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AN APPROACH FOR ESTIMATING SEISMIC FORCE MODIFICATION FACTOR OF HYBRID BUILDING SYSTEMS

Zhiyong Chen[1], Ying H. Chui[2], Ghasan Doudak[3], Chun Ni[4], Mohammad Mohammad[5]

ABSTRACT: When hybrid buildings containing more than one type of lateral load resisting system (LLRS) are designed to resist earthquake loads, the National Building Code of Canada requires that the lowest force modification factors of all LLRSs are used for design purposes. An approach is proposed in this paper to calculate a ductility ratio, μ, and ductility-related force modification factor, R_d, for the entire hybrid structure based on strength, stiffness and ductility of individual types of LLRS. To verify the proposed approach, four- and six-storey buildings with single- and hybrid-LLRS were designed using the proposed approach. These buildings were analysed by conducting a 3-D frequency and non-linear time history response analyses using a finite element program. The results show that using a R_d value higher than the lowest R_d factor suggested by the National Building Code of Canada is justified and that the proposed approach has the potential to be adopted for design purposes.

KEYWORDS: Hybrid structures, Lateral load resisting systems, Seismic response, Force modification factors.

1 INTRODUCTION

In seismic design of buildings, most national and international building codes specify force modification factors to reflect the energy absorption and ductility characteristics of the lateral load resisting system (LLRS) of the building. For instance, Eurocode 8 [1] uses the '*q*' factor while the National Building Code of Canada (NBCC) [2] specifies the product of two factors, ductility- (R_d) and over-strength (R_o) related force modification factor.

In the NBCC, values for R_o and R_d factors are provided according to structural types for each LLRS [2]. For a hybrid structure consisting of more than one type of LLRS, the NBCC requires that the lowest R_dR_o value of all the LLRSs is used. Although the over-strength related force modification factor R_o factor can be expressed explicitly [2], all the parameters in the equation were derived statistically exhibiting the difference between the actual situation and the structural design. In addition, the variation of R_o factors between different LLRSs is small with the maximum difference of 0.7 compared with that of R_d factors. Hence, the suggestion of the lowest R_o factor of the LLRSs for the system over-strength related force modification factor of hybrid buildings is justified. However the suggestion of the lowest R_d factor for hybrid system is conservative and may result in an uneconomical design. The NBCC however, does allow for the use of a more liberal seismic force modification factor if it can be supported by appropriate engineering analyses. A suitable analysis is to conduct non-linear time history analysis of a building designed with different R_d values [3-4]. This process is time consuming and the results are specific to the particular building under investigation.

Hence, a balanced approach that is more user friendly, while less conservative than the method proposed in the NBCC for estimating R_d factor for hybrid structures is desirable. The purpose of this paper is to present an approach of estimating the overall seismic modification force factor for a multi-storey hybrid buildings consisting of different types of LLRS based on the relevant mechanical characteristics of the individual LLRSs, such as ductility, stiffness and strength.

2 SYSTEM DUCTILITY-RELATED FORCE MODIFICATION FACTOR

From a structural mechanics perspective, the system ductility ratio, μ, by which the ductility-related force modification factor, R_d, is determined, of hybrid building can be interpreted as a function of the sub-system ductility, the relative strength and stiffness of the individual LLRSs. Therefore an attempt was made to develop a model that

[1] Zhiyong Chen, University of New Brunswick, P.O. Box 4400, Fredericton, Canada. Email: zhiyong.chen@unb.ca
[2] Ying H. Chui, University of New Brunswick, Canada
[3] Ghasan Doudak, University of Ottawa, Canada
[4] Chun Ni, FPInnovations, Canada
[5] Mohammad Mohammad, FPInnovations, Canada

expresses the system ductility ratio (μ) in terms of these properties.

In order to obtain such a model, two types of hybrid building systems with various combinations of two LLRSs were modelled and analysed using the finite element software, ABAQUS [5]. One type (Figure 1) was a one-storey building with five lateral load resistant elements (LLREs) aligned horizontally and the other one was a five-storey building represented by five LLREs aligned vertically. Based on the structural behaviour of these building models, an approach to estimate the system ductility ratio, μ, and the system R_d factor (Equation (1)) of a hybrid building incorporating two LLRSs which exhibit different ductility characteristics was proposed.

$$R_d = \sqrt{R_{d,HS}^2 \sin^2\left(\alpha \frac{\pi}{2}\right) + R_{d,LS}^2 \cos^2\left(\alpha \frac{\pi}{2}\right)} \qquad (1)$$

where $R_{d,HS}$ and $R_{d,LS}$ are the ductility-related force modification factor of high and low strength LLREs, while α is the strength ratio of high strength LLRE to the LLRS.

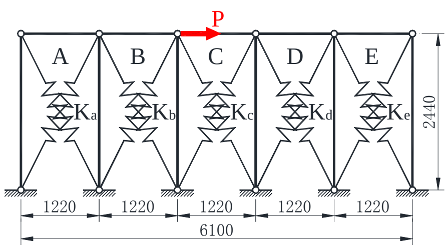

Figure 1: *Single-storey building model*

3 RESPONSE OF HYBRID BUILDING SYSTEMS TO SEISMIC MOTIONS

In order to validate the proposed approach for estimating the ductility-related force modification factor, R_d, 4- and 6-storey buildings with single- or hybrid-LLRS were designed to the NBCC structural requirements applicable to Vancouver with stiff soil condition, using the real R_d factor of low strength LLRE and the R_d factor estimated by the proposed approach based on the R_d factors of shear wall and low and high strength LLREs. Correspondingly, three-dimensional finite element models were developed using a macro-element model to represent the LLRE in finite element software, ABAQUS [5]. The dynamic characteristics and seismic response of the building models were obtained by conducting frequency and non-linear time history analysis. The analysis results show that the fundamental natural periods, inter-storey drift ratios and margin ratios of the hybrid buildings designed with the R_d factor estimated from the proposed approach were equivalent to those obtained from the buildings' analysis using one type of LLRS only (see Figure 2 for six-storey building models).

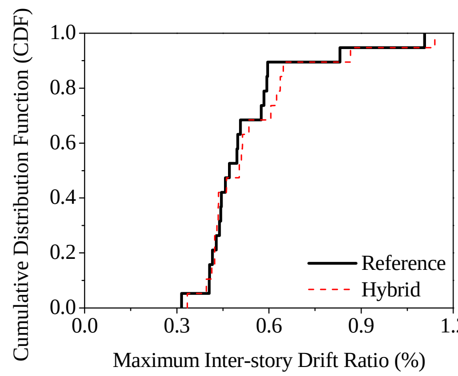

Figure 2: *CDF's of maximum inter-storey drift ratio of six-storey buildings*

Note: "Reference" and "Hybrid" indicate building with single- and hybrid-LLRS, respectively.

4 CONCLUSION

An approach for estimating the ductility ratio, μ, and the ductility-related force modification factor, R_d, of multi-storey hybrid buildings containing two types of LLRS is proposed and validated using the numerical simulation method.

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