Indexed in
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. 04

August 2016, P.P.1792-1798

A Review of the Influential Factors of High Wind Characteristic Parameters in Western China

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Abstract: There have long been numerous studies on wind, an erratic turbulent movement, with the expectation to describe it precisely by theoretical model. However, until now, only the characteristics of wind within 100m above ground level have been clearly understood. The frequently-used wind characteristic parameters are wind speed, wind direction, angle of attack, turbulence strength, turbulence integral scale, and turbulence power spectrum. The main accesses to values of wind characteristic parameters are: field measurement, wind tunnel test, and numerical simulation. Supplementary to one another though, the three accesses may lead to inconsistent computation results, attributing mainly to non-uniform analytical methods of field measurement data and poor simulation precision. Therefore, it is necessary to start respectively from the three accesses to research the influential factors of wind characteristic parameters.

Keywords: *Inland strong wind, Wind characteristics, Influence factors, Field measurement, Wind tunnel test, Numerical simulation*

1. Introduction

In human life, wind is a ubiquitous natural phenomenon. However, high winds with overmuch energy concentration always bring disasters to human being, namely "wind disaster". According to statistics: wind disaster is more influential than earthquakes among natural hazards. Due to high occurrence frequency, and severe secondary disaster, wind disaster causes 40.5 percent of the total economic loss. Serious damage brought by wind disaster not only appears as agricultural disaster and building damage, but also emerges in the field of transportation, military, forestry, electric power, and aviation. Therefore, in addition to meteorological department, wind-related studies and the prevention and control of wind should also be conducted by all other walks of life that are linked to wind. China is a country with a vast territory. Landforms and climates in the country are pronouncedly different between the east and the west. Meteorology defines that high winds are the one with the mean speed greater than or equal to 10.8 m/s (Beaufort scale 6) or the instantaneous speed greater than or equal to 17.2 m/s (Beaufort scale 8). High wind distribution is associated with atmospheric circulation and landforms. There are two main wind zones in China, shown in Fig. 1 : (1) Inland strong wind zone: covering boreal Xinjiang, Inner Mongolia, northern Gansu, and the "Three North" (Northeastern China, Northern China, and Northwestern China); occupying around 96.2 percent of the national strong wind zone. (2) Coastal typhoon zone: referring to China's south-east coastal areas and the peripheral islands with strong winds on it.

Along with the implementation of China's Great Western Development Strategy, and the development of national projects of new energy as well, high winds in western China have attracted increasing attention. There are studies on wind resisting characteristics of engineering site, draught fan, and transmission tower in large-scale wind power projects; of electricity pylons and electric cables in the West-to-East Power Transmission Project; of photovoltaic panels in photovoltaic engineering; and of high-rise, long-span structures, for example. Different from coastal gales in southeastern areas, characteristics of western gales are greatly impacted by landform and monsoon. What's more, wind-blown sand and rock frequently accompany high winds in western China. Nevertheless, studies on western gales with a late start are short on research achievements. *Therefore, it is an important and urgent task to identify characteristics of strong winds in western China.*

Strong wind research used to target at specific engineering instead of strong wind characteristics. The pillar of wind engineering research is design of wind resisting structures, by which response of a structure to the action of wind power is analyzed, aiming to reduce the structure's wind-induced internal force, prevent gust response oscillation, and improve structure reliability as well. By means of field measurement, wind tunnel test, and numerical simulation, researchers have achieved prolonged research development in the field of structure wind engineering. However, there are still great differences between theoretical analysis and actual results due to lack of recognition of wind characteristics. If wind load is regarded as the response (or output) of the structure system to wind (or input), it is crucial to determine wind characteristics. *As there have not been favorable solutions to description of and simulation on wind characteristics yet, research on wind characteristics becomes one of the fundamental projects of wind engineering.*

