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THE TYPHOON WIND HAZARD ANALYSIS IN HONG KONG OF CHINA WITH THE NEW FORMULA FOR HOLLAND *B* PARAMETER AND THE CE WIND FIELD MODEL

Yu-Feng Xiao[1], Yi-Qing Xiao[2] and Zhong-Dong Duan[3]

1 PhD student, School of Civil Engineering, Harbin Institute of Technology, Harbin, Heilongjiang, China, xxff811208@126.com

2 Professor, Shenzhen Graduate School, Harbin Institute of Technology, Shenzhen, Guangdong, China, xiaoyq@hit.edu.cn

3 Professor, School of Civil Engineering, Harbin Institute of Technology, Harbin, Heilongjiang, China, duanzd@hit.edu.cn

ABSTRACT

With the actual record of typhoon being inadequate, how to assess the long-term level typhoon wind risks in regions dominated by typhoon such as Hong Kong more accurately is still arguable. In this paper, an alternative method is proposed with two aspects of improvements in the typhoon hazard analysis for Hong Kong. One is The U.S. Army Corps of Engineers (CE) wind field model which is well demonstrated through comparison with observed typhoon wind speed records. Additionally, the new formula for Holland *B* parameter is introduced. There is reasonable agreement between the wind speed with various return periods in [Code (2004)] and those predicted by this paper, indicating that the method proposed tin this paper is suitable for the typhoon wind hazard and the risk analysis for Hong Kong of China in the future.

KEYWORDS: TYPHOON WIND HAZARD ANALYSIS, CE WINDFIELD MODEL, EXTREME WIND SPEED, MONTE CARLO SIMULATION, HONG KONG

Introduction

The typhoon wind hazard is defined as the probability of typhoon-generated wind speed exceeding a given threshold speed at a given site in a time period. In recent years, it has been found that typhoons usually made landfall in Hong Kong, which is the critical regional economic and political center with high density of population and social wealth and has a high density of tall buildings that are highly susceptible to typhoon induced damage. Thus, assessing typhoon risks and predicting maximum wind speeds are vital for improved construction standards, estimated wind loadings and typhoon disaster mitigation in such a typhoon-prone region.

A feasible and most accepted approach for typhoon hazard analysis in typhoon-prone regions is the Monte Carlo simulation technique pioneered by [Russell (1971)] for the Texas coast. The simulation approach is used widely in the United States in the literatures of [FEMA (2003) and ASCE-7 (1988-2005)] and expanded to estimate design wind speeds for the US Coastlines presented in the works by [Batts *et al.* (1980)], [Georgiou (1985)], [Vickery *et al.* (2000) and Vickery and Twisdale (1995a)] and [Powell *et al.* (2005)] The prediction of typhoon wind speeds of Hong Kong using Monte Carlo simulation is first implemented by [Georgiou (1985)] who used the pressure model given in [Holland (1980)] with the value of parameter *B* be 1 to define the gradient wind speed. This method was expanded by [Isyumov *et al.* (2003)]. However, the wind field model used in these studies is given by [Shapiro (1983)], the accuracy of which is worse than that of the CE wind model. Furthermore, when one validates the wind field model, we found that the degree to which the observed match the model-predicted wind speed changes with the parameter *B*, especially at the time the maximum wind were occurring. The implication of typhoon York was studied and its effect on the typhoon design wind speed and the wind code of Hong Kong is pointed that it needs to be revised in the work by [Pande *et al.* (2002)].

This paper focus on searching for the more reasonable method to predict the typhoon design wind speed in Hong Kong. The CE wind field model will be solved and the formulae presented by [Holland (2008)] and [Li *et al.* (1995)] are to be used to estimate the value of the Holland pressure profile parameter *B* and radius to maximum winds R_{max}, respectively, treating the parameter *B* as the random parameter. This will be helpful to the prediction of the typhoon design wind speed or the typhoon risk analysis for Hong Kong in the future.

