VNU Journal of Science, Earth Sciences 26 (2010) 82-89

Study on wave setup with the storm surge in Hai Phong coastal and estuarine region

Nguyen Xuan Hien* , Dinh Van Uu, Tran Thuc, Pham Van Tien

Faculty of Hydro-Meteorology and Oceanography, Hanoi University of Science, VNU,
334 Nguyen Trai, Hanoi, Vietnam

Received 05 September 2010; received in revised form 24 September 2010

Abstract. Wave setup is the increase of water level within the surf zone due to the transfer of wave-related momentum to the water column during wave-breaking. Wave setup contributes to the total water height in storm and become dangerous to coastal construction. This study presents some results on wave setup with storm surge using numerical model and empirical model. It also estimates the contribution of wave setup in total storm tide level at coastal and estuarine region of Hai Phong. Results show that wave setup at coastal and estuarine region in Hai Phong contributes about 25% to 40% of sea level surge in storm, 32% on average.

Keywords: wave setup, storm surge, Hai Phong.

1. Introduction

A storm surge with high waves often causes severe damage when it coincides with high tides. In Viet Nam, typhoon Damrey in 2005 broke sea dykes and resulted in severe flooding by storm tide in Nam Dinh and Thanh Hoa provinces. Storm surge can several inland from the estuary. Waves ride above the surge levels, causing wave runup and mean water level set-up. These wave effects are significant near the landfall area and are affected by the process that typhoon approaches the coastline.

In the 1960s, the theory of wave setup were developed by Longuet-Higgins and Stewart (1960, 1962, 1963, 1964) [1, 2], it shows that wave setup occurred due to horizontal change of radiation stress. The theory was highly useful in explaining the increase and decrease of sea level causing by waves as well as mechanism of the surf waves in the near shore. Bowen et al. (1968) carried out an experiment to test the theory and prove its reliability throughout simulating the wave crashed onto the shore [3]. Moreover, there was a high correspondence between Longuet-Higgins and Stewart' theory and experiment data. The following studies showed that wave setup can have considerable effects on sea level in coastal zone.

Recently researches on wave setup have approached to use coupled models by combining hydrodynamics model of wave and wave setup. The first researches have been known as Mastenbroek et al. (1993), Zhang and

---

* Corresponding author. Tel.: 84-4-37730409.
E-mail: nguyenxuanhien@vkttv.edu.vn

Li (1997) [4, 5]. However, in these studies, authors did not considered all the effects in breaking wave zone due to using wave model for large area (WAM). Another approach, Shibaki et al. (2001) showed that, by adding radiation stress to the movement equation, obtained results were better than in the case separated run of the models to calculate wave setup and storm surge. Recently, Funakoshi et al. (2008) studied wave setup by using two models, Advanced Circulation Model (ADCIRC) to simulate storm surge, and the SWAN to compute wave field [6]. This research indicated that wave setup accounted for about between 10 and 15 percent of total sea level rise. Some other notable researches include Hanslow and Nielsen (1993), Gourlay (1992) Raubenheimer et al. (2001); the experimental formulas have widely been applied with high reliability (Happer et al., 2001) [7-10].

In Viet Nam, although some studies on storm surges have been conducted in the past, however approach on wave setup and the assessments of its roles in total surge are not clear yet. In this study, storm wind model Boose et al. (1994) with the SWAN model are applied to simulate the wave field, and used some experimental formulas are used to calculate wave setup at some locations near Hai Phong coastal area for several storms.

2. Model Description

2.1. Typhoon wind and wave model.

The Boose et al. model (1994) was adopted to produce atmospheric pressure and wind fields of typhoons. A third-generation wave model, SWAN (Simulating Waves Nearshore), was used to simulate the wave field in the investigated area.

2.2. Wave setup model

The empirical wave setup of Hanslow & Nielsen (1993), Gourlay and Raubenheimer was used in this study. These formulas are follows:

- Hanslow & Nielsen (1993)

$$\bar{h}_w = 0.048\sqrt{H_{rms0}L_0} \qquad (5)$$

where $\bar{h}_w$ is the wave setup at the shoreline, H_{rms0} is the deep water *rms* wave height and L_0 is the deepwater wave length, which is calculated by:

$$L_0 = \frac{gT_P^2}{2p} \qquad (6)$$

in which T_P is the pick wave period from the numerical wave model simulation at the selected output point.

