Calculation of Structural Response to Thunderstorm Wind – moving average approach

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Introduction

In the early 60's wind engineers adopted the random process theory, which was first used in the field of communication studies, for the study of wind action on structures. The dynamic response of a structure to wind turbulence was modelled as a Gaussian random process and using frequency domain analysis and statistical concepts, the expected largest response in a given time can be predicted. Since then, the gust response factor method is found to be a useful and convenient approach to predict the response of a structure to wind load. While the method gives satisfactory results to many wind loading problems, the method has its limitations. One of the assumptions of the method is that the process is stationary. Thus for processes that are distinctly non-stationary, the method would not give good results.

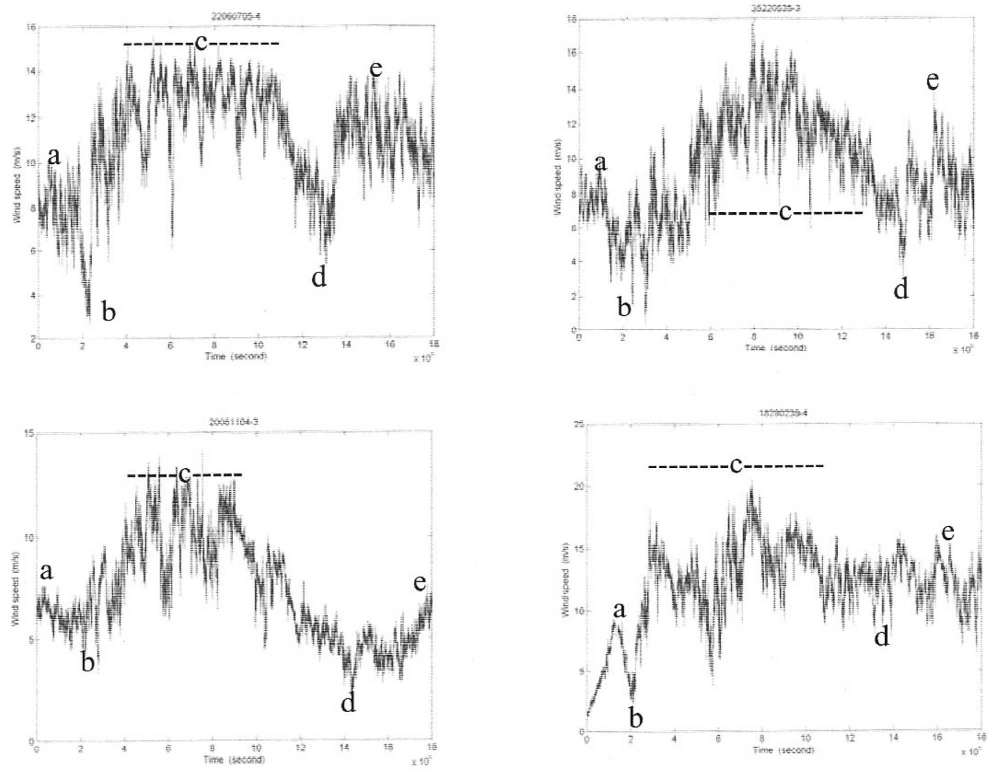
Thunderstorm

Thunderstorms are common occurrence around the world. There are nearly 2000 thunderstorms in progress at any time over the earth's surface. Although their occurrences are so common, it is only in the recent decades that the study of thunderstorm wind has been a topic of interest to wind engineers. Recently, there are more indications that thunderstorm wind plays a significant part in defining the strong wind characteristics of a place. Although its occurrence is worldwide, the frequency of thunderstorm occurrence varies greatly in different geographic regions. It seems wind characteristics of thunderstorm in different regions can also be different. Most thunderstorms are found in tropical and sub-tropical regions. The most destructive wind of a thunderstorm occurs during the mature stage of the thunderstorm, where the downdraught impinging on to the ground resulting in strong gusty winds and heavy precipitation. A thunderstorm usually lasts no more than one hour and it is localized in both time and space.

As a thunderstorm (TS) is transient in nature; the wind generated by a thunderstorm is a very non-stationary process. As such, the existing dynamic gust response factor method (GRF) is not suitable for the analysis of structure under the action of thunderstorm wind. The application of GRF to thunderstorm wind has been studied by Choi[1] and the result confirms that the method is not suitable. The paper also suggested that 'moving average' could be used to tackle the problem.

To have a better understanding of the characteristics of thunderstorm wind, further study using the 'moving average' (MA) approach is carried out by the current paper. Figures 1a, b, c and d are wind speed plots of four thunderstorms.

The individual wind speed plot of each TS looks quite different. However certain pattern of variation can still be identified. Usually before the storm there is a small peak (a). Following which is a low point (b) which can be viewed as the start of the main storm. After point (b) is the main bulk of the storm (c). Normally the highest wind speed of the storm occurs at this region and there can be several peaks in the region. After the main storm (c) there is a low trough (d) which can be followed by another high speed region (e). While points (c), (d) and (e) are quite definite for the fist three plots; they are not so well defined for the fourth storm.



