APPLICATION OF HYDRODYNAMIC MODELLING TO ASSESS THE EFFICIENCY OF HURRICANE PROTECTION MEASURE AT XOM RO DIKE, PHU YEN PROVINCE, VIETNAM

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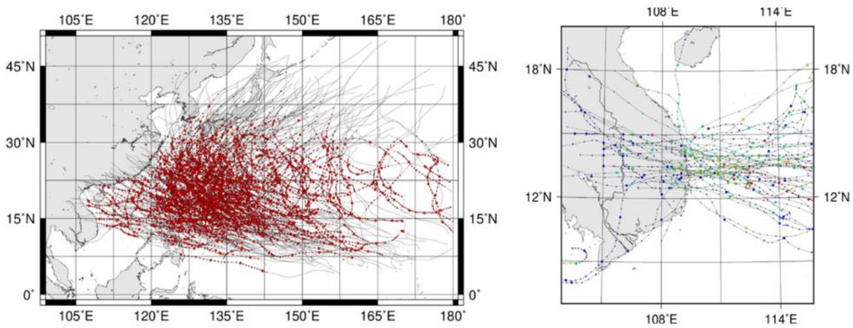
Abstract- Coastal erosion is a phenomenon caused by anthropogenic impact and climate change in recent years. With a rise in highly unpredicted frequency of hurricanes, wave impact on the coasts lead to debris removal and coastline erosion. Sudden sea level rise and unstable surge made by unpredicted trajectory of severe wave impacts could be considered as the main cause of erosion and destruction of coastal constructions such as sea dike, especially in the Xom Ro sea dike in the central Vietnam, which has important mission to protect citizens life and properties of Phu Yen province. The present study is based on the coastal region modeling using hydrodynamic model Mike 21 from Binh Dinh to Binh Thuan province and particularly for the Xom Ro sea dike, Phu Yen province. By assessing different scenarios of hurricane protection of the Xom Ro sea dike under simulated hurricane (level 6, 9 and 12), this study will help to have comprehensive views of the affection of coastal protection measures along with detailed assessment of coastal shoreline status before and after extreme weather conditions.

Keywords- Climate change, flood, hurricane, Hydrodynamic modeling, coastal erosion.

INTRODUCTION

One of the factors that plays a key role on socio-economic development of Vietnam is the "sea". The issues related to coastal erosion can be separated into two main distinguished categories: (a) long-term processes that leads to gradually collapse of coastal shoreline, and (b) episodic processes such as hurricanes, tidal surges and tsunami, which suddenly changes the morphological shape of coastal shoreline and bring significant loss to coastal landforms [1].

The Eastern Sea of Vietnam is in the North-West Pacific (NWP) territory, where there is a high ratio of getting hurricanes. Indeed, extreme weather conditions and severe wave impacts due to anthropogenic actions, disasters such as unexpected hurricane, storm and high sea level rise creates a huge loss of economy and human properties [2]. Vietnam coastline, 3,260 km long (excluding islands), is one of most vulnerable parts effected by Eastern Sea yearly (Figure 1). The central Vietnam consists of a long coastline with many resources, having great potential and advantages for economic development. There are basically 88 erosional sites in the area of above 120 km, alongside the central coast of Vietnam. The coast of the Central Vietnam is experiencing coastline changes at significant rates year by year, mainly at three regions: Thuan An beach - Hue city, Cua Dai beach - Quang Nam province, and Xom Ro commune - Phu Yen province. The significant cause of this is the impact of floods during wet season along with climate change response by anthropogenic influence [3]. In this study, the coastline changes are observed along the coastal areas of central Vietnam. Nowadays, there are many techniques used to solve these problems, but the mathematical modelling is one of the most productive and appropriate explanations. Due to lack of observed data, previous studies are based on the results extracted from earlier finding. Thus, the probability of an error always exists in such condition. However, the present study focuses on a complicated area having high amount of hurricanes every year and other unpredictable factors (tidal processes and sea-water surge). To solve the aforementioned problems, this paper used a double model (East sea model & case study model), with an important observed data of East sea boundary to alleviate the error in results. This study would hope to use hydrodynamic modeling to provide useful data for coastal enhancement and disaster management for coasts in Vietnam central region, notably for Phu Yen province. Besides, this research also assesses the hurricane protection of Xom Ro sea dike with three different scenarios based on simulated hurricane. Consequently, this study aims to evaluate the effects of threatened physical factors that changes the coastal morphology in central Vietnam and in the specific area for case study at Xom Ro commune - Phu Yen province.



a. b.

