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Wind Characteristics during Cyclones in Suva, Fiji, for the Last Six Cyclone Seasons

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Abstract

Wind speeds during the tropical cyclones that affected Suva, Fiji, during the last six cyclone seasons are statistically analysed. Since 2012, there were at least 13 cyclones that affected Suva. The wind data were recorded for the six cyclones seasons from October 2012 to April 2018. NRG#40C cup anemometers with a data-logger were used to record the wind speeds at 34 m and 20 m above ground level (AGL) for the above duration. The main investigation of these cyclones' wind characteristics was based on the determination of turbulence intensity (TI), gust factor and the peak factor. The turbulence characteristics were then compared with the AS-NZ-1170.2-2002 standard and the peak factors were compared with the ISO standards. Detailed studies were carried out for the two strongest cyclones: Cyclone Evan and cyclone Winston, during which the 10-minute-averaged maximum wind speed exceeded 25 m/s at 34 m AGL.

Introduction

Cyclones are inward rotating wind flows to an area of low barometric pressure. Every year cyclones have been affecting Fiji. In the South Pacific region, the cyclones are known as tropical cyclones because they are formed near the equator and are formed over warm ocean waters. For a cyclone to form the first thing is the rise of the warm, moist air upwards. When this moist air rises up the ocean surface, it low causing a low pressure. Then the air of high pressure area is being pushed to the low pressure area. The area is again warmed and the moist air rises again. This cycle continues and causes the build of the cloud. This cloud builds up with the addition of the wind which is fed by the heat and water evaporating from the oceans forming a storm system. This storm system develops an eye when the speed of the rotation increases gradually [6].

Cyclones have three stages in their lifetime. These three stages are:

- The evolution (E) (genesis) - this is when the formation of the cyclone takes place.
- The stage when the cyclone is fully matured (M)- this is when the winds have very high rotational speed and there is a low pressure centre where the clouds are structured.
- The decaying stage- this stage is when the cyclone starts to weaken with the intensity of the cyclone becoming very low and finally it dies out [8].

Fiji witnessed devastating cyclones like Cyclone Winston that impacted the whole nation. There were many casualties, damage to the properties and power cut-offs and other problems. Since 2012, there were at least 13 cyclones that affected Suva. In the present work, the turbulent intensity, the gust factor and the peak factor are estimated during the cyclones.

Turbulent intensity is a measure of the fluctuations in wind speed with time. Normally, the higher the wind speed, lower is the atmospheric turbulence and lower wind speeds have higher turbulence levels. During cyclone, the turbulence is low but during silent periods the turbulence is high. Zhang [10] stated that high turbulence levels will have harmful effects on wind turbines. The turbulence generates loads which cause fatigue to the turbine's major components [3].

Method

A 34 m tall NRG Systems tower was installed in the USP campus in October 2012. Three NRG#40C cup anemometers were used for measuring the wind speed – two at the height of 34 m AGL and one at the height of 20 m AGL. The data from the sensors were logged in to an NRG SymphoniePlus[3] data-logger and stored in an SD card. The data-logger estimates the average wind speed for 10 minutes and also records the maximum gust wind speed during those 10 minutes using 600 samples during the 10 minutes.

The turbulence intensity (TI) is estimated from the ratio of the standard deviation to the mean wind speed and expressed in percentage as shown in equation (1).

$$TI(\%) = \frac{\sigma_u}{\overline{U}} \times 100 \qquad (1)$$

where σ_u is the standard deviation for the averaged 10 minutes wind speed in m/s and $\overline{U}$ is the averaged 10 minutes wind speed in m/s.

Wind gust is the sudden increase of wind speed. The wind speed during this period is the maximum. The gust factor G_T was estimated using equation (2).

$$G_{T,\tau} = \frac{U_{\max,\tau}}{\overline{U_T}} \qquad (2)$$

where U_{max} is the 10 minutes maximum gust wind speed in m/s, T is the 10 minutes averaging period and τ is the sampling time where τ is 1, 3 and 10 seconds; for the present work, τ is 1 second.