- Gourlay (1992):

$$\bar{h}_w = 0.35H_{rms0}x_0^{0.4} \qquad (7)$$

in which x_0 is the surf similarity parameter.

$$x_0 = \frac{\tan a}{\sqrt{H_0 / L_0}} \qquad (8)$$

in which $\tan a$ is the beach slope.

- Raubenheimer (2001):

$$\bar{h}_w = H_{so}(0.019 + 0.003b_{av}^{-1}) \qquad (9)$$

in which H_{s0} is the deepwater significant wave height, and b_{av} is the beach slope:

$$b_{av} = \frac{h_{av}}{\Delta x} \qquad (10)$$

in which Δx is the width of the surf zone and the average water depth:

$$h_{av} = \frac{1}{\Delta x}\int (h+h)dx \qquad (11)$$

where h is the still water depth, and h is the wave setup measured from the still water level. Note that, for a planar beach, b_{av} would be approximately equal to 1/2 of the beach slope.

These empirical water setup equations were developed from field and laboratory data in which moderately sized deepwater waves impinges almost directly on the coastline. The surf zones during these conditions would vary with wave parameters but would be several hundreds of meters wide. These formulas are based on an assumption of steady state conditions during which wave induced currents and water level reach an equilibrium condition. The situation during severe tropical cyclones are different from conditions during which these field and laboratory data were collected. In order to obtain deepwater significant wave height needed for the above mentioned equation, the procedure was as follows: Firstly, the significant wave height H_{s0} at the inshore model output point is deshoaled to the deepwater value to obtain:

$$H_{s0} = \sqrt{\frac{C_g}{C_{go}}}H_s \qquad (12)$$

where, C_g and C_{g0} are wave group speeds at wave output point and deepwater, respectively, given as:

$$C_{g0} = \frac{gT}{4p} \qquad (13)$$

$$C_g = \frac{1}{2}\left[1 + \frac{4ph/L_p}{\sinh(4ph/L_p)}\right]\left[\frac{gT_p}{2p}\tan\left(\frac{2ph}{L_p}\right)\right] \qquad (14)$$

In which, L_p is the wavelength of the peak frequencies of the spectrum given as:

$$L_p = \frac{gT_p^2}{2p}\tan\left(\frac{2ph}{L_p}\right) \qquad (15)$$

The significant wave height in equation 5 and 7 is converted to an rms using:

$$H_{rmso} = \frac{1}{\sqrt{2}}H_{s0} \qquad (16)$$

3. Model calibration

The results of calibration of the wind fields show that the typhoon model of Boose given a good simulation of wind velocity in the Hon Dau station for the two storms [11]. Therefore, this model is used to calculate the meteorology field which is input for the wave model and wave setup in storm.

3.1. Results of wave field.

Figure 1 shown the couple grid in SWAN model.

