The influence of environmental conditions on instrumented building recordings

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ABSTRACT: Structural health monitoring (SHM) is a practical application of continuously recorded data from instrumented buildings. Past research has shown that environmental conditions such as temperature variation, humidity, wind, time of day and human activity can greatly affect the data and thus its usefulness of the data for subsequent analyses. This study analysed a year's worth of instrumented building data from a building in the GNS building instrumentation programme, to quantitatively establish the influence of different environmental conditions to raw building motion (namely building acceleration amplitudes), as a precursor to understanding their effects on building characteristics predictions. The results indicate that there is no general correlation between mean building acceleration amplitudes with temperature and humidity variations. For the wind speed, there is a large amplitude fluctuation at low wind speed and that both the range and mean amplitude steadily decrease as wind speed increases. Furthermore, human activity significantly alters the nature of the recorded acceleration.

1 INTRODUCTION

Structural Health Monitoring (SHM) continuously monitors the condition of structures by tracking their dynamic characteristics. This is typically achieved by continuously recording the structural vibrations using accelerometers and conducting analyses tracking any changes in the dynamic characteristics, such as changes in natural frequencies, mode shapes and modal damping. This information is then used to infer and locate possible damage in structures (Şafak, Çaktı and Kaya, 2010).

System identification is widely used to track changes in dynamic characteristics (Peeters and De Roeck, 2001; Pintelon and Schoukens, 2012). Since extreme events occur in frequently, most of the data collected by a SHM system are the vibrations caused by ambient sources, such as traffic loads, wind, microtremors and their combination. For most operational cases, only response data are measurable while actual loading conditions are rarely known. A system identification procedure will therefore need to base itself on output-only data (De Roeck, Peeters and Ren, 2000). Modal analyses that utilise only response measurements are termed operational modal analysis.

This study analysed a year's worth of instrumented building data from a building in the GeoNet building instrumentation programme (Uma, King Cousins and Gledhill, 2013), to quantitatively establish the influence of different environmental conditions on the application of SHM. This paper focuses on the effects on raw building acceleration amplitudes, as a precursor of a companion study investigating the effects on downstream modal and damage predictions.

2 PAST STUDIES

Ambient vibration measurements have been successfully applied to extract modal parameters of many structures.Notable examples include the analyses on the Transamerica Building in San Francisco (Celebi, 2013), Millikan Library on the Caltech campus (Clinton et. al, 2006) and the Engineering Building at the University of Auckland (Beskhyroun, Wotherspoon and Ma, 2013). Commercial and research software packages exist to assist with the numerical system identification calculation. Well known proprietary packages include ARTeMIS (Structural Vibration Solution, 2013) or the freely available System Identification Toolbox (SIT) developed by Beskhyroun (2011).

Output-only system identification techniques can be divided into time domain techniques or frequency domain techniques. Common time domain techniques includes instrumental variable (IV) method (Ljung, 1999), covariance-driven stochastic subspace identification (SSI-COV) (Juang and Pappa, 1985), random decrement (RD) technique (Asmussen, 1997; Ibrahim, 1977; Ibrahim, Asmussen and Brincker, 1998), data-driven stochastic subspace identification (SSI-DATA) (Van Overschee and De Moor, 1996) and prediction error methods (PEM) (Ljung, 1999).

Common frequency domain techniques includes peak picking (PP) method (Bendat and Piersol, 1993), complex mode indication function (CMIF) using eigenvalue decomposition or Singular Value Decomposition (SVD) (Prevosto, 1982), maximum likelihood (ML) identification (Pintelon et al., 1994; Schoukens and Pintelon, 1991) and spectrum-driven stochastic subspace identification (Van Overschee et al., 1997). A comparison of these techniques is listed in Table 1.