The peak factor g_u is the maximum fluctuations in the wind speed with respect to the standard deviation [5]. It can also be expressed as a function of TI. Thus the equation for the peak factor is shown in equation (3) [9].

$$g_u = \frac{U_{\max,\tau} - \overline{U_T}}{\sigma_u} = \frac{G-1}{TI} \qquad (3)$$

The data that were recorded during the 10 minutes intervals and used to carry out the analysis were: the averaged 10 minutes wind speed $\overline{U}$ in m/s, the maximum gust wind speed U_{max} during the 10 minutes and the standard deviation σ_u for the 10 minutes.

Firstly the entire raw data for the period specified were extracted and processed to obtain an MS-Excel file. The cyclones' dates were noted and the relevant data from the recorded measurements

(corresponding to 13 cyclones) were extracted. The data-set for each cyclone was separated. For each cyclone, the wind speed averages were calculated. For each cyclone, the TI, the gust factor and the peak factor were calculated.

Results and Discussion

The cyclones that affected Fiji during the last six cyclone seasons were Cyclones Evan, Ian, Lusi, Mike, Pam, Reuben, Ula, Winston, Amos, Ella, Zena, Josie and Keni. The 10 minute-averaged maximum wind speed, the maximum gust wind speed, the average turbulence intensity and the direction from which the cyclones approached Suva are presented in Table 1. It can be seen most of the cyclones approached from north-east and north-west directions.

Cyclone	Direction	Max Average 10 minutes wind speed, m/s	Max wind gust speed, m/s	Average TI(%)
Evan	South	25.5	33.6	12.41
Ian	Southeast	12.5	15.6	12.17
Lusi	Northwest	10.6	16.3	15.93
Mike	North	13	17.7	10.69
Pam	Northwest	10.7	18.5	16.43
Reuben	Northeast	13	15.6	10.69
Ula	Northeast	22.1	28.3	14.5
Winston	Northeast	29.5	38.2	13.25
Amos	Northeast	16.3	19.3	9.87
Ella	Northwest	12.5	15	9.92
Zena	Northwest	11.7	15	16.97
Josie	West	11.3	17	16.27
Keni	West	14.2	22.9	21.13

Table 1. Wind speeds and turbulence intensities during the cyclones.

From all these cyclones, two cyclones during which the 10 minute-averaged wind speeds of more than 25 m/s were experienced, were selected for detailed analysis (Cyclone Evan and Cyclone Winston) and the results are presented in this paper. The turbulence intensities for all cyclones at ultimate range is within the range as per the AS-NZ-1170.2-2002 standard which is 14% for 30 m AGL [1].

Cyclone Evan

On December 9th 2012, tropical depression 04F was noted by the Fiji Metrological Services (FMS). The tropical depression developed into a category one cyclone on the 12th December. The name cyclone Evan was given by the FMS [7]. The cyclone first affected Samoa later impacting the western division of Fiji. The effects were also felt in the central division. The cyclone brought a lot of rain for the whole of Fiji group. The cyclone started directly impacting the nation of Fiji on the 16th of December. It developed in to a category 4 cyclone while moving over Fiji. The cyclone brought a lot of damages to the nation causing trees and power lines to fall down; there was also flash flooding but no casualties were reported.

Cyclone Winston

Cyclone Winston began as a tropical depression 09F on the 7th February 2016 near Vanuatu. The tropical depression developed into a category 1 cyclone on the 11th February and was named cyclone Winston by FMS. The cyclone developed in the south-west of Suva then moved towards Tonga and then made a turn towards Fiji and affected Fiji. This cyclone also impacted small island nations like Niue and Tonga but the maximum damage was caused in Fiji. The western division was severely damaged as well as the northern division. During this cyclone, at least 42 people lost their lives and approximately 126 injured [2]. The financial loss due to the damage caused by the cyclone was estimated to be around F$2.98 billion. This cyclone is known to be one of the most devastating cyclones which has hit Fiji.