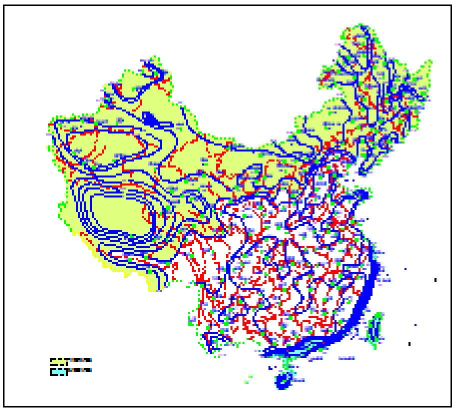

Figure 1: *The image of main strong wind zones in China*

Therefore, to achieve description of and simulation on strong wind characteristics, the paper referred to measurement data from typical strong wind zones in western China. On this basis, the analytical approach to field measurement statistics concerning strong winds and the technology of wind field simulation were studied herein. As a result, the influential factors of precise description of and simulation on strong wind characteristics were identified, and the deductive law of wind field characteristics with respect to the terrains around the wind monitoring station was revealed. These results are of great significance to supplementing data of strong wind characteristics in western China and to disaster prevention and reduction as well. They can also provide references for follow-up wind characteristic studies, and act as a guidance to design of wind resisting structures in western China.

2. Analysis of research status at home and abroad

2.1. Research on strong wind characteristic parameters based on field measurement

Wind monitoring stations should be built up before undertaking field measurement, which requires strong technological and financial support. Also, conventional wind monitoring stations observe the speed and direction of winds at 10m above ground level in open and flat areas. The frequently-used wind characteristic parameters are wind profile power law, angle of attack, turbulence strength, gust factor, turbulence integral scale, and turbulence power spectrum. Apparatus for conventional wind monitoring apparently cannot satisfy the requirements of wind characteristic research. Moreover, wind monitoring stations that are usually tucked away are demanded to inspect observation data so as to timely address problems of abnormal data. Whereas problems often fail to be effectively solved in time due to technician allocation, which results in data loss first and then data distortion. In addition, as the wide variety of analytical approaches to field measurement statistics are unclearly related to each other, it is difficult to draw a universal law from them. Below are relative studies on strong wind field measurement at home and abroad. The main content of wind characteristics research are show in Tab. 1.

Table 1: *Wind parameters*

The average wind characteristics	wind speed, wind direction, wind attack angle
	basic wind speed
	wind velocity profile
The fluctuating wind characteristics	*turbulence strength*
	turbulence integral scale
	turbulence power spectrum

Foreign studies on field measurement of strong wind characteristics emerged earlier than domestic ones. The Davenport spectrum, which is included in building standards for many countries, comes from the statistics of over 90 strong wind records at different heights in different places by Davenport. What's more, he also initiated the wind profile power law model and the concept of surface roughness, in which three different landforms were described, thus laying foundation for research on wind engineering. To compensate for ambiguity of wind resisting parameters for different landforms regulated by different national building standards, many countries (such as Canada, British, Norway, America, and Japan) have developed wind observation for a long time. They classify winds according to various parameters including wind speed, wind velocity, and landform, and establish databases to store fundamental information of wind engineering. For wind environment observation in complicated mountainous terrains, some studies are conducted on aspects such as accelerating effects of over-hill winds, characteristics of fluctuating winds on the leeward side of hills, and wind fields in mountain chains.

Domestic studies on field measurement of strong wind characteristics emerged later. Corresponding early-stage researchers are limited to meteorological ones and investigators on atmospheric sciences, who contribute to research experience of strong wind characteristics in China. Based on year-round 10-minute-gradient observation data from four wind monitoring towers in Poyang Lake districts, He Zhiming (HE et.al, 2011) analyzed the local mean wind characteristics and parameters of wind energy resources as well, through which they obtained the wind shear index of Poyang lake districts and the changing law of local turbulent strength with terrains. With ARCGIS as the platform [1], Gao Yanghua (GAO et.al, 2008) used 1:250,000-scale DEM data and meteorology observation data for analysis of the distribution of wind speed in Chongqing with two interpolation methods of $1/r^2$ and $1/r^2h^3$ [2].

