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Dynamic Response of Temporary Structures due to Wind Loading

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Abstract

Due to the lack of an international standard for the design of temporary stage structures, there have been several instances where temporary stage structures have failed and resulted in injury or death during strong wind events (Tomasetti, 2012). The aims of this project are to identify the dynamic loads, particularly wind loads, imposed on temporary structures, the response of these structures to wind loads, and the way they are currently designed. Current industry standards, such as AS/NZS 1170.2:2011 – Wind Actions, NCC (National Construction Code) and AS/NZS 1170.0:2002 Structural design actions - General principles, do not provide adequate information and guidance for engineers to determine suitable short term loads for their design, instead relying heavily on using engineering judgement based on experience.

By using structural health monitoring technique, wireless senor technology and finite element modelling, we determined the dynamic properties, including natural frequencies of vibration and deflection mode shapes, of a temporary stage structure under wind action. The measured dynamic properties are compared with computed results obtained by finite element modelling,

A greater understanding of the dynamics of this type of structure and their potential structural response to environmental loads, in particular wind loading, can be achieved.

Introduction

A temporary structure can be defined as a structure without a permanent foundation. After it has been used for its purpose, the structure is removed. The use of temporary structures is mainly due to the low cost of materials, quick assembly and tear down time. When designing a building, the design engineer follows a building code and the building must meet these requirements as a minimum requirement. Most of the current design requirements for doing so, such AS/NZS 1170.2:2011 – Wind Actions, the NCC (National Construction Code) and AS/NZS 1170.0:2002 Structural design actions - General principles, do not have sections for temporary structures and leave it to the State and Territory authorities to decide what to do in specific circumstances (Wang et al., 2012).

Due to the lack of an international standard for the design of temporary stage structures, there have been several instances where temporary stage structures have failed and resulted in injuries and/or deaths during strong wind events. Notable failures include, Sugarland 2011 (Figure 1) (7 fatalities. 40 injured) (Tomasetti, 2012), Big Valley Jamboree 2009 (1 fatality, 40 injured) (Sunga, 2009), Radiohead 2012 (1 fatality, 3 injured) (Mills, 2013).

Figure 1. Sugarland Stage Collapse (Callahan, 2012)

These failures occurred when the temporary structures have not been built with sufficient strength to withstand unexpected wind forces. Current industry standards do not provide enough information for engineers to determine suitable loads for their design, instead relying on using their own judgment.

This project investigated current standards of building codes and wind loadings on temporary structures and analysed the dynamic response of these structures due to wind loadings. Past failures and current wind codes were analysed in order to gather a greater understanding of the dynamic responses of these structures. To develop a greater understanding of the dynamic properties of the stage structure, a wireless sensors network consisting of 8 nodes were used to measure the acceleration response of a temporary stage structure under wind actions. These nodes were coupled with weather monitoring equipment to measure the maximum wind gust during the study period. These field data were analysed and interpreted, via power spectral density functions, to estimate the natural frequencies and deflection mode shapes of the structure. These field test results were compared with computed results determined from finite element modelling.

Methodology

Stage Structure

The stage structure tested is called a “14m Roof” owned by Stageset, as shown in Figure 2. The stage has a unique feature which consist of a modified bus hoists to erect column towers and roof instead of traditional cranes. This is a substantial advantage over using a crane as this is easier and safer to use and erect. Ballast requirements are needed also to resist over-turning. The stage is designed with a minimum of 1 tonne ballast on each tower base. The "14m" in its name denotes its roof span which is 14m. The height of the roof's highest point is 10m. The location of the experiment was at Sydney Olympic Park, Homebush NSW.

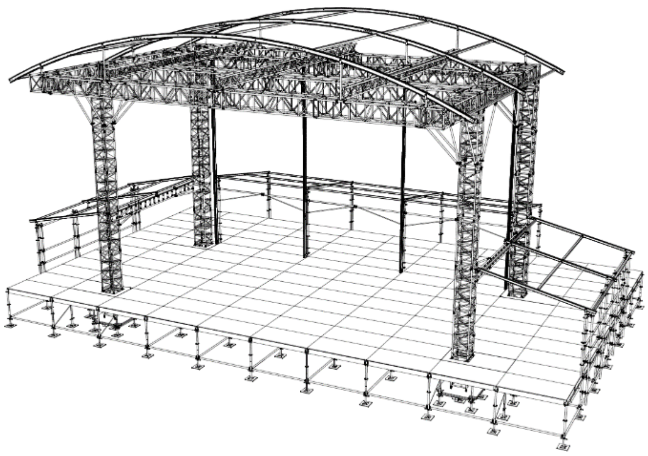

Figure 2. Front Perspective of 14m Roof stage

Testing Equipment

As part of the equipment that was used for the research, we employed the use of wireless nodes. The particular node used was the Microstrain G-Link LXRS. This particular node was used for its ability to measure multiple parameters. These included vibration/acceleration, incline/tilt and for its ability to store real time data to on-board memory as well as transmitting real time data to a host computer device.