Wind Speed Analysis during Cyclones

Figure 1 shows the 10-minute-averaged wind speed and the maximum gust wind speed for Cyclone Evan for the period from 8th December 2012 to 20th December 2012. For cyclone Winston, the data were analysed from 7th February till 6th March 2016 and the averaged and maximum gust wind speeds for this duration are shown in figure 2. The data for analysing these two cyclones were taken from the beginning of the low pressure and until the cyclone died out. The maximum 10-minute-averaged wind speed recorded was 33.6 m/s while the maximum gust wind speed was 25.5 m/s for cyclone Evan as shown in figure 1. For cyclone Winston, the maximum gust wind speed recorded was 38.2 m/s while the maximum 10-minute- averaged wind speed was 29.5 m/s.

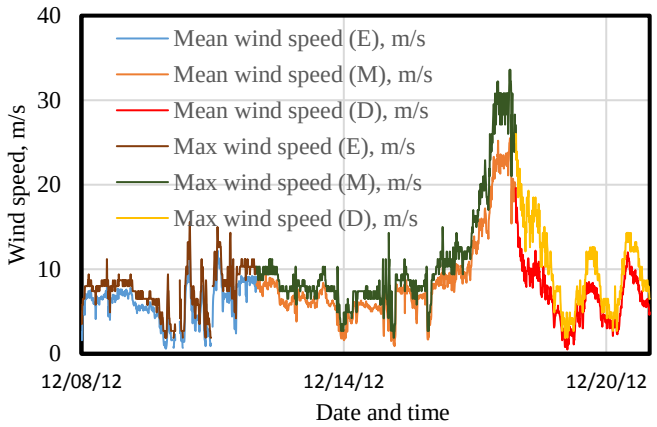

Figure 1. Measured wind speeds during Cyclone Evan at 34 m AGL.

The first stage, E, shown in Figures 1 and 2, is the period of the formation of low pressure and tropical depression. The second stage, M, is when the cyclone reached from the first category till the max category. The final stage, D, shows the cyclone's stage when it started to decay, before completely dying.

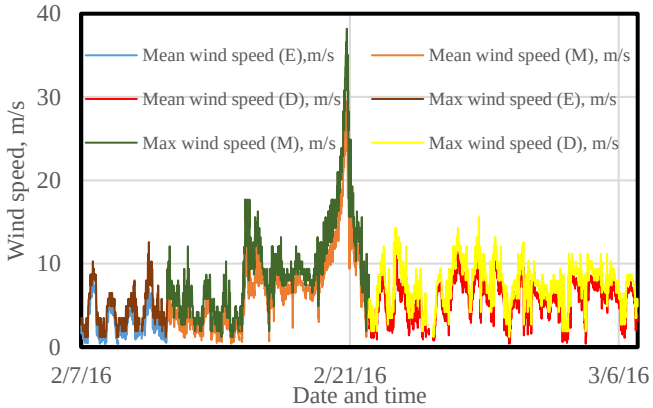

Figure 2. Measured wind speeds during Cyclone Winston at 34 m AGL.

Peak and Gust Factors

The variations of the Gust factors with wind speed for Cyclone Evan and Cyclone Winston are shown in figures 3 and 5. The Gust factor is high at lower wind speeds, as expected. The maximum Gust Factor reached a value of nearly 5 during Cyclone Winston.

The peak factor tends to be in a straight line with respect to the wind speed as shown in figures 4 and 6. The peak factor represents the gust factor in terms of the turbulence intensity. Turbulence is dependent on both standard deviation and the mean wind speed whereas the peak factor is dependent on the standard deviation, thus the influence of the wind does not come into picture when the peak factor is plotted with the variation of the wind speed; however, this is not true for gust factor as it depends on maximum gust wind speed and the average wind speed.

