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Scopus Compendex and Geobase Elsevier,
Geo-Ref Information Services-USA, List B of Scientific
Journals, Poland, Directory of Research Journals

International Journal of Earth Sciences and Engineering

www.cafetinnova.org

ISSN 0974-5904, Volume 09, No. 02

April 2016, P.P.817-822

Comparison of Strong Wind Characteristics between Inland and Littoral of China Based On Field Measurements

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Abstract: There is a shortage of data of strong wind characteristics in Xinjiang. To compare wind field characteristics between inland area and coastal area, the data of strong wind characteristics at Chaiwobao station in Dabancheng, Xinjiang and at Shatian station, Dongguan City are obtained. The instrument configurations used for field measurements are presented, and the data quality is evaluated. Then the average wind field characteristics including wind velocity, wind direction, wind velocity profile and turbulence intensity were compared between the two stations. According to the results, (1) the extreme wind velocity at Chaiwobao station is 39.2 m/ s, which is higher than that of the station in typhoon zone (32.9 m/s). However, the occurrence time of maximum wind velocity is different. The maximum wind velocity occurs in winter and spring in Xinjiang and in summer and autumn in coastal typhoon zone; (2) the wind direction distribution is also different. The regions of strong wind in Xinjiang show a consistent distribution pattern all the year round due to the orientation of the mountains flanking the valley. But in Shatian Town, the wind direction varies with the seasons; (3) As analyzed using the strong wind samples, the land covers of the two districts basically belong to type A. But based on the data of weather observations, the land cover in Chaiwobao distribution basically belongs to type A, and that in Shatian Town type B. The wind velocity profiles are greatly influenced by wind velocity. That is, the higher the wind velocity, the smaller the wind velocity profile index is; (4) the turbulence intensity of the two districts decreases with altitude. It decreases by nearly one half at 80m from the land surface. The turbulence intensity of Chaiwobao station attenuates more rapidly than that in Shatian Town, indicating that the turbulence intensity decreases with higher wind velocity. The above findings provide reference for further studies on strong wind characteristics and for the determination of wind load in structural design.

Keywords: *Field measurement, Inland strong wind, Coastal typhoon, Wind characteristics, Wind velocity profile, Turbulence intensity*

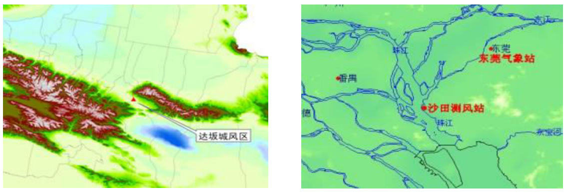
1. Introduction

Wind is the most prevalent natural phenomenon, but strong winds can be disastrous. Given the high frequency of strong winds and severity of secondary disasters, wind disaster ranks the first of all natural disasters in terms of economic loss (accounting for 40.5% of all economic loss caused by natural disasters, higher than that of earthquakes) [1]. As more towering, large-span and light-weight buildings are emerging, the values of wind load are important in structural design [2]. Wind field characteristics of structures are greatly influenced by local topography, and the most reliable method for acquiring wind field characteristics is field measurement [3]. Davenport, the father of modern wind engineering, proposed exponential model for wind velocity profile, concept of surface roughness and Davenport spectrum back in the 1960s[4]. Later Duchene Marullaz put forward the law of turbulence intensity decreasing with altitude. Gust factor, integral turbulence length scale and wind velocity power spectrum are also constructed based on large amount of field measurements [5]. Based on long-term field measurements of wind, the parameters of wind load design are determined in different countries. In China, the field measurements of wind were first conducted by researchers in the field of climate science and atmospheric science. Bao-Shi Shiau et al. [6] studied the wind characteristics in coastal regions of Taiwan by field measurements. An, Wang and Xiao et al. [7-9] carried out field measurements of typhoon. Since the 20th century, field measurements have been applied more and more commonly in structural wind engineering, especially for long-span bridges. For example, Xiang, Chen, Liu, Li and Pang et al. [10-16] analyzed the wind characteristics of bridge sites for sea-, river, mountain and valley spanning bridges. However, very few field measurements are performed for Xinjiang, where strong winds are very frequent.

