 

Ambient Vibration Testing of the Yoker CLT Building

Author:
Thomas Reynolds

September 16, 2019

THE UNIVERSITY *of* EDINBURGH
School of Engineering

1 Introduction

The Yoker CLT (cross-laminated timber) building is a seven-storey building in the Yoker area of Glasgow. It is constructed entirely from cross-laminated timber panels connected by screwed angle brackets between wall and floor panels and fully-threaded screws between adjacent panels. It is located approximately 150m from the north bank of the Clyde river. It is tall compared with the buildings around it.

These tests were carried out on the 9th June 2017 (Day 1) and 5th January 2018 (Day 2). On Day 1, the CLT superstructure was almost complete, with scaffolding fixed to the building on all sides. Internal plasterboard lining had not been fixed, but was stacked on the levels where it was to be fixed. On Day 2, the external cladding was nearing completion, with some panels remaining to be fixed on the upper two storeys. The internal plasterboard lining was complete in all apartments, and most were complete save for decoration and unfurnished.

2 Wind Conditions

On Day 1, there were light north-westerly winds, shown by the upper wind rose in Figure 1. On day two, the winds were very light, ranging from north westerly to north easterly. These charts are based on data from a weather station in Renfrew, immediately across the river and the wind roses show the number of occasions during the 24 hour period in which the 10-minute mean wind speed exceeded the given speed. The light winds during both tests would not have approached the wind speeds used in serviceability calculations, and so the measured building parameters would be expected to change at the higher wind speeds. Higher wind speeds, and higher amplitudes of movement generally result in higher damping and slightly lower natural frequency.

3 Measurement

The vibration of the building under ambient wind conditions was measured using a pair of high-sensitivity PCB Model 393B12 piezoelectric accelerometers. These accelerometers have peizoelectric crystals in them which generate

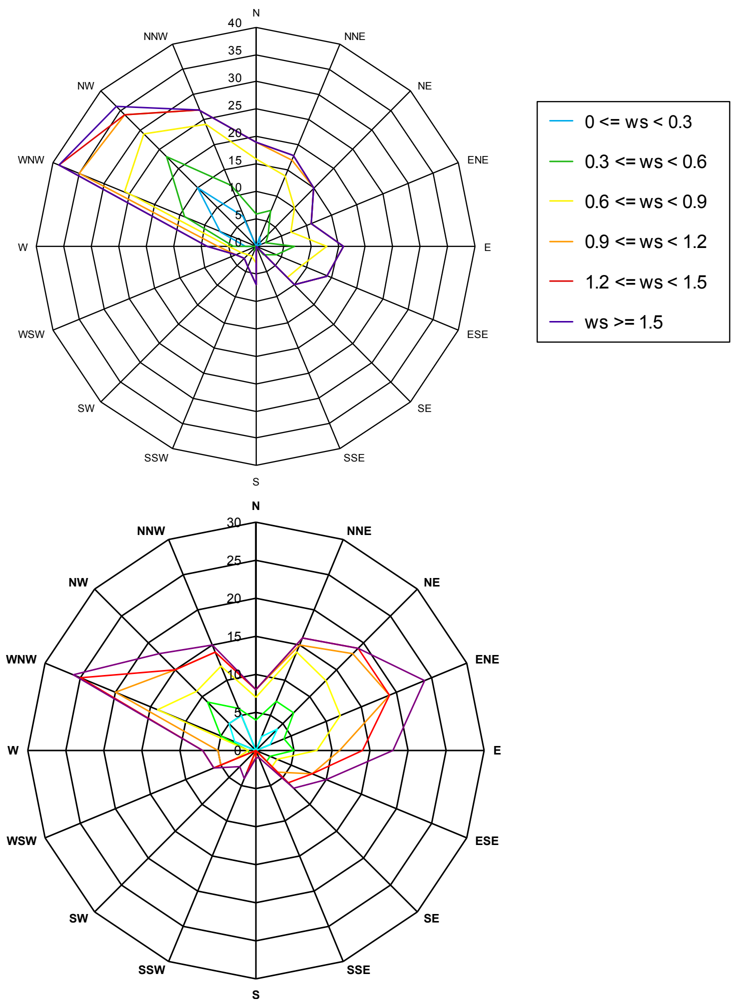

Figure 1: Wind rose for Renfrew 9th June 2017 (top) and 5th January 2018 (bottom) - wind speeds in m/s

a voltage in response to the inertia force they are subjected to, thus measuring acceleration.

