# Stress Analysis of Wind Load under Random Traffic of Long-span Bridge Structures

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**Abstract:** Long-span Bridges are often particularly vulnerable to wind because of their great flexibility. The main wind-related difficulties are the large deflections caused by vibrational instability or the response of random gusts. In this paper, the dynamic response of Bridges is introduced. Meanwhile, the reaction force identification method is studied for evaluating possible inaccuracies in wind load models. In addition, a model-based joint input and state estimation method is used to identify modal wind loads from acceleration data. Various data sets under various wind conditions are also given. Based on the stress impact function, the stress finite element analysis problem is transformed into a stress integral or sum problem. At last, dynamic stress analysis under random traffic as well as the wind loads for long-span Bridges is researched.

## 1. Introduction

Bridge as traffic bottlenecks, play a critical part in the growth of a country's economy. Bridge scientists and experts believe that wind load is an existing problem that can never be ignored for bridge structures, especially for long-span bridges [1]. With the increase of bridge span and the complexity of bridge structure, the role of wind load gets increasingly sensitive. Since the fall of the Tacoma Narrow Bridge, wind has caused many bridges to oscillate. As a result, aeroelasticity is just as crucial for long-span bridges as it is for aircraft. Wind load dynamic analysis has become one of the most significant issues to consider while designing and building long-span bridges. The wind resistance stability of long-span bridges is critical, particularly for sea crossing bridges, bridges with a height drop, and bridges with a high and changing traffic flow, which have new wind load needs along the same span [2]. Bridge designers must deal with the stability of different wind loads at different positions of the bridge in order to cope with the increasing length of the bridge, its span, unstable wind load, increasing complex climate, and increasing pedestrian flow under the condition that existing materials have been fully utilized and no new structure has been developed, that is, wind load stress analysis under random traffic [3].

The analysis of wind loads has become more essential for reliable structural design as bridges have developed longer and more slender spans. Long-span bridges are generally found to be particularly susceptible to wind impacts due to their high flexibility, and their primary wind-related concerns relate to massive deflections caused by oscillatory instabilities or reaction to random wind gusts [4]. Due to the combined effects of random traffic and wind loads, these bridges can experience repeated loading and unloading processes in certain areas, resulting in fatigue damage to structural members and even bridge collapse because of the accumulation of long-term fatigue damage [5].For example, after 39 years of service, the Silver Bridge collapsed in 1967, with vehicle and wind loads causing fatigue damage to key components of the bridge, which was a major cause of the tragedy. Fatigue damage caused by random traffic and wind loads is clearly a matter for discussion. Fatigue damage assessment of bridges requires dynamic stress analysis of local bridge components. However, this is difficult because it requires a complex bridge dynamic finite element model (FEM), as well as different dynamic vehicle models, wind load models and interaction models.

In order to complete the inquiry of dynamic wind load, this paper presents the dynamic analysis process and particular methods of wind load of bridge structures, as well as the research models and research data used by predecessors, including finite element analysis and Kalman technology. The stress analysis of wind load under random traffic is then studied using a long-span bridge as an example. We use it at various wind speeds and draw different conclusions based on the stress under various traffic situations in order to complete the wind load stress study in random traffic.

## 2. Bridge dynamic analysis under wind loading

The majority of modern wind load and response analysis is based on notions of turbulence buffeting and self-excitation related to bridge motion [6]. Even though these ideas are well-established, the exact parameters used in this research might be a major source of confusion. In the classical wind load evaluation, aerodynamic coefficients and admittance functions for each bridge form are generally established by wind tunnel research utilizing scale models. The simplifications and uncertainties of test are simply transferred to the estimated wind loads. Despite advances in computational methods and wind tunnel testing equipment, the local environment and complexity faced by actual bridges cannot be replicated. Due to the lack of specific example data, three assumptions are usually made:The wind field is stable, uniform, and perpendicular to the bridge. Non-stationary events, inhomogeneous or skewed wind fields, and the effects of local topography are all possible outcomes. A sheer number of reports [7], distinct the prediction and measurement of response from the bridge, indicate that there is a flaw for the prediction of wind loading.