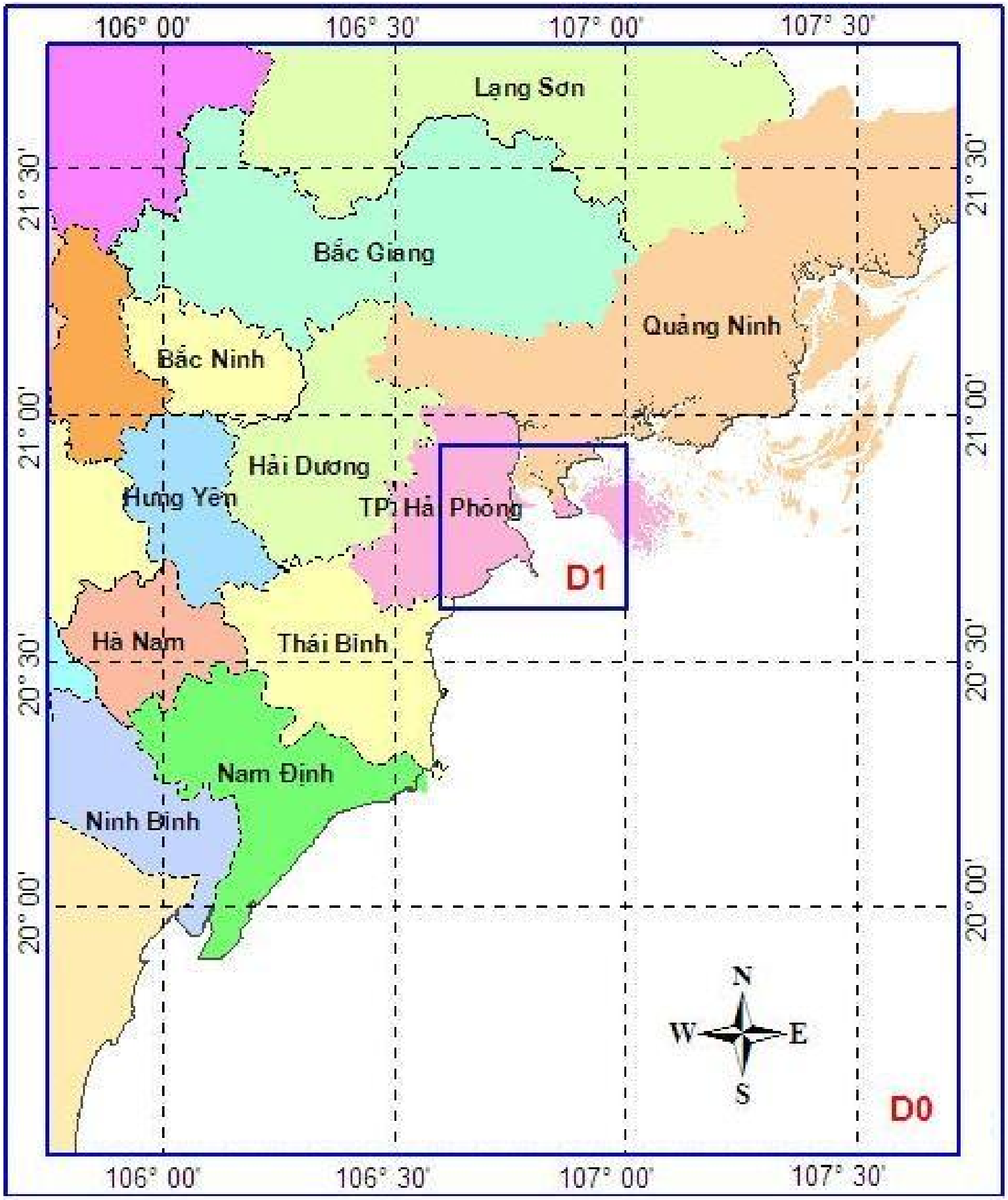

Figure 1. The computation mesh and domain in SWAN model.

The large domain (D0) is from 105.75^{0}E to 108.50^{0}E and from 19.5^{0}N to 21.75^{0}N with the resolution of 500m. The small domain (D1) is from 106.6^{0}E to 107.008^{0}E and from 20.6^{0}N to 20.93^{0}N with the resolution of 100m, time step is 15 minutes. Table 1 shows the results of wave characteristics and comparison between computed with the observation data at the Bach Long Vi station.

Table 1. Significant wave height

Time	Hs(m)	Calculate		
		Hs(m)	Dir(^{0})	Tp(s)
7h, 24/09/2005	1.00	1.13	177	5
13h, 24/09/2005	1.00	0.83	182	5
19h, 24/09/2005	0.50	0.73	191	5
7h, 25/09/2005	0.75	0.68	200	4
13h, 25/09/2005	1.00	1.77	204	6
19h, 25/09/2005	1.00	2.48	206	7
7h, 26/09/2005	2.50	3.18	228	11
13h, 26/09/2005	3.00	4.11	232	9
19h, 26/09/2005	4.00	4.53	226	9
7h, 27/09/2005	3.00	3.20	29	8
13h, 27/09/2005	1.00	2.29	47	9
19h, 27/09/2005	0.75	1.18	53	8

It is founded that the model's results of significant wave height at the Bach Long Vi station are in good agriment with the observated data. Thus, the wave model has a quite good simulation for the regional wind field. Moreover, the significant wave height is from 1 to 2 meters in the near shore and from 3 to 5 meters in the offshore areas.

3.2. Results of wave-setup

Table 2 shows the results of the wave and wave-setup in typhoon Damrey (2005) by three experiment at formulas of Hanslow & Nielsen, Gourlay and Raubenheimer in comparison with the observations.