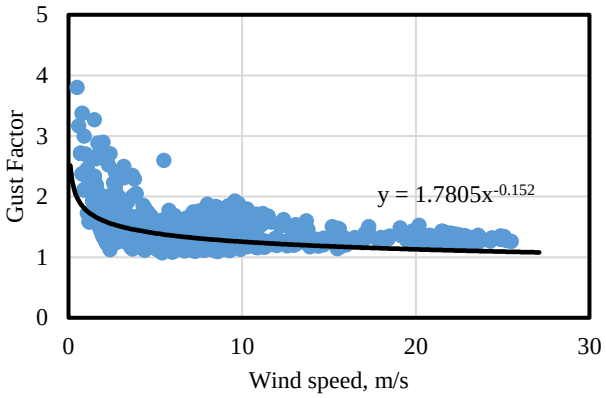

Figure 3. Variation of Gust Factor with wind speed during Cyclone Evan.

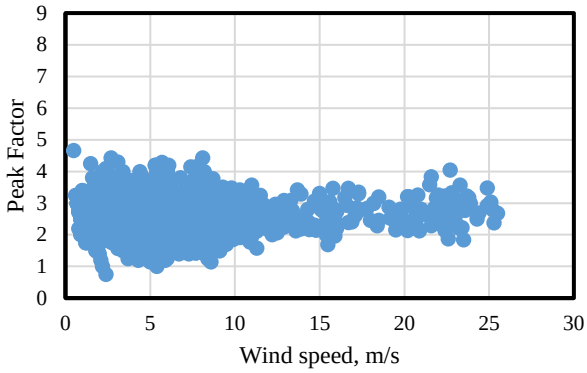

Figure 4. Variation of Peak Factor with wind speed during Cyclone Evan.

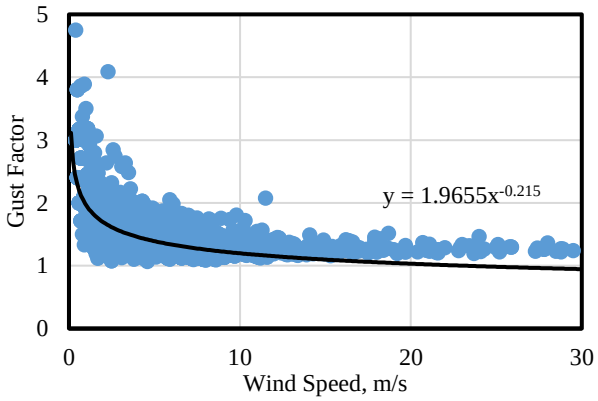

Figure 5. Variation of Gust Factor with wind speed during Cyclone Winston.

From the figures 4 and 6, it can be seen that the average peak factor for Cyclone Evan is 2.54 while for cyclone Winston the mean peak factor is 2.52. According to the ISO standard [4], the average peak factors are 3.9, 3.0 and 2.4 respectively for 1, 3 and 10 second cyclone gust averages. The peak factor that is used for the present analysis is the 1 second gust factor which is lower than the value of 3.9 which shows the calculated averages are lower than the ISO standard gust factor.

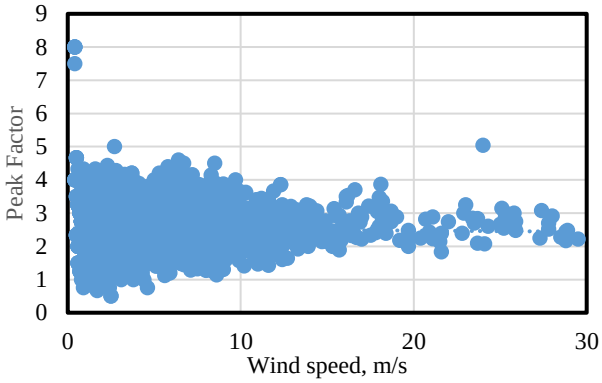

Figure 6. Variation of Peak Factor with wind speed during Cyclone Winston.

The gust factors and the peak factors at different turbulence levels for the two cyclones are shown in Figures 7-10. It is clear that the gust factor increases linearly with the turbulence intensity.

