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Determination of the Characteristics of High Winds in Istanbul

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Abstract

It's known that the field measurements are the most reliable tool in researching the characteristics of winds near the earth's surface. Determining wind characteristics and atmospheric turbulence features bears significance in understanding wind climates in detail, the designs of the structures vulnerable to wind effect, wind turbines and wind tunnel simulations. Therefore, it's an important task to determine the characteristics of turbulence and estimate the behaviour of structures vulnerable to wind effect. In the scope of the present study, an ultrasonic anemometer (USA-1, Metek) capable of recording in three directions perpendicular to each other and having small sampling range was installed at the SabihaGökçen Airport. Wind speed and direction was recorded for 27 months by means of this anemometer. Wind statistics (turbulence intensity, maximum wind speed and gust factor) were determined for use for the calculations of high-rise buildings in Istanbul.

Keywords: wind characteristics; turbulence intensity; non-stationary wind; gust-factor.

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1. Introduction

Every day higher and slenderer buildings have been built throughout the world with the developments in building design concepts and analytic techniques and these buildings have become more sensitive to dynamic effects like wind.

Especially when buildings like high towers are built in areas where although seismic effect is not prevalent, the wind works prevalently, as well as near seas and on hills, it's important to determine correctly and reliably, the behaviour of high buildings against the wind and design buildings, accordingly.

The turbulence characteristics of winds have been the subject of several studies since late 1940's when the author in [1] suggested the first theoretical model for the power spectra of winds, based on the statistical turbulence theorem. Various methods have been developed to determine the dynamic wind effects of structures since 1961 when the author in[2] suggested the atmospheric turbulence near the earth's surface model. The goal of these methods is to determine gust factors and equivalent static wind loads and demonstrates the behaviour of the structure under the wind effect.

Wind flow in the atmospheric surface layer is highly turbulent and the wind loads acting on structures are considerably influenced by the characteristic of turbulent flow. In the past, several field measurements were made regarding the characteristics of atmospheric turbulence. Considerable attempts were made to analyse wind speed spectrum and turbulence characteristics and determine parameters and common behaviour based on the measurements made at numerous altitudes in various areas. Several spectrum forms that are necessary for making a proper definition and understanding the nature of turbulence speeds were suggested (authors [1, 2, 3, 4, 5, 6, 7],etc.).

2. Wind Speed Turbulence Parameters

In calculating the behaviour of high-period slender structures vulnerable to wind effect, the approach suggesting that wind speed, $\mathrm{U(t)}$, is an ergodic process and produced by constant wind speed, $\overline{\mathrm{U}}$, and dynamic fluctuations (turbulence) around that constant wind speed, $\mathrm{u(t)}$, is adopted.

$$\mathrm{U(t)} = \overline{\mathrm{U}} + \mathrm{u(t)} \tag{1}$$

Mean wind speed calculation time, T, i.e. sampling range, as given in Equation (2) often varies being taken as 3-second, 10-minute or 1-hour in wind regulations.

$$\overline{\mathrm{U}} = \frac{1}{\mathrm{T}}\int_0^{\mathrm{T}} \mathrm{U(t)dt} \tag{2}$$

Included among wind speed parameters are mean wind speed, basic wind speed, turbulence intensity, gust factor, the probability distribution of turbulence and its variance, The variance of turbulence is calculated as it is given in Equation (3).

$$\sigma_u^2 = \frac{1}{T}\int_0^T u^2(t)dt \tag{3}$$

The ratio of the standard deviation of turbulence to mean wind speed yields turbulence intensity, as it is given in Equation (4). Where U can be defined as the mean value of the 10-minute wind speed.

$$I_i = \frac{\sigma_i}{\bar{U}} \; (i = u,v,w) \tag{4}$$

Gust factor is expressed as the ratio of the maximum wind speed the mean value of which is found as to T to mean wind speed. T should be ≤ 3600 seconds.