There are much more wind characteristics measurements for coastal areas. By comparing the strong wind characteristics between Xinjiang and coastal typhoon zones, we hope to understand the strong wind characteristics of west inland regions and to provide referenced for wind load design. Average wind field and fluctuating wind field are obtained and four wind parameters are compared, namely, wind velocity, wind direction, wind velocity profile and turbulence intensity.

2. Field measurement:

Data of Chaiwobao wind tower (2009.10-2011.9) in Dabancheng, Xinjiang for two years and the data of Shatian wind tower (2008.9-2011.8) in Dongguan City, Guangdong Province for three years are collected and compared. These two districts are representative of west inland regions and coastal typhoon zones of China, respectively. The locations of the stations are shown in Fig. 1. Due to limited space, only the average wind fields are compared, and the wind characteristic parameters analyzed include wind velocity, wind direction, wind velocity profile and turbulence intensity. Integral turbulence length scale and power spectrum density of turbulent flow are not calculated.



(a) Chaiwobao *(b) Sha Tin*

***Figure 1:** The wind observation tower location*

2.1. Instrument configurations:

Chaiwobao wind tower: CAWS1000-GWS Automatic Wind Energy Observation System, manufactured by China Huayun Group. The average wind field was observed by EL15-2D wind direction sensor and EL15-1A wind velocity sensor. Fluctuating wind field was observed by Wind Master Pro Ultrasonic Anemometer (GILL, UK).
Shatian wind tower: Average wind field was observed by NRG sensor. Fluctuating wind field was observed by WindMaster Pro Ultrasonic Anemometer (GILL, UK). The instrument configurations are shown in Table 1.

***Table 1**: Installation of the equipment*

Wind measuring point	Longitude, latitude and altitude	Station height/m	Wind field type	Installation
Chaiwopu, Dabancheng, Urumchi	E: 87°56′55.9″ N: 43°33′21.9″ H: 1153	100	Mean wind field	Anemometer: 10m,30m,50m,70m,100m Anemoscope: 10m,50m,70m,100m
			Fluctuating wind field	WindmasterPro3-axis ultrasonic anemometer: 70m
Datan village, Shatian, Dongguan	E: 113°34’48.5’’ N: 22°51’15.1’’ H: 5m	80	Meanwind field	NRG anemometer and NRG anemoscope: 10m,20m,40m,60m,80m, respectively
			Fluctuating wind field	WindmasterPro3-axis ultrasonic anemometer: 75m

2.2. Observation data:

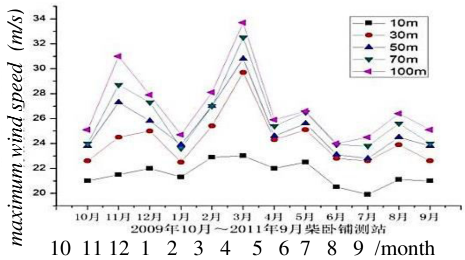
(1) Observation time of average wind field
Chaiwobao wind tower: Two years, starting from October 2009 to September 2011.
Shatian wind tower: Three years, starting from September 2008 to August 2011.
(2) Data quality
Chaiwobao wind tower: Due to a once-in-60-years snow storm in January, 2010 in north Xinjiang, the temperature was extremely low, causing damage to some sensors and hence an absence of data. Thus the data integrity was 98.9%.

Shatian wind tower: Due to accidental failures of data recorder, the data from 08:00 on December 2nd to 23:00 on December 3rd 2008 were missing, and the data integrity was 99.8%.

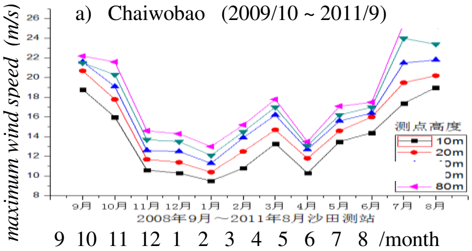
3. Comparison of average wind field characteristics:

3.1. Wind velocity:

The data of average wind field are validated, interpolated and corrected to obtain full sequences. On this basis, the maximum monthly wind velocity (10min average) and extreme wind velocity (3s gust) are calculated for the two districts, as shown in Fig. 2 and 3.