Figures 1a, b, c, d Wind speed v.s. Time for four thunderstorms

As can be seen from Figure 1, the wind speed variation is not just random fluctuation above certain mean value. It seems the wind speed is made up of two parts; one that which rises and falls with the passage of the TS and the other is a random fluctuation of the small scale turbulence. The first component is a function of the point in time relative to the TS and its value is very different at different point of the TS. If we consider that the non-stationarity of the TS process to be mainly due to this component, the TS wind can be represented by a non-stationary component and a stationary random component. In the following study the first component is represented by a running mean (RM) process and the second component is represented by the fluctuation above this RM. The value of the running-mean at any time j is obtained as the average of the data from $j-T_{RM}/2$ to $j+T_{RM}/2$. .

$$\bar{u}_{RM}(j) = \frac{1}{T_{RM}} \int_{j-T_{RM}/2}^{j+T_{RM}/2} u(t)\,dt \qquad (1)$$

The second component is the fluctuation term u'_{RM} which is the fluctuation about the running-mean.

$$u'_{RM}(j) = u(j) - \bar{u}_{RM}(j) \qquad (2)$$

where T_{RM} is the averaging period of the running mean. In the present study, different values of the averaging period, T_{RM}, have been tried out, ranging from 10 seconds to 300 seconds. The effect of changing the value of T_{RM} is presented in Figure 2 in which the first graph shows a plot of the instantaneous wind speed of a TS and the subsequent pairs of graphs show plots of the $\bar{u}_{RM}$ and u'_{RM} for T_{RM} of 10, 60 and 300 seconds. It can be seen that the larger the T_{RM}, the smoother is the $\bar{u}_{RM}$ and the u'_{RM} has bigger values and less random; the smaller the T_{RM}, the more fluctuation is the $\bar{u}_{RM}$ and the u'_{RM} has smaller values and more random.

For comparison, Figure 3 shows plots of $\bar{u}_{RM}$ for T_{RM} of 10, 30, 60, 180 and 300 seconds of a TS (storm 1 in Figure 1). The effect of the averaging period in reducing the amount of fluctuation of the $\bar{u}_{RM}$ can be seen. Furthermore, the points (a), (b)... (e) as discussed in Figure 1 can been seen more readily from the 60sec. and 180 sec. graphs.