$$G(T) = \frac{\max[(\bar{U})]}{\bar{U}(T)} \tag{5}$$

3. Defining non-stationary wind speed

According to the traditional approach, longitudinal wind speed U(t) at a certain altitude, which is used for estimating the behaviours of high structures vulnerable to wind effect, is assumed to be an ergodic random process being the sum of mean constant wind speed component $\bar{U}$ and longitudinal turbulence speed component u(t). However, wind speed isn't always stationary; when there are sudden changes in wind speed, wind speed will become a non-stationary process. This is the case especially when high wind speeds occur. In such cases, mean wind speed should be defined as being time-dependent, compared to the constant speed described in the previous section. Non-stationary wind speed is expressed as the sum of the time-varying mean wind speed and the turbulent wind speed. $\bar{U}(t)$ is the component of time-varying mean wind speed that represents the temporary tendency of wind and u(t) is the component of wind speed that can be modelled as the stationary process with zero mean. This model which is given in Equation (6) allows mean wind speed to change randomly in the course of time.

$$U(t) = \bar{U}(t) + u(t) \tag{6}$$

Turbulence is found by subtracting time-varying mean wind speed from wind speed record. The time-varying wind speed is subtracted from non-stationary wind data by means of empirical mode decomposition (EMD), a data processing method developed by authors in [8]. Wind speed data is decomposed into intrinsic mode functions (IMF), which are generally few in number, by means of empirical mode decomposition. Such decomposition is applied to nonlinear and non-stationary processes. The basic procedure used for the empirical mode decomposition is simply described as follows.

Envelope curves are obtained by joining the upper and lower maximum and minimum values of non-stationary wind speed $U(t)$ with a cubical curve in time definition area. Then the mean value of the two envelopes is calculated. The value of the first intrinsic mode function, $c_1(t)$, is found by subtracting that value from actual wind speed data. However, two conditions should be satisfied.

1) At the data range that is being worked on, the number of maximum and minimum points and the number of points passing through zero should be equal to each other or differ by 1 at most.

2) At any point, the mean value of the envelope yielded by local maxima and the envelope yielded by local minimums should be zero.

The difference between $U(t)$and $c_1(t)$ yields new wind speed data and repeating the same process, the second intrinsic mode function, $c_2(t)$, is found. This procedure is applied until residue value becomes the least value or monotonic function. The residue represents the time-varying wind speed. Original wind speed record is expressed as the sum of IMF's and the residue, as it is given in Equation (7).

$$U(t) = \overline{U}(t) + u(t) \quad \textbf{\textit{(7)}}$$

where$N$is the number of IMF components and $r(t)_N$ is the residue. EMD subtracts the time-varying mean wind from the wind speed in time definition area without any preliminary information. After the time-varying wind speed $\overline{U}(t)$ is found, stationary turbulence data is found by subtracting the time-varying wind speed from the original data.

4. Determination of the Characteristics of High Winds in Istanbul

An ultrasonic anemometer was installed at 15 m height from the ground in the open and at a distance far enough not to be influenced by take-off and landings of aircrafts at the SabihaGökçen Airport in Istanbul in order to determine the characteristics of high winds in Istanbul (Figure 1).

Fig. 1. Installation of anemometer at the SabihaGökçen Airport

In the period of 15 May 2012 - 15 August 2014, 27-month 3D 25 wind speed data (25 Hz) and direction per second in every dimension was recorded. The study aimed at determining the statistics of high wind turbulence and wind spectrum. The results of the study have implications about the wind turbulence in Istanbul and those values can be used for the designs of high structures and wind turbines.

4.1. Description of the area where high wind measurement is made and the assessment of the area meteorologically

The SabihaGökçen International Airport is the second airport in Istanbul, which was constructed within the borders of the District of Pendik in the Province of Istanbul.