Wind loads on huge structures are difficult to quantify in a practical manner. A possible approach for this technological difficulty is the inverse estimate load from response data, also known as force identification. These approaches necessitate a FME of the structure and limited vibration data. There have been several techniques to force identification in recent years, but no study on the inverse estimation of wind loads has been done. Therefore, it is important to evaluate the applicability of state-of-the-art force detection methods using full-scale data. The method allows for the rapid derivation of state space equations for modeling dynamic systems. These equations for reduced-order multi-modal systems are well known, but they are also used to provide a complete picture of the situation. The equations of motion of a bridge in finite element format can be generated using a linear dynamics model which is ideal for analyses of wind-induced reaction under normal in-operation situations:

$$M_0\ddot{u}(t) + C_0\dot{u}(t) + K_0 u(t) = f(t) \tag{1}$$

where $(.)_0$ denotes still-air qualities, i.e., contribution from the structure only. The physical DOF response is represented by the $u(t) \in R^{n_{DOF}}$ vector, and $f(t) \in R^{nDOF}$a force vector. The following is the measurement vector Y, which contains accelerations and displacements in specified structural DOFs:

$$y(t) = S_a\ddot{u}(t) + S_d u(t) \tag{2}$$

where $S_a$ and $S_d \in R^{n_d \times n_{DOF}}$ are binary matrices which select the measured DOFs. The system equations are translated into state-space form by inserting the modal state variable $x(t) = [z(t)^T\ \dot{z}(t)^T]^T \in R^{2n_m}$ :

$$\dot{x}(t) = A_c x(t) + B_c p(t) \tag{3}$$

$$\mathrm{y(t) = G_c x(t) + J_c p(t)} \tag{4}$$

$$\mathrm{A_c} = \begin{bmatrix} 0 & \mathrm{I} \\ -\Omega^2 & 2\Xi\Omega \end{bmatrix} \tag{5}$$

$$\mathrm{B_c} = \begin{bmatrix} 0 \\ \mathrm{I} \end{bmatrix} \tag{6}$$

$$G_c = [S_d\Phi - S_a\Phi\Omega^2 - S_a\Phi 2\Omega\Xi] \tag{7}$$

$$J_c = [S_d\Phi] \tag{8}$$

The method makes no assumptions about wind loads, even though the loads are determined directly from acceleration data using a combination of inputs and state estimation processes. The computed frequency domain characteristics of the load seem to be realistic, except for the reduction of the effects of several known faults in the modal model. The expected loads are higher than the wind field predicted by the design model. Both buffering and self-excitation forces are present, but they are currently calculated in combination and cannot be isolated. There is a clear parallel pattern in the time series of expected modal forces and wind turbulence compared to the wind speed table data. The results suggest that the technique can be used to estimate wind loads on bridges under multi-variable wind conditions if further improved and validated. The researchers had to overcome certain practical and theoretical limitations. The output data limit the number of modal forces that can be replicated. Large span bridges are characterized by multiple modes with high wind-induced excitation, thus requiring the use of large and optimally performing sensor networks to reproduce the entire dynamic behavior. Proper evaluation of acceleration data during wind load investigations is also a limitation, as near-static forces are not always accurately estimated. This source of error can be reduced if strain measurements are provided.

## 3. Stress analysis of wind load under Ramdom traffic

In the last two decades, several studies on coupled wind–vehicle–bridge networks have been performed. There has been research on linked road automobile and bridge systems experiencing wind loads, for example. In crosswinds, Xu [9] and other researchers tested connected train and cable-supported bridge systems. Nevertheless, almost all of these researches employed a basic FEM of the bridge to concentrate on overall bridge reactions, for example, the dynamic displacement and acceleration. Only a few cars have been included in these studies, which are normally dispersed in a consistent manner on a bridge. There's a high likelihood that several vehicles, including various kinds of vehicles, will be present at the same time on the long-span bridge. Wu and Chen [10] used cellular automata to completely model on long-span bridges for random traffic flow with great results.

The stress impact lines at critical places of vital bridge components were computed using ANSYS finite-element technology, which would then be fitted using MATLAB application to create the stress impact equation. Then, by using Monte Carlo simulation methodology in MATLAB, simulating the random selected traffic sample based on the bridge's 24-hour traffic volume records. Because a complete interaction assessment of the wind-vehicle-bridge network, especially for large span bridges, can become very difficult in situations with stochastic heterogeneous traffic. Finally, the critical location stresses of critical bridge members are determined by the product of the stress influence surface equation and similar dynamic wheel loads. In addition, the stress influence line function is combined with the bridge longitudinal unit-length wind load to determine the integration of the stress influence line function with the bridge longitudinal unit-length wind load. The stress response of Bridges is studied by ANSYS for model verification, and the results are compared with those calculated by the proposed technique.

This simplified method takes the time course of the relevant vehicle loads as external forces and considers the dynamic impact of the bridge and the vehicle, replacing it with a full vehicle model. The stress response of the vehicle on the bridge is evaluated by directly using the stress impact surface equation. Several cars, including six different types of vehicles, were scattered in the chaos of traffic. The assumption for specific road vehicles traveling along the bridge is constant speed and no change in traffic lanes.