Figure 1: Yearly hurricanes trajectory with level 12, a) NWP, and b) central Vietnam [4]

MATERIAL AND METHODS

1.1 Numerical modelling

Mike 21 SW belongs to Mike software family of DHI was used in this study [5]. The discretization of the governing equation in geographical and spectral space was performed using cell center finite volume method. In the geographical area, an unstructured work strategy was utilized. The time joining was performed utilizing a fragmentary advance methodology where a multi-grouping express strategy was applied for the spread of wave activity. MIKE 21 SW incorporates the physical phenomena as follows:

$$\frac{\partial N}{\partial t} + \nabla.\left(\vec{\nu}.\mathrm{N}\right) = \frac{\mathrm{S}}{\sigma} \qquad (1)$$

Equation (1) says:

N (σ, θ): wave's frequency.
t: time.
$\vec{\nu}$: (C_x, C_y, C_σ, C_ϕ): : wave's velocity in 4D environment.
∇: the difference equation in $\vec{\nu}$, σ and θ.

1.2 Model set up

1.2.1 Model 1 (East sea model)

The East Sea model was used to simulate the tidal processes, waves, and sea-water surge from the offshore areas to coastline areas. Figure 2 reveals the model structure and the boundaries of the model from Mindoro, Taiwan, Luzon, Babalac, and Malacca. In hydro-dynamic (HD) module, these boundaries contain the water level boundary data and tidal data which are built from harmonic constants. With the SW (wave spectrum) module, these boundaries are considered as the supposition of "lateral boundary". According to quality demand, the grid in the study area was divided into smoothest levels. The grid was also divided at a smaller level for better results in the shallow coastal areas.

1.2.2 Model 2 (Xom Ro sea dike)

To evaluate the hurricane protection efficiency of the Xom Ro sea dike in the simulation with the hurricane LINGLING, it was decided to separate this 2D model into three scenarios as:

- Scenario 1: Evaluation of Xom Ro areas without sea dike system.
- Scenario 2: Xom Ro sea dike (modified) by cutting off 3 sea dikes in the original design with 12 sea dikes, keeping the original length (970.65m).
- Scenario 3: Original design of sea dike system with 12 sea dikes.

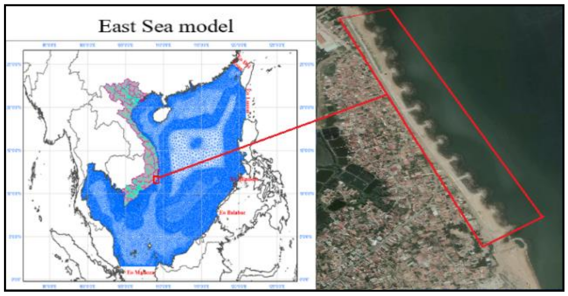


Figure 2: The model structure & boundaries - East sea model

The range and grid of the different scenarios in the study is shown in Figure 3. The spatial range of the calculated model was chosen large enough to ensure that it could minimize the influence of uncertain factors which were in the boundaries of the simulated models.

