

INTRODUCTION

1. General justification for the thesis

Due to recently effects of global climate change, nature disaster get increasingly complicated, especially storms, following by sea level rising that causes flood. The rising of storm surge might cause coastal flooding and dike break, especially in the spring tide duration. One of the most effective methods to protect the coastal zone and reduce risks caused by storm surge flooding is to study, calculate and predict the extreme storm-induced water level. Factors that caused maximum water level in storm include tide, storm surge and wave setup, where storm surge is the most important factor.

While at offshore condition, maximum water level in storm is mostly induced by storm-induced wind stress and air pressure, at inshore condition, storm-induced wave dynamic propagating from offshore to inshore is transferred to potential water column due to shallow water effects on mean water level changing. The rising of onshore mean water level due to wave is called wave setup and there are studies in the world proved its significant contribution to the inshore maximum water level in storm. Wave setup period is longer than wave period when it propagate inshore-ward and happen in a time period that is longer than wave period. Wave setup is created by impact of accumulated wave sets with shore-ward direction and during a long enough time duration, so that they cause ability of remaining high statistic water level.

According to various assessments, minimum time required to form up a wave setup is 1 hour. During a storm, long-lasting duration of wave setup consists with duration of storm-induced wave and last for hours. During strong monsoons, wave setup might last for days. According to linear wave theory, wave setup high reaches about 19% of breaking wave high in the case of linear wave propagation in coastal zone with small slope. Variation of wave setup high depends on beach slope, wave direction and coastline. There are experimental studies proved that wave setup near the coastline in

storm condition is approximately 20% of or higher than offshore significant wave high, and in many cases, the role of wave setup is higher than the role of wind-induced surge in contributing to maximum water level in storm.

In flood risk assesment for coastal areas in the storm conditions, maximum water level calculation when storm occures in the coastal zone plays a particular important role. Weaver, R.J (2004) shows that, in some cases, wave setup contributes 30 – 50% of total water level in coastal area. As a result, the consideration of wave setup at maximum water level in storm will help the assesment of flooding possibility due to maximum water level in storm becomes more accurately.

Risks of storm surge to the coastal areas might get more serious in the future. Firstly, population growth and socioeconomic development will keep gathering in the coastal areas. Second, due to the climate change, intensity and trajectory of storms might get harder to be predicted, stronger storm intensity and flood risk in coastal areas are not exceptions.

Hai Phong is not only a large economic center in North Vietnam but also one of the most active economic area in Vietnam. Located close to the coastline, Hai Phong is one of the most exposed cities/provinces to the nature disasters included storms and storm surges. Nowday, all the social-economic activities and infrastructures in Hai Phong are protected by dykes system included 24 coastal dykes and 18 river dykes. Hai Phong is a low land with 1 – 2 m of elevation, so that it is easy to be inundated in flooding.

According to a study of Ministry of Natural Resource and Environment, Viet Nam, due to climate change effects, mean sea level in Hai Phong area might rise from 42 to 86 cm depends on each social-economic developing scenario. Rising sea level causes increasing inundating hazard for coastal area and might cause changing in phase and amplitude of harmonic tidal wave due to changing in coastline and topography and this changing will make maximum water level in storm unpredictable and strongly impact on coastal zone, especially coastal urban cities.

In Vietnam, although there were a lot of studies on sea level varying in

storm condition but almost of these studies just concerned the change of water level in large scale. Sea level variation in coastal zone, where sea level variation including wave setup contribution, and potential flooding hazard role are not well concerned, especially when coastal inundating hazard is assessed. Therefore, a study of maximum water level in storm that included tide, storm surge, wave setup and coastal inundating hazard has a large scientific significance. An application for Hai Phong area - a crowded area and is usually attacked by storms - has a large practical significance. Research results will help reducing negative effects from storm surge, conserving and repairing, developing coastal structures, protecting coastline, social-economic developing needs, protecting environment and sustainable development.

2. Objectives of the thesis

- Proposing a research methodology to calculate maximum water level in storm based on storm surge and wave setup assessing and calculating method in the coastal zone.

- Proposing methods to assess impact of sea level rise due to climate change on the astronomical tidal regime and change of maximum water level in storm also potential inundation in the coastal zone.

- Applying these methods to calculate maximum water level in storm for Hai Phong coastal zone to contribute in social-economic development and nature disaster prevention.

3. Restriction of the thesis

- Study objects: maximum water level in storm in shore line, including tide, storm surge, wave setup, mean water level which includes rising sea level due to climate change and coastal inundating risk.

- Study restriction: Certain areas in Hai Phong coastal zone and nearby coastal areas. Study duration is from 1950 to 2010.