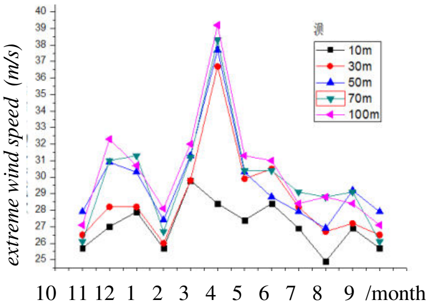


a) Chaiwobao (2009/10 ~ 2011/9)

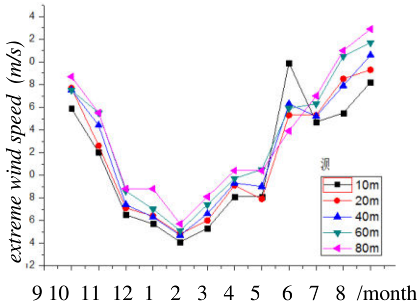


b) Sha Tin (2008/9 ~ 2011/8)

***Figure 2:** The monthly maximum wind speed of every measuring point*



a) Chaiwobao (2009/10 ~ 2011/9)



b) Sha Tin (2008/9 ~ 2011/8)

Figure 3*: The monthly extreme wind speed of every measuring point*

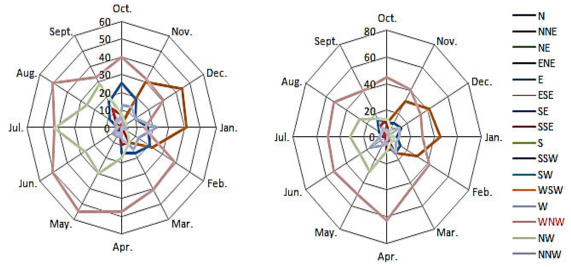
It can be seen that for Chaiwobao station, ① the maximum wind velocity at the altitude of 10, 30, 50, 70 and 100m is 23.0m/s, 29.7m/s, 30.8m/s, 32.5m/s and 33.7m/s, respectively, showing an increasing trend with altitude; ② both extreme wind velocity (39.2 m/s) and maximum wind velocity (33.7m/s) occur at the altitude of 80m; ③ the wind velocity is larger in winter and spring and smaller in summer and autumn. The occurrence of maximum wind velocity in March is due to cold air activity, while the minimum wind velocity in July is due to subtropical high.

At Shatian station, ① the maximum wind velocity at the altitude of 10, 20, 40, 60 and 80m is 19.0m/s, 20.7m/s, 21.8m/s, 24.0m/s and 25.5m/s, respectively, showing an increasing trend with altitude; ② both extreme wind velocity (32.9 m/s) and maximum wind velocity (25.5m/s) occur at the altitude of 80m; ③ the maximum monthly wind velocity occurs in July and August, 2009, due to Typhoon Molave and local severe convective weather in thunderstorm, respectively.

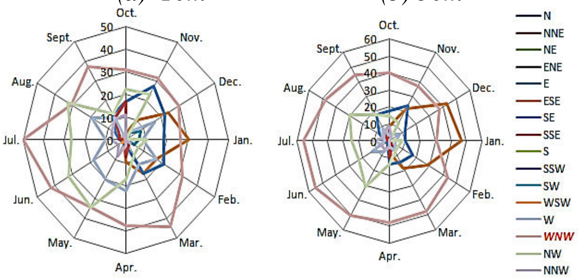
Comparison of average wind velocity at the two stations shows that ① on the wind velocity profile, wind velocity increases with altitude in the two districts; ② the extreme wind velocity in Xinjiang (39.2m/s) is larger than that in coastal typhoon zone (32.9m/s); ③ The maximum wind velocity occurs at different seasons in the two districts, that is, during winter and spring for Xinjiang, and summer and autumn for coastal typhoon zone; ④ The variation trend of maximum monthly wind velocity and extreme monthly velocity at the altitude of 10m at Chaiwobao station is different from that at other altitudes due to the effect of local topography on surface layer.