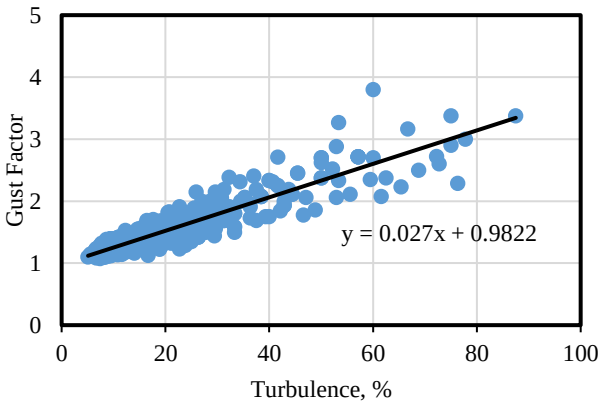

Figure 7. Gust Factor at different turbulence levels during Cyclone Evan.

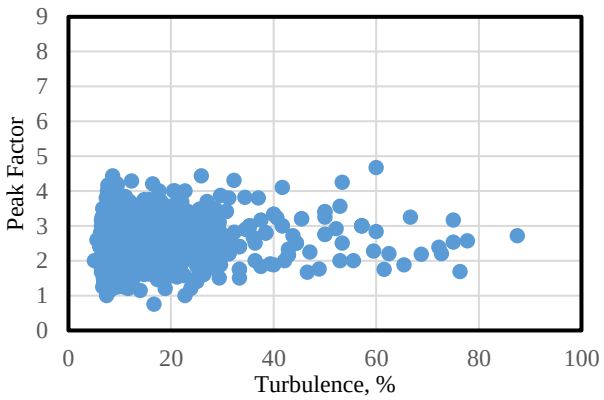

Figure 8. Peak Factor at different turbulence levels during Cyclone Evan.

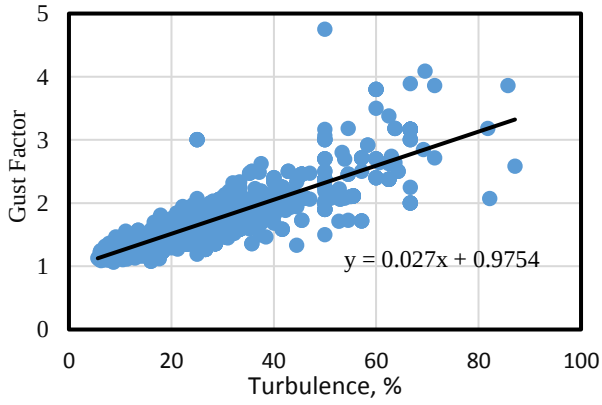

Figure 9. Gust Factor at different turbulence levels during Cyclone Winston.

The maximum gust factor during Cyclone Evan was nearly 4, while that during Cyclone Winston was nearly 5. The scatter for the peak factor is higher for Cyclone Winston with some values becoming significantly higher. The high turbulence levels are due to low wind speeds. These low speeds normally exist during the relatively calmer periods of the cyclones.

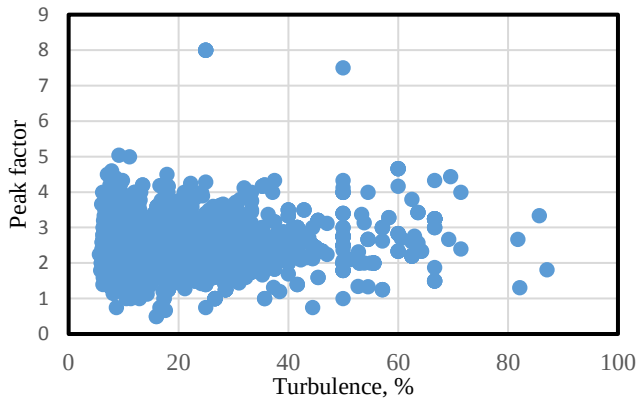

Figure 10. Peak Factor at different turbulence levels during Cyclone Winston.