4. New academic contributions of the thesis

- Quantitative assessment of the contribution of wave induced water level rise to the maximum water level near the coastline in storm, and recommendation for the inclusion of wave setup in the computations of total storm surge. The recommended procedure is then applied for Haiphong coastal areas.

- Initial assessment of the impacts of sea level rise due to climate change to the astronomical tidal waves and to the maximum water level rise.

5. Scientific and practical significance of thesis

Temporal and spacial variations of maximum water level in storm and the other components consisting of storm surge, wave setup, tide are nature phenomena which directly effect on social – economic activities, first of all are designing standards for shipping, structures in open ocean or in coast, coastline protecting structures, nature disasters prevention in coastal zones. So, studies of mechanism and processing of maximum water level in storm calculation which include wave setup, tide and coastal potential inundation have a scientific significane and pratical significane for social - economic activities, national defence and security and nature risk prevention.

Study result of Hai Phong area will be a valueable reference document for planing management policies, social - economic development, environment protection in Hai Phong.

6. Thesis structure

Thesis is presented in 120 pages, including: Introduction: 10 pages; Chapter 1: Overview of previos research: 13 pages; Chapter 2: Maximum water level in storm calculation method: 36 pages; Chapter 3: Computations of storm surge taking into account wave induced water level rise, applying to Hai Phong Coastal areas: 49 pages; Conclusions and recomendations: 3 pages; References: 24 Vietnamese documents; 50 English documents. Data is presented in 22 tables, 64 figures.

CHAPTER 1

OVERVIEW OF PREVIOUS RESEARCH

1.1. Studying situation in the world

There are a lot of methods to assess, calculate and predict storm surge such as statistic, data analysis, field experiment, numerical models or combining two methods above.

There are many studies that assess, calculate and predict storm surge in the world using data analysis and statistical method. In general, this method is simple, easy to use but there are some existing problems. First, in order to set up empirical functions, charts with high confidence using statistical, observed time series should be long enough and this is a big problem of many hydrological stations all over the world. Second, predicted storm surge values are just correct for locations near the station, with farther locations, the accuracy decreases.

For the first period using numerical model to simulate storm surge, it just simulated, calculated separated phenomenon such as tide, wave, storm surge. After that, there were some studies on tide– storm surge – storm wave interaction. Recently, some numerical models are developed to simulate surge, tide and wave at the same time, so that one can have conclusions about their relationship.

In fact, with coastal structures or nature beaches, a negative effect of storm is the total water level rising in the coast. Recently, there are many studies about maximum water level in storm in areas which are usually affected by storms such as Florida (USA) and Queensland (Australia). These studies calculated frequency of maximum water level in storm including wind-induced surge, due to combination of pressure and tide, and wave setup, and also extreme water level in sea level rise due to climate change.

As mentioned before, observed data showed that mean sea level variation in the coast is partly contributed by impact of offshore wave. The rising of water level in wave-breaking zone is called wave setup. Field experiments show that, wave setup might have significant impacts on water

level variation in the coast and contributes to coastal inundation formation (in combination with storm surge). This effect is particular strong in shallow water zones, shallow bays, estuaries.

A method studying wave setup is using multi-combining models such as meteorological model, hydro-dynamic model and wave model in cooperation with additional radiation stress components due to wave in hydro-dynamic model. Many studies shows that, in different zones with different topography conditions, the contributions of wave setup to the maximum water level in storm are different. According to the other approach, some experts presented empirical functions to calculate wave setup based on results of different physical model and observed data.

Storm surge which reaches a certain critical value will exceed or break defence structures, such as dykes, embankments, and will cause coastal inundation. Inundation caused by storm surge is the most devastative nature disaster in the world. Coastal zones which are usually effected by storms and located in shallow continental shelves and low land are stronger effected.

1.2. Studying situation in Vietnam

Following the trend in the whole world, in Vietnam, studies of sea level also focus on tide and storm surge. Statistic method is simple, easy to use, but due to the limitation of observed data length and continuity, event 6hr-data in some stations cannot catch surge values, the accuracy is usually limited. Especially storm surge estimation using this method is just correct for sites near the station. With stites far from the station, estimation result is less accurate. Numerical model development approach to simulate and calculate storm surge is used much more in following studies.

Beside numerical model development to simulate surge, recent studies tend to use commercial model or open code model to set up and calculate storm surge for Vietnamese coastal zones.

1.3. Conclusion for chapter 1

Study on maximum water level in storm and contributors such as storm surge, wave setup, tide as well as interaction between them is a big

problem both international science and Vietnamese science concern. Studies on sea level variation in storm condition is viewed to develop logically and inheritable, from simple to complicated problem, from very first simple statistical study to simulation models for individual components and then components-interaction simulation models.