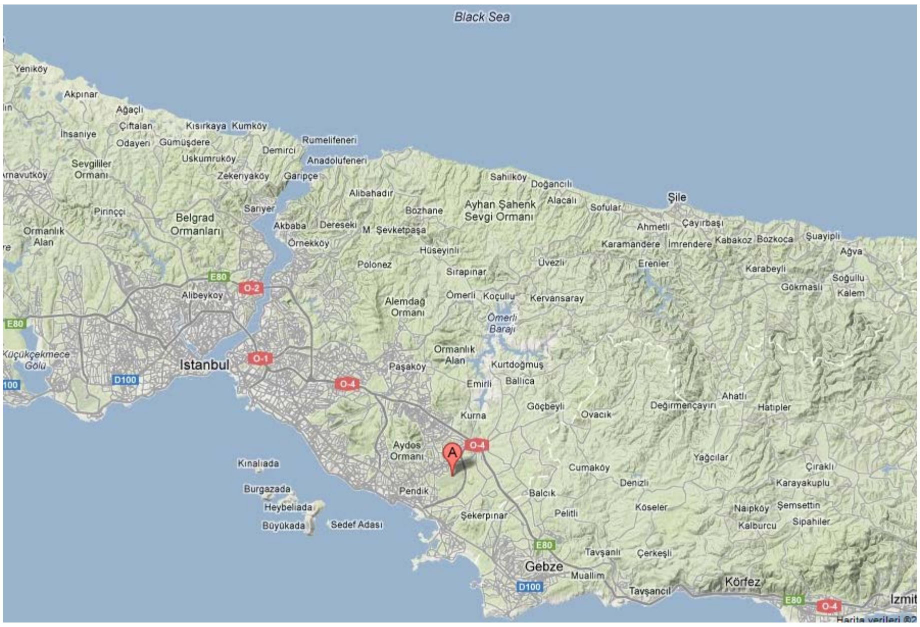


Fig. 2. SabihaGökçen Airport where high wind measurement is made

The Airport Directorate of Meteorology in the SabihaGökçen Airport started its activities on 2 January 2001 and the first measurements were made on 5 January 2001. The station continues making measurements at 41.1^{o} Northern Latitude and 29.5^{o} Eastern Longitude at 99.3 metre above sea level.

In the airport, the mean wind speed was as 3.9 m/s. Although the most severe winds are