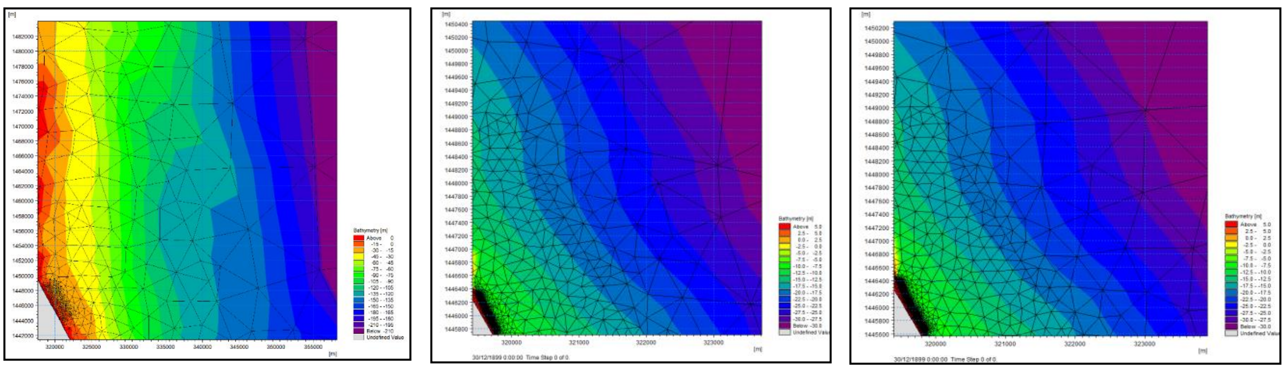


Figure 3: The model 2 structure of Scenario 1/ Scenario 2/ Scenario 3

The model grid was an unstructured mesh with the triangle components. In areas with complex topography, the grid was divided more smoothly to evaluate comprehensively the impact of the Xom Ro sea dike to decrease wave max height in SW module. The study area was set up on the basis of 10m ÷ 15m together with a total of 7367 elements.

1.3 Data and material

The topographic details of supplementary study areas of the eastern sea of Vietnam were acquired from SRTM15_PLUS V1.0 of Scripps Institute of Oceanography, University of California, USA. This was a dataset of 15″×15″ resolution (about 450m) [6]. The tidal water level data was gathered and tuned, referring to the national elevation system. Real wave data was extracted from Phu Quy & Con Dao meteorology stations (1995 - 2015). With regards to other meteorological data used in this study i.e. atmospheric pressure and wind forcing data, were obtained from the CFSR (Climate Forecast System analysis) of the National Center for Environmental Prediction - National Oceanic and Atmospheric Administration Commissioned Corps (NCEP / NOAA) [7]. The LINGLING hurricane was formed on November 6, 2001 and ended on November 12, 2001 and its data was collected from Japanese meteorological agency [8]. The average speed of the whole hurricane is 15.2 (km/h). The forecasted trajectory of this simulated hurricane in this study was based on the trajectory of LINGLING hurricane (2001), with the movement around 205 km to the South. This hurricane LINGLING (level 12) is one the most typical hurricane in Vietnam in recent years and it could be considered as a good data for simulation of different scenarios. The selection of predicted hurricane trajectories is important to simulate sea-water surge, the values of wave extreme is the principle which are based on statistics of the trajectories of hurricanes affecting this study area in the past. The selection of the type of its orbit is likely to cause the largest seawater surges and waves. The Vietnam coast is in the northern hemisphere, the wind rule of the hurricane always has a counterclockwise spiral, so in theory, the hurricane will cause the seawater surges to the North. The area with the highest wind speed during a hurricane is usually distributed within 30 - 70 km in the radius of the center of the hurricane, with the max wave height above 18m.

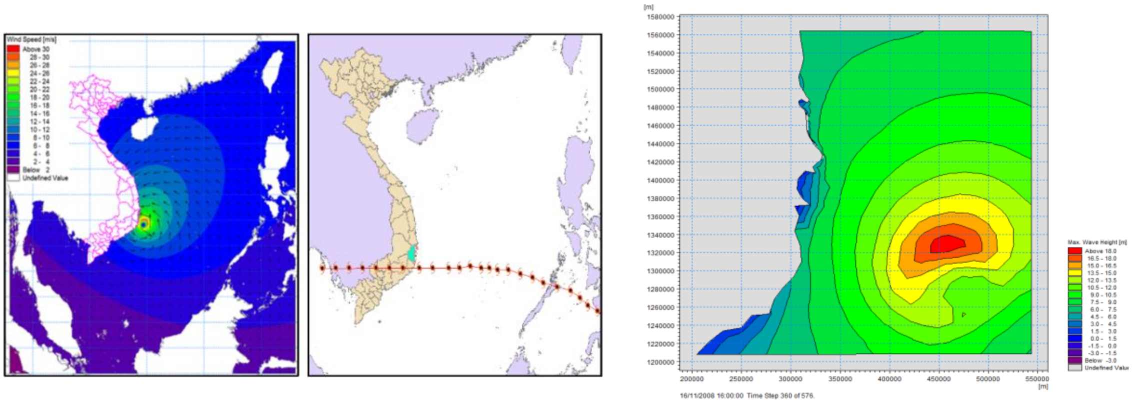


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Figure 4: a) Wind & trajectory of hurricane LINGLING, and b) Simulated hurricane LINGLING

