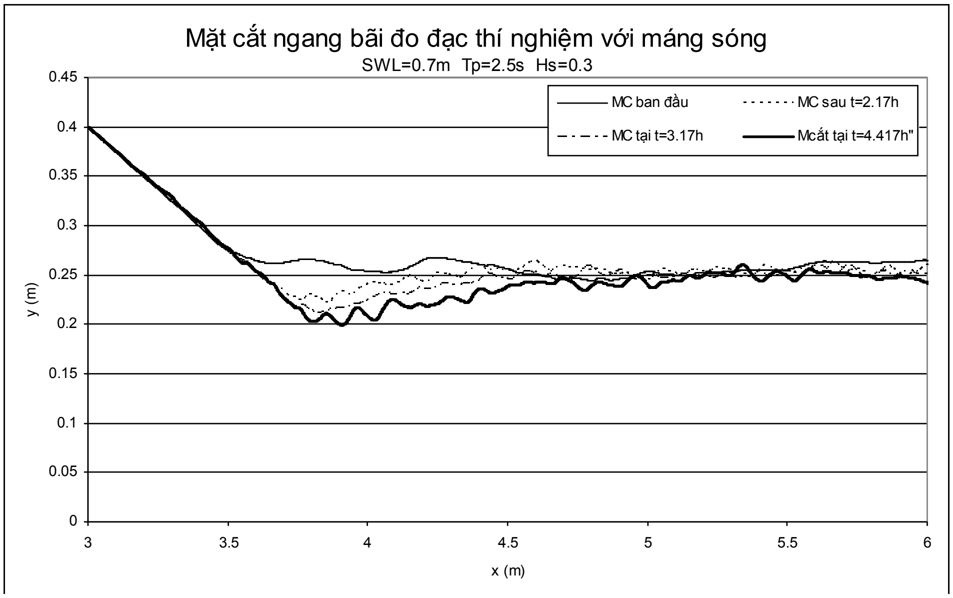


Figure 2. Scour development over time: result from numerical model (upper) and measurement in wave flume test (lower)(water depth = 0,7m, Hs = 0,3m and Tp =2,5s)

Table 2 - Comparison with physical modelling results

Buried toe	**SWL (m)**	**Wave conditions** H_s **(m)**	H_{rms}	**Tp (s)**	**Dimension** **S (m)**	**L (m)**	**Duration (h)**	**Scour depth** h_x **(cm)**	**Scour length** L_x **(m)**	**Ratio** h_x/H_s
Numerical model	0.7	0.3	0.21	2.5	0		2.17	3	0.5	0.138
	0.7	0.3	0.21	2.5	0		3.17	5.3	1.5	0.244
	0.7	0.3	0.21	2.5	0		4.417	7	2	0.323
Physical model	0.7	0.3	0.21	2.5	0		2.17	3	0.3	0.1
	0.7	0.3	0.21	2.5	0		3.17	5	1	0.23
	0.7	0.3	0.21	2.5	0		4.417	6.5	1.7	0.3

3. Result analysis

Geometrical conditions have considerable influence on the dimensions of the scour in front of the toe of the dike. In more detail, the steeper is the dike slope, the deeper is the scour and vice versa. Erosion intensities are different with different types of toe protection structures. Buried toe type create the deepest scour, next is the coarse rock apron type and the last is cylinder type. The cylinder type of toe protection structures create rather shallow scour due to the limitation of the numerical model, which does not take the reflective waves into consideration.

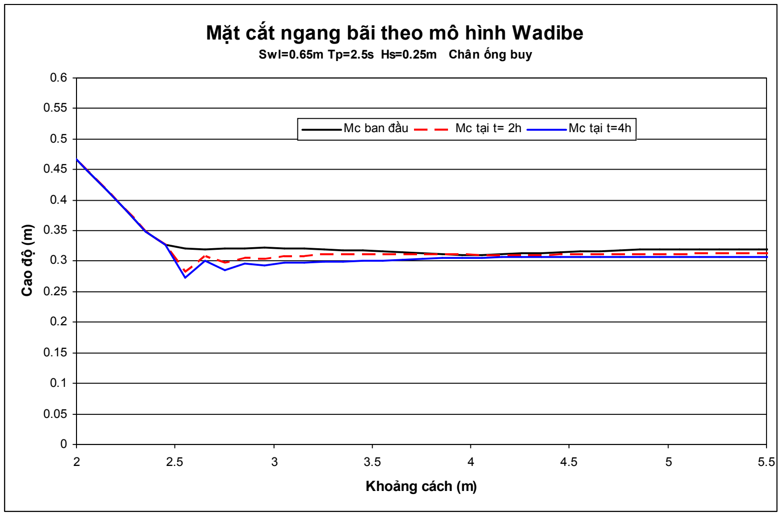


Figure 6. Scour development over time in case the toe protection structure is cyclinder