Table 1. Comparison of Output-Only System Identification Methods

Methods		IV	SSI-COV	SSI-DATA	PEM	PP	CMIF	ML
Natural Frequencies	Availability	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Accuracy	Good	Good	Good	Poor	Depends	Depends	Depends
	Sensitivity	Low	Low	Low	High	High	High	High
DampingRatios	Availability	Yes	Yes	Yes	Yes	No	No	Yes
	Accuracy	Good	Good	Good	Poor	-	-	Depends
	Sensitivity	Low	Low	Low	High	High	High	High
Mode shapes	Availability	Yes	Yes	Yes	Yes	No	Yes	Yes
	Accuracy	Depends	Good	Good	Poor	-	Depends	Depends
	Sensitivity	Low	Low	Low	High	High	High	High
Computation time		Fast	Fast	Slow	Very Slow	Very Fast	Fast	Slow

During the service period of a structure, the time-varying environmental conditions can alter a system's dynamic properties (Sohn, 2007). Furthermore, environmental conditions can be regarded as noise to system identification analyses and resulting in perceived change in system dynamic properties predictions. The experimental study by Sohn et al. (1999) highlighted that the first three natural frequencies of the Alamosa Canyon Bridge varied 4.7%, 6.6% and 5.0% respectively during a 24 hour period when the temperature of the bridge deck was varied by 22 ^{o}C. Other similar examples include the studies by Nayeri et al. (2008), Yuen and Kuok (2010), Fujino et al. (2000) and Mikael et al. (2013).These studies highlighted strong correlations between frequency (actual or perceived) and temperature. Consequently, quantifying the actual and perceived influence of environment effects are significant to the development of any structural health monitoring applications.

3 CASE STUDY – DATA FROM THE GNS SCIENCE BUILDING, AVALON

3.1 Building instrumentation

This study makes use of instrumented building data from the GNS Science main office buildings at Avalon, New Zealand. The GNS Avalon offices consist of two separate buildings, Unit 1 and Unit 2.The buildings are occupied by approximately 300 staff. A paper by Uma, Cousins and Baguley (2010) provides a comprehensive summary for the seismic instrumentation.

This building was instrumented as a part of GeoNet Building Instrumentation programme funded by the Earthquake Commission (EQC). The instrumentation consisted of ten tri-axial accelerometers including a free field sensor. These sensors are distributed over the two units, both are low-rise reinforced concrete two-way moment resisting frame building built prior to 1976. The instrumentation utilised CUSP-M sensors produced by Canterbury Seismic Instruments Ltd and a central data logger unit. The CUSP-M sensors are distributed at various levels of the buildings as shown in Fig. 1. A GPS receiver is located at the roof level of one of the building and it provides accurate timing with 1ms precision.

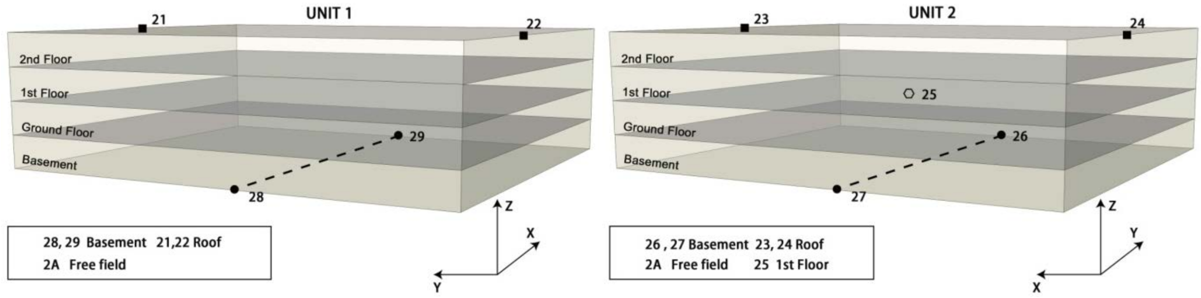


Figure 1.Accelerometer locations of GNS Science Building (Source: Uma, Cousins and Baguley (2010))

3.2 Information about the data and the data analysis

This study focused on the correlating the GNS Science Unit 1 building response with different environmental conditions. The varying conditions studied include temperature, humidity, wind speed, time of day and level of building activity. Hourly temperature, humidity and wind speed data were acquired from the closest available station WallacevilleEws from National Institute of Water and Atmospheric Research (NIWA) (www.niwa.co.nz). Acceleration data were taken from GeoNET database as SAC files. The sampling rate of acceleration data was 50 Hz. A 10th-order bandpass filter with a lower cutoff frequency of 0.4 Hz and a higher cutoff frequency of 21 Hz was used to reduce the signal noise. The analysis covered a period from 1/1/2013 to 31/12/2013.

