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A study of Weibull parameters using long-term wind observations

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Abstract

The two parameters of a Weibull density distribution function were calculated for three different locations; a city area, an extremely exposed area in a city centre and an open sea area in Hong Kong. A long-term data source, consisting of thirty years (1968–1997) of hourly mean wind data, was adopted and analysed. Based on these data, it was found that the numerical values of the shape and scale parameters for these weather stations varied over a wide range. The shape parameter varied from 1.63 to 2.03 and the scale parameter ranged from 2.76 to 8.92. The yearly Weibull probability density function distribution for the city area indicated that the wind data could be grouped into two distinct periods, 1968–1981 and 1982–1997. Seasonal Weibull distribution for the three locations were compared and wider distributions were observed in the more open areas.

Keywords: Wind data; Weibull distribution; Wind energy application; Hong Kong

1. Introduction

Over the last two decades a number of papers have appeared in the literature concerning efforts to develop an adequate statistical model for describing wind speed frequency distribution. The use of this frequency distribution approach can provide a simple method to predict the energy output of a wind energy conversion

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system (WECS). Much consideration [1–10] has been given to the Weibull two-parameter (k, shape parameter and c, scale parameter) function because it has been found to fit a wide collection of wind data.

There are several methods available for the calculation of these two parameters. Stevens and Smulders [1] obtained the values of k and c using five different methods; method of moments, method of energy pattern factor, maximum likelihood method, Weibull probability and the use of percentile estimators. The comparisons of these analytical findings had indicated that no significance discrepancies between the results from the different methods were observed. Gupta [2] carried out work on estimating the annual and monthly Weibull parameters for five locations in India and these revealed two parameters which varied over a wide range. The values of the shape parameter could be used at hub height without any modification but the values of c required alteration that might be estimated from the usual power law which generally holds good up to a height of 100 m. Justus et al. [3] applied the Weibull and log–normal distribution to wind speed data from more than a hundred stations of the USA National Climatic Centre and concluded that the Weibull Distribution rendered the best fit. Corotis et al. [4], however, preferred the Rayleigh distribution, a special case of Weibull distribution, for the wind data. Hennessey [5] found that the energy output of WECS calculated by the Rayleigh distribution is within 10% of the output based on the Weibull distribution. Rehman et al. [6] studied the Weibull parameters for ten different locations in Saudi Arabia. Various numerical values of the two parameters at the stations were highlighted and it was concluded that wind data were well represented by the Weibull density function. Garcia et al. [7] carried out a case study on the performance of two different functions, the Weibull distribution and the log–normal distribution. The work indicated that both approaches fitted the data well. In particular, the Weibull distribution was pointed out to be the better distribution that could provide a very useful model to estimate the potential wind energy.

It was believed the wind characteristics were merely important for builders, bridge designers, architects and ship designers in the past. Nowadays, wind analysis not only provides extremely valuable information for engineers in the field of structural and environmental designs, but also to researchers involved in renewable energy studies. Towards to the end of this century, a higher living standard has created a greater demand for energy supply. Limited energy resources coupled with ever increasing demand leads to the necessary and immediate action of seeking a solution in order to overcome this energy shortage. Recently renewable energy such as wind can be thought as one of the alternative energy solutions. Wind observations are generally collected in the form of very large numbers of points. It is remarkably useful that a wide range of wind characteristics can be summarized by specifying only two parameters via shape factor, k and scale parameter, c. These two parameters are sufficient to specify the available wind and to enable assessments and evaluations of wind the power to be made.

The present work used the Weibull two-parameter function to describe the wind speed frequency distribution for a given set of wind data which covers a period of 30 years in Hong Kong. The objectives are to provide information to enhance the understanding of wind distributions in regions where wind data are not available and to highlight the discrepancies of the calculated parameters of measurements taken from three different types of locations — an open sea area (e.g. an island), a completely exposed area (e.g. high up in a city centre) and a city area within the territory.

2. Weibull distribution

The Weibull distribution (named after the Swedish physicist W. Weibull, who applied it when studying material strength in tension and fatigue in the 1930s) provides a close approximation to the probability laws of many natural phenomena. It has been used to represent wind speed distributions for application in wind loads studies for sometime. In recent years most attention has been focused on this method for wind energy applications not only due to its greater flexibility and simplicity but also because it can give a good fit to experimental data. The Weibull distribution function, which is a two-parameter function, for wind speed is expressed mathematically as

$$f(v) = \left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{k-1} \exp\left[-\left(\frac{v}{c}\right)^{k}\right] \tag{1}$$

and the cumulative distribution function is

$$F(v) = 1 - \exp\left[-\left(\frac{v}{c}\right)^{k}\right] \tag{2}$$

where v is the wind speed, k is a shape parameter and c is a scale parameter. With a double logarithmic transformation, Eq. (2) can be written as

$$\ln\{-\ln[1 - F(v)]\} = k \ln(v) - k \ln C \tag{3}$$

Plotting $\ln(v)$ against $\ln\{-\ln[1\text{–}F(v)]\}$ should yield a straight line. The gradient of the line is k and the intercept with the y-axis is $-k \ln C$.