The new formula for Holland *B* parameter

The definition of the Holland B parameter

The Holland parameter *B* is an exponent factor that specifies the shape of the radial pressure profile, which can be seen from Eq.(1) and is an important input parameter to the wind field model described later.

$$p(r) = p_0 + \Delta p \exp\left(-\left(R_{\max}/r\right)^B\right) \tag{1}$$

where p(r) is the surface pressure at a distance r from the typhoon center, p_0 is the central pressure, Δp is the difference between the peripheral pressure(p_∞) and the central pressure. The range of the parameter *B* is from 1.0 to 2.5 proposed in the work by [Holland (1980)], but Holland based his study on very few cyclones because there was no aircraft reconnaissance in Australia. For the U.S. coastal area, radial pressure profile was fitted to the exponential form to hundreds of aircraft data sets in [Cardone *et al.* (1994)] to derive the value of Holland *B* and the range is from 05 to 2.5, which is also used in[Vickery *et al.* (2000)] and is the same as those in [Willoughby and Rahn (2004)], but the range from 0.75 to 2.5 is proposed to be more reasonable in [Cox and Cardone (2007)] As we know, the range of parameter *B* is different from region to region. As for the southeast China sea, the range need to be further studied and the range from 0.8 to 2.5 is used in this paper.

The new formula for Holland B parameter and comparison with other formulae

The Holland *B* parameter was first treated as a random parameter in the work by [Vickery *et al.* (2000)] and can be estimated through various methods.

For the region where the aircraft data are available, *B* is a fitting parameter with no particular theoretical value in the literatures by [Vickery et al. (2000)], [Powell et al. (2005)] and [Willoughby and Rahn (2004)].

Other than the methods described above, empirical formulae to calculate the estimate of *B* are proposed for those regions where the aircraft data are not available. Such as the formula proposed by [Love G (1985)] which is

$$B = 0.25 + 0.3\ln(\Delta p) \tag{2}$$

, the empirical formula to evaluate the value of *B* presented by Hubbert et al. (1991) which is

$$B = 1.5 + \left(980 - p_0\right)/120 \tag{3}$$

and the empirical formula to evaluate *B* presented by Holland & Harper (1999) which is

$$B(t) = 2 - \left(p_0(t) - 900\right)/160 \tag{4}$$

Compared to the formulae to calculate the parameter *B* described above, the new formula proposed by [Holland (2008)] has been tested against aircraft data and can be described as

$$b_s = -4.4\times10^{-5}\Delta p^2 + 0.01\Delta p + 0.03\frac{\partial p_c}{\partial t} - 0.014\psi + 0.15V_T^{\,x} + 1.0,$$
$$x = 0.6\ (1-\frac{\Delta p}{215}) \tag{5}$$
$$B = b_s(\frac{v_{mg}}{v_m})^2 \sim 1.6b_s$$

where Δp is the pressure drop to the cyclone center in hPa; $\partial p_c/\partial t$ is the intensity change in hPa h^{-1}; ψ is the absolute value of latitude in degrees; and V_T is the cyclone translation speed in ms^{-1}.; v_{mg}/v_m is the conversion factor from gradient to surface wind.

The comparison of different formula for calculating the parameter B is shown in Figure 1. The relationships presented in [Hubbert *et al.* (1991)] and [Holland and Harper (1999)] are statistically the same, but there is a lot of scatter in the one proposed by [Love G (1985)]. Given its derivation, Eq.(5) is used in this paper, which is much more robust and developed from aircraft reconnaissance and allows some variation in B due to translational speed and intensification.