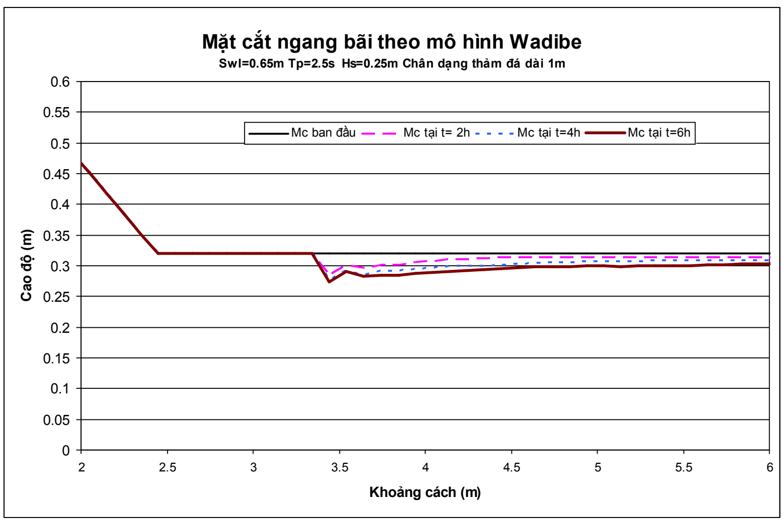


Figure 7. Scour development over time in case the toe protection structure is a coarse rock apron

Different types of toe protection structures create different extent of scour. In more detail, buried toe and coarse rock apron types create rather scours with a length of 0.5-1m while the cylinder type creates steep scour with small extent (less than 0.5m) close to the toe of the dike. Time for the full development of the scour in the wave flume test is 4 – 5 hours. The cylinder type for toe protection has the fastest time for the scour to reach the equilibrium. In case of the buried toe type, the time for the full development of the scour can reach 6 hours.

Numerical model takes the influence of the foreshore slope on the development of the scour into consideration. The foreshore with steeper slope has more erosion. According to the simulation results, the erosion processes start with the cover sand layer on the toe and then with the sand at the toe. Consequently, the quantity of sand taken out at the toe decreases resulting in the decrease of structural failure of the toe protection structures. This simulation results have special meaning in determining the quantity of sand to be put at the toe in case the beach nourishment solution is applied.

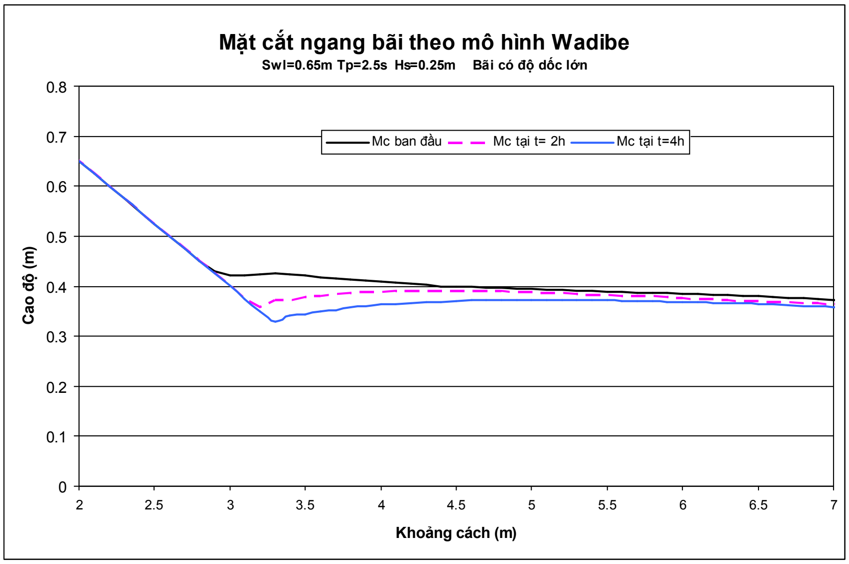


Figure 8. Scour development over time in case of a steep sloping foreshore

According to the simulation results, a crown wall of more than 25cm can increase the erosion intensity at the toe. Besides, the toe protection structures with the crown wall combined with the cylinders create deeper scour compared with the combination of crown wall and the coarse rock apron. These results are fairly suitable to the results of physical model in the wave flume.