In Vietnam, there are studies that basically solved scientific and practical problems to understand sea level variation in storm conditions for Vietnamese coastal zone and to be practical applied. However, previous studies just concerned about sea level variation in storm conditions in large scale which means tidal elevation and storm surge, have not yet concerned about regional scale, specific characteristics of shoreline where shallow water wave directly effects on mean sea level variation. And so, for coastal inundation risks estimation, results of sea level variation in storm conditions of the above studies do not satisfy the requirement.

So, it is necessary to set up a progress to calculate maximum water level in storm in the coastal zone which consist with different requirements for coastal management. Besides, assessment of tidal regime changing due to climate change and rising sea level effect that leads to the changing of maximum water level in storm is also important, especially in assessment of coastal inundation risk in storm condition.

CHAPTER 2

MAXIMUM WATER LEVEL IN STORM CALCULATION METHOD

2.1. Maximum water level in storm calculation progress

In Vietnam, in previous calculation progress for structure designing, salinity intrusion calculation, ocean-induced inundation evaluation, ones just considered maximum water level in storm in large scale such as tidal elevation and storm surge but small scale. The role of wave, especially wave in storm condition, is just considered when designing specific structures through wave runup and wave pressure. In shallow water zone,

shallow wave effect directly on mean sea level changing but wave setup is not counted in total water level calculation progress when evaluating coastal inundation risk.

Components which create maximum water level in storm such as storm surge, tide, wave setup have a close relationship with each other, they effect and are effected each other. This relationship is nonlinear and in principle, maximum water level in storm calculation process need to connect with wave, tidal and storm surge models in a system. Nowadays, combination of numerical models is conducted with different kind of models and have achieved many positive results. But, with a specific area, ability of providing topography information for different kinds and different scale of model (wave, currents, tide) is very difficult. So, general approach dealing with water level basic components, which is calculated using single model, might show results closer to real situations because they are independently verified in each step of the progress.

In this thesis, author chose the second approach, set up maximum water level in storm calculation progress through: tide, storm surge and wave setup. Studying and applying these modeling components to calculate maximum water level in storm, where they focus on wave setup, is a new contribution to complete coastal water elevation progress calculation for inundation risk evaluation. It is practical significance in coastal structure calculation and design.

Total water elevation calculation step by step for coastal sites: 1) Identifying parameters of the storm, including: storm centre location; storm direction; storm speed; maximum wind speed; maximum wind radius; 2) simulating wind field in storm; 3) simulating wave field in storm; 4) wave setup; 5) simulating storm surge (combination with tide) using hydrodynamic model; 6) maximum water level in storm calculation.

2.2. Meteorological field model

This thesis use wind in storm condition model of Boose et. al., 1994. This model bases on forces-synthesis to simulate and calculate wind field

distribution in storm. Wind field is calculated in each specific time for locations inside and outside the storm eye. Parameters for wind field calculation includes: storm centre location; storm direction and its speed; storm eye radius; maximum wind speed and surface parameters.

2.3. Storm surge model

This study uses ADCIRC model, USA, a hydrodynamic model for coastal zone, under tidal, wind and pressure - induced forces. ADCIRC is a 2D or 3D hydrodynamic model, using finite element method and unstructured grid with high flexibility, is consist with estuaries and coasts where are shallow water zone and complex coastline such as in Hai Phong.

2.4. Wave field model

This study used WAM model to calculate open ocean wave and SWAN model to calculate coastal wave in storm condition. SWAN model is the third generation model, calculates 2D wave spectrum using balance equation solution of wave impact in combination with wave propagation from deep water zone to shallow water zone, simultaneous exchange with wind energy through source equation and wave energy dissipation. This model can simulate, calculate almost arising wave problem, development, propagation and dissipation such as wind-induced wave arising, wave phenomena in shallow water zones like wave deflection, wave energy dissipaton throughout organics, bottom friction or obstacles, energy dissipation due to wave breaking, current – wave interaction and wave – wave interaction.

2.5. Wave setup calculation

This thesis use empirical function of Hanslow & Nielsen (1993) that bases on field experiment results on offshore significant wave high – wave setup relationship at many different beaches.

$$\bar{\eta}_w = 0.04\sqrt{H_{s0}L_0} \quad (2.1)$$

Where: $\bar{\eta}_w$ is wave setup at near shore position , H_{s0} is deep water wave high and L_0 is deep water wave length.

2.6. Model verification

2.6.1. Wind field and storm pressure model verification

Wind simulation in storm condition is verified using observed data at Hon Dau meteorological station in storm durations. Results show that model simulates good wind field distribution trend and wind speed. We verified bias and accuracy between calculated and observed wind speeds using deviation parameter (BIAS) and root mean square parameter (RMS). Verification results show that: in general, BIAS value is 1,73 m/s with positive value, it means calculated value is higher than observed value. In general, RMS value is 3,99 m/s which is reasonable in storm condition.