During this period, a total 8734 earthquakes occurred in the Wellington Region. Among these, there were 23 earthquakes were over magnitude 5.0 that produced moderate ground shaking at the site. In order to focus on the effects of the relatively small varying environmental conditions on the building, data from July to September 2013 containing strong ground motion (approximate duration of the Seddon earthquake sequence) were excluded. This paper only presents the environmental conditions effect on the acceleration amplitude, the effect on the modal properties (frequency, damping ratios and etc.) will be presented in a companion study.

4 ENVIRONMENTAL EFFECTS ON THE AMPLITUDE OF ACCELERATION

4.1 Processing of data

Results presented in this study unless specifically specified are absolute acceleration values in the horizontal plane. Acceleration data were collated on an hourly and daily basis. Minimum, mean, root mean square and maximum calculated correspondingly for these periods. A moving average with a one-day window size was applied to the yearly analyses to smooth the data and to remove erratic data. A ‘day’ period of 8am to 8pm and a ‘night’ period of 8pm to 8am were defined to isolate periods with and without human activity. The 2013 ‘night’ accelerations from sensor 21 in Unit 1 are shown in Figure 2.

4.2 The effect of temperature on the acceleration amplitudes

Figure 3 shows the mean amplitude distributions plotted against different temperatures. Roof acceleration data is the resultant of two horizontal components. No obvious correlation can be observed. Figure 4 plots the hourly minimum, mean and maximum acceleration amplitude as a box and whiskers plot as a function of temperatures. Again, no correlation can be concluded from the figure.

