AMBIENT VIBRATION TESTING AND MODAL ANALYSIS OF MULTI-STOREY CROSS-LAMINATED TIMBER BUILDINGS

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ABSTRACT: The ambient movement of three modern multi-storey timber buildings has been measured and used to determine modal properties. This information, obtained by a simple, unobtrusive series of tests, can give insights into the structural performance of these forms of building, as well as providing information for the design of future, taller timber buildings for dynamic loads. For two of the buildings, the natural frequency has been related to the lateral stiffness of the structure, and compared with that given by a simple calculation. In future tall timber buildings, a new design criterion is expected to become important: deflection and vibration serviceability under wind load. For multi-storey timber buildings there is currently no empirical basis to estimate damping for calculation of wind-induced vibration, and there is little information for stiffness under wind load. This study therefore presents a method to address those gaps in knowledge.

KEYWORDS: CLT, multi-storey, tall building, modal analysis, damping, serviceability

1 INTRODUCTION

Eight- or nine-storey timber buildings have been constructed and are well perceived in towns and cities around the world. As engineers strive to take multi-storey timber building to new heights, it is necessary to understand how these existing buildings are behaving in-service, and how their performance relates to that predicted at the design stage.

Due in part to their flexible connections between storeys, multi-storey timber buildings with shear wall structure may require a different approach to prediction of their dynamic properties than other structural forms, such as the method for predicting lateral natural frequency proposed by Leung et al. [1]. It is conventional to estimate damping based on measurements of buildings previously constructed in a similar form [2]. This study provides such measurements for CLT construction.

In this study, the modal properties of the buildings were obtained by output-only modal testing. That is to say, the building was not artificially excited; rather its movement was measured under the dynamic loads imposed by the ambient conditions during the tests. These tests allow measurement of the as-constructed behaviour of the structure.

2 BACKGROUND

2.1 STRUCTURAL FORM OF THE BUILDINGS

The results of tests on three multi-storey timber buildings are presented in this paper: the Limnologen buildings in Växjö, Sweden; Stadthaus, in London, UK and the UEA Student Residence in Norwich, UK. The buildings are shown in Figure 1.

Figure 1: From left to right, the Limnologen, Stadthaus and UEA Student Residence buildings.

The four eight-storey residential buildings on the Limnologen block are all constructed with the first storey in cast concrete and the others with a combined CLT and stud and rail load bearing timber system. The buildings
have five apartments in each storey (storey 2-7) and two shafts with elevators and stair cases.

In each plane the apartments are structurally connected only point-wise and with specially designed connections with the aim of reducing the structurally born sound. Such apartment separating walls are indicated in Figure 1. This implies that lateral load introduced in the CLT flooring diaphragm can only be transferred between the apartments at those connection points.

The UEA Student Residence building, designed by Ramboll engineers, uses platform CLT construction, with each wall panel resting on the floor panel below it and connected using angle brackets. The building is in an L-shape, with a seven-storey block and a five-storey block.

The Stadthaus was completed in 2008, and has eight stories of CLT on a reinforced concrete first storey. Like the University of East Anglia building, it used platform CLT construction with angle bracket connections, but also used screw reinforcement in the perpendicular-to-grain direction in the floors to provide additional strength and stiffness [1].

3 METHODS

Three piezoelectric accelerometers were used, with a sensitivity of 10 V/g and designed to measure transient acceleration at frequencies of 0.1 Hz and above. They were mounted on aluminium blocks and placed onto the roof. The mass of the accelerometers and the block was sufficient to keep them in place by gravitation, and ensure they moved with the structure, meaning that no anchorage to the structure was necessary. This meant that no disruption was caused to the residents of this fully-occupied building.

For the Limnologen buildings, the three accelerometers were moved around the roof to obtain data at 8 points, in two perpendicular directions at each point. For each pair of readings, an accelerometer was placed at a common reference point to ensure that the measurements at locations across the structure could be transformed to a common scale. For the other two buildings, preliminary results are presented in this paper based on measurements at a single point.

The excitation force applied to the structure is assumed to be provided primarily by the turbulent wind load on the building, but also by the ambient movement of people and mechanical systems in the building. The ambient vibration response of the structure was processed using the random decrement technique [3] to obtain an equivalent free-decay response at each measurement point and in each direction. These free decays could then be analysed using conventional modal-analysis techniques.

4 RESULTS

The results gave natural frequencies and damping ratios for each building, as shown in Table 1. These results are all based on vibration measured in three axes at a single point on the building. Results based on the multi-output tests on the Limnologen building are given in the full paper. The UEA building was tested at two stages during construction, showing the influence of non-structural elements on its modal properties.

### Table 1: Natural frequencies and damping for the first two modes of each building, based on analysis at a single point

<table>
<thead>
<tr>
<th>Building</th>
<th>Mode number</th>
<th>Frequency (Hz)</th>
<th>Damping (% of critical)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limnologen</td>
<td>1</td>
<td>2.28</td>
<td>2.3</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>2.48</td>
<td>1.0</td>
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<tr>
<td>UEA Test 1</td>
<td>1</td>
<td>2.70</td>
<td>3.6</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>UEA Test 2</td>
<td>1</td>
<td>2.45</td>
<td>5.4</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Stadthaus</td>
<td>1</td>
<td>2.26</td>
<td>1.9</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>2.99</td>
<td>2.2</td>
</tr>
</tbody>
</table>

### 5 CONCLUSIONS

This study has shown that output-only modal testing can be used to identify modal parameters in a multi-storey CLT building. The test resulted in no disruption to the building occupants, and so is suitable for a wide study of damping in this type of building in service, which could inform the design of future tall timber buildings.

### ACKNOWLEDGEMENTS

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### REFERENCES