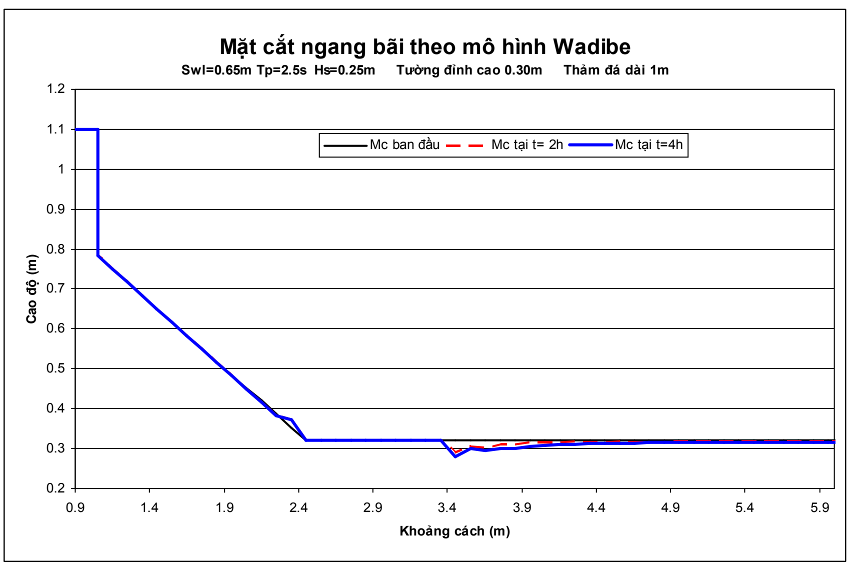


Figure 9. Scour development over time with the combination of crown wall and coarse rock apron as the toe protection structures

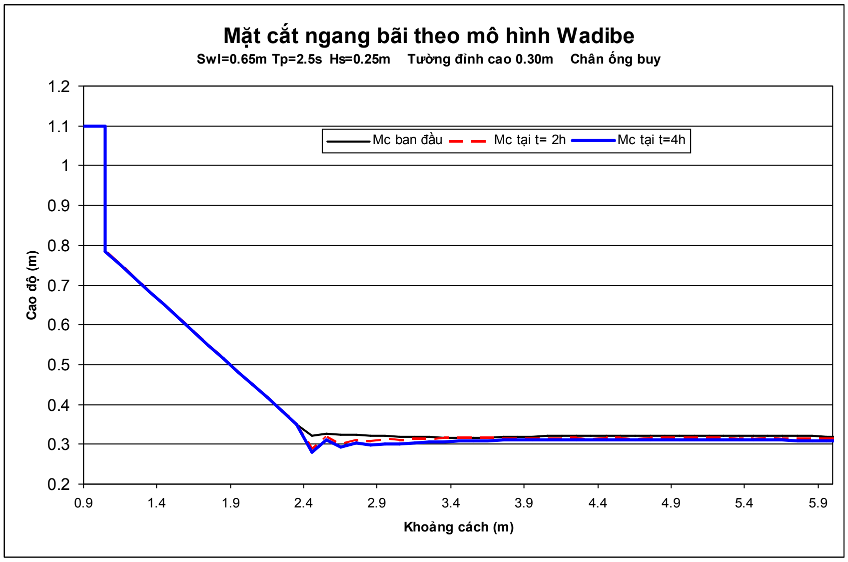


Figure 10. Scour development over time with the combination of crown wall and cylinder as the toe protection structures

4. Applying the model to an actual case

In this section, the model was applied to simulate an actual case, which is the toe eroison of Thinh Long sea dike in Hai Hau, Nam Dinh caused by the Damrey typhoon in 2005 (September 20 – September 29 in 2005). The morphological scale used in this simulation was NL = 4 based on the diameter D50 at Thinh Long.

The wave parameters are chosen based on the reports on this typhoon, with Hs = 6.5 m, Tp = 9 s. The water level variation at Thinh Long during the Damrey typhoong is shown in Figure 11. Geometrically and structurally, Thinh Long sea dikes have the cylinder as the toe protection structure and a slope of 1/4.0

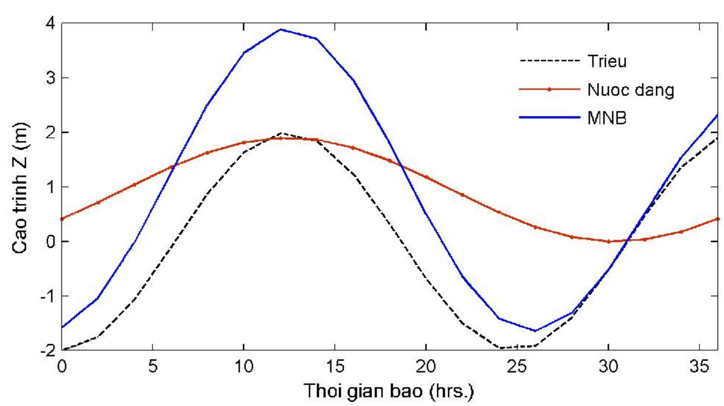


Figure 11. Design water level at Thinh Long

The field measurement results of toe erosion development at Thinh Long (carried out by Vietnam Institue of Mechanics) before and after the typhoon are shown in Figure 12. In this study, the chosen profile for the calculation before the typhoon is the profile measured on September 1st 2005 with the purpose of testing the simulation capability.