The variations of the standard deviation with the wind speed during the two cyclones are depicted in Figures 11 and 12. The standard deviation shows the spread of in the wind speed. From the analysis, it is seen that when the wind speed is very low, the standard deviation is less but when the wind speed increases the standard deviation also increases. During cyclones, the wind speed is not constant due to frequent gusts, that increase the wind speed suddenly. Thus the spread of the 10-minute-averaged wind speed increases. Within the 10 minutes period, the standard deviation increased which is due to the increase in the mean wind speed.

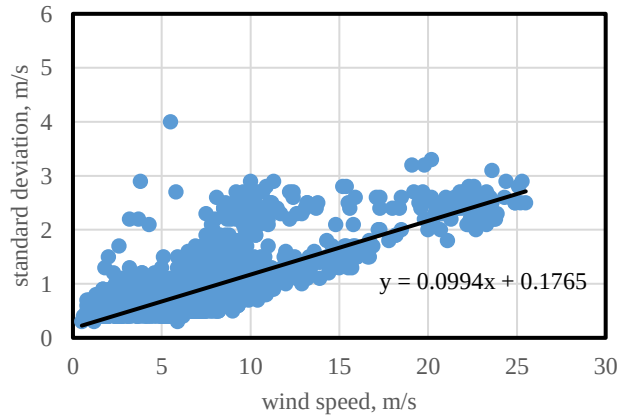

Figure 11. Standard deviations at different wind speeds during Cyclone Evan.

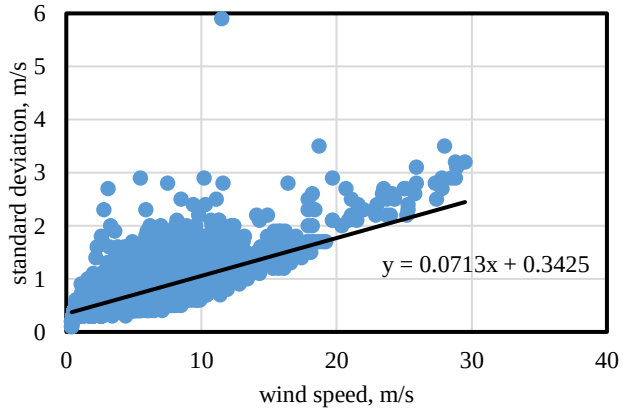

Figure 12. Standard deviations at different wind speeds during Cyclone Winston.

From figures 11 and 12, it is clearly seen that standard deviation increases with wind speed. It is interesting to note that a number of values of the standard deviation during Cyclone Winston are above the trendline compared to those during cyclone Evan.

Conclusions

Detailed analysis of the wind characteristics of two of the 13 cyclones that affected the nation of Fiji during the last six cyclone seasons is presented. The two cyclones were Cyclone Evan and Cyclone Winston, that were major cyclones with the maximum ten-minute-averaged wind speeds exceeding 25 m/s at the height of 34 m AGL. Cyclone Winston's overall average wind speed was 5.82 m/s but during the peak of the cyclone, the maximum gust wind speed was 38.2 m/s. For cyclone Evan, the overall average wind speed was 7.37 m/s, but during the peak of the cyclone, the maximum gust wind speed was 33.6 m/s. The maximum gust factor during the Cyclone Evan was nearly 4, while that during Cyclone Winston was nearly 5.On the other hand, the maximum gust factor was nearly 5 during Cyclone Evan and about 8 during Cyclone Winston. Comparing the peak factors of the cyclones to the ISO standards, the peak factors fall in the acceptable range of 3.9 of 1 second gust factor of the ISO standards. The turbulence levels during the six cyclone seasons are nearly close to 14% which is close to the AS/NZS 1170.2:2002 standards. However, during Cyclone Keni, the turbulence intensity exceeded 20%.

Acknowledgments

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