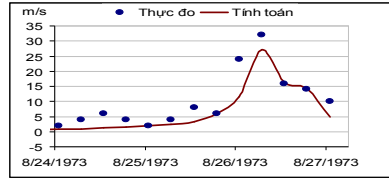


Figure 2.1. Model verification in storm Kate, 1973

2.6.2. Hydrodynamic and storm surge model verification

Calculated field is the whole Gulf of Tonkin with unstructured grid included 13332 grid points, minimum grid distance is 50 m (estuary area in Hai Phong), maximum grid distance is 25 km (in the midden of gulf area). Calculated topography field is from different scaled nautical charts supported by Nav of Vietnam, open ocean boundaries are filled with harmonic constants from global harmonic constants set in ADCIRC model.

a. Tide simulation problem

This model is for tide simulation in studying area in 2010. The results show that, tides is simulated good. Calculated water elevation variations in January, 2010 show high corresponding in phase and amplitude.

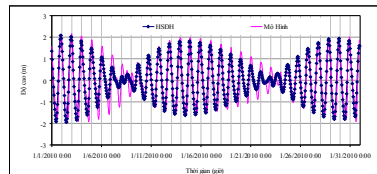


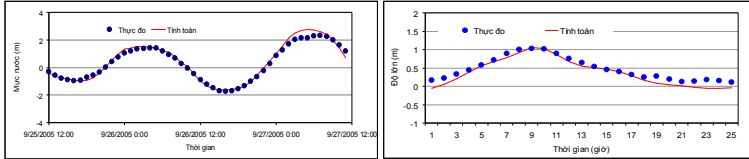
Figure 2.2. Tidal elevation simulating verification at Hon Dau

Harmonic tidal waves (M2, S2, N2, K2, K1, O1, P1, Q1) extracted from model and analysed form observed data at Hon Dau station are not so different, absolute error in tidal wave amplitudes do not exceed 7 cm.

b. Storm surge simulation

The model is kept verifying in storm surge simulation during some storms (Carla, 1962, Kate, 1973, Frankie, 1996, Niki, 1996, Damrey, 2005).

Verifying results show that, in other storms, surge simulation in storm



a) Total water level

b) Storm surge

Figure 2.3. Model verification in storm Damrey, 2005

condition is quite good, calculated water level extracted from the model at Hon Dau station quite close to the observed one, absolute error of maximum water level in those storms is from 0,03 to 0,32 m, peaks time lag is small, just from 0 to 3hours, correlation coefficients of calculated and simulated time series are high, from 0,7 to 0,92, but BIAS coefficient is from -0,06 to 0,1 m and RMS index is from 0,27 to 0,36 m. These values are acceptable in storm surge simulation.

2.6.3. Wave simulation verification in storm condition

WAM model simulated offshore wave in storm condition as the input data for SWAN model to simulate coastal wave in storm condition. This model is verified with observed buoy data in two real storms (Frankie, 1996 and Wukong,

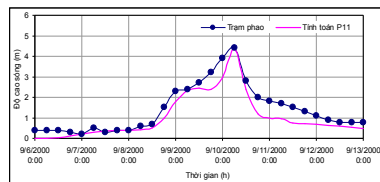


Figure 2.4. Wave model verification in the storm Wukong,

2000). Verification results show the correspondence of observed and calculated maximum wave high values at buoys. Statistical verification results show that, average BIAS value is -0.29 m (negative value is acceptable), it means calculated wave high tends to be lower than observed one from buoys. Mean RMS value for two storms is 0,42 m which is acceptable in significant wave high calculation in storm condition.

2.6.4. Maximum water level in storm calculation verification

Wave setup observation in storm condition is difficult due to

dangerous weather. To have wave setup values in coastal zones, they separate wave setup through water level difference between coastal and offshore positions. In Vietnam, there is no observation of wave setup, but there are field observation after storm to identify maximum surge high at sites closed to the shoreline. Water level values at coastal zone are considered to include wave setup. Survey results in Washi storm, 2005 show that, there is significant different in surge high at some coastal sites comparing to surge high in Hon Dau station and this difference is due to wave setup, the surge high difference due to storms might reach 70 cm (table 2.1).

