Engineering Structures 33 (2011) 3043–3053

Contents lists available at SciVerse ScienceDirect

Engineering Structures

journal homepage: www.elsevier.com/locate/engstruct

Elastic and ductile design of multi-storey crosslam massive wooden buildings under seismic actions

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ARTICLE INFO

Article history:
Available online 29 June 2011

Keywords:
Cyclic tests
Cross-laminated panels
Ductility
Earthquake design
Multi-storey buildings
Push-over analysis
Seismic performance
Timber
Wood

ABSTRACT

The paper discusses the seismic design of multi-storey buildings made from cross-laminated timber panels ('crosslam'). The use of seismic analysis methods such as the modal response spectrum and the non-linear static (push-over) analysis is discussed at length, including issues such as the modelling of crosslam walls and connections, the evaluation of the connection stiffness, and the schematization of floor panels. It was found that it is crucial to account for the flexibility of the connections (hold-downs and angle brackets) between upper and lower walls, since otherwise the vibration periods of the building would be underestimated. The basics of capacity design to ensure the attainment of ductile mechanisms in crosslam timber structures under seismic actions are presented. The ductile failure mechanism is characterized by plasticization of connectors (hold-downs, angle brackets and screws) between adjacent wall panels and between panels and foundations. The crosslam panels and the connections between adjacent floor panels must be designed for the overstrength of the connectors to ensure that they remain elastic during the earthquake and the ductile failure mechanism is attained. Based on the results of preliminary quasi-static cyclic tests, a value of 1.3 was found for the overstrength factors of hold-downs and angle brackets. A case study multi-storey crosslam massive wooden building was then analysed using the non-linear push-over analysis as implemented in the N2 method recommended by the Eurocode 8. The building was modelled using shell elements and non-linear links to schematize the hold-downs and angle brackets. The building ductility, calculated from the bilinear curve equivalent to the actual non-linear push-over curve, was then investigated. Such a quantity, defined as the ratio of the displacement at the near collapse state and the maximum elastic displacement of the top floor, was found to rise from 1.7 to 2.5 when ductile instead of brittle hold-downs and angle brackets are used. Furthermore, the maximum peak ground acceleration the building can resist raised from 0.2g to 0.4g, demonstrating the importance of using ductile connectors in seismic design.

1. Introduction

Different methods can be used for the design of seismic-resistant buildings. The most basic approach would be to evaluate the forces induced on a building by an earthquake with a high return period and design the structure in elastic phase. Since statistically the chance of a high intensity earthquake occurring during the lifetime of a building (in most cases 50 years) is not particularly high (about 10%), the elastic design leads to significant overdesign of the building elements. For this reason the elastic approach is generally used only in low to moderate seismicity regions. The alternative design approach is based on the principles of ductile design. A ductile structure is able to dissipate energy during the seismic event by undergoing through plastic deformation. One of the advantages is the possibility to survive high intensity earthquakes as long as the displacement demand in the ductile parts of the structure does not exceed the displacement capacity. The ductility also allows more economical structures to be built as the design seismic actions can be reduced depending upon the ductility ratio [1]. Such an approach is generally followed for building design in medium to high seismicity regions.

Current codes of practice [2] suggest two different approaches for design of ductile structures in earthquake-prone regions. The first approach, well known and widely used, is referred to as the Force-Based Design (FBD) method since it mainly focuses on designing the strength of the structure [1]. The objective is the evaluation of the behaviour factor q, which is employed to transform the elastic response spectrum into a design spectrum. In this way a non-linear structure can be designed using a linear-elastic static or dynamic (modal response spectrum) analysis under seismic action, with the structural ductility only implicitly considered when evaluating the behaviour factor q.

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doi:10.1016/j.engstruct.2011.05.020