On Day 1, they were placed at the location shown in Figure 2. The accelerometers were mounted on a steel block so that they measured acceleration at right-angles to one another. A smaller, slightly less sensitive accelerometer on top of the other two measured the vertical component of acceleration in order to discount any vertical component of movement in the analysis of wind-induced lateral vibration. The accelerometers were left in place for approximately 1 hour between 2pm and 3pm, during which time there was relatively little work proceeding on site. Drills were being used to connect adjacent panels on the roof, and people occasionally walked past the accelerometer location getting to and from the roof.

On Day 2, four accelerometers were used to capture the mode shapes of the building as well as the natural frequencies and damping ratios. The first test placed accelerometers at the same location as the Day 1 test. The second pair of accelerometers was moved around the top floor of the building, measuring the movement of each point relative to the reference location shown in Figure 2. The reference accelerometers were therefore in place for approximately 3 hours, with the other accelerometers at each location for a half hour period.

4 Analysis

The random decrement method was used to take the measured movement of the building in the ambient wind and to use it to estimate the signature of the building response. Figure 3 shows the process of the random decrement technique: a pair of trigger levels is imposed on the time-history of acceleration. Along the time-history, every point between the two trigger levels is used as the start of a sample of a certain length; in this case, the length is two seconds. These samples may overlap, as is the case for Sample 1 and Sample 2 in Figure 3. The hour of data measured at Yoker CLT resulted in several thousand samples.

The samples are then averaged, resulting in a random decrement signature for that time history, which represents the expected movement of the building given an initial acceleration between the trigger levels. The dynamic component of force applied to the building by the wind is random and has a mean value of zero, so the expected movement corresponds to the building