The summary of the hurricanes and tropical depressions that were affecting Phu Yen province in the period of 1951 - 2015 could be seen that it is having a similar orbit in the East-West direction. This is also the type of orbit that can create the most dangerous waves surge to the coastal areas when the hurricane reaches to the mainland. Among the hurricanes mentioned above, LINGLING (2001) was one of the strongest hurricanes and it had a complicated orbit in East-West direction, so finally, it was selected for the simulation in this research (Figure 4a, b).

1.4 Calibration and validation at Model 1

The calibration and validation of model 1 was based on the observed and collected data extracted from reliable sources i.e. real wave data at Phu Quy & Con Dao stations and sea tide data from Global tide FES2014 model (Satellites monitoring data of AVISO organization) [9]. Figure 5 shows the locations of 55 testing points (P1 ÷ P55), in which the tidal water surge levels were predicted and the locations of coastal navigation stations in the islands. The primary thing for adjustment of the SW model is the bed resistance with the Manning's coefficient.

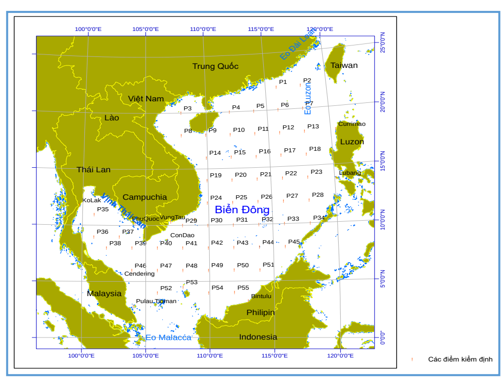

Figure 5: The comparison of points between Model 1 & FES2014

The results were compared in Figures 6 and 7, in which, these comparations illustrate the correlation between results in Model 1 and forecasted tide (global tide FES2014 model) at important & typical point: P14, P19, P24 and P30. These results were compared with high correlation coefficient as 0.98 and 0.99 (Figure 8) with pre-defined periods 1/1/2001 - 12/31/2001.

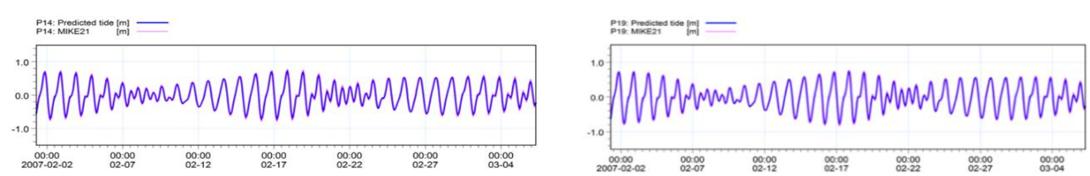

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Figure 6: The water level contrast between Model 1 and the Global tide FES2014 model, a) point P14, and b) point P19

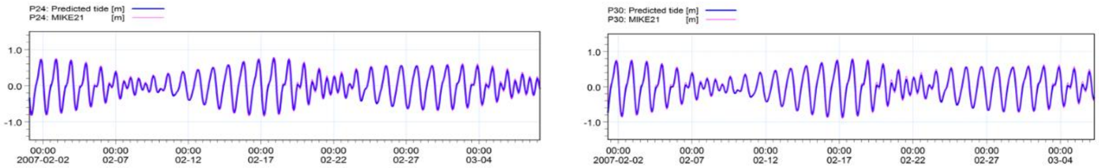

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Figure 7: The water level contrast between Model 1 and the Global tide FES2014 model, a) point P24, and b) point P30