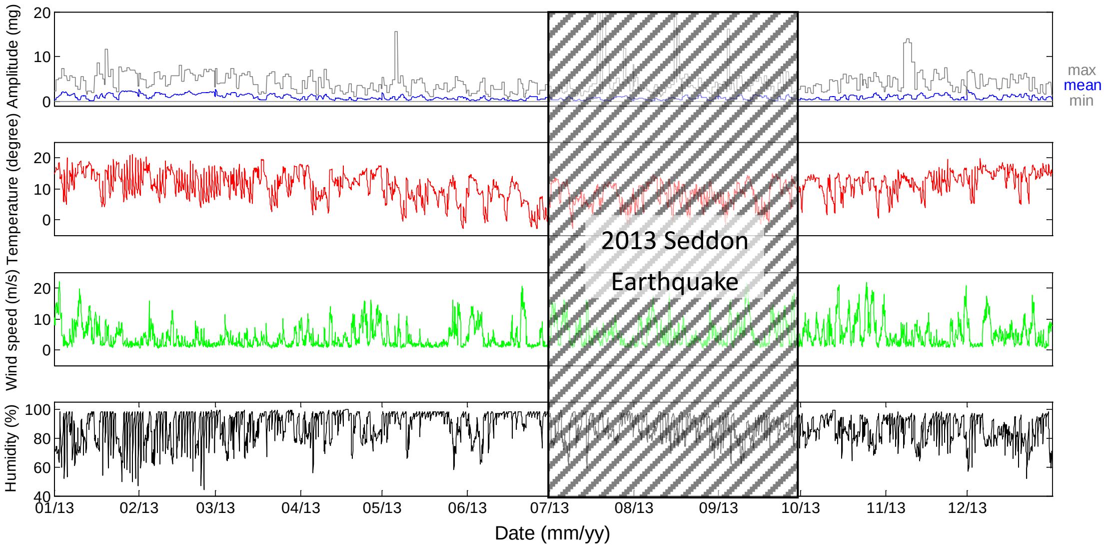


Figure 2.Unit 1roof acceleration (sensor 21) in 2013

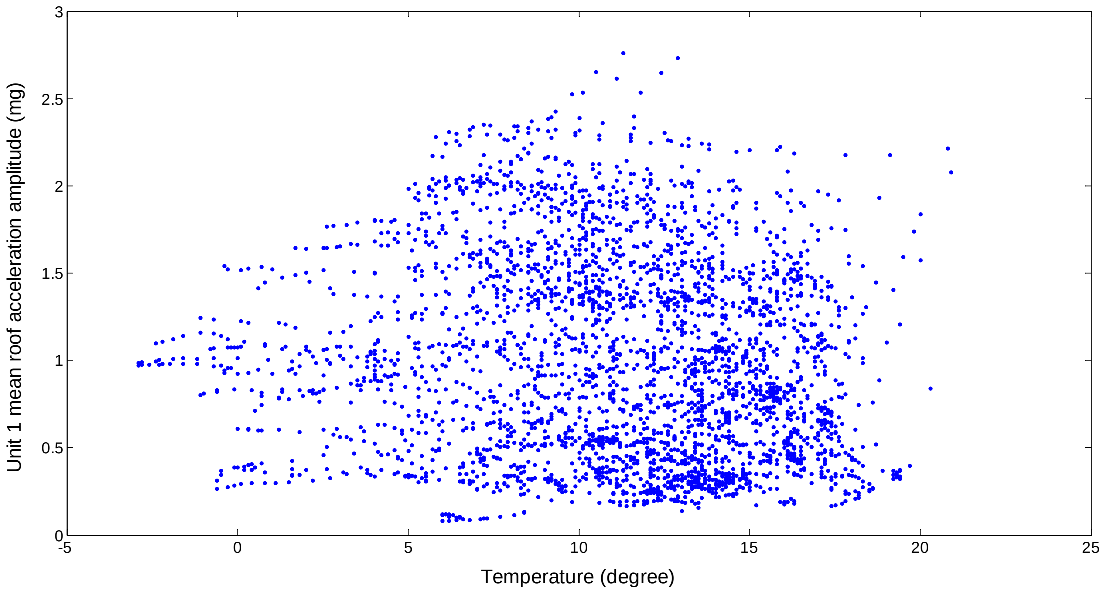


Figure 3.Unit 1 mean roof acceleration as a function of temperature

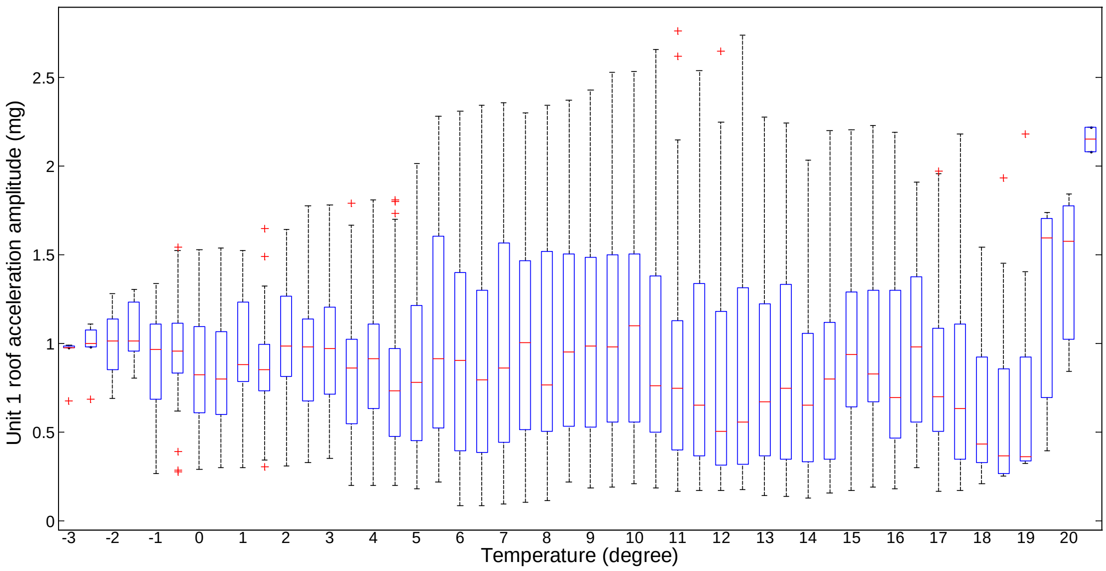


Figure 4.Box and whiskers plot of Unit 1 roof hourly acceleration amplitude as a function of temperature

4.3 The effect of wind speed on the acceleration amplitude

Figure 5 shows the mean hourly acceleration amplitudes plotted against wind speeds. The data is also plotted in Figure 6 as a box and whiskers plot highlighting the minimum, mean and maximum of the hourly data. It is apparent that there is a large amplitude fluctuation at low wind speed and that both the range and mean amplitude steadily decrease as wind speed increases.

