# Monitoring of Wind-Induced Building Motion for Three Wellington Buildings

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## 1 INTRODUCTION

This paper describes the results of monitoring of wind-induced building motion for three buildings in central Wellington during 2009 and 2010. This is part of an ongoing research programme to develop an improved methodology for wind design of buildings. The research is a collaborative programme involving BRANZ, Opus, University of Auckland and GNS [1]. The research has been funded by the Building Research Association of New Zealand.

## 2 DESCRIPTION OF THE BUILDINGS

We refer to the three buildings as Buildings A, B and C, which are named in the order that monitoring commenced. As part of our agreement with the owners of Buildings B and C, we have not named these buildings.

- Building A is the Victoria University of Wellington Student Accommodation Tower Building. It is 10 storeys high. It has a rectangular planform, and has a steel frame structure. Monitoring by GNS has been ongoing since the beginning of 2009.
- Building B is 25 storeys high. It has an approximately square planform, and has a structure consisting of concrete perimeter columns with a central core. It was monitored by Opus during the period from 21 August 2009 to 15 October 2009.
- Building C is 17 storeys high. It has an approximately square planform, and has a concrete structure including a wall on one side, and an offset core adjacent to the concrete wall. It was monitored by Opus during the period from 21 October 2009 to 22 February 2010.

Multiple modes of vibration have been identified for each building through spectral analysis of the motion time histories. The first three modal frequencies for each building are listed in Table 1.

**Table 1. Measured modal frequencies for the three buildings**

| Building | Mode 1 | Mode 2 | Mode 3 |
|---|---|---|---|
| A | 1.42Hz Y (~NS) | 1.56Hz X (~EW) | 2.10Hz Torsion |
| B | 0.54Hz Y (~EW) | 0.55Hz X ( ~NS) | 0.84Hz Torsion |
| C | 0.63Hz X (~NS) | 0.65Hz Y (~EW) | 0.65Hz Torsion |

## 3 INSTRUMENTATION

Building A has been instrumented as a part of the Geonet Building Instrumentation Programme funded by the New Zealand Earthquake Commission (EQC) [2]. This is a long term programme that aims to install earthquake strong motion instruments in up to 30 structures across New Zealand. The authors are grateful to GNS Science who provided the recorded data. Data recording for Building A in 2009 was triggered by motion of the building and was therefore not continuous (continuous recording has commenced in 2010, subsequent to the analysis of the data for this paper). Consequently, it was not possible to analyse the data to the same extent as that for Buildings B and C. There are twelve 3-axis CSI CUSP-M accelerometers installed in Building A, at locations throughout the building. Wind speed and direction are measured with a Vaisala ultrasonic anemometer, mounted approximately at the centre of the roof at a height of 1m above the roof. The recording rate is 200 samples/s.

The instrumentation in Buildings B and C was mounted on the roofs of the buildings. It included two Colibrys Si-Flex 3-axis accelerometers and a Gill WindSonic ultrasonic anemometer. Recording was continuous at a rate of 50 samples/s for Building B. This was reduced to 25 samples/s for Building C in order to allow a 3 week interval between data card changes. The accelerometer equipment is capable of resolving accelerations down to about 0.02mg at the natural frequency of a building of around 0.5Hz. This corresponds to a movement of the building of around 0.02mm. The two accelerometers were mounted at diagonally opposite corners of the roof (NW corner and SE corner), which enabled the X, Y and torsion modes of vibration of the building to be measured. The anemometer was located at a height of 3m above the roof at the NW corner of each building. This location meant that the anemometer was exposed for the common northerly winds, but was sheltered by the building for the less common southerly winds. Only data for northerly winds has been included in the analysis for buildings B and C in this paper.

## 4 DATA ANALYSIS

Table 2 lists a summary of accelerations measured during the single biggest building-motion event for each building. The best quality data set was measured for Building C.