Table 2.1 Surge in Hai Phong area, in storm Washi, 2005

Index	Location	Storm surge (m)	Note
1	Hon Dau	1,21	From observed water level
2	Dinh Vu	1,93	Traces from survey of Flood Prevention Department
3	Do Son dyke	1,95	

Maximum water level in storm calculation from Hai Phong coastal sites to adjacent provinces of some storms and comparing with observed data show that, if we do not count the wave setup, calculation results of maximum water level in storm limited line from model is significant lower

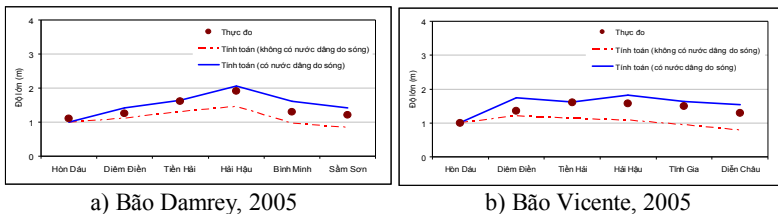


Figure 3.5. Maximum water level in storm verification

at coastal sites while keep reaching approximate value at Hon Dau station. Meanwhile, if we count wave setup on calculation, surge-limited line is asymptotic to and a little higher than observed data. It should be note that, at Hon Dau, wave setup is negligible because the depth in this area is quite large. Meanwhile, if we count wave setup on calculation, the surge-limited line is asymptotic to and a little higher than observed data.

2.7. Conclusion of chapter 2

Chapter 2 presents a maximum water level in storm calculation process bases on components such as: 1) Wind field model and pressure field model in storm condition based on Boose et. al. (1994) which analyzes and synthezies of forces to simulate and calculate wind field distribution in storm condition; 2) Coastal circulation and storm surge simulation model is ADCIRC model, USA, with finite element method, unstructured grid which is very flexible, suitable with estuaries with shallow water zones and complicated coastline such as Hai Phong area; 3) Wave model in storm condition is WAM model to simulate offshore wave and SWAN model, Netherland, to simulate coastal wave based on principle that wave can be presented by wave spectrum of 2D wave effect; 4) Wave setup in storm condition calculation function for coastal sites based on empirical function of Hanslow and Nielson (1993).

CHAPTER 3

EVALUATION OF WAVE-EFFECTED STOM SURGE FOR HAI PHONG COASTAL REGION

3.1. Reaserch field overview

Hai Phong is coastal city, Eastward of North Coastal, which has over 125 km seashore included islands. The depth of Hai Phong sea is not high. The 2m contour of depth moves around Do Son cape, then decreases to 5m offshore. Sea bottom decreases with Gulf of Tonkin, about 30-40m. Hai Phong climate is subtropical, which has hot and humid, rainy summer, cold and dry winter. The average temperature is 32.5°C in summer, 20.3°C in winter, over 23.9°C of annual average. The annual average of rainfall is about 1600-1800mm. The average humidity is 85-86%. In summer, the prevail wind direction is East, South-East, and South, in winter, it is North-East, North, and East.

Hai Phong has homogeneous diurnal tidal regime. The water level average in Hon Dau region is about 186cm. The wave is not high, with observed maximum 5,6m. In winter, the prevail wave direction is Eastward

while is South-East and South in summer. This region stands of storm and tropical low pressure, with approximately 1 storm per year, 30% total quantity Vietnamese storms. Storms often land to Hai Phong in July (28%), August (21%) and September (29%), with attached water level increasing (maximum 3,0m).

3.2. The effected storms in Hai Phong coastal region

According to the data base of 63 storms in Hai Phong from 1950, the statistical characteristics (storm orbit and intensity) are analysed. The input data from JTWC include position and 6 hours interval maximum wind velocity .

The landed direction of storms focus from West-South West to North West, highest in the West-North West (44% of total). The movement velocity is from 5km/h to above 40km/h, with the average 17km/h. The maximum wind velocity is about 65m/s, average 28m/s. The maximum central pressure deviation is from 3hPa to 88hPa, average 27hPa.

3.3. Storm surge in Hai Phong city

3.3.1. The storm surge – tidal interaction in Hai Phong

Table 3.1. *The scenarios of storm surge – tidal interaction*

STT	Nhóm kịch bản	Lực tác động	Biên độ (m)	Pha triều (°)	Mô tả pha thủy triều
1 ~ 32	TWP	Thủy triều, gió và áp	0,5 1,0 1,5 2,0	0 45 90 135 180 225 270 315	<p> P0° : mực nước thấp nhất P45° : sau khi mực nước thấp nhất P90° : mực nước tăng P135° : trước khi mực nước cao nhất P180° : mực nước cao nhất P225° : sau mực nước cao nhất P270° : mực nước giảm P315° : trước mực nước thấp nhất </p>
33 ~ 64	TWPR	Thủy triều, gió, áp và ứng suất sóng	0,5 1,0 1,5 2,0	0 45 90 135 180 225 270 315	
65 ~ 68	OT	Thủy triều	0,5 1,0 1,5 2,0		
69	WP	Gió, áp			

This thesis used numerical model to simulate storm surge for 69 cases in Damrey storm (2005). There are different tidal regime between landed storm times (table 3.1). The results show that storm surge are clearly related to the tidal state with respect to the tidal amplitude and phase in Hai Phong coastal. Storm surge is increased in low water and decreased in the high water phase.