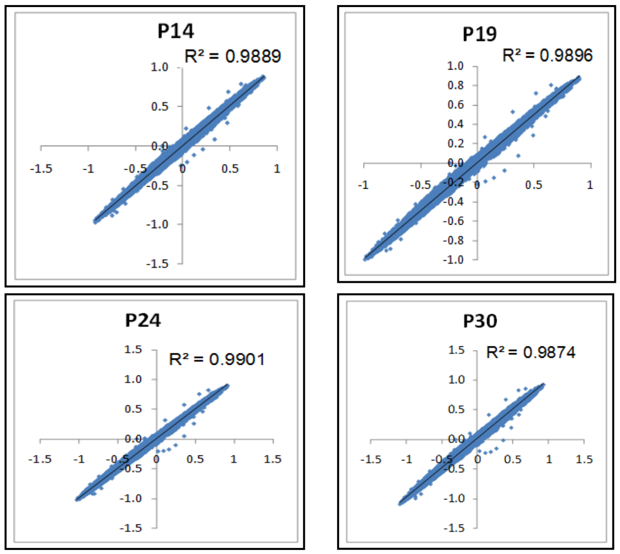

Figure 8: Sea level correlation among Model 1 and Global tide FES2014 model at points P14, P19, P24 and P30

The observed data was extracted from meteorology stations in Phu Qui and Con Dao for the enhancement of Model 1, shown in Figure 9.

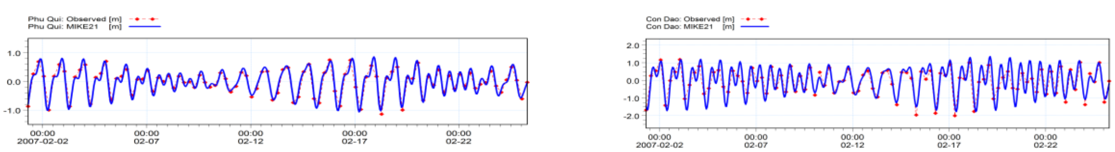

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Figure 9: The comparison of water level between Model 1 and observed data collected, a) at Phu Qui station, and b) at Con Dao station

1.5 Calibration and validation at Model 2

In this study, it was decided to use the nearest station - Quy Nhon station due to lack of stations for calibration and validation of Model 2 at Phu Yen province. The calibrated and validated results consisting of real values of water level data of Quy Nhon station (November 2007 and December 2009) are presented in Figure 10.

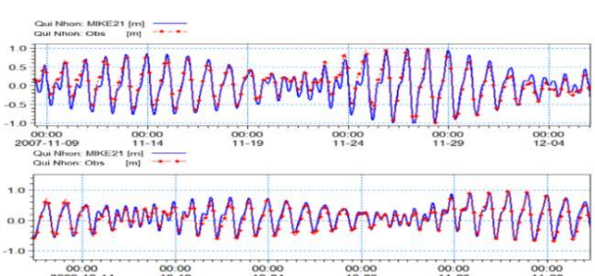

Figure 10: The comparison of water level between Model 1 and observed data collected at Quy Nhon station

The second model was calibrated using Quy Nhon observed data. The calibration and validation results of the model 2 in November 2007 and December 2009 presents high similarity and it could be considered as good quality for application.

APPLICATION

The influence of hurricane LINGLING (level 12) is compared with Xom Ro area based on two criteria's as sea wave direction and highest height wave level.

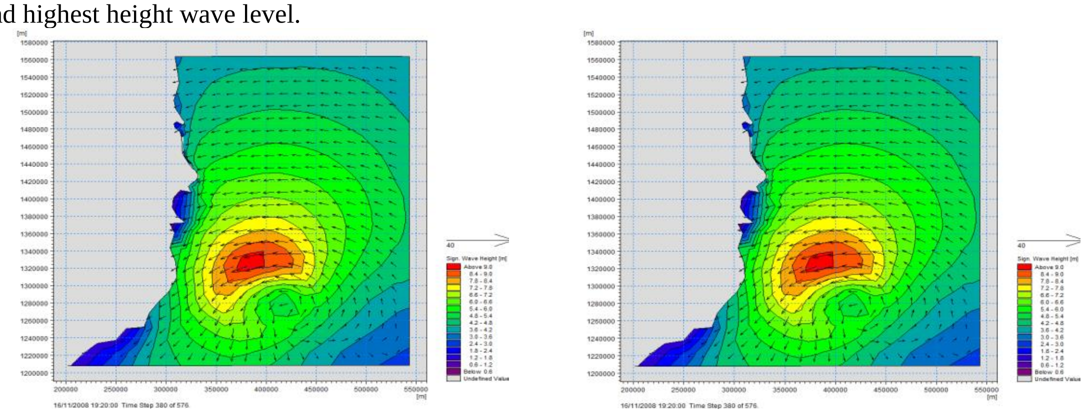

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Figure 11: Wave height distribution, a) with hurricane event level 12 in East sea, and b) with impact of hurricane event when reaching Phu Yen province