Since 2000, wind characteristic observation has been increasingly focused on in the field of structure wind engineering, especially in long-span bridge structures. Ge Yaojun put forward an approach to taking a weighted average of the benchmark wind speeds of corresponding several wind monitoring stations near a bridge site as the benchmark wind speed at the bridge site. By analyzing the basic wind speed data from standard wind monitoring stations in peripheral areas of Sidu River Valley Bridge site, Pang Jiabin (PANG et.al, 2008) fitted the changing relationship between basic wind speeds and altitudes. He also compared two frequently-used analysis methods concerning research on field measurement of turbulent characteristics of winds, namely the vector method and the scalar method. With the help of PAR wind profiler [3], Zhu Ledong (ZHU et.al, 2011) conducted field measurement on wind parameter profiles (including mean wind profiles, angle of wind direction, angle of attack, and turbulent strength) and characteristics of turbulent flows in cwms at Baling River Bridge site [4]. Lu Anping (LU et.al, 2013) used the maximum likelihood parameter estimation method and the probability weighted moment method separately to estimate the parameters of the type Ⅰ, Ⅱ and Ⅲ extreme value distributions, the result showing that the maximum likelihood parameter estimation method of higher precision was optimal for the type Ⅰ, Ⅱ and Ⅲ extreme value distributions [5].

Based on previous wind speed observation records, Li Yongle(LI et.al, 2014)analyzed the wind direction distribution in the Nanjing Yangtze River Bridge on Beijing-Shanghai High Speed Railway. The result proved that it is feasible to deduct surface roughness coefficients from maximum monthly wind speeds at different heights. Recently, in order to investigate the causes of daily strong winds on a bridge site in a deep valley of a high altitude and with a high temperature difference, Li Yongle et al. carried out field measurement on wind characteristics in the Dadu River bridge site with the CAW600-RT automatic-weather-station hand anemometer and portable thermometer [6]. They also analyzed the mean wind speed's relevance to temperature, sunlight, topography and so on. Liu Ming [7] (LIU, 2013) conducted field measurement on the wind field in the Xihoumen bridge site, and obtained characteristics of both mean winds and fluctuating winds in the respective bridge site and coastal areas of monsoon climate accordingly. Based on meteorological stations' statistics near a bridge site, Liao Haili (LIAO et.al, 2013) applied meteorology analysis to calculate the maximum wind speed. The extreme-value type I method and the virtual standard weather station method were respectively adopted to calculate once-in-a-century maximum wind speed at the bridge site, and the virtual standard weather station method was selected in the paper as the benchmark wind speed at the bridge site [8].

Liu Jianxin [9] (LIU et.al, 2008) summarized the attributes of wind environments and bridge structures in western China, analyzed what should be researched on with respect to bridge wind engineering in western China, and introduced relative wind environment observation and wind tunnel test. Based on wind velocity data of the Yupanshan meteorological station in the center of the Hangzhouwan bay, Liu Jianxin adopted the maximization principle of probability plot correlation coefficient and the maximum likelihood method to analyze the optimal probability distribution type of wind velocity in all directions. He also discussed the relationship between the optimal distribution type and the changing law of probability plot correlation coefficient with shape parameter, and concluded that to deduct basic wind speed by joint distribution was more scientific. In combination with the practical engineering of Shanxi Yumenkou Yellow River Bridge, Zhang Yue [10] (2008) used a data processing system of wind speed observation based on Borland C++ Builder to analyze the year-round field measurement data at the bridge site, and obtained seven strong wind characteristics. In her research into inland strong wind characteristics, Gao Liang [11] (2012) exponentially fitted the mean wind speed and the maximum wind speed at the same site and at the same time, and concluded that wind profile power increased with the increasing wind velocity. Moreover, she compared the observation data of a ultrasonic anemometer and that of a conventional 2D anemometer at the same height, and found out that: (1) the observation value from the ultrasonic anemometer was 104 percentage higher than that from the conventional 2D anemometer; (2) the wind direction angle observed from the ultrasonic anemometer was more stable, while changed at a large magnitude from the conventional 2D anemometer. The Special wind observation tower and its instruments simply show in Fig. 2.