seen during winter months, it's observed that the mean wind speed reaches 4.48 m/s during July and August.

Although the wind blows from northerly and easterly directions, it blew from 30^{o} at most by %17.4. It was observed that the wind blew from 240^{o} by 3.2% when it blew from southerly and westerly directions. Figure 3 shows wind blowing rates by directions.

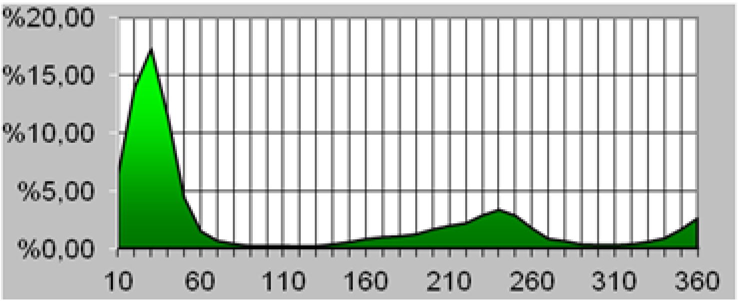
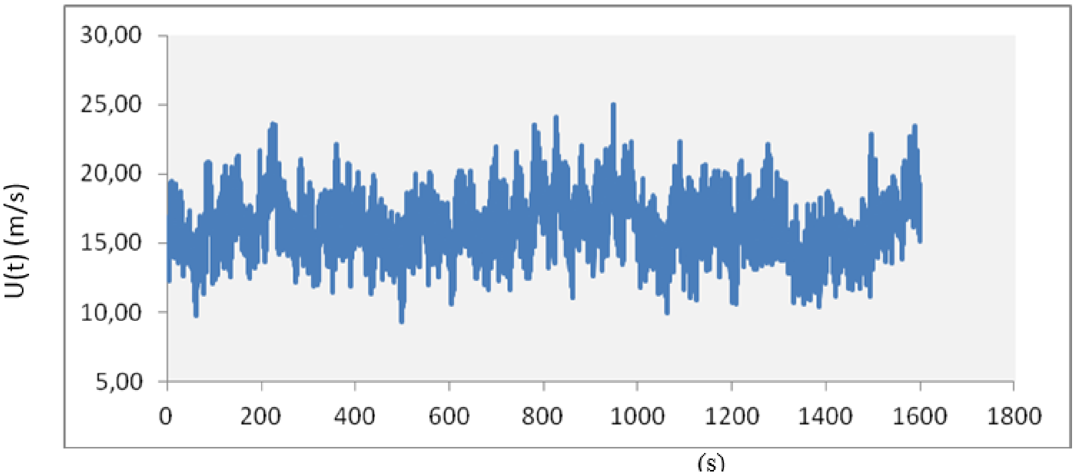
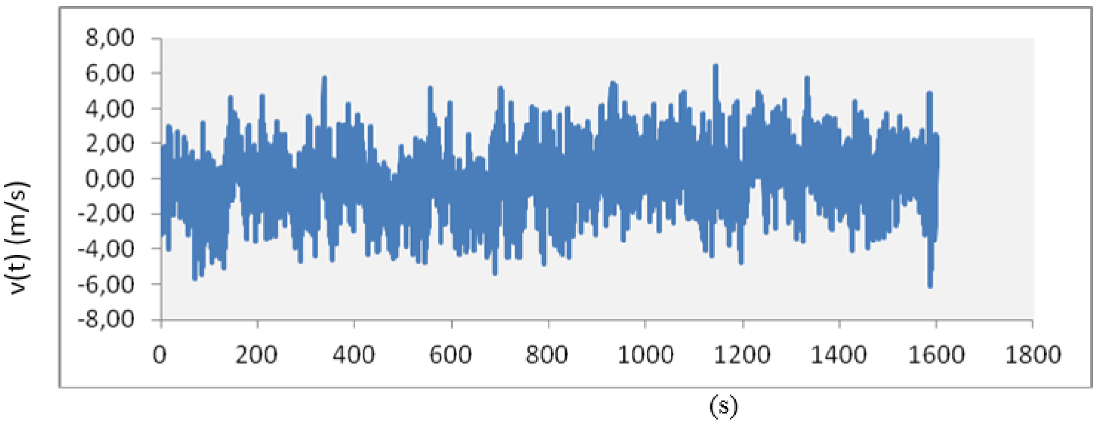