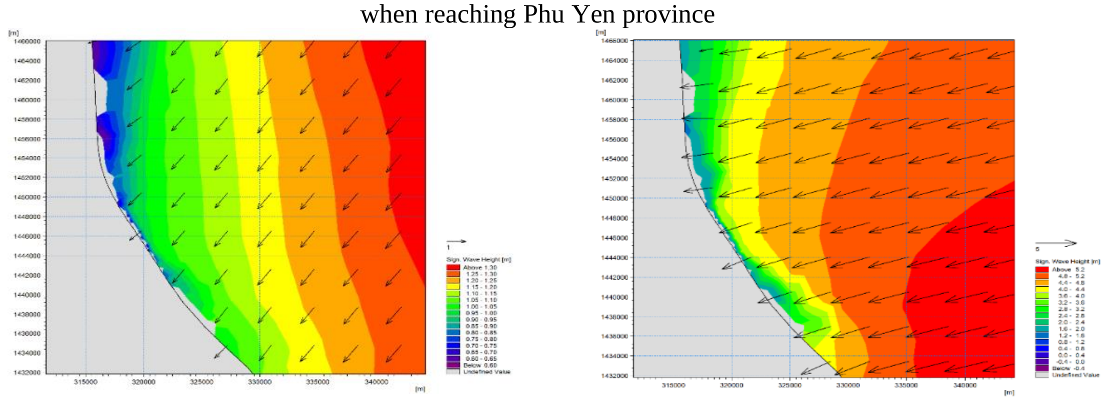

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Figure 12: Wave height distribution, a) with hurricane event level 12 in East sea in Scenario 1, and b) with impact of hurricane event when reaching Phu Yen province in Scenario 1

Wave height distribution with hurricane event in East sea were more in South-West direction while that feature turn to straight West when reaching mainland at Xom Ro sea dike. Also, there is a preliminary assessment with similar wave height distribution in three simulated scenarios in the same periods for two cases before (Figure 12a, 13a, 14a) and after (Figure 12b, 13b, 14b) the hurricane reaches mainland.

Along with model 1 & 2 simulations, this study assesses the hurricane protection efficiency of Xom Ro sea dike, which undertake main responsibility of the safety of Xom Ro commune as well as Phu Yen province. The selected 3 assessed points are t_1, t_2 and t_3 which affected significantly by hurricane impacts (Figure 15).

The results illustrate that the wave reduction effect of scenario 3 is the best when compared with the rest results (Table 1). The practical application of simulated results can be utilized by the industry to predict future hurricanes with the same intensity and its effect to the coastline protection construction.

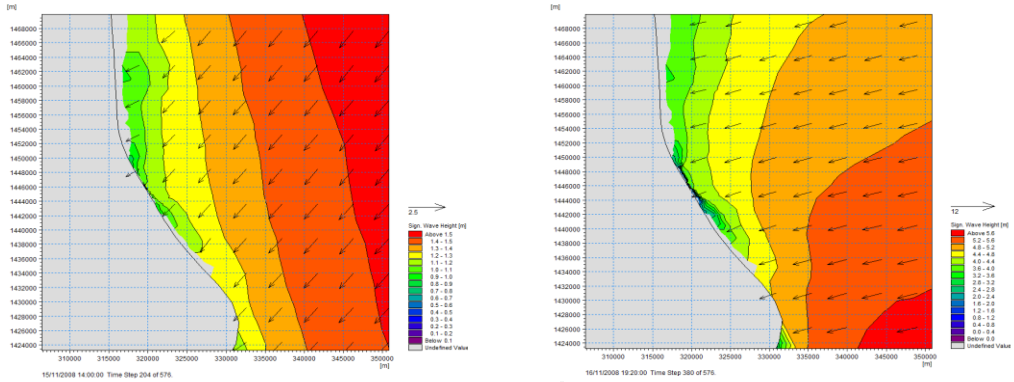

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Figure 13: Wave height distribution, a) with hurricane event level 12 in East sea in Scenario 2, and b) with impact of hurricane event when reaching Phu Yen province in Scenario 2