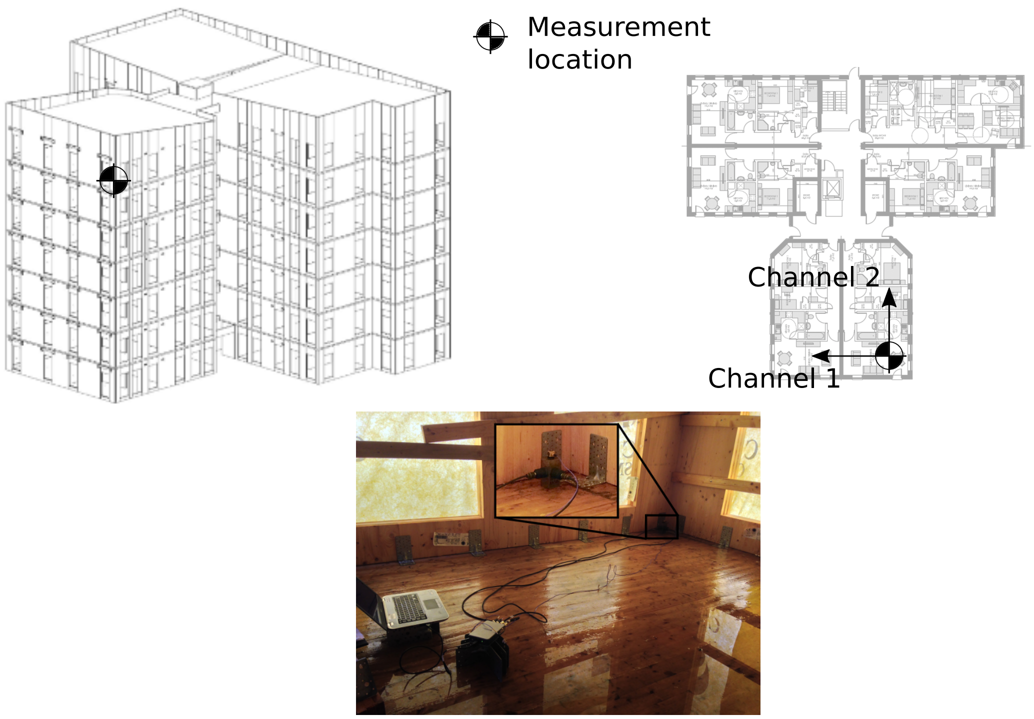

Figure 2: Placement of accelerometers in the building

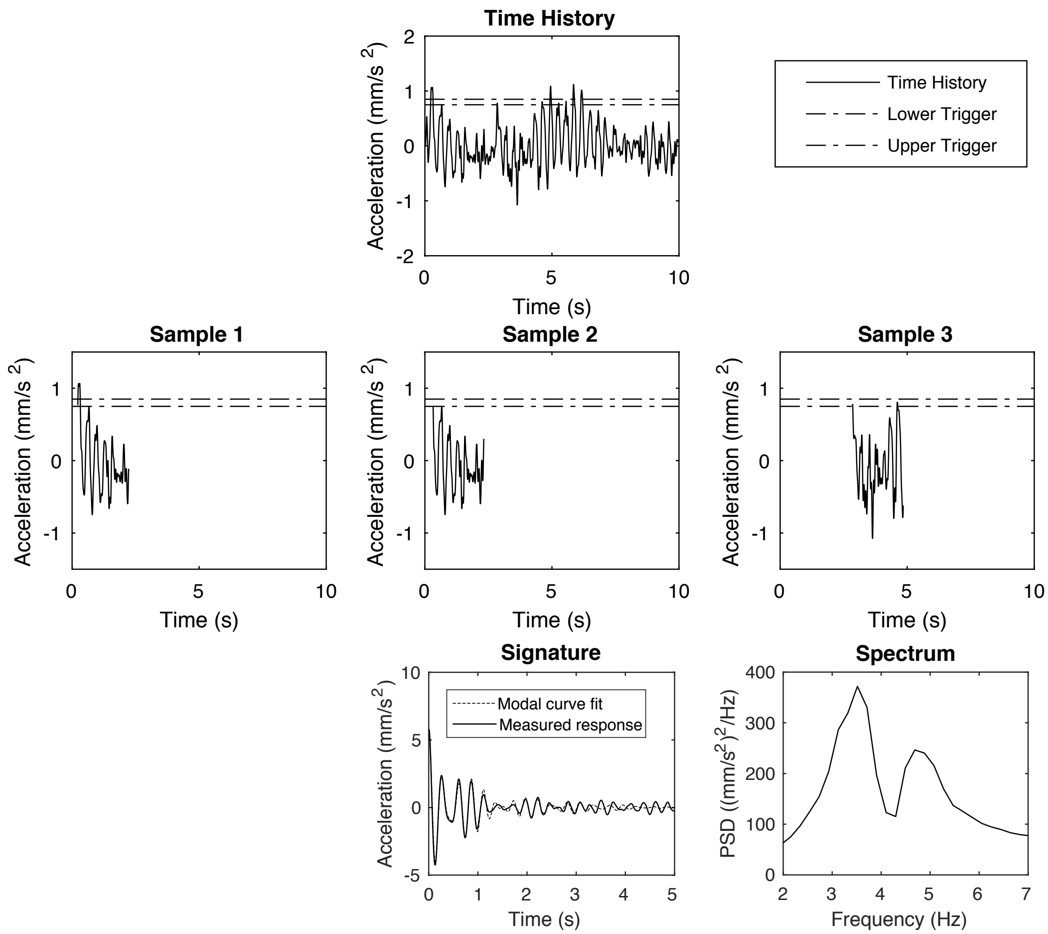

Figure 3: The process of the random decrement method.

oscillating with zero force applied to it. The result is a sinusoidal signal that decays towards zero as shown in the Signature in Figure 3. If samples are taken from the other channel at the same times as the first and averaged in the same way, then corresponding signature are found for each of those channels. These correlated signatures allow calculation of the direction of movement in each mode. If we were to carry out the same measurement at points all round the building, we could draw mode shapes for the building, and more fully understand how it is moving in each mode of vibration.