Table 2. Calculated wave and wave-setup in Damrey storm (2005)

Location	Storm surge (cm)	Significant wave height (cm)	Wave setup (cm)		
			Hanslow & Nielsen	Gourlay	Raubenh-eimer
Lach Huyen	123	127	36,29	28,49	24,12
Nam Trieu	140	134	36,98	29,35	25,04
Lach Tray	150	134	37,23	29,67	25,38
Van Uc	144	143	37,68	30,24	26,16

The results from the three formulas show a different wave setup height in typhoon condition. In typhoon Damrey, maximum wave setup was 37.68 centimeters at Van Uc in Hanslow & Nielsen formula; 30.24 centimeters in Gourlay formula and 26.16 centimeters in others. As a whole, wave setup in selected points account for about 20 and 30 percent of total of storm surge calculated by Nguyen Xuan Hien et al. (2009), and between 16 and 24 percent of total surge in storm (it is supposed that the total surge consists of storm surge and wave-setup). It is found also in other studies of Tanaka and Shuto (1992), Hanslow and Nielsen (1992), Tanaka et al. (2008) for other regions [7,12,13]. Regarding the space, the wave-setup in typhoon Damrey in Hai Phong distributes unequaly (despite little difference only) and not similar phase with the total storm surge. There was a maximum of the total storm surge at the Lach Tray estuary, but the maximum of wave-setup was at the Van Uc estuary, where also appears the highest value of the significant wave height. It proves that topography has a noticeable influence on wave height and wave-setup.

4. Assessment of contribution of wave-setup to the total storm surge in Hai Phong

According to Tanaka and Shuto (1992), Hanslow and Nielsen (1992), Tanaka et al. (2008), wave-setup is different in various points, depending on coastal topography, depth, slope [7,12,13]. In order to estimate the contribution of wave-setup to total storm surge at several points in the Hai Phong region, authors calculated wave-setup in several storms effect on Hai Phong including: Kate (1973), Vera (1983), Fankie (1996), Marty (1996), Nikie (1996) and Damrey (2005). Tables from 3 to 8 show the results of wave-setup by different methods for several points in Hai Phong and the results of calculating storm surge by the ADCIRC model.

Table 3. Typhoon Katie 1973

Location	Storm surge (cm)	Significant wave height (cm)	Wave setup (cm)		
			Hanslow & Nielsen	Gourlay	Raubenh-eimer
Lach Huyen	55	116	5649	30.34	27.03
Nam Trieu	64	113	55.66	29.63	25.90
Lach Tray	49	102	52.75	27.19	23.80
Van Uc	42	116	57.14	30.91	27.02

Table 4. Typhoon Vera 1983

Location	Storm surge (cm)	Significant wave height (cm)	Wave setup (cm)		
			Hanslow & Nielsen	Gourlay	Raubenh-eimer
Lach Huyen	57	94	63.38	32.26	21.17
Nam Trieu	75	103	65.19	32.65	21.47
Lach Tray	91	100	64.14	31.81	20.64
Van Uc	66	133	89.13	38.8	25.72

Table 5. Typhoon Fankie 1996

Location	Storm surge (cm)	Significant wave height (cm)	Wave setup (cm)		
			Hanslow & Nielsen	Gourlay	Raubenh-eimer
Lach Huyen	85	158	51.14	34.99	27.04
Nam Trieu	98	152	50.82	34.63	26.69
Lach Tray	109	151	51.12	34.97	27.01
Van Uc	97	154	51.59	35.48	27.51

Table 6. Typhoon Marty 1996

Location	Storm surge (cm)	Significant wave height (cm)	Wave setup (cm)		
			Hanslow & Nielsen	Gourlay	Raubenh-eimer
Lach Huyen	57	112	40.99	27.53	22.61
Nam Trieu	75	111	36.17	26.06	21.58
Lach Tray	91	108	34.45	25.44	20.94
Van Uc	66	124	39.42	28.04	24.80

Table 7. Typhoon Niki 1996

Location	Storm surge (cm)	Significant wave height (cm)	Wave setup (cm)		
			Hanslow & Nielsen	Gourlay	Raubenh-eimer
Lach Huyen	66	142	47.06	40.38	19.94
Nam Trieu	71	148	51.39	41.47	19.65
Lach Tray	71	147	50.81	40.72	19.21
Van Uc	69	182	56.36	48.07	23.64

The computed results for the above mentioned typhoons are corresponded to previous researches. The values of wave-setup are different at various points in Hai Phong region because of the difference topographic conditions such as depth, slope and shape of seashore. Table 8 shows the role of wave-setup for coastal points in Hai Phong region calculated by averaging of all storms for the three formulas.