Nodes were attached to the structure using a 17 mm timber base plate in between the casing of the node and corner block member. Half couplers were then used to attach the equipment securely to the test member, as shown in Figure 3. A soft-cloth insulation was placed in between the couplers and the member to help reduce any noise that might be picked up by the nodes. A total of 8 nodes were attached to the structure: 4 connected on the top of the structure (one in each corner) and 4 on the bottom of the structure (one in each corner).

Figure 3. Typical Node Connection

A wireless weather station was used to collect all weather information for this project. The key weather data needed was wind speed. This wind speed was measured by using the weather station's cup anemometer. The anemometer was mounted in on the top rear corner of the stage offset by 2m. This offset was used to ensure wind passing over and around the building do not interfere with the readings.

Analysis Software

The numerical results for the structure were obtained using SPACE GASS. The model of the structure was prepared by van der Meer Consulting and was checked for accuracy. The model was found to be sufficient to perform an in-depth dynamic analysis and identify the natural mode shapes. There were slight modifications and refinements made to the model to improve its overall accuracy. Optimal pin connection were used at the base structure, as it does not have enough self-weight to resist overturning as counter weights are used.

The field data collected were analysed through the program MATLAB. Welch Power Spectral Density Estimates were used to analysis the data in MATLAB

Results and Discussion

Computed Results

The SPACE GASS model was used to determine the first 10 natural modes of the structure. The modes and corresponding natural frequencies found are shown in Table 1.

Natural Mode	Natural Frequency (Hz)	Natural Period (Sec)	Tolerance	Iterations
1	1.333	0.75	0.000977	12
2	1.615	0.619	0.000651	12
3	1.872	0.534	0.000789	12
4	6.577	0.152	0.000914	14
5	6.636	0.151	0.000006	21
6	6.998	0.143	0.00081	14
7	7.063	0.142	0.000854	14
8	8.181	0.122	0.000862	14
9	>10.0			

Table 1. Dynamic natural frequencies (Hz, Sec) of the 14m Roof

The results are as expected and the structure does not seem to be behaving erratically. We will be looking closely at the first 3 fundamental modes as the other results are of a single member not the whole structure. The first fundamental mode shape resembles a total global X movement (Figure 4). The second mode shape is a global Z movement (Figure 5), while the 3rd is a twisting action (Figure 6).