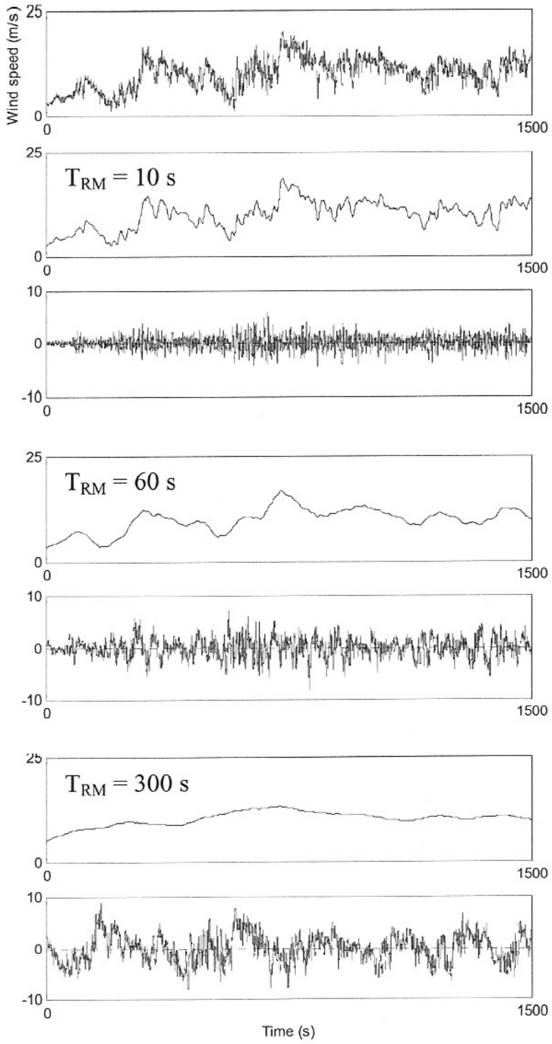


Figure 2 Plots of $\bar{u}_{RM}$ and u'_{RM}

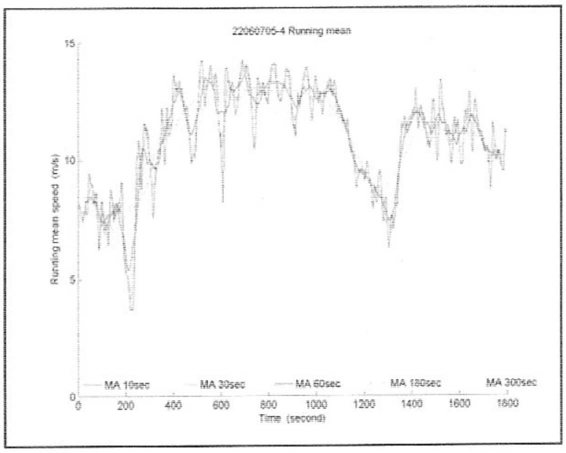


Figure 3 $\bar{u}_{RM}$ for different T_{RM}

Response using moving average

With the TS wind process separated into the two components as discussed, the response can also be calculated as the sum of the two components. The problem now is to select what value of T_{RM} to be used. It is clear that a large T_{RM} will probably introduce non-stationarity into the u'_{RM} component. Thus a shorter T_{RM} is desirable. On the other hand, too short a T_{RM} will result in severe fluctuation of the $\bar{u}_{RM}$ process which may introduce dynamic amplification to (peak response bigger than static response of peak RM wind speed) and complicates the calculation.

The amount of dynamic amplification is of course also a function of the property of the structure under investigation. In the present study, a SDOF arc lamp (no = 0.5 Hz, Damping = 0.01 and mass = 6000 kg) is used to illustrate the method. With this structure, the time history response due to $\overline{u}_{RM}$ is calculated and compared with the peak static response. For the range of T_{RM} (10 to 300 second) being calculated, no dynamic amplification is observed

Using the usual terminology of the GRF method, the total response can be calculated using the following equation.

$$\hat{x} = \overline{x}_{RM} + g\,\sigma_{x_{RM}} \qquad (3)$$

where $\overline{x}_{RM}$ is the static response to the peak running-mean speed, g is the peak gust factor and $\sigma_{x_{RM}}$ is the root-mean-square fluctuation about the running mean. The second term in the equation is calculated using the normal GRF method with the spectral density terms being calculated from the fluctuation about the running-mean. The relative contribution of the two components in equation 3 for different T_{RM} is given in Figure 4 where the responses are expressed as a ratio of the peak time history response to the instantaneous speed. In general, the $\overline{x}_{RM}$ (RM) decreases with increasing T_{RM} while the response to the fluctuation above the running mean (RA RM) increases. For the six TS cases plotted, it seems the (RA RM) in general contributes more than the (RM) and more than 50% of the total response. However for the smaller T_{RM} (less than say 100 seconds), (RM) can be larger than (RA RM).

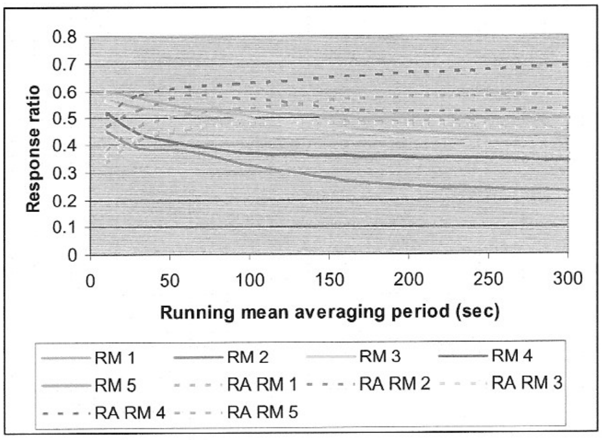


Figure 4 Response ratio v.s. Averaging period

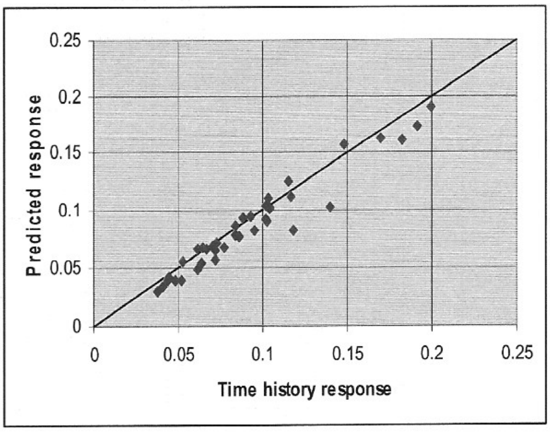


Figure 5 Predicted v.s. time history response

The prediction using equation 3 is also compared with the peak time history response to the instantaneous speed. As it is understood that large T_{RM} is not appropriate, a value of 60 seconds is used and is plotted in Figure 5. It can be seen that the prediction matches reasonably well with the time history response.

Conclusion

A method using the moving average approach is proposed for the calculation of dynamic response to thunderstorm wind, a non-stationary process. Result of the prediction is satisfactory.

References

CHOI E.C.C., Hidayat F.A., (2002) "Dynamic response of structures to thunderstorm winds" Journal of Progress in Structural Engineering and Materials, UK, Vol 4, No. 4, (2002) pp408-416.