3. Description of wind data measurements

In order to understand the weather system well, an adequate source of measured weather data is a prerequisite. The relationship between the climatic data and energy performance of wind machines relies heavily on both the quality and quantity of the meteorological observations.

It is believed that weather data based on not less than 30 years can be adopted for most wind-related energy system design and analysis. This is because shorter periods, less than 30 years, may inherit variations from the long-term average. Thus longer periods, in terms of years, can yield quantitative, representative as well as persuasive results.

The wind data adopted for the present study was obtained from the Hong Kong Observatory (HKO) [11]. The Observatory has retained records of the surface meteorological observations from several locations within the territory since 1884. For this current investigation, meteorological observations were obtained from three different weather stations, namely King's Park, Central Plaza and Waglan Island. Measurements were recorded by automated instruments and transmitted to the Observatory at one-minute intervals via telephone circuits. Wind data was captured at a position of 89.6 m above mean sea-level by a R.W.

Table 1
Yearly long-term shape parameters, k and scale parameters, c, at King's Park Station

Year	k	c
68	1.23	2.53
69	1.14	2.41
70	1.09	2.44
71	1.06	2.53
72	1.12	2.19
73	1.15	2.60
74	1.06	2.21
75	1.07	2.22
76	1.13	2.36
77	1.10	1.79
78	0.99	2.17
79	1.04	1.81
80	1.14	2.13
81	1.04	2.38
82	1.34	2.98
83	1.33	3.22
84	1.50	3.14
85	1.46	3.15
86	1.58	3.22
87	1.77	3.08
88	1.53	2.82
89	1.44	2.95
90	1.67	3.29
91	1.68	3.19
92	1.53	2.90
93	1.54	3.71
94	1.87	3.43
95	1.65	3.41
96	1.72	3.09
97	1.54	2.92
30 year long-term	1.20	2.64

Munro Mk 4 cup-generator anemometer at King's Park, whilst measurements were recorded by a Teledyne Geotech WS-201 anemometer at Waglan Island and Central Plaza, at the heights of 82.1 m and 378 m above mean sea-level, respectively.

A complete set of wind speed data for the King's Park station over the 30 year period from 1968 to 1997 was analysed in the main part of the current work. Due to the availability of the wind observations, two seasonal (Autumn and Winter) analysed results obtained from the stations of Waglan Island and Central Plaza were utilised for comparison. Based on these data, sets of statistically calculated values were obtained and presented. The two-parameter Weibull function was adopted and analysed for wind observations from the three different locations in this study. Equation (3) was applied to obtain the values of k and c with the aid of common statistics software.

4. King's Park wind data analysis

Table 1 shows the computed shape and scale parameters for the wind data measured at King's Park Station. It can be seen that the shape parameter for a city area varies over a wide range from the lowest of 0.99 to the highest of 1.87 with an average of 1.35. It is interesting to note that these k values have an