Fig. 3. Blowing rates (%) by directions at the SabihaGökçen Airport

4.2. Analyses made

A 30-minute sample of the wind speeds recorded at the SabihaGökçen Airport is shown on Figure 4 for longitudinal, horizontal and vertical directions simultaneously.





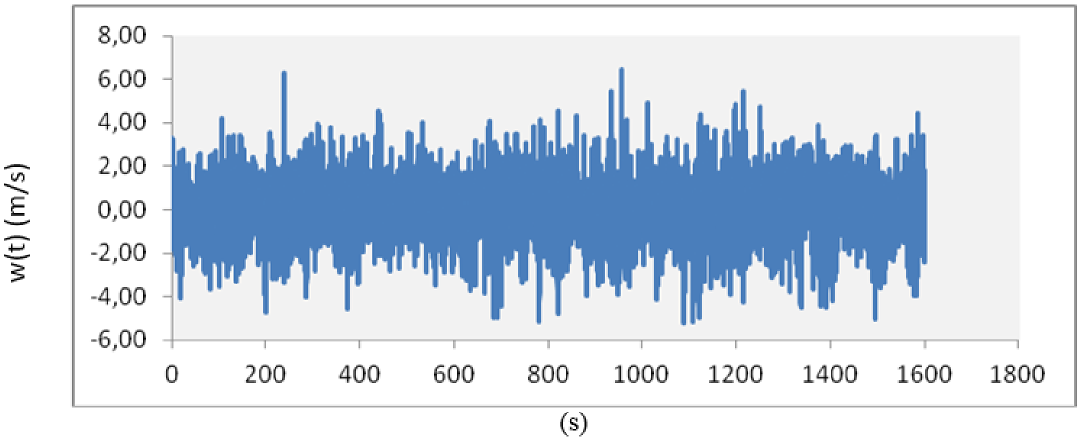


Fig. 4. Variation of longitudinal, horizontal and vertical wind speeds in time

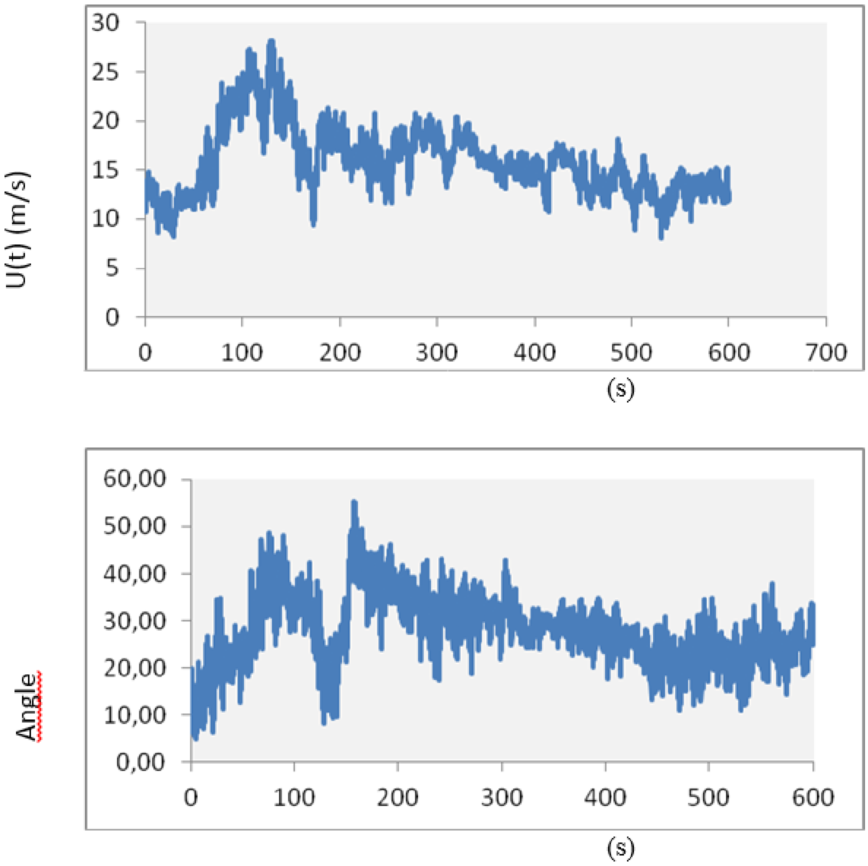


Fig. 5. Longitudinal wind speed and wind direction

Figure 5 shows the variation of the longitudinal wind speed at the time when maximum wind speed occurs as to wind direction as long as recording was made at the SabihaGökçen Airport. It's observed that the wind direction changes suddenly at the range where wind speed changes suddenly and reaches peak value.

The empirical mode decomposition (EMD) was applied to these records and time-varying mean wind speeds and stationary turbulence data were found. Empirical mode decomposition analyses were made by using c++ program.

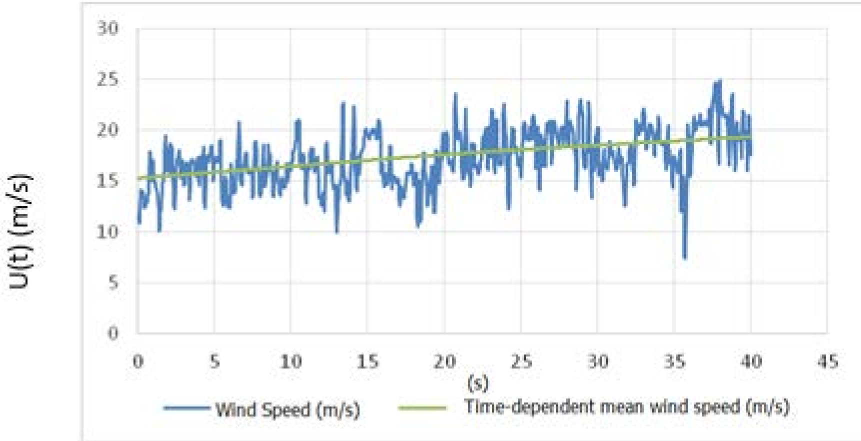


Fig. 6. Time-varying mean wind speed

Figure 6 shows non-stationary wind speed data and time-varying mean wind speed found by way of empirical mode decomposition.

Table 1 gives the maximum wind speeds and turbulence intensities recorded in the period 15 May 2012 - 15 May 2014 at the SabihaGökçen Airport. $I_u$represents the longitudinal wind speed turbulence intensity, $I_v$the horizontal wind speed turbulence intensity, and $I_w$represents the vertical wind speed turbulence intensity.