3.2. Wind direction:

Wind directions at each altitude are calculated (wind direction corresponding to the 10min-average maximum wind velocity). The wind rose plots for each month and each year are obtained, as shown in Fig. 4.



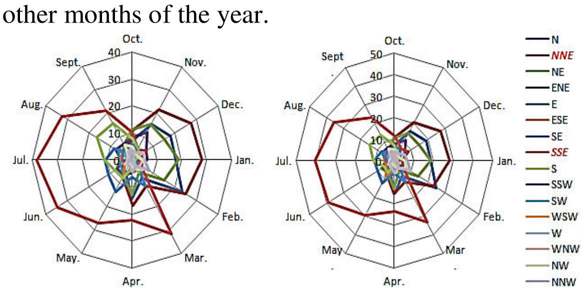
(a) 10m *(b) 50m*



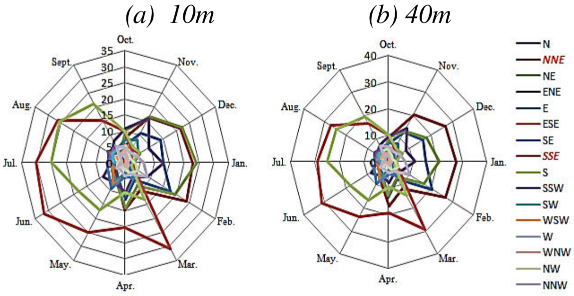
(c) 70m *(d) 100m*

Figure 4*: The monthly wind rose of Chaiwobao measuring point during 0ct.2009~Sep.2011*

As shown in Fig. 4, ① west-northwestern (WNW) wind is consistently the dominant wind direction at each altitude during the observation period (October 2009 to September 2011); ② Except from December to January when east-southeast (ESE) wind is the dominant wind direction, WNW wind is dominant in other months of the year.



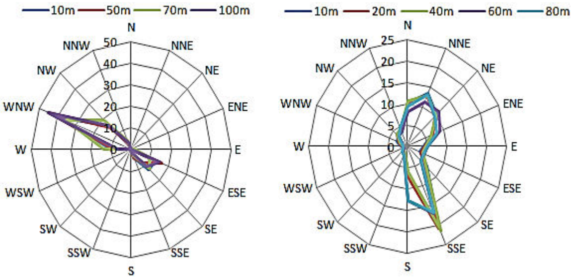
(a) 10m *(b) 40m*



(c) 60m *(d) 80m*

Figure 5*: The monthly wind rose of Sha Tin measuring point during Sep.2008~Aug.2011*

In Fig. 5, ① wind direction at each altitude does not vary significantly, and south-southeastern (SSE) wind and north-northeastern (NNE) wind are dominant; ② wind direction varies rhythmically throughout the year. The dominant wind direction is northeastern (NE), north-northeastern (NNE), south-southeastern (SSE) and southern (S) in September, October to January, February to July, and August, respectively.