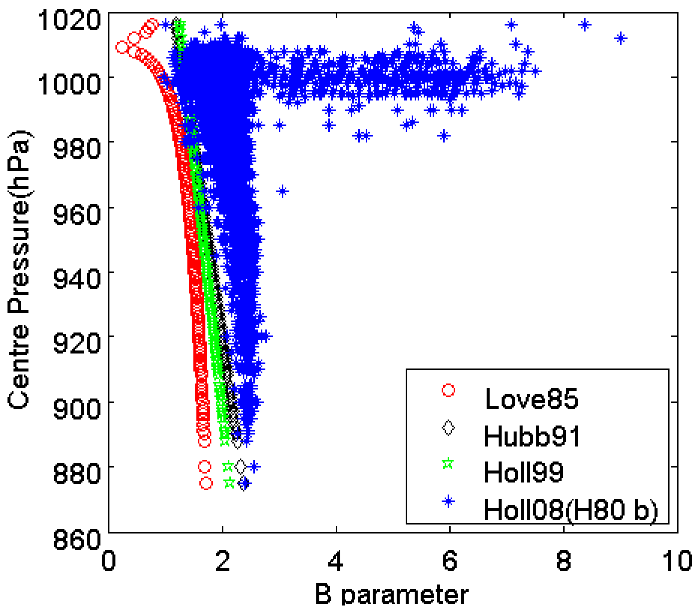


Figure 1 Comparison of *B* Derived From Different Formula

The effect of the new formula for Holland *B* on the CE wind field model

The U.S. Army Corps of Engineers (CE) wind field model

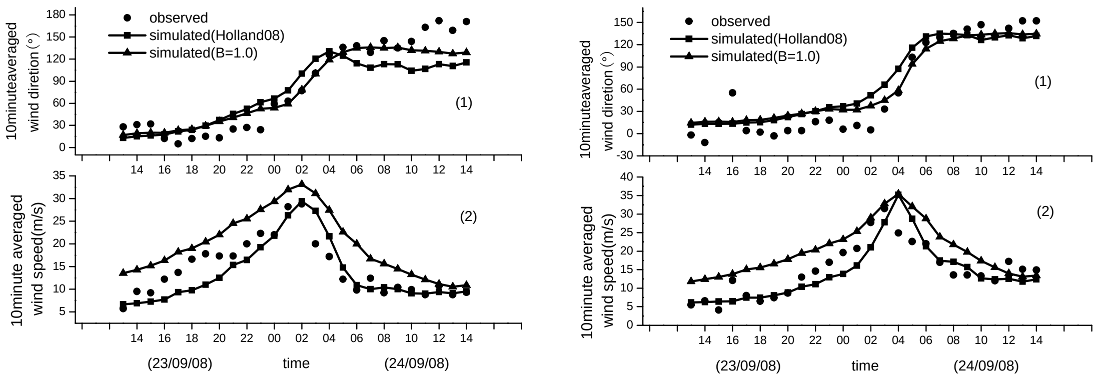
There are two key parts of the typhoon wind hazard analysis. The first part is the reliable typhoon wind field model. In this paper, it is based on the solution of the CE wind field model proposed in the work by [Thompson and Cardone (1996)] by using the finite difference method, i.e. the equation of motion in a moving Cartesian coordinate system whose origin is the typhoon low center

$$\frac{d\vec{v}}{dt} + f\left|\vec{k}\times\left(\vec{v}-\vec{v}_g\right)\right| = -\frac{1}{\rho}\nabla p + \nabla\cdot\left(K_H\nabla\vec{v}\right) - \frac{C_D}{h}\left|\vec{v}+\vec{v}_c\right|\left(\vec{v}+\vec{v}_c\right) \tag{6}$$

where p is the atmospheric pressure and has the following form described by Eq.(1). The details of the wind field model are given in the work by [Thompson and Cardone (1996)].

The effect of the new formula on the wind field model

After the validation of the CE wind field model by comparing the simulated results to the observed ones with the typhoon Hagupit provided by Guangdong meteorology agency of China, the results are shown in Figure 2 and Table 1. As shown in Figure 2 (a) and (b), in all the cases, the deviation of the simulated speeds from observed ones of the maximum winds is greater than 12% for the results derived in the work by [Georgiou (1985)] with the value of *B* be one, which is unacceptable. But the deviation is never greater than 12% for the results derived with the formula given in [Holland (2008)], indicating that the wind field model with the new formula for Holland *B* is suitable to predict the typhoon wind speed because there are uncertainty arising from a combination of instrument error, representativeness of the location, and local downdrafts and other effects that are not representative of the overall cyclone circulation.