The stress response of the bridge's critical location under solely wind loads was evaluated based on the experiment's output, with the findings presented in Figure 1. Which three different average wind velocity of 15, 20, and 25 m/s, with a time length of 600 s, are implemented.

According to the wind-induced data, the stress magnitude created by wind loads are not considerable, and even for a 25 m/s wind speed, the amplitude range is only [3.5, 2] MPa. As wind speed rises, the amplitude change diminishes, and the average stress values induced by wind loads are diminish, seldom surpassing 1 MPa.

The stress response of the bridge's crucial position under random traffic load was further investigated, and the findings are shown in Figure 2, which covers two types of random traffic flows, free traffic flow and busy traffic flow respectively, during a 600-second time period. Figure 3 shows the vehicle-induced stress versus the wind-induced stress with a wind speed of 25 m/s with unrestricted traffic flow.

The results show that the stress amplitudes caused by random traffic loads are significantly larger than those caused by wind loads, even at 25 m/s wind speed. The stress concentration amplitude induced by the congested traffic flow (80 vehicles on the bridge at one time) does not exceed that induced by the free traffic flow (40 vehicles on the bridge at one time), which is very interesting and can be attributed to the fact that the surface stress effect function has both positive and negative values and that the cumulative results for many vehicles are in a specific order. For the vehicle-induced stress response, there are multiple positive sharp maxima, with each high value indicating that the vehicle has passed a critical threshold. Thus, the number of extreme values is greater in congested traffic flows than in free traffic flows. The vehicle-induced stresses have a greater impact on the stress response of the bridge and critical locations. In addition, the total number of stress cycles in a random traffic flow is completely determined by the number of vehicles.

Furthermore, the relationship between wind and vehicle-induced loads is clearly derived [11]: for large-span bridges, the dynamic impact of vehicles is relatively small, and the effects of vehicle speed and pavement unevenness conditions are negligible; dynamic stresses vary with wind speed and the number of cycles increases; the combined effects of wind and vehicles may potentially cause fatigue problems in large-span bridges, while traffic or wind loads alone cannot cause significant fatigue problems.

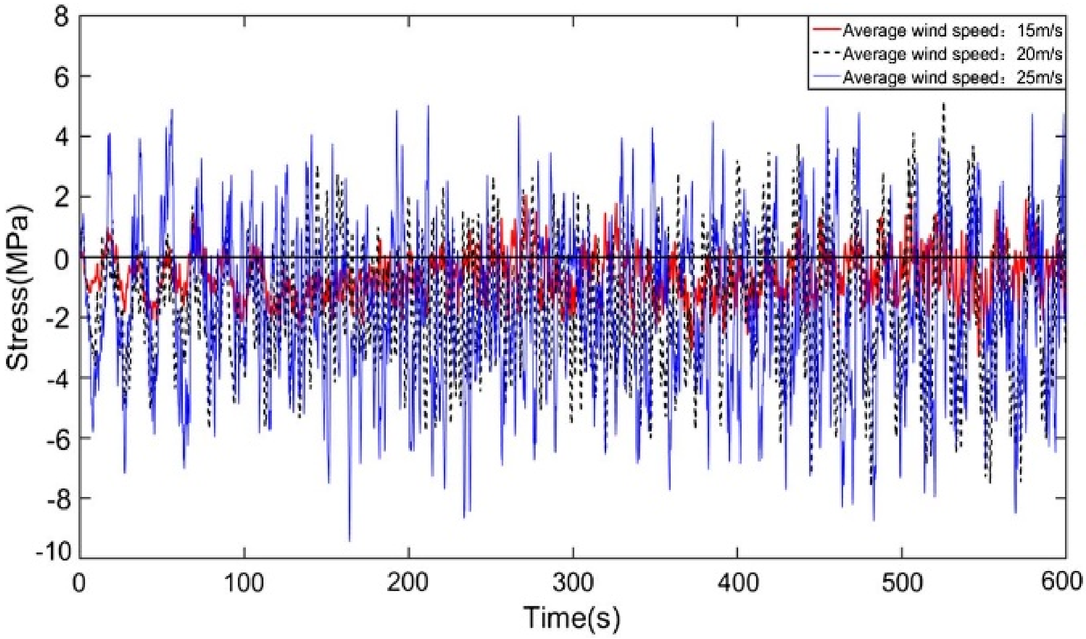


Figure 1. Stress performance with different wind speed [5].