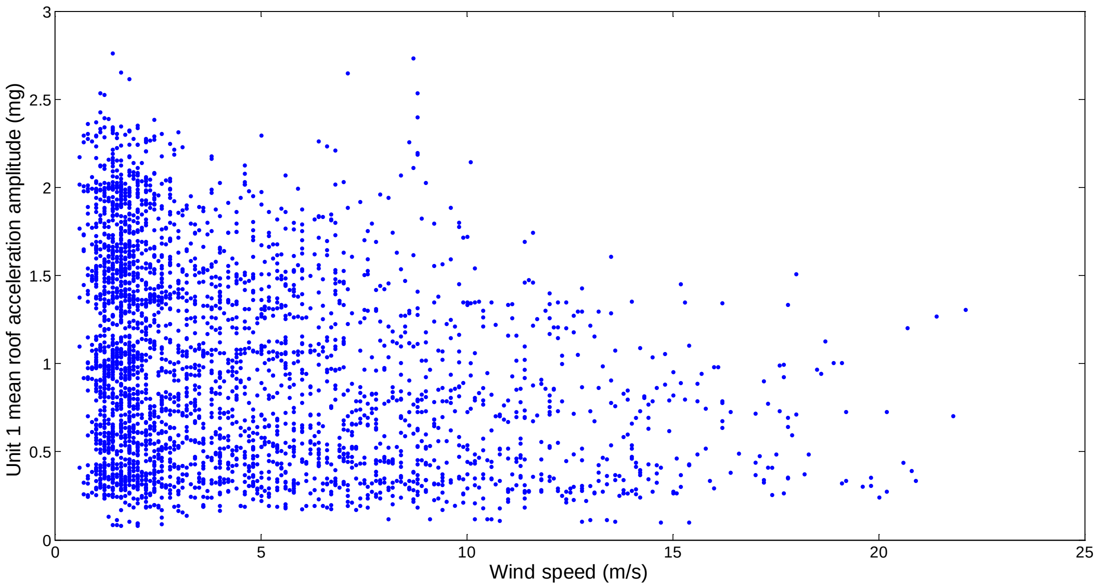


Figure 5.Unit 1 mean roof acceleration as a function of wind speed

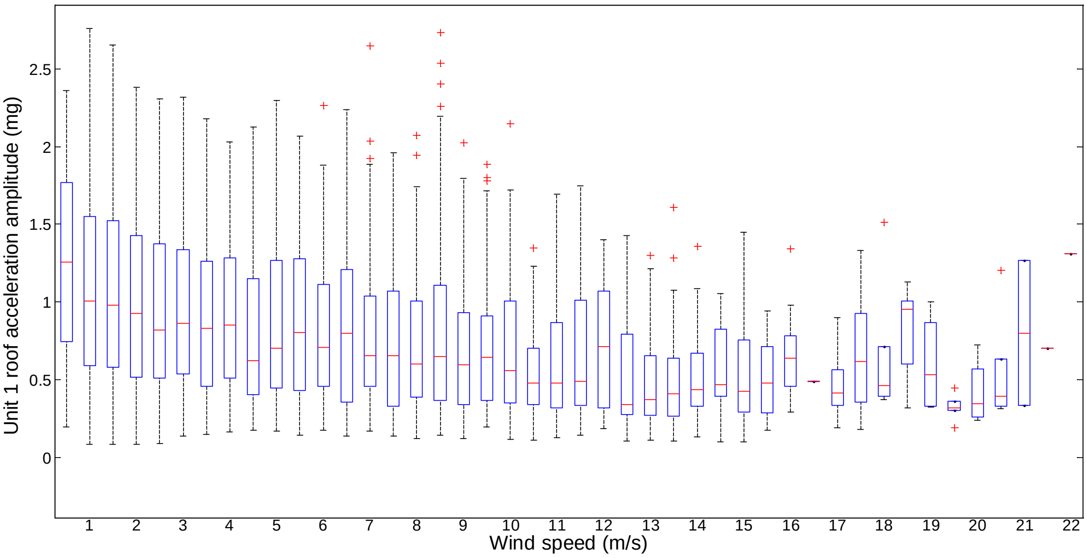


Figure 6.Box and whiskers plot of Unit 1 roof hourly acceleration amplitude as a function of wind speed

4.4 The effect of relative humidity on the acceleration amplitude

Figure 7 shows the mean amplitude distributions plotted against relative humidity. No obvious correlation can be observed. Further Figure 8 plots the hourly minimum, mean and maximum acceleration amplitude as a box and whiskers plot as a function of relative humidity. Again, no correlation can be concluded from the figure.