(a) Shangchuandao (b) Yangjiang

Figure 2: Comparison of Observed and Simulated Wind Speeds of Typhoon Hagupit with *B* Determined by Holland08 and *B* set as one

Table 1: Comparisons Between the Observed Wind Speeds of Hagupit at Different Anemometers and the Simulated Results Predicted by the CE Wind Field Model

hurricane	stations	height(m) (lat,lon)	roughness length(m)	observed(m/s)*	parameter*B*	simulated (m/s)*	error**
Hagupit	Shang chuandao	11.0 (21.73N,112.77W)	0.02	28.80	1.0	33.1	14.93%
					Holl08	29.4	2.09%
	Yangjiang	10.7 (21.83N,111.97W)	0.02	31.50	1.0	35.4	12.38%
					Holl08	35.2	11.79%

* maximum wind

**error=(simulated value-observed value)/observed value

The typhoon wind hazard analysis with the new formula for Holland *B*

Representation of the key typhoon parameters

The second part is the probabilistic distribution of the key typhoon parameters characterizing the structure and intensity of the storm. These parameters include annual occurrence rate(λ), approach angle(θ), distance of closest approach(D_{min}), translation velocity(V_T), central pressure difference(Δp), filling model, radius to maximum winds(R_{max}) and the Holland pressure profile parameter. The definition of the other key typhoon parameters except the R_{max} and the filling model. can be referred in [Xiao *et al.* (2009)] with the different parameter estimates.

The formula proposed by [Li *et al.* (1995)] is used to calculate the value of R_{max} which is derived by

$$R_{\max} = R_6 (V_6 / V_{\max})^k \tag{7}$$

where R_6 = the radius to 10.8 m/s wind speed in km; V_6 = 10.8 wind speed in m/s; the value of the coefficient k = from 1/0.5 to 1/0.7; and V_{max} = the maximum sustained (1-minute) surface wind speed (10m level) in m/s given in Best track dataset. The exponential filling model developed by [Vickery and Twisdale (1995b)] and adopted by [Powell *et al.* (2005)] and modified in this paper, which is

$$\Delta P(t) = \Delta P_0 \exp\left(-\left(at+b\right)\right) \tag{8}$$

where $a=a_0+a_1\Delta p_0+\varepsilon$; ε = a normally distributed error term ; and Δp_0 = the central pressure difference at the time of landfall.

The correlation between the key typhoon parameters

The correlation between R_{max}, Δp and latitude shows much scatter but a generalized linear model for the natural log of R_{max} provides a useful estimation

$$\ln R_{\max} = c_0 + c_1 \Delta P + c_2 \psi + \varepsilon \tag{9}$$

where ε = a normal random variable. When a simulated storm enters into the simulation circle centering the sites of interest, an R_{max} is randomly chosen given the value of Δp and latitude (ψ). R_{max} is computed at each time step but the random error term is computed only once for each landfall. The sampled value of R_{max} derived from Eq.(7) for a storm generated in the simulation is held constant until landfall and censored to remain above 8km and below 150km. the relation between the Holland pressure profile parameter B derive from the Eq.(5) and R_{max} data for the storm entering into the simulation circle, one finds that a normal distribution is for B with a mean value determined as a function of R_{max} and latitude (ψ) and the resulting model for B is given by

$$B = d_0 + d_1 R_{\max} + \varepsilon \tag{10}$$

where ε = a normal random variable. When a simulated storm enters into the simulation circle centering sites of interest, B is randomly chosen given the value of latitude (ψ). (so as to give R_{max}). B is computed at each time step but the random error term is computed only once for each landfall. The sampled value of B derived from Eq.(10) for a storm generated in the simulation is held constant until landfall and censored to remain above 0.8 and below 2.5.

Data sources

The sample of the key typhoon parameters are calculated based on the Best track dataset from CMA (during1949-2008) and the information of the radius to wind speed ranking sixth is provided by the Qingdao oceanic bureau of China (during1949-2002).

Results and comparison to results of other studies

The results of the distributions and distribution parameters are given in Table 2, the coefficients in Eq.(8) for Hong Kong are given in Table 3.