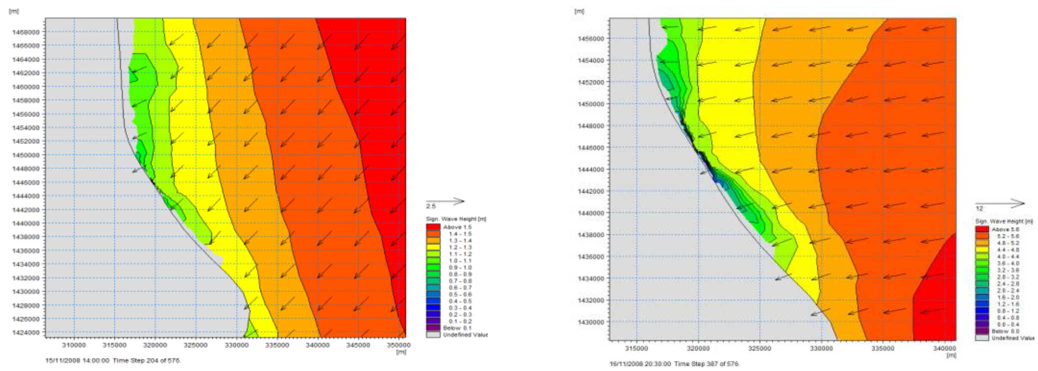

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Figure 14: Wave height distribution, a) with hurricane event level 12 in East sea in Scenario 3, and b) with impact of hurricane event when reaching Phu Yen province in Scenario 3

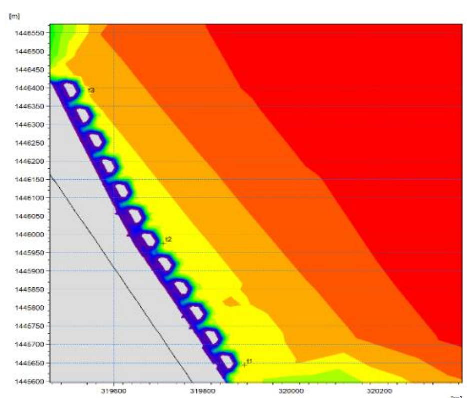

Figure 15: Location of 3 assessed points at Xom Ro sea dike (t_1, t_2 and t_3)

Table 1-Wave height distribution in 3 scenarios

Point	Scenario 1	Scenario 2	Scenario 3
t_1	4.35m	4.33m	4.34m
t_2	4.34m	3.05m	2.81m
t_3	4.27m	2.41m	1.67m

CONCLUSION

Following conclusions can be drawn from conducted study:

- The study has simulated and assessed the impact of simulated hurricane LINGLING (2001) level 12 for case study at Xom Ro sea dike in 3 different scenarios. The structural efficiency of hurricane protection measure is reached to its peak with the scenario 3 (original design) when compared with the rest results. Indeed, the maximum wave height in scenario 3 is 4.34m (t_1) and it decreases to 1.67m in the position t_3, but it decreases only 1.92m in the scenario 2 and approximately remains unchanged in the scenario 1 (half of sea dikes decreased).
- The simulation of models is performed, calibrated, validated, measured, and observed via using strong sources from meteorological stations, forecasted results from the Global tide FES2014 model along with satellite observation. The quite accurate results in 2 models conclude the confidence of applications for other purposes.
- Scenarios illustrate the best efficiency of original design of Xom Ro sea dike as well as provide details of peak wave height as aforementioned demonstration. As the result, these results extracted from case study could be considered as valuable consultation for coastal planning & coastal disaster management.

A future direction for this study is to re-set up models with the actual shape, specific materials, enhance the preciseness of dimension as well as other properties of the construction would play vital role for having better results.

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