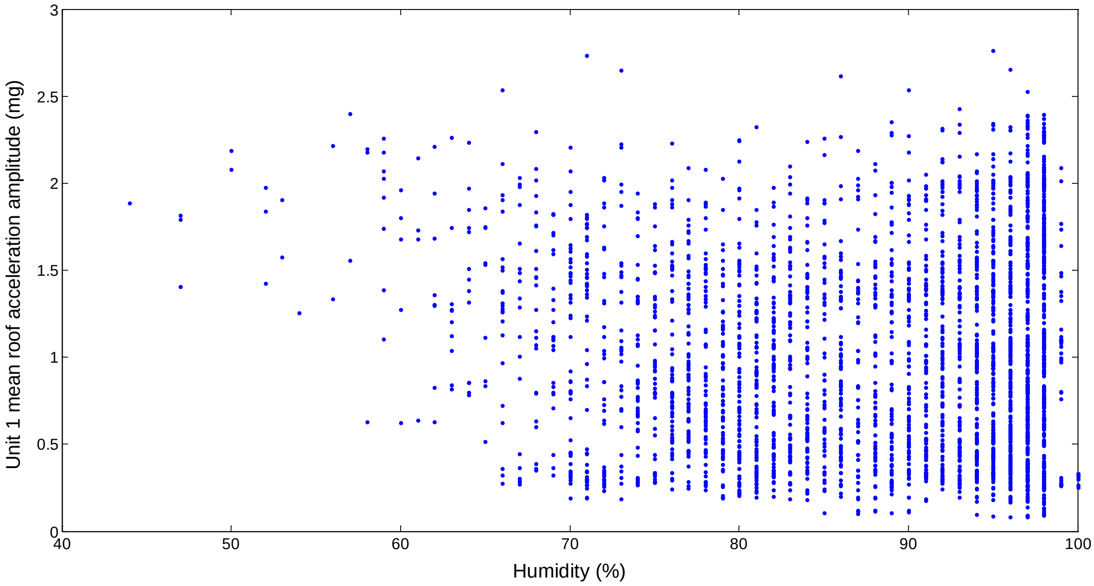


Figure 7.Unit 1 mean roof acceleration as a function of relative humidity

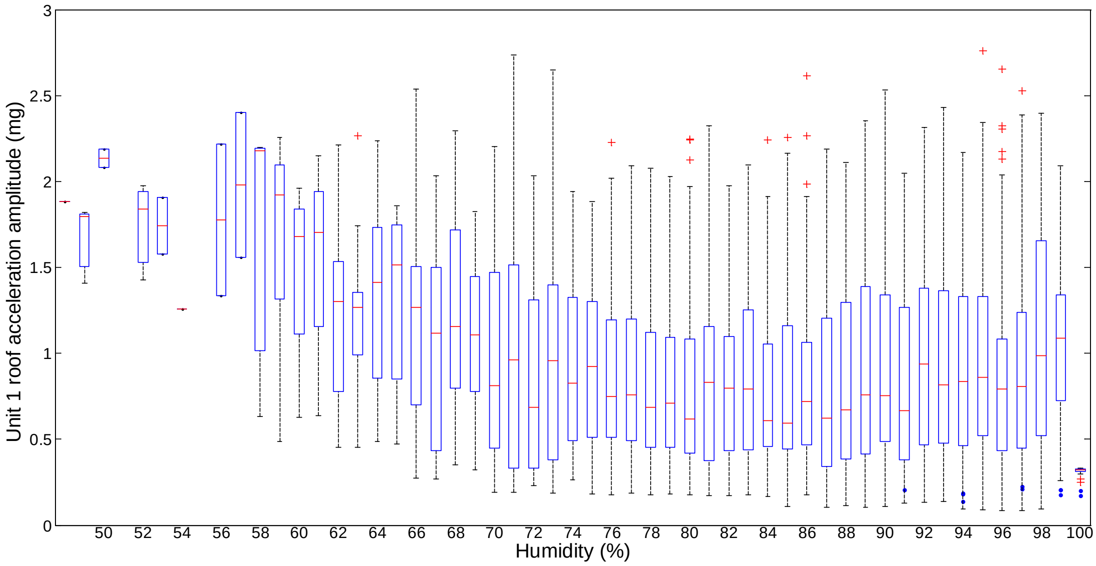
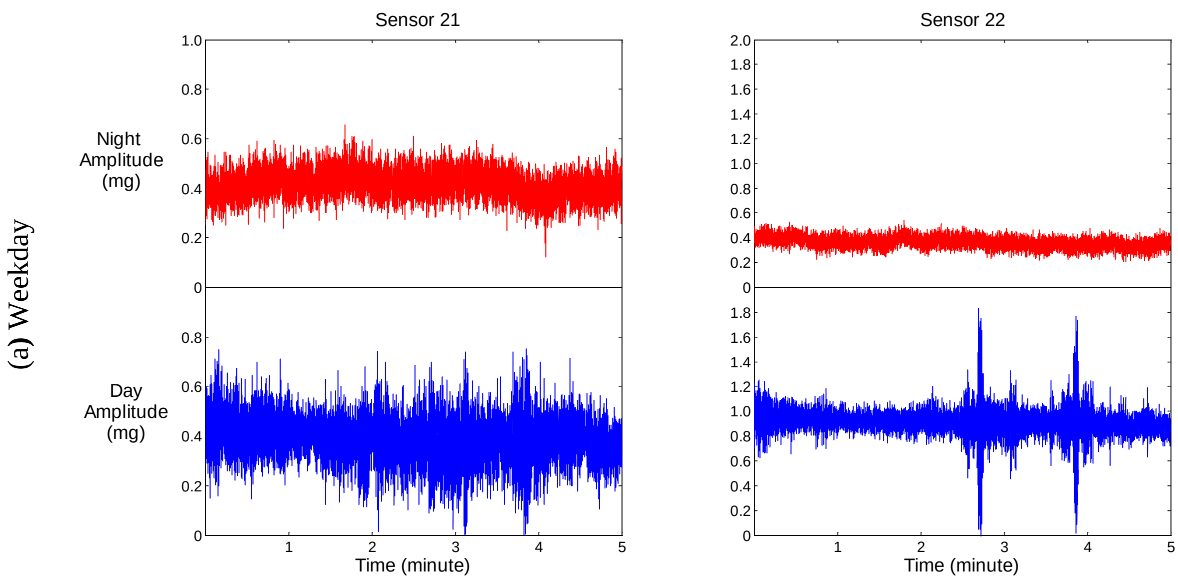


Figure 8.Box and whiskers plot of Unit 1 roof hourly acceleration against relative humidity

4.5 The effect of human activity on the acceleration amplitude

Figure 9 depicts the time history of raw roof acceleration for a 5 minute interval beginning from 12 noon and 2 am, during a weekday and during weekend for both Unit 1 and Unit 2. This figure clearly highlights that human activity significantly alters the nature of the recorded acceleration, both in terms of amplitudes and frequency content. Specifically, in the night data, a constant level of fluctuation similar to a uniform white noise is evident. In contrast, the day signal during weekdays has spikes, pulses and others possibly periodic contaminations. To quantify the differences in a statistical sense, daily ‘night’ and ‘day’ minimum, mean and maximum are plotted against each other in Figure 10. This highlights that for the data considered, 96.3% of the ‘day’ maximum are similar to the night maximum. 69.2% of the ‘nightly’ minimum is less than the ‘day’ minimum, suggesting that there is generally a greater background activity during the day. Lastly, the mean data shows that 64.8% of the times, the average ‘day’ activity is higher than the night activity, this evidence can be further enhanced by removing the data included weekends and holidays.