Table 2: the Estimation of Key Typhoon Parameters for Hong Kong

simulation circle	key typhoon parameters	distribution	parameter estimation
diameter=1000km	λ	Poisson	λ=6.1167
	θ(deg.)	Binormal	$\mu1$=-71.2252,$\sigma1$=28.1456
			$\mu2$=61.8480,$\sigma2$=44.3987
			$a1$=0.7807,$a2$=0.7879
	V_T(km/h)	empirical	
	Δp(hPa)	empirical	
	R_{max}	empirical	
	D_{min}(km)	Trapzoid	a=0,b=0.0009816

	B_Holl08	Normal	μ=1.9990,σ=0.2320

Table 3: the Coefficients of the Filling Model for Typhoon in Hong Kong

city	a_0	a_1	μ_b	σ_b	σ_z
Hong Kong	0.0135	0.0005	-0.0133	0.1485	0.0214

The coefficients in Eq.(9) and (10) for Hong Kong are given in Table 4 and Table 5, respectively.

Table 4: Results of correlation between the R_{max} and other parameters for typhoon in Hong Kong

city	c_0	c_1	c_2	σ_z
Hong Kong	5.3259	-0.0249	-0.0161	0.4543

Table 5: Results of Correlation Between the Holland B and R_{max} and Latitude for Typhoon in Hong Kong.

city	d_0	d_1	σ_z
Hong Kong	2.1968	-0.0007	0.5035

Based on the two parts described above, the typhoon wind hazard analysis is done for Hong Kong based on the following form

$$1\text{-}1/T = F_v \tag{11}$$

where F_v is CDF of the annual extreme-value series. 1000 years of storms are simulated with the number N of storms for each year determined by v. The peak value for each storm is recorded to derive the maximum one among the N values. The set of 1000 peaks are ranked by magnitude to establish F_v. The design wind speed with various T can be derived by solving the Eq.(11). After tropical depression are excluded, the storms entering into the site sub-region with a circle diameter of 1000km are selected to derive the probabilistic distributions and parameter estimates of key typhoon parameters. The results are shown in Table 6.

Table 6: Comparison with Previous Studies about the 60-Minute Mean Wind Speeds (m/s) at 10m-level in B Terrain as a Function of Return Period for Hong Kong

method	distribution	return period(years)		
		50	100	200
HKCode*		38.73	44.01	44.18
Georgiou(1985)	Weibull	38.60	40.90	43.20
This paper	Weibull	36.73	40.29	43.67

*Code of Practice on Wind Effects in Hon Kong 2004.

Seen from Table 6, the results given by [Georgiou (1985)] are greater than those in this paper except for the return period equal to 200 years which has the opposite case and the deviation is not greater than 5.09%. It may be attributed to a combination of all the tropical cyclones not just those reaching typhoon intensity with setting the value of B to be one proposed in the study of [Georgiou (1985)]. The design wind speed in [Code (2004)] is greater than those in this paper and the deviation is no more than 9.23%. It may be due to the uncertainty about the nature of typhoon and the inclusion of data of the non-tropical storm used in the [Code (2004)].

Conclusion

An alternative method of typhoon hazard analysis in Hong Kong is proposed with inclusion of the CE wind model and two formulae for calculating two key typhoon parameters. From the results derived by this method, it is found that the Weibull distribution with tail length parameter γ>4 is the best fitting distribution for the simulated extreme wind speed in Hong Kong of China. Given that there are many uncertainty arising from a combination of instrument error, representativeness of the location, and local downdrafts and other effects that are not representative of the overall cyclone circulation and the assumed roughness length which will also introduce uncertainty, the results indicate that the method proposed tin this paper is suitable for the typhoon wind hazard and the risk analysis for Hong Kong of China in the future.

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References

ASCE-7. (1988), "Minimum Design Loads for Buildings and Other Structures.".

Batts, M. E., Simiu, E., and Russell, L. R. (1980), "Hurricane wind speeds in the United States", Journal of the Structural Division, 106(10), 2001-2016.

Cardone, V. J., Cox, A. T., Greenwood, J. A., Thompson, E. F., and OCEANWEATHER, I. (1994), "Upgrade of tropical cyclone surface wind field model." , US Army Engineer Waterways Experiment Station.

Code, H. K. (2004), "Code of Practice on Wind Effects in Hong Kong 2004.".