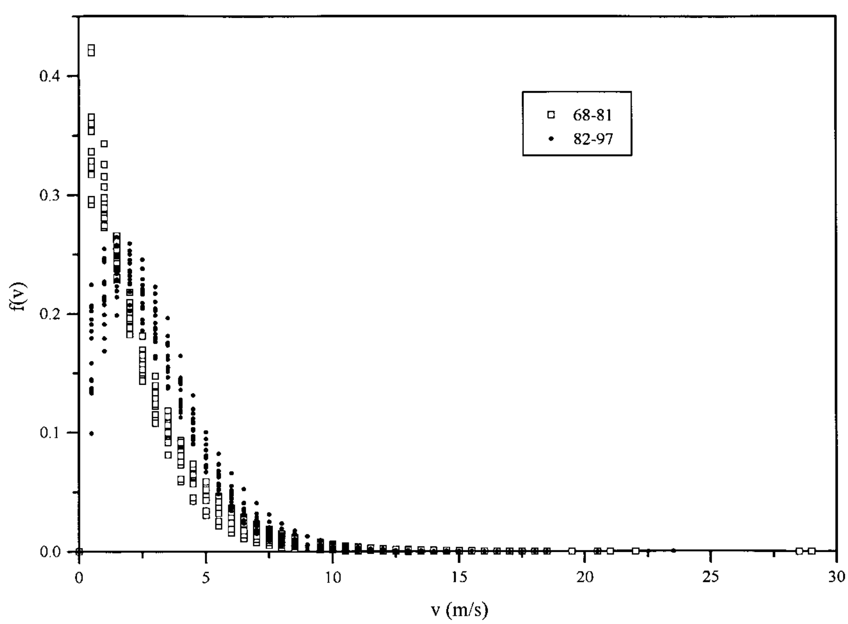

Fig. 1. Yearly Weibull probability density function distributions for the period from 1968–1997 at King's Park Station.

increasing trend, particularly in the years from 1982 onward. The lowest values of the scale parameter is 1.79 and is found in the year of 1977 whilst the highest value is 3.71, occurred in the year of 1993. The average scale parameter is 2.74. The scale parameter also shows a rising tendency from 1982. To assess the long-term effect, the 30 year wind data were analysed and the resulting 30 year long-term shape and scale parameters are 1.20 and 2.64, respectively. These long-term parameters tend to be smaller than the average values (i.e. 1.35 and 2.74) from the individual years. This indicates the nonlinear nature of the wind data analysis.

In order to observe the Weibull distribution geographically, the Weibull probability density distributions for each of the 30 years were analysed and are shown in Fig. 1. It can be seen that these data fall into two distinct periods: 1968–1981 and 1982–1997. The first group tends to have a steep slope and a narrow peak at a wind speed of around 0.5 m/s whilst the second group has a wider span and a flatter peak at a slightly higher wind speed. This indicates that wind conditions during the 1968–1981 period tended to concentrate more on the lower wind speed (hence calmer weather) than those during the 1982–1997 period. Furthermore, there appeared to be wider spread in the wind speed variations during the 1982–1997 period. The monthly values of the long-term k and c are shown in Table 2. The range of k is between 1.1 and 1.4 but the c value changes from a low of 2.39 to the largest value of 3.04. The highest c value is in October and the lowest is found in January and December. The long-term seasonal k and c values are highlighted in Table 3. In general, values of the scale parameter are low during the winter and high during the summer and monsoon periods.

5. Comparison between the three locations

Table 4 presents the values of the two parameters in autumn and winter at

Table 2
Monthly long-term shape parameters, k and scale parameters, c, at King's Park Station

Month	k	c
Jan	1.40	2.39
Feb	1.30	2.73
Mar	1.31	2.89
Apr	1.28	2.60
May	1.25	2.41
Jun	1.23	2.61
Jul	1.17	2.69
Aug	1.09	2.41
Sep	1.11	2.51
Oct	1.38	3.04
Nov	1.33	2.65
Dec	1.32	2.39

Table 3
Long-term shape parameters, k and scale parameters, c, at King's Park Station

Period	k	c
Spring	1.31	2.60
Summer	1.13	2.57
Autumn	1.24	2.74
Winter	1.33	2.51
Whole Year	1.20	2.64

three different locations — a city area (King's Park), a highly exposed area in a city centre (Central Plaza) and an open sea area (Waglan Island). It can be seen that the highest values of k and c are found in the Waglan Island, which is the frontier between the territory and the Pacific Ocean. Relatively higher k and c, are obtained in Central Plaza, comparing with King's Park.

The Weibull probability density distribution for autumn and winter of the three stations are shown in Figs. 2 and 3, respectively. The curves of Waglan Island Weibull distributions of autumn and winter show similar but different from the other two sites. It is due to its geographical location that strong winds from the Pacific Ocean are easily to encounter; the observed maximum speed is 25 m/s in the autumn. An evenly distribution is found at the speed of 3.75 m/s of the winter distribution curve for the Central Plaza. A low range of speed is also observed at King's Park during winter time.

6. Conclusions

Numerical estimations using the Weibull two-parameter function to describe the wind speed frequency distribution for a given set of wind data over the period of 30 years (1968–1997) were carried out. The values of shape parameter, k and scale parameter, c, at three different locations are presented and examined. The wind data obtained from the city area weather station showed that the two parameters of Weibull distribution both have a tendency to grow from 1982. Two distinct groups of years (1968–1981 and 1982–1997) were observed in the Weibull probability density function distribution that the span width of the wind speed

Table 4
Two seasons numerical values of Weibull parameters for three different locations

Season	King's Park		Central Plaza		Wagla Island	
	k	c	k	c	k	c
Autumn	1.73	3.72	1.64	6.31	2.02	8.92
Winter	1.63	2.76	2.14	5.07	2.03	8.29

