Non-stationary characteristics of field measured gust in high altitude deep canyon

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SUMMARY:
Short-rise-time gust is a kind of non-stationary wind with sudden change of wind speed, which often occurs in high altitude mountainous areas. In this paper, the short-rise-time gusts at high altitude deep canyon were measured and analysed. The empirical mode decomposition (EMD) method is employed to separate the time-varying mean components from time history of gust. A rational function equation was proposed to fit the regulazed time-varying mean wind speed. The fluctuation of gust is a zero-mean non-stationary process, which can be modulated into a stationary process by normalization. Then, a correlation analysis of fitting parameters of normalized time-varying mean wind and fluctuating wind PSD was carried out, and the result showed that the correlation of each parameter is quite weak, meaning that no redundant parameter could be reduced. Based on the above analysis results, a short-rise-time gust model was proposed to simulate short-rise-time gusts with different duration and wind speed.

Keywords: Short-rise-time gust, Non-stationary, Field measurement

1. INTRODUCTION

Extreme winds have great threat to constructed structures, such as long-span bridges. Field measurement is one of the most effective method to obtain natural environmental wind data. For the time varying mean component of non-stationary wind, it is separated from the record data by many methods, such as wavelet transform (WT) (Huang et al, 2009) and empirical mode decomposition (EMD) (Xu et al, 2004). The fluctuation of typhoon is regarded to be stationary (Xu et al, 2004) and could be analysed directly. While that of thunderstorm downburst is a non-stationary process (Huang et al, 2015). The non-stationary process of fluctuation were described by evolutionary power spectral density (EPSD). It also can be described by non-stationary wind spectra model after modulation (Huang et al, 2015). However, the study usually focused on the typhoon or thunderstorm downburst. The short-rise-time gust, a extreme wind type happened in mountainous areas get less attention of researchers. The wind tunnel test (Dong et al, 2022) pointed out that the short-rise-time gust would cause the overshoot of the structural response and cause potential safety problems, but the wind time history data in wind tunnel test is assumed as half-wave sine shape, which might be quite different from the real situation.

To explore the non-stationary characteristics of mountainous short-rise-time gusts, in this study, a field measurement in high altitude mountainous area has been carried out firstly. Then, the gusts were classified according to the development process. The time varying mean wind speed is separated and described by a unified model. While the fluctuation is normalized to stationary process, which was summarized by stationary wind spectra. At last, a short-rise-time gust model was proposed to generate different gusts.

2. MEASUREMENT POSITION AND INSTRUMENTS

The measured position is Murong Bridge located in the southwestern China. The altitude of canyon bottom is about 2600m and the altitude difference between mountains and the canyon is 500m-1500m. The canyon is north-south direction. The instrument of measurement is a three-dimensional ultrasonic anemometer installed on a lattice tower about 10 meters high from the bridge deck. The anemometer can observe three-dimensional fluctuating wind speed of 0 ~ 45m/s, with sample frequency of 10Hz and accuracy of 0.01m/s.

3. ANALYSIS OF GUST CHARACTERISTICS

Short-rise-time gust mainly refers to a kind of extreme wind whose wind speed increases to a high wind speed or decreases rapidly in a short time. The process of sudden increase or decrease of wind speed often occurs within 10 minutes or even 5 minutes. In the process of gust, the wind speed has obvious non-stationary characteristics. Thus, the non-stationary wind speed model should be used in the analysis of gust. The commonly used non-stationary wind speed model is as follows:

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

Where, $U(t)$ is the wind speed, $\bar{U}(t)$ is the time-varying mean wind speed, $u(t)$ is fluctuating wind speed which usually is a zero mean stationary process.