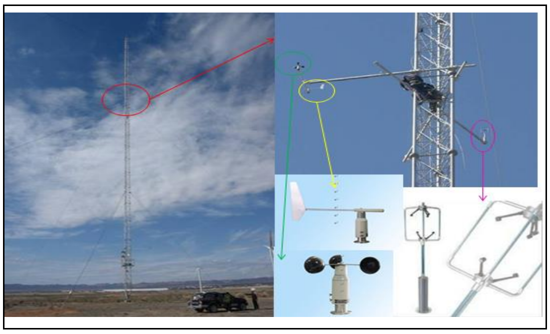

Figure 2: *Special wind observation tower and its instruments*

From the research on strong wind (typhoon) characteristics in coastal areas, Song Lili (SONG et.al, 2012) first discussed the judgment criteria and processing method of field measurement data quality, and further studied parameters of wind field characteristics [12]. An improved maximum entropy principle based distribution model and bi-parameter Weibull distribution model were employed by Ye Lin(YE et.al, 2014) to fit wind speed distribution and power density distribution characteristics in wind field. The result showed that the proposed MEP model was a suitable option for carrying out wind energy resource assessment in areas with different distribution of wind speed and wind power density [13]. Wang Xu (WANG et.al, 2013) measured the wind data from eight anemometers installed respectively on a 40m tower at the height of 10m, 20m, 30m, and 40m during typhoon “Muifa” on the east coast of Shanghai, through which the parameters of fluctuating wind characteristics were analyzed [14]. According to the field measurement of surface boundary layer wind field during the passage of typhoon Kalmaegi, Fung-wong, Jangmi, and Morakot, and the super-high altitude wind field during the passage of Fanabi, Megi, and Lionrock, Shi Wenhai (SHI et.al, 2012)compared turbulence intensities at different time intervals of surface boundary layer and super-high altitude typhoon field [15].

2.2. Research on strong wind characteristic parameters based on wind tunnel simulation

There have been increasing wind tunnel test based studies on wind field characteristics of local terrains and their impact on constructions in the area at home and abroad. For example, Shuyang Cao and Tetsuro Tamura (Cao and Tamura, 2006) studied how roughness degrees both of the hill surface and of the upstream ground affected the speed-up ratio of turbulence field over the hill [16]. Atsushi Yamaguchi, a researcher from the wind engineering laboratory of Tokyo University, Japan undertook wind tunnel simulation with different wind direction angles on coastal ShakotanHanto in northern Japan; experiments with the same principle were done by researchers from Western University, Ontario, Canada on terrains in Hong Kong. During wind resisting design for Beipan River Bridge, Sidu River Bridge, Aizhai Bridge, and Sanshui River Bridge, Chinese researchers conducted wind tunnel simulations in the peripheral areas of the above four bridges. For example, at Sidu River Bridge, Pang Jiabin [3] (PANG, et.al, 2008) carried out detailed research on the influence of valley wind accelerating effect, over-hill wind, and valley slope shielding effect on valleys, and pointed out that the valley wind accelerating effect should take into account the impact of altitudes and slope boundary layers. Taking Aizhai bridge as the engineering background, Chen Zhengqing (CHEN, et.al, 2008) [17] tested the wind field characteristics of cwms in wind tunnel, and revealed the ratio of wind velocity at the height of bridge deck in the terrain model to the gradient wind speed of the wind field in front of the valley model. He pointed out that when considering the magnification effect of wind speed in valley, the height of measuring point and the shape of mountain on both sides should be taken into consideration. In order to obtain the distribution law of mean wind speed and fluctuating wind velocity in hilly terrains, Sun Yi and Li Zhengliang et al. [18] conducted wind tunnel tests on ten 3D axisymmetric hill models with ten different slopes and heights. Taking Sanshui river bridge as an engineering background, Bai Hua (BAI, et.al, 2012) obtained the wind field characteristics of the bridge site located in the west valley region through the wind tunnel test of a terrain model [19]. They also proposed a method of calculating design wind speed of the bridge in agreement with the wind speed profile and the magnitude of the gradient wind speed measured at the bridge site in wind tunnel test.