**Table 2. Summary of accelerations measured during the single biggest building-motion event for each building.**

| **Measured** | **Building A** | **Building B** | **Building C** |
|---|---|---|---|
| X direction at center of building (mg) | 2.1 | 1.1 | 1.8 |
| Y direction at center of building (mg) | 3.2 | 2.9 | 3.0 |
| Combined XY at center of building (mg) | 3.3 | 2.9 | 3.6 |
| Deflection at center of building (mm) | | 2.7 | 1.9 |
| Torsion (mg) | 2.3 | 0.7 | 3.6 |
| Corner (mg) | 3.6 | 3.2 | 5.8 |
| Date | 23 May 09 | 26 Aug 09 | 08 Jan 10 |
| Airport mean wind speed (m/s) | 23 | 16 | 14 |
| Airport wind direction | 210 | 300 | 340 |
| **Estimated annual maximum accelerations** | | | |
| Combined XY at center of building (mg) | 4 | 12 | 14 |
| Corner (mg) | 4 | 14 | 23 |

Figure 1 shows a 100s long recording of accelerations measured for one of the biggest acceleration events for Building C. It may be seen that the frequencies are similar for all 3 modes. The biggest acceleration occurs for torsion. Figure 2 shows the building displacement at the center of the building for the central 10s of the same recording. The motion is normal to the wind direction. The 5s prior to the maximum acceleration is shown in black, the 5s after is in red.

For Buildings B and C, we have calculated the correlation between wind speed and acceleration (at the center of the building) for various wind speed measures. These wind speed measures comprised output from the anemometer on the building, and also the wind speed measured at Wellington Airport. The latter is the meteorological anemometer station that we have typically used for comparison with wind events in the city. Table 3 lists the correlation for a power-law best fit for each of the wind speed measures, for Buildings B and C, for all hours when the 1-hour mean wind speed at the building for northerly winds exceeded 7m/s. We have recorded 55 hours of data in this category for Building B, and 535 hours for Building C. The best correlation for both buildings is achieved for the effective wind speed (the average of the 1-hour mean wind speed and the maximum gust speed in the hour). Therefore, the effective wind speed has been used for the subsequent analysis. Surprisingly poor correlation occurred for the wind speed for the 10s prior to the maximum acceleration, particularly for building C. On occasions, the biggest accelerations occurred during an apparent lull between gusts. It is possible that this is partly due to the less than ideal location of the anemometer on the building. The correlation with the airport wind speed data is also poor, which shows that it is essential to have on-site wind speed measurement available to do this analysis.