3.1. Time-varying Mean Wind Speed

There were 20 sudden rise short-rise-time gusts observed. One of the time history of gust is shown in Fig. 1. The moving average method with different window lengths were used to extract the time-varying mean wind speed. The 10-minute moving average cannot reflect the sudden change, while the 30-second moving average contains much fluctuation. The time-varying mean speed can also be obtained by adding the residual and the last third order intrinsic mode functions (IMFs) of EMD, which can reflect the sudden change process and does not include lots of fluctuation components. The time-varying mean wind speed was normalized and fitted. The normalized equation is:

$$\tau = \frac{t}{T} \tag{2}$$

$$Y(\tau) = \frac{U(t) - U_0}{U_{max} - U_0} \tag{3}$$

Where, τ is the normalized time, t is the actual time, T is the duration of gust. $Y(\tau)$ is the normalized wind speed, $U(t)$ is the wind speed, U_{max} is the maximum speed and the U_0 is the speed at start point.

A three-parameter rational function with zero starting and ending points in the [0, 1] interval was used for fitting. The equation is shown in Fig. 2. and it shows the function can better fit the time history of gust.

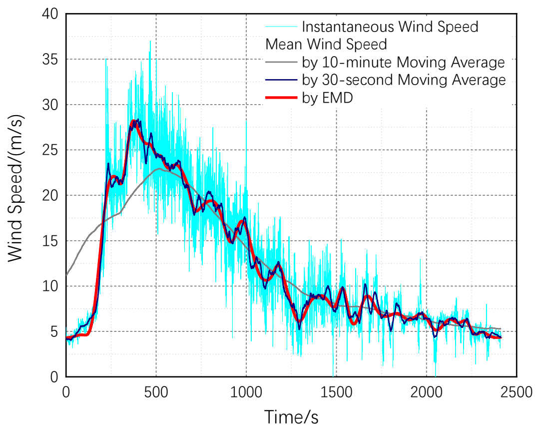

Figure 1. The time history and time-varying mean wind speed of short-rise-time gust.

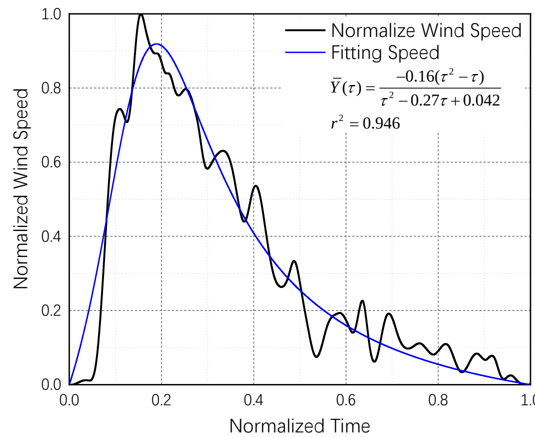

Figure 2. The normalized wind speed and the fitting curve, fitting equation of gust.

3.2. Spectra Characteristics of Fluctuation

The time history of the fluctuation after separating the time-varying mean wind speed are shown in Fig. 3. which still has non-stationary characteristics. The fluctuation was normalized by:

$$y(t) = \frac{u(t)}{\bar{U}(t)} \tag{5}$$

Where, $y(t)$ is the normalized fluctuation, $u(t)$ is fluctuation wind speed, $\bar{U}(t)$ is the time-varying mean wind speed. The Fig. 4 showed that after normalized, the fluctuation is nearly stationary, and the power spectral density (PSD) could be described and fitted by:

$$s_{uu}(n) = \frac{a}{(1+bn)^{\frac{5}{3}}} \tag{6}$$

Where, $s_{uu}(n)$ is the PSD, n is normalized frequency, a and b are fitting parameters. The fitting result was shown in Fig. 5, showing the PSD could be well fitted by Eq. 6.

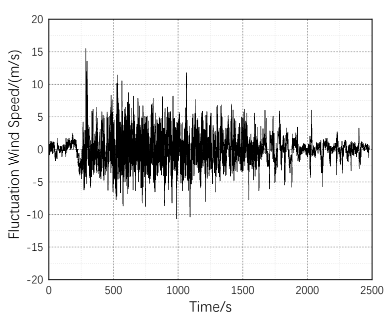

Figure 3. Time history of fluctuation.