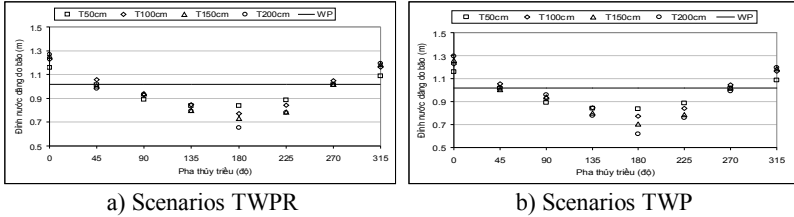


Figure 3.1. Storm surge in scenarios

3.3.2. Storm surge result

Storm surge that calculated for 63 past storms is quoted result in coastal points, follows the important dykes in Hai Phong.

The results show that, Hai Phong coastal has fairly complex topography, seashore is separated by estuaries and islands. It makes storm surge variation follows coastal shape and bottom topography. An Hai dyke region has higher storm surge values, Do Son beach has lower values .

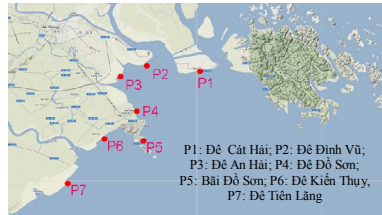


Figure 3.2. Calculated points position

The results also show that, storm surge in Hai Phong coastal distributes in range 20cm to above 210cm. The average value is about 60-70cm. The maximum value is from 20cm to 130cm (90%).

3.3.3. Wave setup result

The wave setup result show that, wave setup depend on offshore significant wave height and point topography. For all the storms, the value of wave setup is 16% to 18%

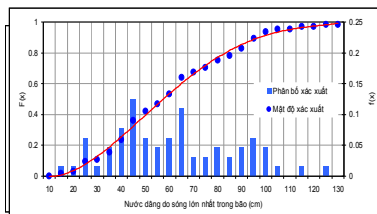


Figure 3.3. Distribution and probability density of storm surges in Do Son dyke

offshore significant wave height. Wave setup in storm at Hai Phong coastal points has a difference: at Dinh Vu and An Hai dykes, due to deeply onshore, the value of wave setup is smaller than the others. On the other hand, the value at Tien Lang and Kien Thuy dykes is higher. The average value is 60cm. The distribution is in range 20-130cm. The maximum value is from 30cm to 100cm (80%).

3.3.4. Maximum water level in storm result

Maximum water level in storm at Hai Phong is contributed by tidal, storm surge and wave setup. Their contribution depend on storm characteristic and landed storm positions. Storm Elisie (1954), Toraji (2007), Kamuri (2008)... has big contribution of wave setup. The contribution of storm surge and tidal is very small, because these storms landed to Quang Ninh at low tide. In the other hand, storm Kelly (1981), landed to Thanh Hoa (far from Hai Phong) at high tide, makes the big contribution of tidal to extreme water level. In general, wave setup contributes a lot for maximum water level (maximum water level can reach only 78% itself without wave setup contribution). The distribution of maximum water level is from 40cm to 420cm. The average value is from 180cm to 200cm. The maximum value is from 70cm to 300cm (90%).

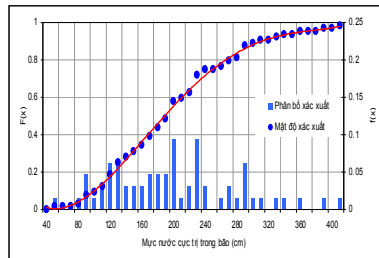


Figure 3.5. Distribution and probability density of extreme storm-induced water level in Do Son dykes

3.4. Return period of storm surge, wave setup and maximum water level in storm

The values of storm surge, wave setup and maximum water level in storm are gathered to determine return period from statistical distribution function (Log-Pearson III). The result show that, maximum water level in

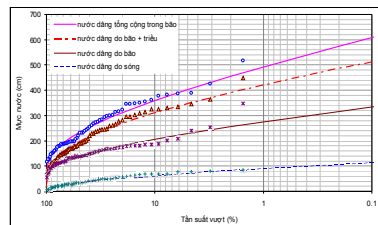


Figure 3.6. Return period for water level in Do Son dyke

Hai Phong is in range 527-579 cm with 1000 year return period, the 100 year return period is in range 494-540 cm, reach nearly to Hai Phong dykes (5,5m) and can cause flooded risk to human. The contribution of wave setup is from 199cm to 130cm (20%-30% to maximum water level in storm).