The spectrum at the bottom right of Figure 3 shows a peak at around 3.5Hz, and one at a little under 5Hz. Modal analysis was carried out by

	Frequency	Damping	Peak Trigger	Direction
Day 1				
Mode I	3.38 Hz	6.0% to 8.0% *	4mm/s^2	Channel 2
Mode II	3.57 Hz	2.0% to 4.5%	6mm/s^2	Channel 1
Mode III	4.66 Hz	4.0% to 4.5%	7mm/s^2	Between 1 & 2
Day 2				
Mode I	3.05 Hz	3.0% to 4.0%	4mm/s^2	Channel 2
Mode II	3.10 Hz	3.0% to 4.5%	6mm/s^2	Channel 1
Mode III	4.10 Hz	2.0% to 2.5%	5mm/s^2	Between 1 & 2

Table 1: Measured modal parameters (* downward trend of damping with amplitude)

curve-fitting the random decrement signature. The curve fit is plotted with the signature in Figure 3. Only one second of the signature is used for this curve fitting, since the start of the signal is most accurately determined by the averaging process, and three complete periods of vibration are sufficient for analysis. Each channel can be used separately for the triggering process described here.

4.1 Day 1 Analysis

The analysis for Day 1 suggests that there are, in fact, two modes of vibration near 3.5Hz: one at 3.38Hz in the direction of channel 2, and one at 3.57Hz in the direction of channel 1, as shown in Table 1. This is confirmed by a separate analysis using Stochastic Subspace Identification. The other frequency at 4.66Hz is detected clearly and at similar amplitude in both channels, and so appears to be a torsional mode.

4.2 Day 2 Analysis

All three modes had reduced in frequency in the later analysis on Day 2, showing that any stiffening effect of the non-structural elements attached to the structure was outweighed by their additional mass. The damping ratios were either similar or reduced. In the case of Mode I, the damping ratio measured on Day 2 was substantially lower than on Day 1. This is likely to be due to the more detailed measurements taken on Day 2 giving a more accurate estimate for this mode.

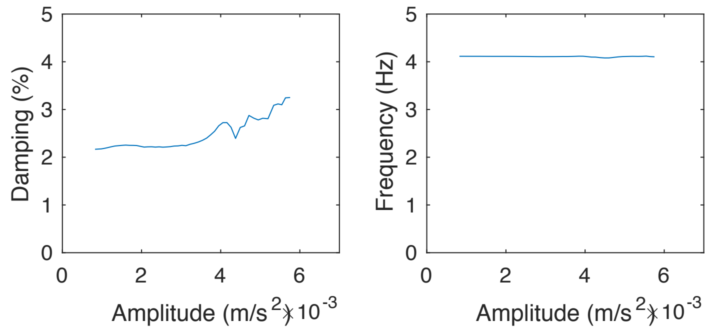

Figure 4: Variation of natural frequency and damping ratio with amplitude for Mode III on Day 2.

4.3 Amplitude of acceleration

The 'Peak trigger' column in Table 1 indicates the highest trigger level (see Figure 3) for which an apparently reliable damping ratio was obtained. It should be noted that these accelerations are far below the 70mm/s^2 given as acceptable by ISO 10137 for this frequency. This is to be expected, because the wind speeds are far below the serviceability limit state speeds. The damping ratio may therefore be different at the higher amplitude at the serviceability limit state, and it would generally be expected to be higher.

The amplitude of movement of the building varies constantly throughout each test, which allows an analysis of the variation of damping and frequency with amplitude. Figure 4 shows that variation for Mode III on Day 2, and indicates the substantial change in damping and subtle change in frequency.

5 Conclusions and Further Work

The initial, Day 1, measurements described here give stable estimates of three modes of vibration of the building in its unclad state. The analysis was complicated by the presence of two very closely-spaced modes at around 3.5Hz. A more sophisticated set of measurements, with more accelerometers, was carried out on Day 2 on the fully clad building, and confirmed the presence of the two modes, while also showing the effect of the non-structural elements added between the tests. The effect was to reduce the natural frequencies significantly, with little effect on damping ratios.

Further analysis is being carried out to identify and illustrate the mode shapes for the three modes identified.

As is almost always the case with ambient vibration testing, as opposed to forced vibration testing, the modal properties relate to amplitudes well below those of interest in design. Longer-term monitoring which captured a few storms could give data relevant to the serviceability limit state, and this could be of interest in work on this or other buildings, to make this kind of assessment more useful to designers.