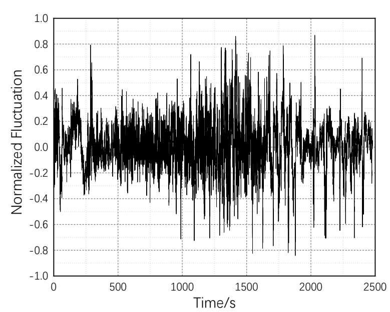

Figure 4. Time history of normalized fluctuation.

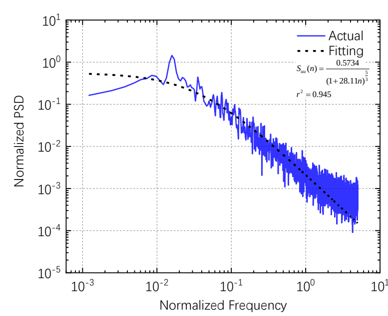

Figure 5. PSD of normalized fluctuation.

3.3. Parameter correlation analysis

A correlation analysis of 20 groups of gust fitting parameters was carried out, as shown in Figure 6. The lower bound of parameter p_1 is set as – 15 to avoid too large fitting parameters, forming a concentration phenomenon. The q_1 and q_2 have weak negatively correlation, while a and b, as fitting parameters of PSD, are positively correlated. There was no significant correlation between other parameters. It shows that there are no redundant parameters. However, the dispersion of parameters makes it difficult to simulate gusts of various shapes

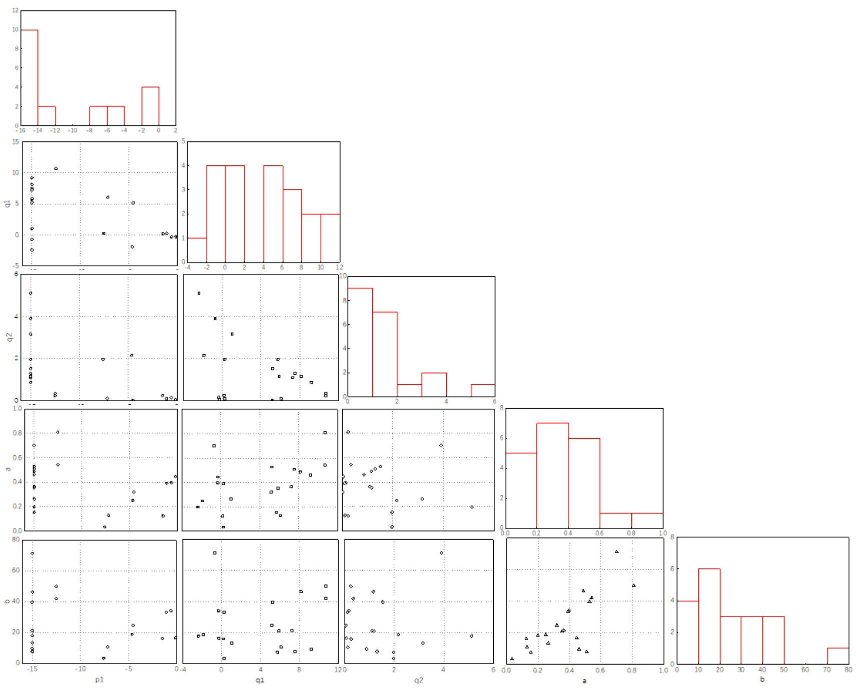

Figure 6. The correlation of fitting parameters.

4. CONCLUSIONS

In the study, a time history of short-rise-time gust was analyzed. The conclusions are summarized as: (1) The time-varying mean wind speed can be separated by EMD and described by a three-parameter rational function after normalized; (2) The fluctuation of short-rise-time gust is non-stationary and its PSD was fitted by a two-parameter spectral equation after normalization. The normalized time-varying mean wind speed fitting equation and normalized fluctuation PSD can be used to simulate short-rise-time gust with different maximum speed and duration.

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