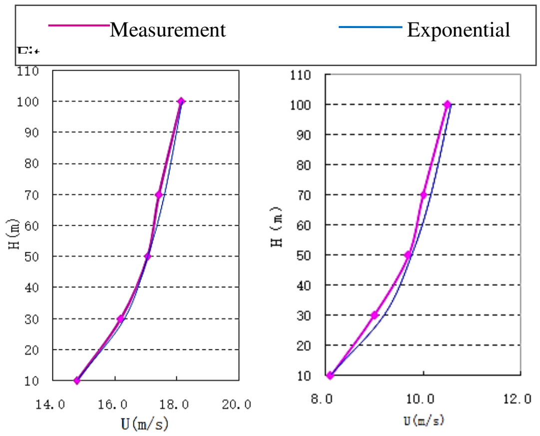
(a) Chaiwobao *(b) Sha Tin*

***Figure 6**: The yearly wind rose of Chaiwopu measuring point and Sha Tin measuring point*

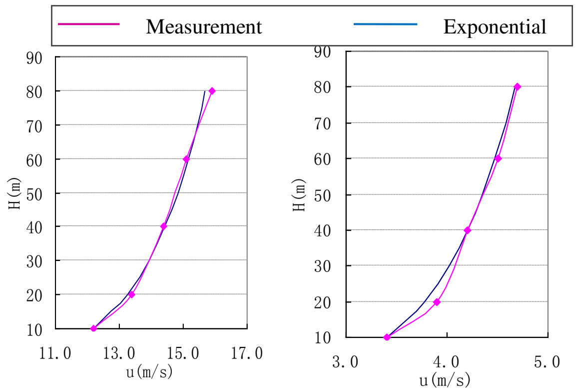
Wind directions at the two wind towers are compared in Fig. 6: ① the dominant wind direction is WNW in Xinjiang, and the second dominant wind direction is ESE, due to the influence of mountain orientation. For example, the yearly frequency of WNW at 10m altitude is 39.3% and that of ESE is 13.6%; the yearly frequency of WNW at 50m altitude is 44.4% and that of ESE is 16.8%; the yearly frequency of WNW at 70m altitude is 34.9% and that of ESE is 10.0%; the yearly frequency of WNW at 100m altitude is 44.9% and that of ESE is 15.4%; ② the dominant wind direction in coastal typhoon zone is SSE and NNE. The yearly frequency of SSE at 10m altitude is 19.6% and that of NNE is 13.4%; the yearly frequency of SSE at 20m altitude is 20.8% and that of NNE is 12.8%; the yearly frequency of SSE at 40m altitude is 21.5% and that of NNE is 13.4%; the yearly frequency of SSE at 60m altitude is 17.1% and that of NNE is 11.1%; the yearly frequency of SSE at 80m altitude is 16.9% and that of NNE is 13.0%; ③ wind direction distribution of the two districts shows a different pattern. Due to the influence of mountains flanking the valley, the wind direction is consistent throughout the year at Chaiwobao station. In contrast, the wind direction of Shatian station varies with seasons.

3.3. Wind velocity profile:

Strong wind characteristics are important for wind load calculation in structural engineering, so we select strong wind data from all samples. Since the data of the two districts come from different sources, they are processed in different way. For Chaiwobao station, the 10min-average wind velocity equal to or above 10.8m/s (6 on the Beaufort scale) at 10m altitude is defined as strong wind; for Shatian station, the 1h-average wind velocity equal to or above 10.8m/s at 10m altitude is defined as strong wind (36 time levels were recorded during the observation period). Using the measured wind velocities at each altitude, the velocity profile index is calculated by least squares method for the two wind towers. The index is 0.09 during the strong wind period at Chaiwobao station and 0.121 at Shatian station. Based on conventional meterological observations, the wind shear exponent is 0.116 at Chaiwobao station and 0.153 at Shatian station (Fig. 7).



(a) Chaiwopu: α=0.09 α=0.116
(Strong wind) (Conventional average wind)



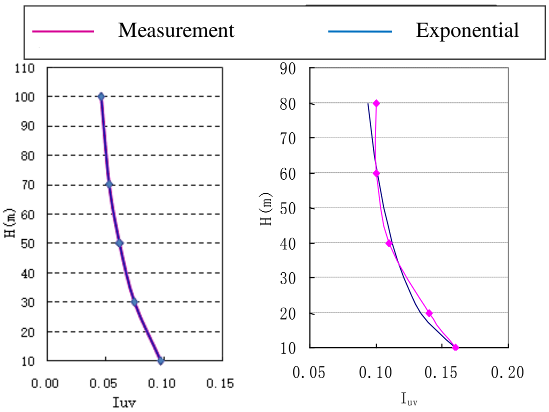
(b) Sha Tin: α=0.121 α=0.153
(Strong wind) (Conventional average wind)

***Figure 7**: Wind velocity profile of every measuring point*

According to velocity profile index, the land covers of the two districts basically belong to type A (α=0.12); according to average velocity profile index, the land cover of Chaiwobao station basically belong to type A, and that of Shatian station type B (α=0.16). The velocity profile index decreases with the increase of wind velocity.