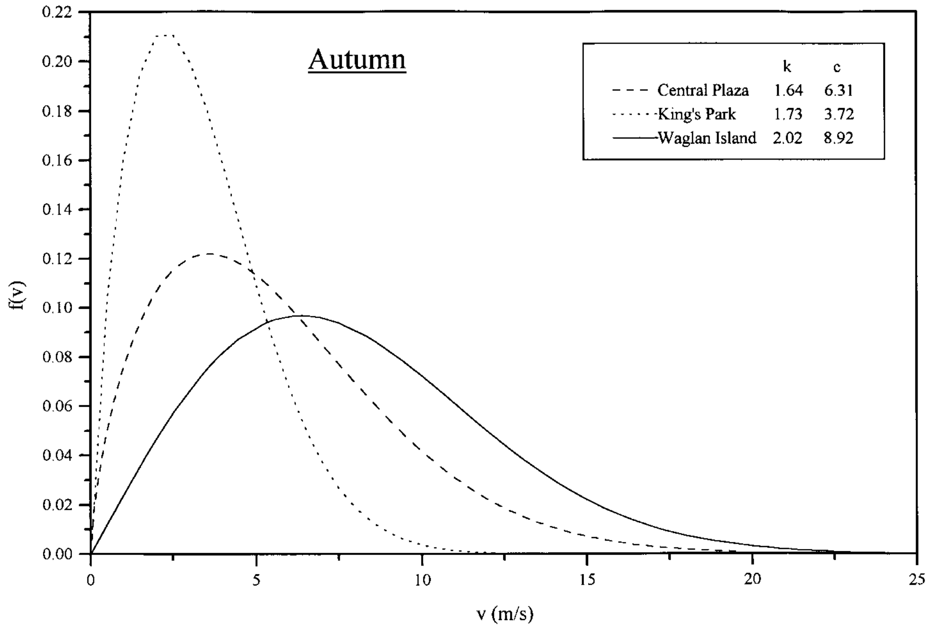

Fig. 2. A comparison of Weibull probability density function distributions for autumn season of the three locations in the territory.

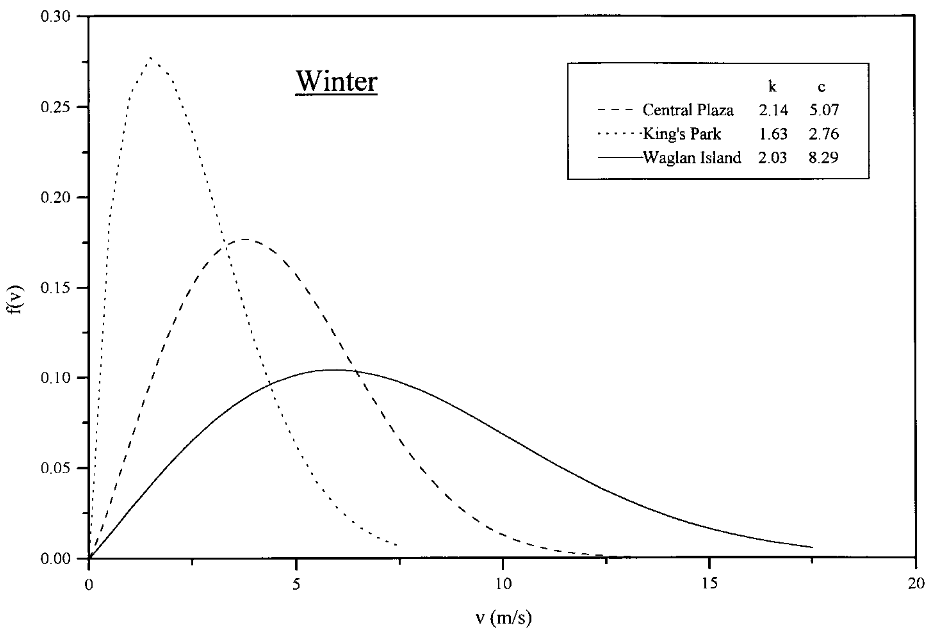

Fig. 3. A comparison of Weibull probability density function distributions for winter season of the three locations in the territory.

distribution had extended over the past 16 years. When comparing the seasonally results of the city area with two other geographically different sites, a wider range of the two-parameter values were observed. In order to have a comprehensive wind database and obtain good predictions from wind-related assessments, adequate wind information and an understanding of the prevailing conditions is a pre-requisition. The current work covers the initial stage of wind assessments for the territory. It identifies key elements associated with the Weibull parameters, providing a basis for future work.

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