Table 3.3. Return period for maximum water level in storm

Characteristic	Return period (year)	Cat Hai dyke	Đinh Vu dyke	An Hai dyke	Đò Son dyke	Đò Son beach	Kien Thuy dyke	Tien Lang dyke
Maximum water level in storm (cm)	1000	572	544	564	527	538	553	579
	100	535	509	528	494	500	516	540
	50	447	424	440	414	412	427	447
	20	407	386	401	378	373	388	405
Storm surge (cm)	1000	351	333	347	327	319	334	349
	100	264	241	298	236	220	250	290
	50	247	225	277	220	203	231	268
	20	204	186	226	180	163	187	215
Wave setup (cm)	1000	185	169	202	162	145	166	191
	100	158	144	170	137	120	139	159
	50	157	148	150	156	156	161	162
	20	149	141	143	149	148	153	154

3.5. The impact of sea level rise due to climate change to water level regime and flooded risk to Hai Phong coastal

3.5.1. Tidal regime impact

To evaluate the impact of sea level rise to tidal regime, scenario A1FI is used (upper boundary 86cm), with the simulate time is 1 year.

The result show that, in case of sea level rise is 86cm, the main tidal wave has a change of amplitude. With diurnal tide wave

(K1, O1), the contour line changes to Northward. With semi-diurnal tide wave (M2, S2), the contour line has more complex trend. The contour line

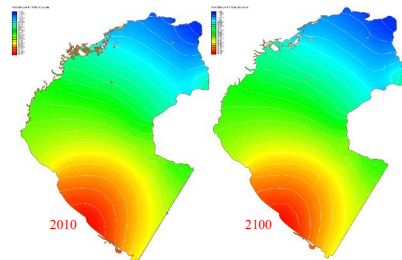


Figure 3.7. The contour of amplitude of K1(m)

of phase of tide wave has unclear change. The amplitude of tide wave K1 and O1 increase from 1,9 to 3,1cm (2,1 - 4,3%). In the other hand, the amplitude of tide wave M2, S2 mainly decrease. About tidal phase, at all points, the tidal wave has modification of phase but very small.

3.5.2. Maximum water level in storm impact

Sea surface temperature causes storm. In theory, climate change will change sea surface temperature, then intensity and frequency of storms will be changed. But, statistical data in East Vietnam sea has not asserted this phenomenon. Hence, evaluation of climate impact to maximum water

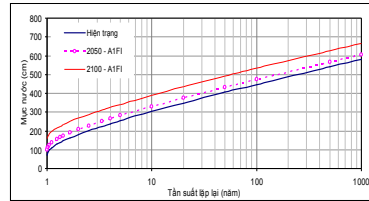


Figure 3.8. The extreme water level frequency rate at Do Son dyke in sea water increasing case caused

level in storm is limited in average water level. The result of frequency distribution of maximum water level is data base to calibrate maximum water level in different period in future. Thus, in each certain time, water level value will be added mean sea level due to climated change. According to A1F1 scenario, sea level rise in Hai Phong in 2050 will be increased 27cm and 86cm in 2100. At that time, maximum water level in storm at all periods will be increased 27cm and 86cm, relatively.

3.5.3. Coastal inundation risk evaluation for Hai Phong city

Storm surge is one of the main reasons of coastal inundation. Maximum water level in storm changing directly effects on coastal defence structure and threaten the back-dyke area because water level can exceed the dykes. Inundation risk in storm condition not only depend on maximum water level in storm but also depend on dyke high and dyke structure. There are 6 dyke systems in Hai Phong area with 103 km total length. But, almost of the dykes are less stable due to lack of upgrating, due to key embakments and drains in the dyke system and due to human life near the dykes. In Hai Phong dyke system, there are still some dykes lower than 4 m. At these dykes, recent maximum water level in storm exeeded them. The 1000-year return period for maximum water level in storm can exceed the whole dyke

system. If this thing happens, erosion problem will also appear in the back side of the dyke, not only in the front side of the dyke due to wave and currents.

If water level exceeded the dykes, storm wave will effect directly on the whole body of structures, this will be much more dangerous than overflow due to wave runup. Danger level will increase with time when sea level rise due to climate change will cause increasing in maximum water level in storm. In 2100, according to the climate change and sea level rise scenario, 100-year return period for maximum water level in storm has already higher than the whole dyke system in Hai Phong.