3.4. Turbulence intensity:

For turbulence intensity calculation, different data of strong winds are selected. At Chaiwobao station, the 10min-average wind velocity equal to or above 10.8m/s (6 on the Beaufort scale) at 10m altitude is defined as strong wind; for Shatian station, the 10min-average wind velocity equal to or above 8m/s at 10m altitude is defined as strong wind. Turbulence intensity is calculated as the ratio of standard deviation to mean of wind velocity for every 10min at each altitude. The vertical profiles of turbulence intensity during strong winds are plotted through averaging of the turbulence intensity at each altitude (Fig. 8).



(a) *Chaiwobao* (b) *Sha Tin*

Figure 8*: Turbulence intensity profile of every measuring point*

As seen from Fig. 8, ① the turbulence intensity for Chaiwobao station at the altitude of 10m, 30m, 50m, 70m and 100m is 0.10, 0.07, 0.06, 0.05 and 0.05, respectively. The turbulence intensity ratio between the altitude of 10m and 70m is I10:I100=1:0.5. Turbulence intensity at the altitude of 70m decreases by 50% as compared with that at 10m; ② for Shatian station, the turbulence intensity at the altitude of 10m, 20m, 40m, 60m and 80m is 0.16, 0.14, 0.11, 0.10 and 0.10, respectively. The turbulence intensity ratio between the altitude of 10m and 80m is I10:I100=1:0.63. Turbulence intensity at the altitude of 80m decreases by 30% as compared with that at 10m; ③ turbulence intensity decreases with altitude, and the turbulence intensity at Chaiwobao station attenuates more rapidly than at Shatian station.

Exponential model is fit to the turbulence intensity using least squares method: $I = I_{10}\left(\frac{z}{10}\right)^{\alpha}$. The wind shear exponent is calculated asα=-0.001 for Chaiwobao station and α=-0.255 for Shatian station.

Comparison of turbulence intensity between the two districts indicates that ① the turbulence intensity at Shatian station is higher by about 0.05 (over 50%) than that at Chaiwobao station. This is related to wind velocity and the selection criteria for strong wind samples; ② the turbulence intensity at Chaiwobao station decreases more rapidly with altitude as compared with Shatian station; ③ the turbulence intensity fitted by using the exponential function is inconsistent with the fitted velocity profile index.

4. Conclusion:

The field measured strong wind data at two wind towers in Xinjiang and coastal typhoon zone are compared and analyzed. The following conclusions on wind field characteristics are reached for these two districts:

(1) As to average wind velocity, ① it increases with altitude in the two districts; ② the extreme wind velocity at Chaiwobao station is 39.2 m/ s, which is higher than that of the station in typhoon zone (32.9 m/s); ③ the occurrence time of maximum wind velocity is different. The maximum wind velocity occurs in winter and spring in Xinjiang and in summer and autumn in coastal typhoon zone. The wind velocity varies with season (monsoon climate).

(2) As to wind direction, ① the dominant wind direction is WNW in Xinjiang, and the second dominant wind direction is ESE. Consistency of wind direction throughout the year is primarily attributed to the orientation of mountains flanking the valley; ② in Shatian station, the dominant wind direction is SSE and NNE, and the wind direction varies seasonally.

(3) As to wind velocity profile and turbulence intensity, ① using the strong wind samples, the land covers of the two districts basically belong to type A. But based on the data of meterological observations, the land cover in Chaiwobao distribution basically belongs to type A, and that in Shatian Town type B; ②the wind velocity profiles are greatly influenced by wind velocity. The higher the wind velocity, the smaller the velocity profile index is; ③ the turbulence intensity decreases with altitude and it decreases by about one half at the altitude of 80m as compared with the land surface. The turbulence intensity fitted using the exponential function is inconsistent with the fitted velocity profile index; ④ turbulence intensity at Chaiwobao station attenuates more rapidly as compared with Shatian station, indicating that turbulence intensity decreases with the increase of wind velocity.

Acknowledgements:

The research is supported by the National Natural Science Foundation of China (90915001, 51408042), Xi'an Construction and Technology Project (SJW2014012), The School Doctoral Research Initiation Foundation Project (118211407), China Postdoctoral Science Foundation (2014M560737).

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