Table 8. The contribution of the wave-setup to the total surge.

Location	Contribution (%)			
	Hanslow & Nielsen	Gourlay	Raubenheimer	Average
Lach Huyen	41.19	31.70	25.36	32.75
Nam Trieu	41.13	31.60	25.10	32.61
Lach Tray	40.64	31.08	24.57	32.10
Van Uc	43.35	33.46	27.12	34.64

The results show that wave-setup has big contributed to total surge. On average, the wave-setup is highest at Van Uc with 34.6 percent of total surge, but the shortest is 32.1 percent at Lach Tray. Besides, experiment formulas give different results of wave-setup, thus, the highest value is from the formulas of Hanslow & Nielsen and the lowest value is created by the formulas of Raubenheimer.

5. Conclusion

Along with wind surge and different air pressure, wave setup is one of the important components in total storm tide. In the study, wind and pressure field model, wave model and wave setup model were applied to study in the Hai Phong estuarine region. The results canbe summarized as follows:

- Although in this study, model calibration was not inplemented due to lack of experiment and field data, the contribution of wave setup on total water level in storms is similar to other studies;

- Due to complex topography in the Hai Phong coastal area, wave setup is different at each point. It also shows that, only small difference can be found at each empirical formula. Wave setup at coastal in Hai Phong contribute about 25% and 40% of sea level surge in storm, average is 32%;

- However, the results will be more reliable if a large number of storms are taken into acount. It is necessary to combine numerical model with meteorology model, wave model and hydraulic model in next study

Acknowledgements

This paper has been prepared as a part of Project KC09.23/06-10. The authors would like to express their thanks to the support.

References

[1] Longuet-Higgins,M.S., Stewart, R.W., A note onwave setup. *J.Mar. Res.* 21 (1963) 4.

[2] M.S. Longuet-Higgins, R.W. Stewart, Radiation stresses in water waves; a physical discussion with application. *Deep Sea Res.* 11 (1964) 529.

[3] A. J. Bowen, D. L. Inman, V. P. Simmons, Wave set-down and set-up. *J. Geophys. Rea.* Vol. 73. N 8. (1968) 2569.

[4] C. Mastenbroek, G. Burgers, P.A.E.M. Janssen, The dynamical coupling of a wave model and a storm surge model through the atmospheric boundary layer. *J. Phys. Oceanogr.* 23 (1993) 1856.

[5] M.Y. Zhang, Y.S. Li, The dynamic coupling of a third-generation wave model and a 3D hydrodynamic model through boundary-layers. *Cont. Shelf Res.* 17 (1997) 1141.

[6] Y. Funakoshi, S.C. Hagen, P. Bacopoulos, Coupling of hydrodynamic and wave models: case study for Hurricane Floyd (1999) Hindcast. *J. Waterw. Port Coast Ocean Eng,* 2008.

[7] D. J. Hanslow, P. Nielsen, Wave setup on beaches and in river entrances, *Proceedings of 23rd International Conf. on Coastal Engineering,* 240-252, 1992.

[8] M. R. Gourlay, Wave set-up, wave run-up and beach water table: Interaction between surf zone hydraulics and groundwater hydraulics, *Coastal Engineering,* Volume 17, Issues 1-2, 93-144, 1992.

[9] R. T. Raubenheimer, Guza, S. Elgar, Field observations of wave-driven setdown and setup. *J. Geophys. Res.* 106 (2001) 4629.

[10] B. A. Happer et. al. Queensland Climate Change and Coastal Vulnerability to Tropical cyclones, Stage 3, *Queensland Goverment,* 400pp, 2001.

[11] Nguyen Xuan Hien, Pham Van Tien, Duong Ngoc Tien, Dinh Van Uu, Using ADCIRC model for simulation of storm surge in coastal and estuaries of Hai Phong during typhoon Damrey 2005. *VNU Journal of Science, Natural Sciences and Technology* 3S, 25 (2009) 431.

[12] H. Tanaka, N. Shuto. Field investigation at a mouth of small river, *Proceedings of 23rd International Conference on Coastal Engineering,* 1992, 2486-2499.

[13] Hitoshi Tanaka, Nguyen Xuan Tinh, Wave Setup at River Mouths in Japan. *Journal of Water Resources and Environmental Engineering,* No. 23, 2008.