3.6. Conclusion of chapter 3

Maximum water level in storm calculation process has been verified in practical condition. Good agreement between calculated maximum water level in storm using proposed process and field survey data shows that the proposed process is useful and the needs to count the wave setup when calculating maximum water level in storm in coastal sites. Calculated results for previous storms show that: 1) Storm surge in Hai Phong coastal zone is from 20 cm to 210 cm, the average value is from 60 to 70 cm; 2) Wave setup has a close relationship with offshore significant wave high and studying topography and is from 16% to 18% of offshore significant wave high. Wave setup in storm condition in Hai Phong coastal zones is from 10 to 130 cm, the average value is 60 cm; 3) Maximum water level in storm is contributed by tidal elevation, storm surge and wave setup in storm condition. The contribution of each factor depend on individual characteristic of each storm and its location. Wave setup has significant contribution to maximum water level in storm, in general, maximum water level in storm without wave setup just reaches 78% of that with wave setup. Maximum water level in storm in Hai Phong is from 40 cm to 420 cm, the average value is from 180 to 200 cm;

Tide have a significant impact on storm surge in Hai Phong area, storm surge is higher when landed storm time is low water and is lower when is high water.

Return period for maximum water level such as storm surge, wave setup and maximum water level in storm for sites at Hai Phong coastline show that, 100-year return period for maximum water level in storm is from 412 cm to 447 cm above mean sea level, exceeds almost all the dykes and cause inundation.

Assessment impact of sea level rise due to climate change on tidal regime show that, amplitude of astronomical diurnal waves tends to increase, while the amplitude of semi-diurnal waves tends to decrease.

There are no regulation to assess of sea level rise effects due to climate change on storm surge and wave setup so its effects on maximum water level in storm should be counted to mean water level changing. 100 year return period for maximum water level in storm in 2100 in A1FI scenario changes from 555 cm to 612 cm in related to mean sea level.

Evaluation of inundation risk capability show that, for now, dyke systems in Hai Phong is not well prepared for 100-year return period for maximum water level in storm. At the end of the XXI century, corespond with A1FI scenario, maximum water level in storm with the same return period might increase 86 cm. This will lead to a lot of unpredicted consequences to nature, environment and society – economy.

CONCLUSIONS AND RECOMMENDATIONS

A. Conclusions

1. Studying on mechanism and process of maximum water level in storm taking into account storm surge, wave setup, tide and inundation risk for coastal zone has both scientific and practical significance for social - economic, defence security, nature risks prevention activities. In the context of climate change, we need to consider the effect of sea level rise on tidal regime changing and maximum water level in storm as well as coastal inundation risk.

Previous studies on water level variation in storm helped us get familiar with water level variation for Vietnamese coastline and are applied in practice. However, these studies have just concerned water level changing in storm in large scale, there are tidal elevation and storm surge, but have

not concerned regional scale, specific characteristics of the coastline, where shallow water effects directly on mean water level changing. Therefore, calculation results tend to be lower when evaluating coastal inundation risk.

2. The thesis sets up a process to calculate maximum water level in storm with calculating tools including: 1) Wind field model in storm; 2) Coastal circulation and storm surge model; 3) Wave model in storm; 4) wave setup calculating empirical function. The results of maximum water level in storm calculation are consisted with observed data. As the results, the author concluded that wave setup component is needed to be considered in calculation of maximum water level in storm at shore line.

3. Based on the calculation results for storms in the past, the maximum water level in storm at Hai Phong area is the combination of tidal, storm surge and wave setup in storm condition. The contribution of each component depends on particular characteristic of each storm and each specific sites. Wave setup has significant contributed to maximum water level in storm. In general, average maximum water level in storm of many storms without-wave setup case just reach 78% compare to with-wave setup case. Maximum water level in storm in Hai Phong area is from 40 cm to 420 cm or above, with average value is 160 -180 cm. 100-year return period for maximum water level in storm at sites in Hai Phong coast is about 380 cm to 426 cm above mean sea level, exceeds almost dykes in Hai Phong.

4. Calculated results show that sea level rise due to climate change can change tidal regime in Hai Phong coastal area: the amplitude of astronomical diurnal waves tends to increase, while the amplitude of semi-diurnal waves tends to decrease. Calculated result shows that there is not enough evidence to conclude that sea level rising due to climate change have impact on maximum water level in storm. So, author recommend that sea level rising scenarios can be applied for maximum water level in storm calculation in the future.

5. Calculation results show that existing Haiphong's sea dyke system cannot to meet the requirements for flood prevention from maximum water level caused by storm in the condition of sea level rise due to climate

change.

B. Recommendation

1. Process and method to calculate storm surge, wave setup, maximum water level in storm, coastal inundation risk in Hai Phong area can be applied to identify maximum water level in storm, helping in infrastructure designing in Hai Phong coast. These results can also be applied in the other coastal area.
2. More field experiments on wave setup are needed to be conducted in Hai Phong as well as in the other Vietnamese coastal zones.
3. Further investigation and simulation of the impacts of climate change and sea level rise on storm characteristics are needed to be continued in the future for Vietnamese coastal zones so that we can have more accurate assessment of climate change and sea level rise impacts on maximum water level in storm.