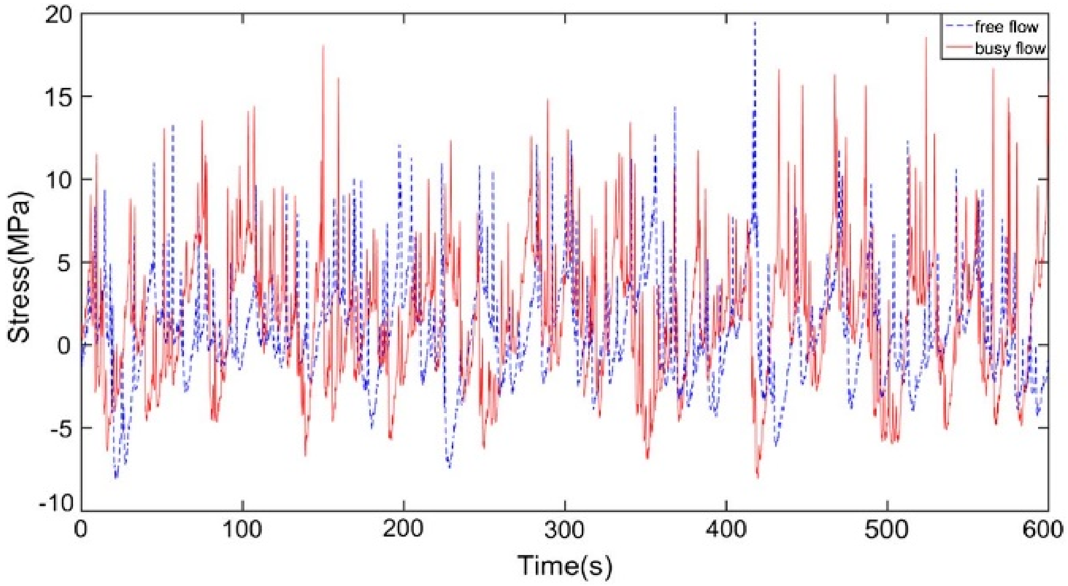

Figure 2. Stress performance of free and busy flow [5].

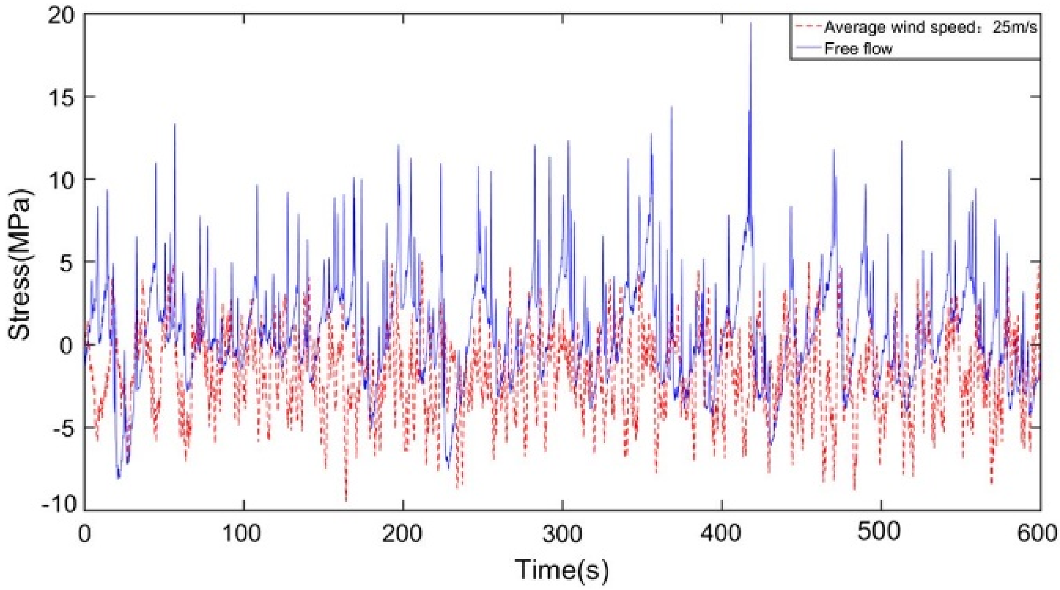

Figure 3. Stress performance of the bridge for free flow and 25 m/s wind speed [5].

## 4. Conclusion

Due to the gap in the dynamic wind load analysis, the inverse wind load estimation is implemented for the evaluation and the method is found that is beneficial in determining wind load on bridge with variable wind conditions. According to the stress analysis for the dynamic wind load under random traffic, vehicle-induced stress plays a more significant affect in stress response on the bridge compared with wind-induced stress, even at a 25 m/s speed. This paper provides the current evaluation method for static and dynamic wind load on long span bridge, and compared the stress distribution by wind load and vehicle-induced load on bridge.

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