Cox, A. T., and Cardone, V. J. (2007), "Specification of tropical cyclone parameters from aircraft reconnaissance," Proceedings of the Tenth International workshop on wave hindcasting and forecasting and coastal hazard symposium, Oahu, Hawaii, November 11~16.

FEMA. (2003), "HAZUS-MH MR1: Technical Manual.".

Georgiou, P. N. (1985), "Design wind speeds in tropical cyclone-prone regions.," , The University of Western Ontario.

Holland, G. J. (1980), "An analytic model of the wind and pressure profiles in hurricanes", Monthly Weather Review, 108(8), 1212-1218.

Holland, G. J., and Harper, B. A. (1999), "An updated parametric model of the tropical cyclone," Proceedings of the Twenty third Conference on Hurricanes and Tropical Meteorology, Dallas, Texas.January 10~15 , 104-115.

Holland, G. (2008), "A revised hurricane pressure–wind model", Monthly Weather Review, 3432-3445.

Hubbert, G. D., Holland, G. J., Leslie, L. M., and Manton, M. J. (1991), "A real-time system for forecasting tropical cyclone storm surges", Weather and Forecasting, 6(1), 86-97.

Isyumov, N., J, M. M., Case, P. C., Lythe, G. R., and Welburn, A. (2003), "Predictions of wind loads and responses from simulated tropical storm passages," Proceedings of the Eleventh International Conference on Wind Engineering, Lubbock, Texas, June,2~5.

Li, X. L., Pan, Z. D., and Yu, J. (1995), "An adjustment method for typhoon parameters", Journal of Oceanography of Huanghai and Bohai Seas, 13(2), 11-15.

Love G, M. K. (1985), "The operational analysis of tropical cyclone wind fields in the Australian northern region." , Bureau of Meteorology, Northern Territory Region.

Pande, M., Ho, T., Mikitiuk, M., Kopp, G. A., and Surry, D. (2002), "Implications of Typhoon York on the design wind speeds in Hong Kong", Journal of Wind Engineering & Industrial Aerodynamics, 90(12-15), 1569-1583.

Powell, M., Soukup, G., Cocke, S., Gulati, S., Morisseau-Leroy, N., Hamid, S., Dorst, N., and Axe, L. (2005), "State of Florida hurricane loss projection model: Atmospheric science component", Journal of Wind Engineering & Industrial Aerodynamics, 93(8), 651-674.

Russell, L. R. (1971), "Probability distributions for hurricane effects", Journal of the Waterways, Harbors and Coastal Engineering Division, 97(1), 139-154.

Shapiro, L. J. (1983), "The asymmetric boundary layer flow under a translating hurricane", Journal of the Atmospheric Sciences, 40(8), 1984-1998.

Thompson, E. F., and Cardone, V. J. (1996), "Practical modeling of hurricane surface wind fields", Journal of Waterway, Port, Coastal and Ocean Engineering, 122(4), 195-205.

Vickery, P. J., Skerlj, P. F., Steckley, A. C., and Twisdale, L. A. (2000), "Hurricane wind field model for use in hurricane simulations", Journal of Structural Engineering, 126(10), 1203-1221.

Vickery, P. J., Skerlj, P. F., and Twisdale, L. A. (2000), "Simulation of hurricane risk in the US using empirical track model", Journal of Structural Engineering, 126(10), 1222-1237.

Vickery, P. J., and Twisdale, L. A. (1995a), "Prediction of hurricane wind speeds in the United States", Journal of Structural Engineering, 121(11), 1691-1699.

Vickery, P. J., and Twisdale, L. A. (1995b), "Wind-field and filling models for hurricane wind-speed predictions", Journal of Structural Engineering, 121(11), 1700-1709.

Willoughby, H. E., and Rahn, M. E. (2004), "Parametric representation of the primary hurricane vortex. Part I: Observations and evaluation of the Holland (1980) model", Monthly Weather Review, 132(12), 3033-3048.

Xiao, Y. F., Duan, Z. D., and Xiao, Y. Q. (2009), "Typhoon hazard analysis in southeast China coastal region with the CE wind field model," Proceedings of the Tenth international Conference on Structural Safety and Reliability, Osaka,Japan,September,13~17.