Table 1. Maximum wind speeds and turbulence intensities of high wind speed records

Data Set	U(t)(m/s)	Iu	Iv	Iw
DS 1	28.15	0.16	0.12	0.07
DS 2	27.16	0.18	0.14	0.07
DS 3	26.01	0.18	0.13	0.08
DS 4	25.89	0.19	0.14	0.09
DS 5	24.97	0.17	0.13	0.07
DS 6	24.11	0.19	0.14	0.08
DS 7	23.78	0.21	0.16	0.09
DS 8	23.5	0.2	0.15	0.09
DS 9	22.49	0.19	0.14	0.08
DS 10	22.16	0.2	0.15	0.08
Mean:	**24.82**	**0.19**	**0.14**	**0.08**

Figure 7 shows the distribution of gust factors for various wind speeds with 10-minute mean that are found by the empirical mode decomposition method. Table 2 gives the gust factors of the 10 wind data sets with the highest speed.

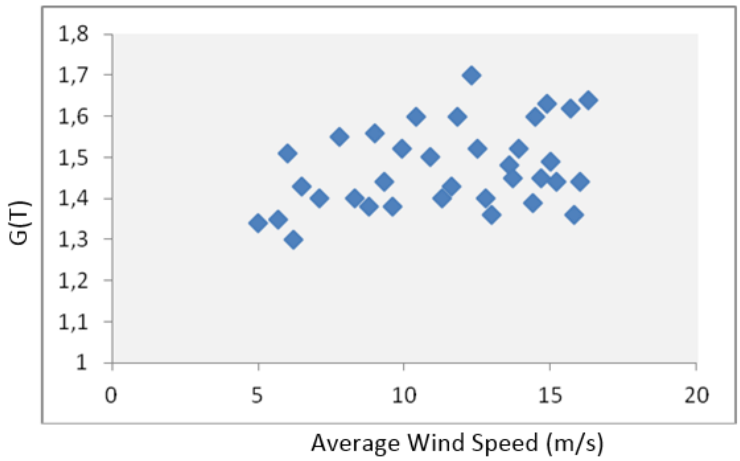


Fig. 7. Distribution of gust factors for various wind speeds with 10-minute sampling range

Table 2 Gust factors of the 10 wind data sets with the highest speed

Data Set	U(m/s)	G(T)
DS 1	28.15	1.64
DS 2	27.16	1.62
DS 3	26.01	1.49
DS 4	25.89	1.48
DS 5	24.97	1.39
DS 6	24.11	1.52
DS 7	23.78	1.45
DS 8	23.5	1.48
DS 9	22.49	1.36
DS 10	22.16	1.4
Mean:	**24.82**	**1.48**

5. Conclusions

This section of the study aimsto determine wind statistics turbulence intensity, maximum wind speed and gust factor) for use in the calculations of high-rise buildings in Istanbul. Information on thewind statistics in Istanbul was obtained by using an ultrasonic anemometer that was installed on 15 May 2012 at the SabihaGökçen

Airport, in which 3D 25 wind speed data (25 Hz) and direction per second in every dimension can be recorded. The results obtained are briefly summarised below.

1) The empirical mode variation method was used to find the time-varying mean speeds of non-stationary wind data. So, more realistic results were obtained when calculating wind statistics.

2) The mean gust factor obtained from wind data sets in an open area was found as 1.48. This value gives a result close to the 10-minute mean gust factor 1.55 reported in the study conducted by authors in [9].

3) It was observed that sudden variation occurred in the wind direction during the time intervals when wind speed showed sudden rises and decreases. It can be said that the reason of non-stationary wind speeds is the sudden variations in the wind direction.

4) The turbulence intensity was found as 0.19 longitudinally, 0.14 horizontally and 0.08 vertically at the Airport. The ratio of turbulence intensity among them is 1:0.73:0:42 . It's observed that quite close values are found when compared with the mean turbulence intensities found in the open by authors in [10].

5) It was observed that the turbulence intensity decreased as the mean wind speed increased in the three directions.

6) It was observed that the variation in turbulence intensity depending on mean wind speed in the open area was lower when compared to the variation in turbulence intensity in areas where buildings are densely located (author is [11]).

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