STRUCTURAL CHARACTERIZATION OF MULTI-STOREY BUILDINGS WITH CLT CORES

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ABSTRACT: The behaviour of multi-storey buildings braced with Cross-Laminated-Timber (CLT) cores and additional shear walls is examined based on numerical analyses of various 3-dimensional configurations. Two ways of calibrating numerical model are proposed according to codes and experimental test data respectively, including calibration of parameters that characterise connections between CLT panels in building cores and shear walls. Results of analyses of entire buildings are presented in terms of principal elastic periods, and base shear and up-lift forces. Discussion addresses primary issues associated with behaviour of such systems and modelling them.

KEYWORDS: CLT, core, seismic action, numerical model

1 INTRODUCTION

In recent years the CLT panels have become quite widely employed in Europe and elsewhere to build multi-storey residential and mercantile buildings. These buildings are often characterised by the presence of many internal and perimeter shear walls. In the modern context an equivalent construction technology is to use beams and columns to resist effects of gravity loads, and CLT building core substructures and other CLT shear walls to resist effects of lateral loads. Advantages of such systems can include creation of large open interior spaces, high structural efficiency, and material economies. It has to be noted that available seismic codes do not provide guidance on the most crucial aspects of how to design this type of structural systems. The aim of work discussed here is behaviour of complete multi-storey superstructures. Results presented below are from numerical analyses on various 3-dimensional configurations, based on connection parameters calculated according to Eurocode 5 [1] or experimental cyclic-loading test data.

2 CASE-STUDY BUILDINGS

Numerical modal response spectrum analyses were conducted [2], for alternative case-study building superstructures having footprint dimensions of 17.1m by 15.5m. Seismic Force Resistant Systems (SFRS) include a building core that is 5.5m by 5.5m on plan and partial perimeter shear walls constructed from CLT panels. The number of storeys is varied, with Model 1 having five storeys and Model 2 eight storeys, as shown in Figure 1.

(a) Model 1 – 5 storey (b) Model 2 – 8 storey

Figure 1: Full building FE models

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Storey heights are 3m, resulting in total superstructure heights of 15m and 24m for five and eight storey cases. The earthquake action for these case study buildings was calculated according to Eurocode 8 [2] and Italian Regulation [3], using design response spectra for building foundations resting on type C and D soil. The chosen site location of L’Aquila in the region of Abruzzo, corresponds to the highest seismic zone classification for Italy. In the case studies equivalent static force designs were carried out based on a force modification factor, \( q \), of 1.5. This precautionary value was assumed since not enough studies on buildings braced using CLT cores are available yet.

3 SFRS MODELS

Numerical models of SFRS were created using the SAP2000 Finite Element code [4], Figure 2. CLT panels were modelled with linear elastic isotropic 2-D Shell elements. Connections between the SFRS and foundation and at interfaces between storeys were modelled with link elements.

![Figure 2: FE models of SFRS](image)

A comparison was made between results of numerical models having link elements calibrated against European design code information (Model A), and models having link elements calibrated against experimental data (Models B and C). This enabled evaluation of the effects of modelling hypotheses on extracted information like elastic periods, and base shear and up-lift forces. Model B was calibrated according to experimental results, using results from the SOFIE project. It became also necessary to adopt unconventional hold-down anchors for which experimental characterisation is available, because the seismic base shear and the corresponding overturning moment for the 8-storey building are very high. For these reasons, for this building special high-strength IVALSA hold-down anchors were employed (Model C).

4 RESULTS

The obtained results exhibit some large variation in the elastic lateral vibration periods due to alteration of the connection stiffness, i.e. between effects of code and experimentally calibrated estimates of stiffness. In particular, the periods calculated based on the code-based calibration were up to about 40% lower than those calculated on the experimentally-based calibration. Variation of the connection stiffness do not cause large variation in the total base shear forces for the entire SFRS in the case either the 5 storey building. Differences between cases are greater, in relative terms, for the 8 storey building. Proportions of the total base shear force carried by the building core are only weakly sensitive to connection stiffness characteristics, which largely reflects that elevated horizontal diaphragms were modelled as being rigid in-plane. Maximum up-lift forces at hold-down anchors were most sensitive to connection stiffness assumptions in the case of the 8 storey building. This reflects amplified effects of flexural deformation within storeys compared with the 5 storey building. As results illustrate, discrepancies are mainly due to uncertainty in determining the initial stiffness of the connections and effects of modelling hypotheses. Finally it should be recalled that the obtained design forces are based on adoption of an assumed behaviour factor, \( q \), of 1.5. However, there is need to determine through other studies whether the value used or a different \( q \)-factor is applicable to SFRS having a building core and discontinuous perimeter shear walls constructed from CLT panels.

5 CONCLUSIONS

Analyses of relatively tall and slender CLT buildings demonstrate the importance of realistically representing their seismic force resisting system. This includes paying close attention to the representation of base connections and inter-storey connections. If such attention is not paid the result can be highly inaccurate prediction of the fundamental lateral vibration period, and therefore inappropriate sizing of structural elements. It is also to be observed that up-lift forces due to seismic overturning moments can be very large. Therefore there is need to focus attention on development of special high capacity anchoring systems for CLT walls.

REFERENCES