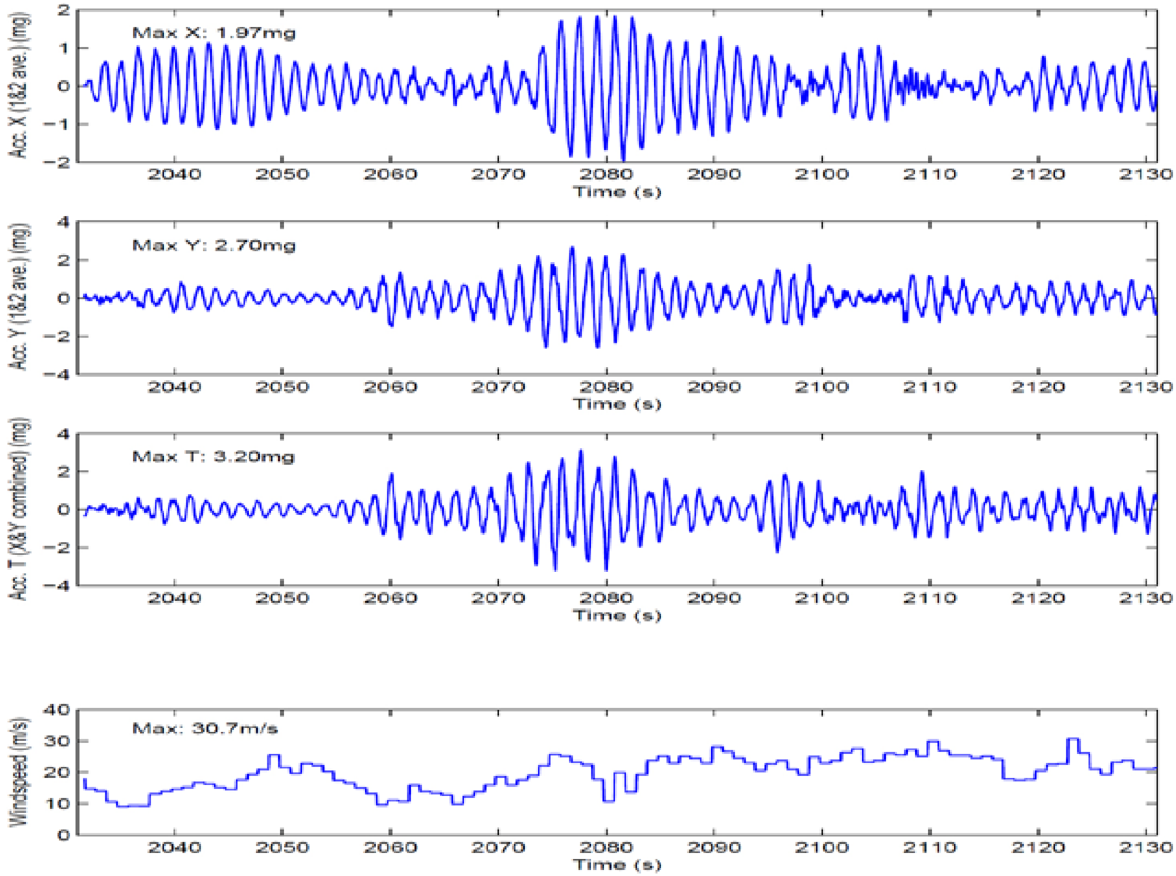


**Figure 1. Building C. Accelerations recorded 13 Feb 2010 10:45am**
**(X at building center, Y at building center, Torsion, Windspeed on roof)**

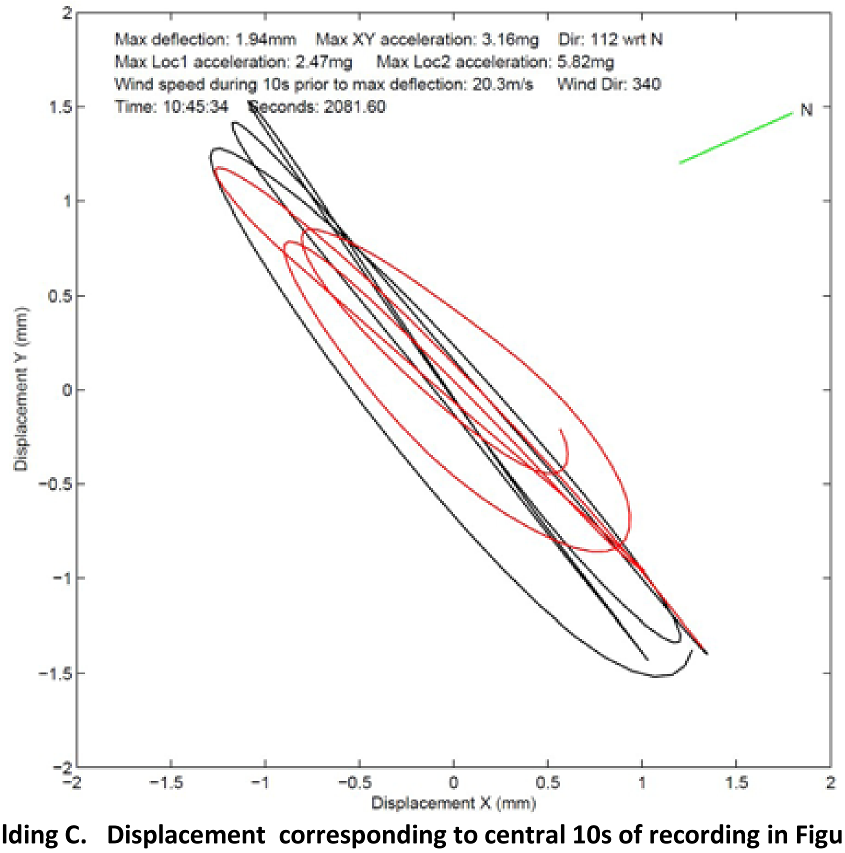


**Figure 2. Building C. Displacement corresponding to central 10s of recording in Figure 1**

**Table 3. Correlation for power-law best fit of measured acceleration vs wind speed, for various wind speed measures (All northerly wind data with Vmean 1hour >7m/s)**