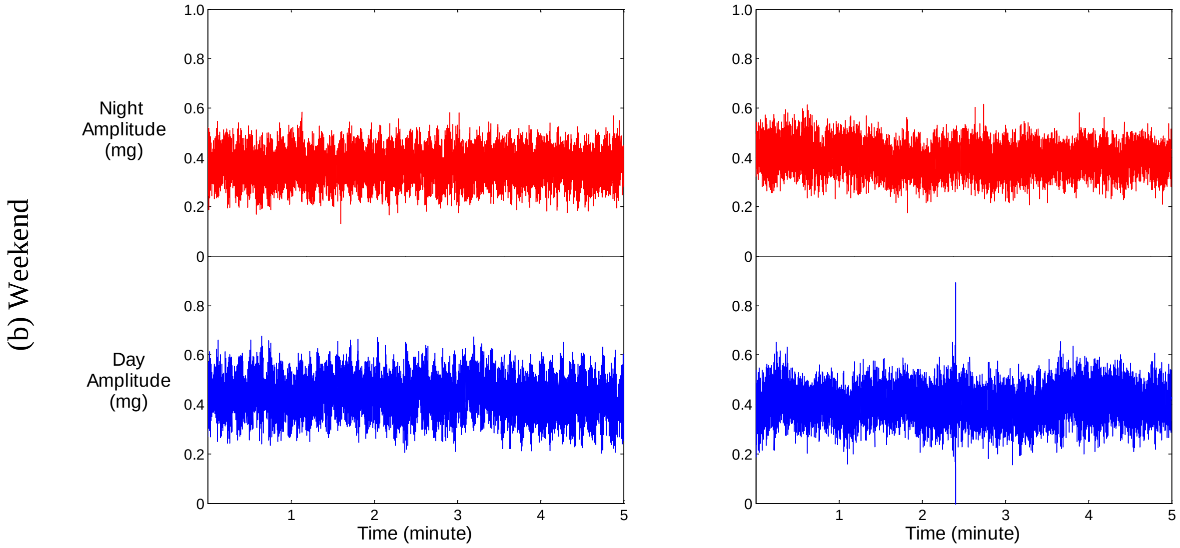


Figure 9.Comparison of Night Amplitude and Day Amplitude of Unit 1 mean roof acceleration amplitude

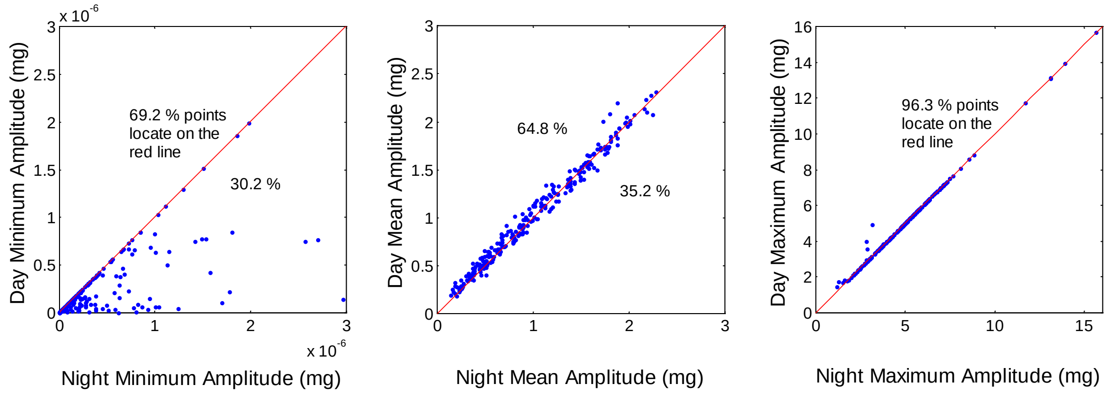


Figure 10.Daily 'Day' acceleration amplitudes against daily 'Night acceleration amplitudes

5 CONCLUSION

This study presents the environmental conditions on the acceleration amplitude of the GNS Science Building Unit 1 using ambient vibration data. The results show no general correlation existed in the acceleration amplitude change under the changing temperature and humidity. For the wind speed, there is a large amplitude fluctuation at low wind speed and that both the range and mean amplitude steadily decrease as wind speed increases. Furthermore, human activity significantly alters the nature of the recorded acceleration. The presented results provide good reference for further the companion study on the effect on the modal properties (frequency, damping ratios and etc.).

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