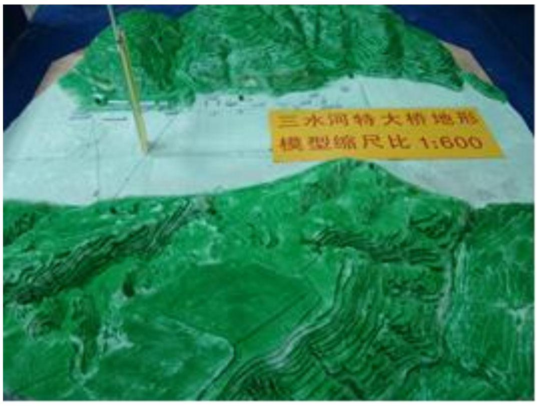

Figure 3: *Bridge site terrain model and pressure rake*

2.3. Research on strong wind characteristic parameters based on numerical wind tunnel simulation

The core of numerical simulation is to calculate fluid mechanics. Along with the development of CFD and computer, numerical simulation has been widely applied. In the year as early as 1977, VaslieMelling from London University used numerical wind tunnel to simulate the 2D and 3D cube structure under the conditions of laminar flows, where the 2D simulation result was favorable while the other was poorly accurate. In 1998, Maurizi A., Palma J.M.L.M. and Castro F.A et al. conducted numerical simulation on the wind environments of a mountainous area in northern Portugal. In 2000, Kim H.G and Patel V.C. et al. simulated the wind environment of liquids flowing through a valley, whose results agreed well with field measurement results.

Domestic research on numerical wind tunnel simulation has a late start, thus there are rare corresponding studies on wind environments in mountainous areas. Some universities studied wind fields at bridge sites, such as Tongji University, Southwest Jiaotong University, Hunan University, and Chang'an University. In 2005, Hu Fengqiang from Tongji University took Beipan River Bridge as the engineering background to simulate wind environments at the bridge site. The same year witnessed numerical simulation by Xiao Yiqing and Li Chao et al. on the 3D wind field in a certain mountainous terrain with the use of different turbulence models, and the result showed that Realizable k-ε model fitted the wind fields of complex mountainous terrain better. During the construction of Shanxi Yumenkou Bridge, Zhang Yue (ZHANG, et.al, 2008) from the wind tunnel laboratory in Chang'an University used the Realizable and SST turbulence model, and, according to structures with real bridge and structures without real bridge, simulated wind fields at the bridge site and the peripheral areas of it under seven working conditions [10]. In this way, the characteristics and law of typical valley wind field in western mountainous areas were obtained.

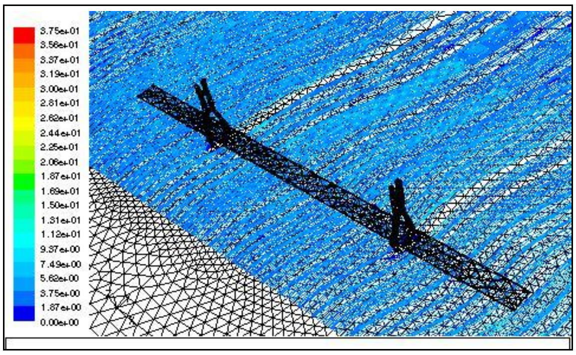

Figure 4: *Wind field streamline of the Yumenkou Yellow River Bridge location*

Hunan University also conducted corresponding numerical simulation on wind environments at the Hunan Aizhai Bridge site. Selection of numerical simulation computation method has become a new research focus. Taking a long-span suspension bridge adjacent a high-steep mountain as the engineering background, Li Yongle (LI, et.al, 2011) [21] conducted numerical simulation for the wind field distribution of the bridge site with complex landforms and topographies in deep valley with CFD commercial software FLUENT. To study the appropriate boundary transition section shape of terrain model for mountains gorge bridge site, Hu Peng (HU, et.al, 2013) [22] used a kind of transition section curves based on the theory of flow around cylinder with ideal fluid. An ideal 2D platform terrain was used as the analysis model to comparatively analyze the flow separation behavior and the distribution characteristics of average wind field after airflow flowed along the two transition sections (namely the curve section with equivalent slope of 0.58 and the ramp transition section with included angle of 30°) by CFD commercial software FLUENT.