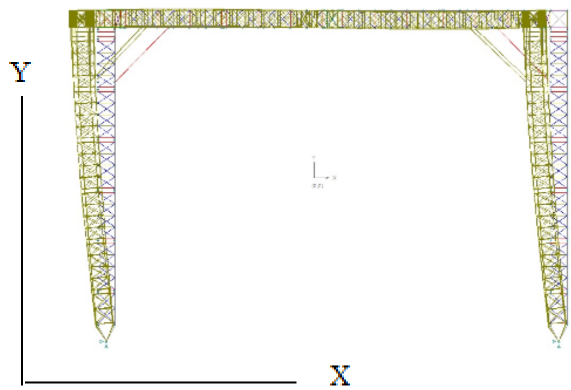

Figure 4. Mode Shape 1

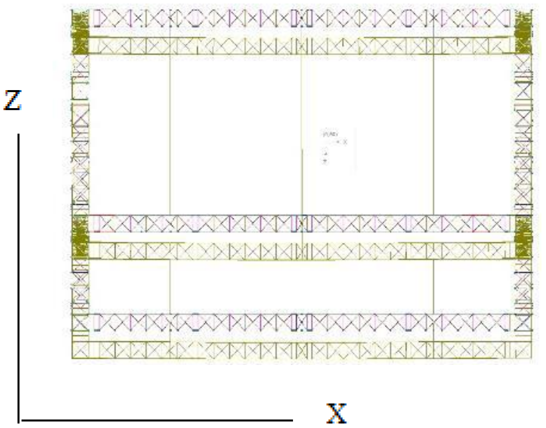

Figure 5. Mode Shape 2

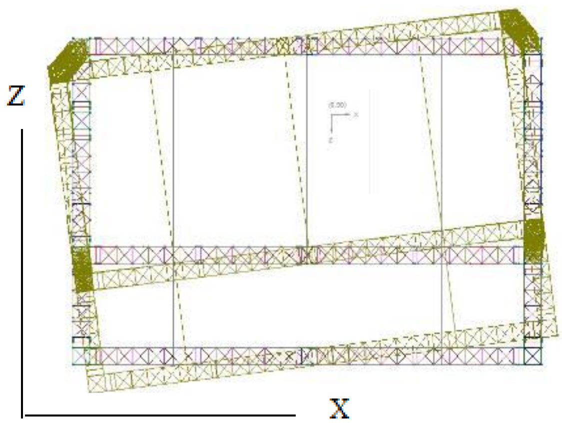

Figure 6. Mode Shape 3

Wind Speed During Tests

The peak wind gust measured during the test period occurred at 17:32 21/02/2014 at a speed of 36.7km/h. The Bureau of Meteorology weather station located at Sydney Olympic Park (Archery Centre) ID: 066212 showed the peak wind gust at 35km/h at 16:11 21/02/2014. The difference in peak times can be attributed to a storm that was in the area at the time of both readings.

Wireless Sensor Data

Data received from the Microstrain nodes sensors was analysed. The 4 nodes attached to the base tower, being so close to the ballast support of the stage, showed little movement. This is evident when trying to find a dominant frequency in the data as no peak is visible in the results. The window of acceleration data chosen to be looked at is 10 minute period, 5 minutes before and after the peak wind guest event from our recorded weather data. The frequencies calculated from the data showed consistent results matching the numerical model.

For the Global Z axis, Figure 7 shows 1.699Hz as the first dominate frequency. This was followed by the next peak which was 1.895Hz vs. 1.872Hz from the model. This represents the twisting action of the structure which showed up in both Global Z and Global X Axis results. Figure 8 also shows correlation between the measured results and computed results. It shows a first dominate peak at 1.236Hz, representing the Global X axis, which agrees reasonably well with the numerical analysis of 1.333Hz with a difference of 7.8%. It is noteworthy that the second peak in Figure 8 is almost identical: 1.855Hz vs. 1.872Hz from which has been shown earlier for the twisting action mode.

A summary of the test results and comparison with the computed results are shown in Table 2.

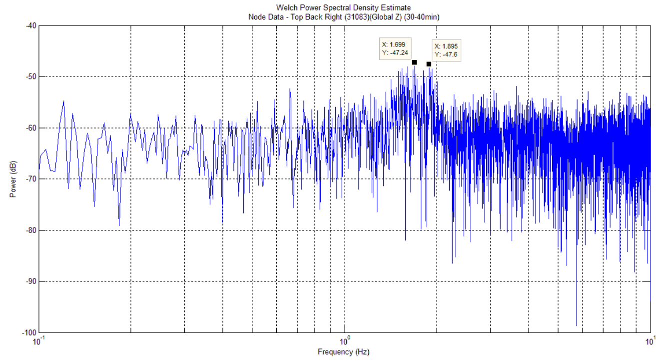

Figure 7. PSD Result Global Z Axis

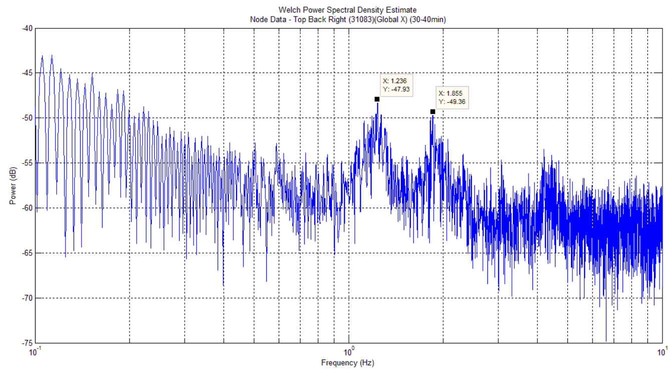

Figure 8. PSD Result Global X Axis

	Numerical Results (Hz)	Tested Results (Hz)
Mode 1	1.333	1.236
Mode 2	1.615	1.699
Mode 3	1.872	1.895, 1.855

Table 2. Results Comparison

Conclusions

Past failures of temporary stage structures were researched and investigated in order to understand why they failed. Evidently, a lack of guidance in national and international design codes contribute to uncertainties in the design and erection of this type of structures, which continue to experience failures during strong wind events.

Wireless sensors were calibrated and used for testing on a temporary stage structure: a 14m Roof. Natural frequencies of the test structure were identified from Power Spectral Density estimates for the field data obtained using MATLAB and these were compared with computed results determined from a numerical model of the structure.

Results from the computer model and field measurements were compared and it was found that overall the computer model results and field measurement results agree reasonably well. The results also show that even though there is a lack of standards for the design of temporary structures, it is possible to achieve a safe design based on reliable finite element modelling to determine the dynamic properties and sound engineering judgements.

Continual research in this area, based on field monitoring and finite element modelling, will achieve a greater understanding of the impact of dynamic loads on temporary structures to prevent stage failures in future.

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