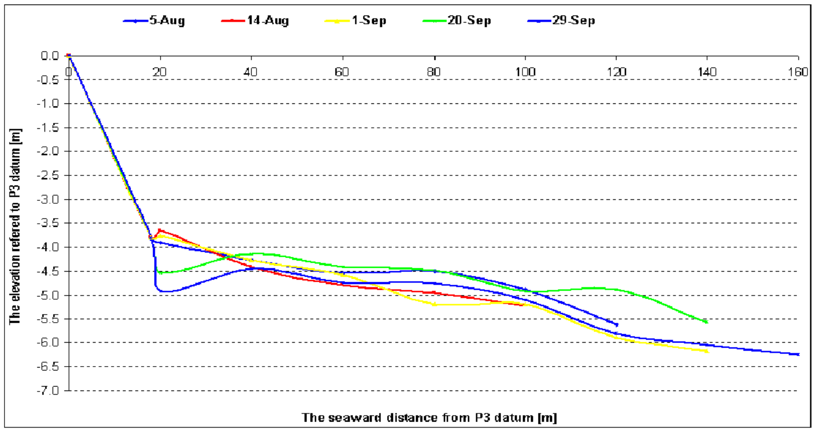


Figure 12. Toe erosion development at Thinh Long before and after Damrey typhoon

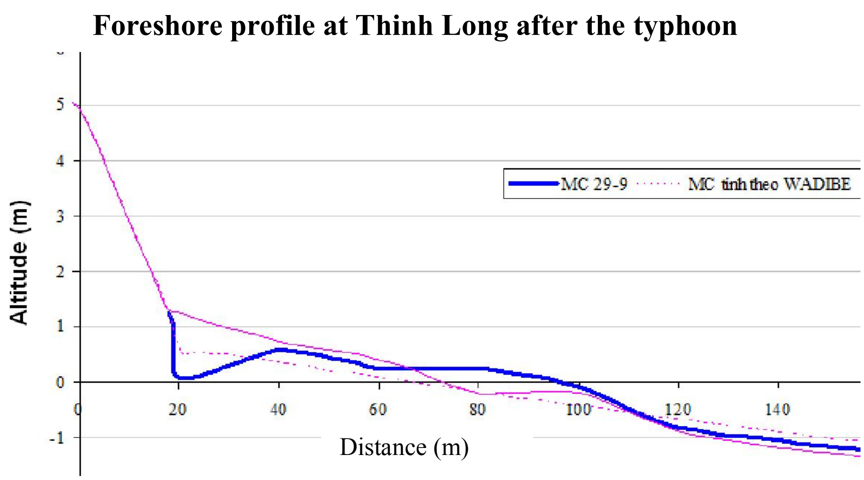


Figure 13. Results of erosion computation after the typhoon by WADIBE-CT
(source: Vietnam Institute of Mechanics)

The simulation duration is 36 hours. The sediment characteristics are: diameters D_{50} = 200µm, D_{90} =250µm, porosity 40%. The calculation results of toe erosion development in comparison with field measurement are shown in Figure 13.

In general, from September 1st to September 29th, the scour depth is 1.1m (from field measurement). The scour depth calculated by WADIBE-TC was 0.72m, which made a difference of 38cm. However, as it has been said above, during the field measurement at Thinh Long, there was a depression and it resulted in more erosion. In addition, the reliability of the input data such as wave, wind, water level and profile has certain influence on the simulation results and result analysis.

In spite of the deficiency of the input data, the results of the simulation of Thinh Long beach have show that WADIBE-TC model can be used to calculate and forecast the scour in front of the toe of the structures in stormy conditions.

5. Conclusion

The erosion development of the toes of the structures after a typhoon is a quick process requiring hydrodynamic model in order to calculate and simulate. The scour depth is under the influence of many parameters, not only the geometrical dimension of the toe and the slope, but aslo the hydrodynamic factors, such as wave, wind, foreshore slope, sediment, etc. In fact, there are rather high number of empirical formulas calculating the scour depth, however the results are unreliable, mostly are overestimated and not take all impacts into account.

Calculation based on the simulation of cross-shore sediment transport as used in WADIBE-TC model has shown fairly realistic results and this model can be applied to forecast the toe erosion of the sea dikes, as well as the scour in front of the structures in stormy conditions.

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