All in all, the intentions of most wind characteristic research projects are restricted to applications of civil engineering, with the main focus on the impact of landforms on attack angles and wind direction angles and its application to design wind speed determination. There are rare in-depth studies on influential factors of strong wind characteristic parameters. Most of the field measurement and simulation on strong wind characteristics in China targeted at cross-sea bridge engineering in Type A and Type B topography regulated by "wind resisting standards". The rest ones mostly dealt with wind environment characteristics in deep valley zones in southwestern China. However, few studies were conducted on strong wind characteristic parameters in western China. The terrain feature of western China is undulating topography with high mountains and deep valleys, show in Fig. 5.

Figure 5: *The terrain feature of western China*

2.4. Scientific issues necessary for further research

As noted above, the three accesses to influential factors of strong wind characteristic parameters in western China have scientific problems and insufficient of field measurement data and poor simulation precision. Specifically, in those aspects, show in Tab. 2.

Table 2: *Scientific problems and insufficient of field measurement and simulation.*

Main problems	
in field measurement	sparse wind monitoring stations
	without supplementary apparatus
	understaffed
	non-uniform data analysis methods
in simulation	simulation scale
	entrance cross section.

Main problems in field measurement: (1) sparse wind monitoring stations. The primary reason for this phenomenon is that abundant technological and financial support is needed in establishing wind monitoring stations. (2) without supplementary apparatus. Conventional wind monitoring stations observe the speed and direction of winds at 10m above ground level in open and flat areas. The frequently-used wind characteristic parameters are wind profile power law, angle of attack, turbulence strength, gust factor, turbulence integral scale, and turbulence power spectrum. Apparatus for conventional wind monitoring apparently cannot satisfy the requirements of wind characteristic research. (3) understaffed. Wind monitoring stations that are usually tucked away are demanded to inspect observation data so as to timely address problems of abnormal data. Whereas problems often fail to be effectively solved in time due to technician allocation, which results in data loss first and then data distortion. (4) non-uniform data analysis methods, whose reason is that the wide variety of analytical approaches to field measurement statistics are unclearly related to each other. This issue requires to be further studied.

Main problems in simulation: (1) determination of simulation scale. The determination of a model's scale ratio directly impacts on simulation precision, which is associated with and limited by the size of wind tunnels for test use. Too high scale ratio for a confined wind tunnel will cause a lack of space for simulative operation, and thus the simulation precision drops; while too low scale ratio will weaken the impact of terrains on wind fields at the same time when the simulation space is broadened, resulting in poor simulation precision. The principle of model end treatment is to guarantee that there is no abrupt change of flow fields of wind passing by the model ends. (2) determination of entrance cross section. As wind parameters and geological information at the entrance cross section are unknown or nearly unknown, it is undoubted that the simulation precision is inaccurate.

3. Conclusion

Despite the mounting quantities, subdivided research points, and certain achievements accordingly, studies on wind characteristic parameters based on various methods are mostly targeted at winds in the middle and eastern areas in China. There have been rare studies on winds in western China, the domestic area with largest wind energy storage and widest distribution of strong winds, and most of these rare studies merely focus on specific engineering work. Along with the promulgation of the Belt and Road Initiative, the fundamental effect brought by research on strong wind characteristics in western China becomes prominent in engineering and economic development of western areas. Therefore, existing corresponding field measurement data is fully used in the paper by reanalysis with different analytical methods, and wind tunnel tests and numerical simulation are conducted accordingly. This can serves as a further exploration of and complement to strong wind characteristics in western China, and provides technical support for follow-up studies on wind characteristics.

4. Acknowledgments

The research is supported by the National Natural Science Foundation of China (90915001), Xi'an Construction and Technology Project (SJW2014012), The School Doctoral Research Initiation Foundation Project (118211407), Atural Science Basic Research Plan in Shaanxi Province of China (2013JQ7031), and Fundamental Research Funds for the Central Universities (3108211511070).

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