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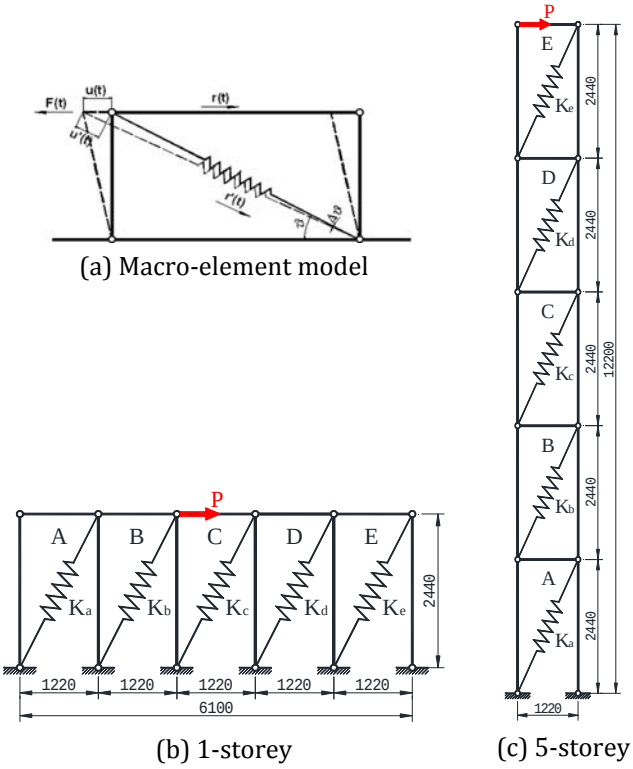
Seismic Force Modification Factor for Mid-rise Hybrid Wood Buildings

KEYWORDS: Seismic Factor; Mid-rise; Hybrid buildings, Lateral load-resisting element (LLRE)

OVERVIEW OF PROJECT

In seismic design of buildings, the National Building Code of Canada (NBCC) specifies ductility-related force modification factor, R_d, to reflect the energy absorption and ductility characteristics of the lateral load-resisting element (LLRE) of the building. Values of R_d factor are provided by NBCC according to the types of LLRE constructed with a specific material. For a hybrid structure consisting of more than one type of LLRE or materials, NBCC specifies that the lowest R_dR_o (R_o is the over-strength related force modification factor) value of all the LLRE's is used. This is conservative and may result in an uneconomical design solution. A more liberal R_d factor can be used if it can be supported by appropriate analyses, such as conducting non-linear time history analyses of the building models designed with different R_d values. This process is time-consuming and the results are specific to the particular building under investigation. The objective of this project is to develop a simplified, semi-mechanics approach for estimating the system R_d factor for the hybrid wood buildings incorporating two LLRE's with different ductility characteristics.

Numerical models capable of conducting non-linear time history analyses were used in the project. The models were implemented via the commercial finite element software, ABAQUS. A macro-element model to represent the LLRE (Fig. 1a) was adapted to improve the efficiency of finite element analysis (FEA) of multi-storey buildings. Initially two types of hybrid building, as shown in Fig. 1b and c, were analysed: (a) five LLRE's horizontally aligned (1 storey), and (b) five storeys represented by LLRE's vertically aligned (5 storeys). The hybrid buildings were assumed to consist of two types of LLRE with different mechanical characteristics, including ductility, strength and stiffness: low ductility (LD) and high ductility (HD) elements. The first stage involved deriving the relationship between the system R_d factor, and the mechanical properties of two types of LLRE by conducting reversed cyclic loading analysis. For the purpose of evaluating the approach to estimate the system R_d factor of hybrid buildings, non-linear time history analysis was performed with 22 scaled "Far-Field" earthquake records.



(a) Macro-element model

(b) 1-storey

(c) 5-storey

Fig. 1. Light wood frame building models

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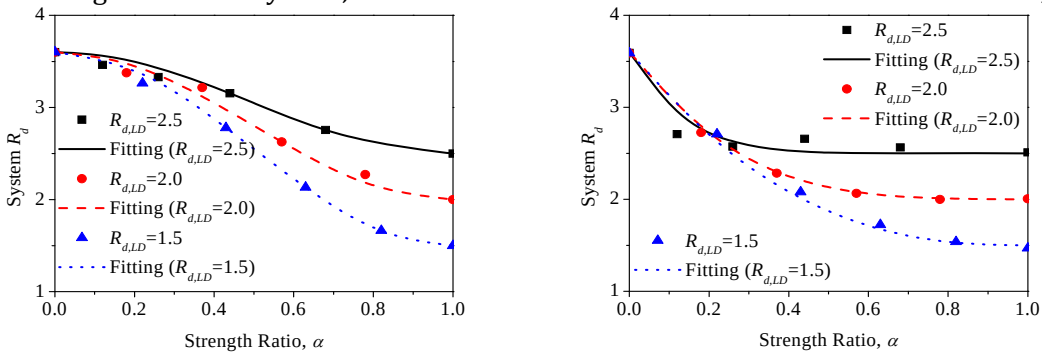
KEY RESULTS

Based on the analysis of hybrid buildings (Fig. 1b and c), the relationships among the system ductility-related force modification factor and the LLRE R_d, and the strength ratio α of the LD element relative to the total strength of whole system, and stiffness ratio of the individual LLRE's was derived, Fig. 2.



(a) 1-storey (b) 5-storey

Fig. 2. System R_d of hybrid wood buildings

The empirical equations of the fitted curves are shown in Eqs. (1) and (2).

1-storey $$R_d = R_{d,LD}\sin^2\left(\alpha\frac{\pi}{2}\right) + R_{d,HD}\cos^2\left(\alpha\frac{\pi}{2}\right) \quad (1)$$

5-storey $$R_d = \left(R_{d,HD} - R_{d,LD}\right)\left(1-\alpha\right)^t + R_{d,LD} \quad (2)$$

where $R_{d,i}$ is the ductility-related force modification factor of LD or HD element, and the exponent t is a function of the stiffness ratio of LD element, K_{LD}, and HD element, K_{HD}, which can be calculated using Eq. (3).

$$t = -5.9\frac{K_{HS}}{K_{LS}} + 10.2 \quad (3)$$

For most multi-storey buildings encountered in practice, they are unlikely to be as simple as the 1-storey and 5-storey structures anlaysed. However, Eqs. (1) and (2) provide the base information to derive system force modification factor for practical multi-storey buildings that contain different LLRE's aligned both vertically and horizontally. Two approaches are possible to address the practical situations:

- Method A – Use the smallest storey R_d derived from Eq. (1) as the system R_d of the complete hybrid building. This approach is conservative and yet simple.
- Method B – Alternatively a two-step approach can be used. First, Eq. (1) can be used to derive system R_d for each storey. The storey system R_d values are input into Equation (2) to estimate whole building system R_d. This approach involves more calculations but should be less conservative compared with Method A.

Regarding the over-strength related force modification factor, R_o, since its value is rather narrow even for different material-specific LLRE's, hence the lowest R_o factor of the LLRE's is suggested to be used as the system over-strength related force modification factor of hybrid structures until such time that more reliable information is available.