| Wind Speed Measure | $R^2$ Building B | $R^2$ Building C |
|---|---|---|
| The mean wind speed at the building for the whole hour | 0.71 | 0.74 |
| The maximum wind speed during the hour | 0.76 | 0.82 |
| The effective wind speed (av. of 1-hour mean & maximum gust) | 0.78 | 0.86 |
| The mean wind speed over the 100-second period centered on the occurrence of the maximum acceleration | 0.56 | 0.65 |
| The mean wind speed over the 10-second period immediately preceeding the occurrence of the maximum acceleration | 0.61 | 0.32 |
| Mean wind speed at Wellington Airport averaged over 1 hour. | | 0.20 |
| Maximum wind speed at Wellington Airport . | | 0.49 |

The plot in Figure 3 shows a good correlation between wind speed and acceleration. However the best fit line is a little low for high accelerations. The data was further analysed by averaging the measured accelerations within 0.4mg wide bands up to 2.0mg and averaging all the data above 2.0mg. The resulting plot is shown in Figure 4. There is a very good power-law fit to the measured data. The exponent of the power-law fit calculated for the two buildings is 2.89 for Building B, and 3.10 for Building C.

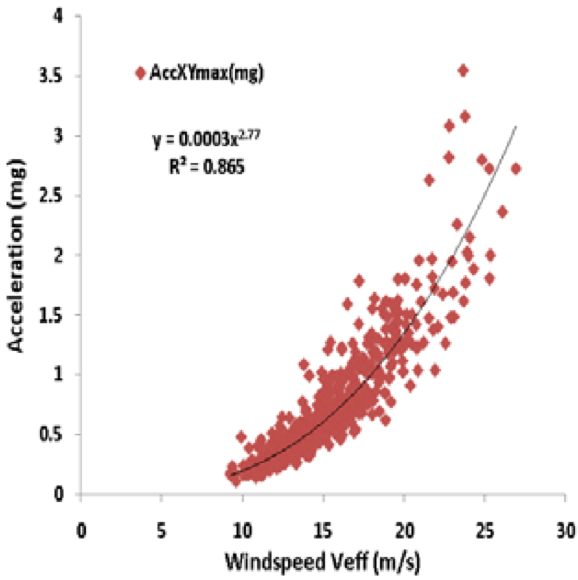


**Figure 3. Building C. Relationship between wind speed and acceleration. Northerly winds, Vmean > 7m/s.**

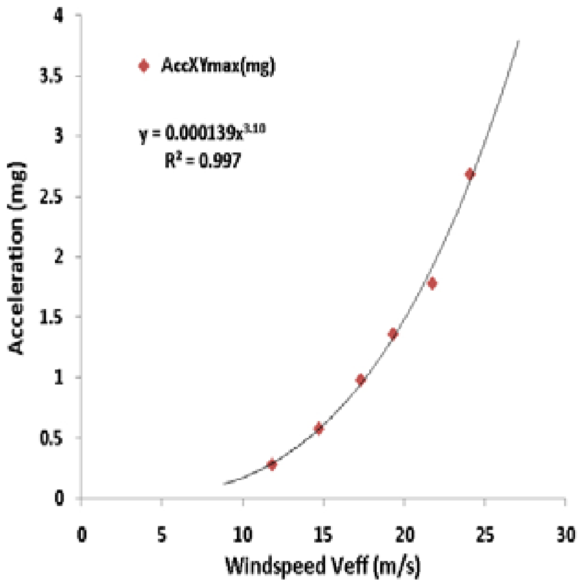


**Figure 4. Building C. Data averaged in acceleration bands.**

## 5 CONCLUSIONS

We have examined the relationship between wind speed and acceleration for two buildings. The accelerations are approximately proportional to the cube of the wind speed for both buildings. This demonstrates that accurate estimation of the wind speed is critical for accurate design predictions of wind-induced building motion.

## 6 REFERENCES


[1] Carpenter P & Cenek PD (2008). "Research programme: improved prediction of wind induced building motion", AWES13, Hobart, Australia, 4-5 Dec, 2008

[2] SR Uma, Cousins WJ, and Young, J. 2010. "Seismic instrumentation in Victoria University Wellington - Student Accommodation Building", GNS Science Report 2010/30.