7th Canadian Conference on Earthquake Engineering / Montreal / 1995
7ième Conférence canadienne sur le génie paraséismique / Montréal / 1995

Seismic Torsional Provisions in NBCC

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ABSTRACT

This paper examines the ability of the National Building Code of Canada (NBCC) static torsional provisions to limit additional ductility demands on lateral load resisting elements at the edges of asymmetrical buildings. A single mass monosymmetric system with resisting elements in both principal structural directions is used as structural model. The earthquake excitation is bi-directional. It is found that the Code is adequate in limiting additional ductility demand of the edge elements along the asymmetrical direction of the model. Significant additional ductility demands are observed in the elements along the symmetrical direction of the model because when designing the elements in this direction the Code does not consider the torsional effect resulted from the asymmetry in the perpendicular direction. A modified procedure is proposed to take into account the bi-directional effect of torsion such that using the modified procedure, the Code is adequate in limiting additional ductility demands on elements along both principal structural directions.

INTRODUCTION

Evaluation involving comparison of torsional provisions among different codes including the National Building Code of Canada 1990 (NBCC) can be found in several studies (Chopra and Goel, 1991; Rutenberg et al., 1992; Tso and Zhu, 1992; Chandler and Duan, 1993; De Stefano et al., 1993). In these studies, the building was idealized as a monosymmetric system having a single rectangular slab supported by lateral load resisting elements, and subjected to horizontal ground motion in one direction. Most researchers used a model having lateral load resisting elements in the direction parallel to the ground motion only. De Stefano et al. (1993) used a model having additional lateral load resisting elements in the direction perpendicular to the ground motion direction. In reference to the unidirectional ground motion, these added elements were referred to as "transverse" elements. However, the transverse elements were assumed to remain in the elastic state throughout the earthquake. This is an unlikely scenario considering that real buildings are exposed to ground motions in two orthogonal directions simultaneously during an earthquake. Thus, the results from their studies may not be relevant to actual building.

In the present study, the National Building Code of Canada 1990 static torsional provisions are evaluated. The main objective is to determine if there are excessive additional ductility demands due to torsion in the resisting elements of asymmetrical buildings designed following the NBCC static torsional

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considered in this study. The stiffness eccentric system SES used in previous studies represents a special case here where $e=\eta$. For centrally located CR configurations, the three values of e considered are 0, 0.05, and 0.10.

The torsionally balanced (TB) model (Tso and Wong 1993) is adopted here as the reference model to quantify the effect of torsion. It has identical stiffness distribution as its torsionally unbalanced (TU) counterpart. No torsional provision is used in the strength design of the reference model, and the total strength in each principal direction is distributed to the respective lateral force resisting elements in proportion to their element stiffnesses.

STRENGTH DISTRIBUTION

The nominal design lateral forces in the X and Y directions are given, respectively, by

$$F_x = \frac{Ma_x}{R_x} \quad \text{and} \quad F_y = \frac{Ma_y}{R_y} \tag{2}$$

a_x and a_y are the design spectral accelerations taken from the 5 percent damped Newmark and Hall acceleration spectrum normalized to a peak ground acceleration of 0.2g. The strength reduction factors R_x and R_y are assumed to be the same and equal to 5. The nominal design strengths F_x and F_y are distributed to the X and Y elements, respectively, based on static equilibrium consideration. The design strengths for the elements can be expressed as

$$f_i = f_i^0 \Gamma_i \equiv f_i^0 \left(1 + \frac{e_d s_i}{\rho_k^2} \right) \tag{3}$$

where f_i^0 is the i^{th} element strength of the reference system, and Γ_i is the i^{th} element strength ratio. In the above equation, e_d is the design eccentricity specified by NBCC for the given direction, and s_i is the lever arm between the CR and the i^{th} element normalized by b. Since the element strengths of the reference system do not include modification from torsional provisions, the deviation of the element strength ratio Γ_i from unity is a direct measure of the change of the element design strength caused by the torsional provisions. In a dimensionless form, NBCC 1990 specifies the design eccentricities e_{d1} and e_{d2} as follows

$$e_{d1} = 1.5e + 0.1 \quad \text{or} \quad e_{d2} = 0.5e - 0.1 \tag{4}$$

which ever leads to a more severe demand to the element under consideration.

In the present study, particular attention is given to the edge elements in both the X and Y directions. The strength ratios for the longitudinal edge elements (elements 1 and 3) are shown in Fig. (2). Due to the location of CM relative to CR, element 1 is the element located at the stiff edge while element 3 is at the flexible edge. Figure (2) shows that the strength ratio variation for the stiff edge elements is insensitive to the location of CR (η) and the associate range of eccentricities (e). The strength ratio is in the neighbourhood of unity for the whole range of torsional stiffness parameter ρ_k. The Code allows a minor reduction of design strength (up to 20%) for highly eccentric configurations. For the flexible edge elements, the strength ratio curves in all three graphs are larger than unity. They increase as ρ_k decreases or as the eccentricity e increases. The increase is particularly large for the highly eccentric CR direction (NBCC Supplement 1990). Thus, the strength of transverse element 4 is designed for the seismic forces acting along the X direction alone. Being symmetrical in this direction, element 4 is designed to include only the effect of the accidental eccentricity. In reality, however, element 4 also participates in resisting the torque caused by the earthquake motion along the Y direction. The load induced on element 4 due to Y direction loading can be significant, particularly when the eccentricity e is large. Therefore, the effect of eccentricity in the orthogonal direction should be included. One commonly used procedure to take into account bi-directional earthquake motions is to design for the more severe of the following load combinations:

(i.)100% X directional effect + 30% Y directional effect;
(ii.)100% Y directional effect + 30% X directional effect.

To check the viability of such a procedure (denoted as NBCC* procedure) for the design of edge elements of torsionally unbalanced systems, the elements of the structural model were redesigned using this procedure. The design strength ratios for the longitudinal edge elements 1 and 3 remain essentially unchanged since the 30% X directional effect is very small. However, there is change in the design strength ratio for the transverse element 4, as shown in Fig. (3). The change is particularly noticeable for systems having large eccentricity. There is little change in the mean ductility ratios for longitudinal elements 1 and 3. The ductility ratio for element 4 based on NBCC* is shown in Fig. (5b). When compared to Fig. (5a), one can observe the decrease of ductility ratio from above unity to below unity for systems with large eccentricity.

CONCLUSIONS

The following conclusions are drawn based on the seismic responses of a single mass structural model used in this study:
(1.) The torsional provisions in NBCC 1990 appear to provide adequate strength to the edge elements in the longitudinal direction such that there is no additional ductility demand on these elements. However, the strength of transverse elements can be underdesigned such that they may experience additional ductility demand due to torsion induced in a design level earthquake.
(2.) Recognizing the importance of a bi-directional design for torsional effects, the current NBCC design procedure is modified as outlined. This procedure can provide a design for the model such that no additional ductility demand occurs on any of the edge elements under design level earthquake.

ACKNOWLEDGMENT

The writers wish to thank the Natural Sciences and Engineering Research Council of Canada (NSERC) for supporting the work presented herein.

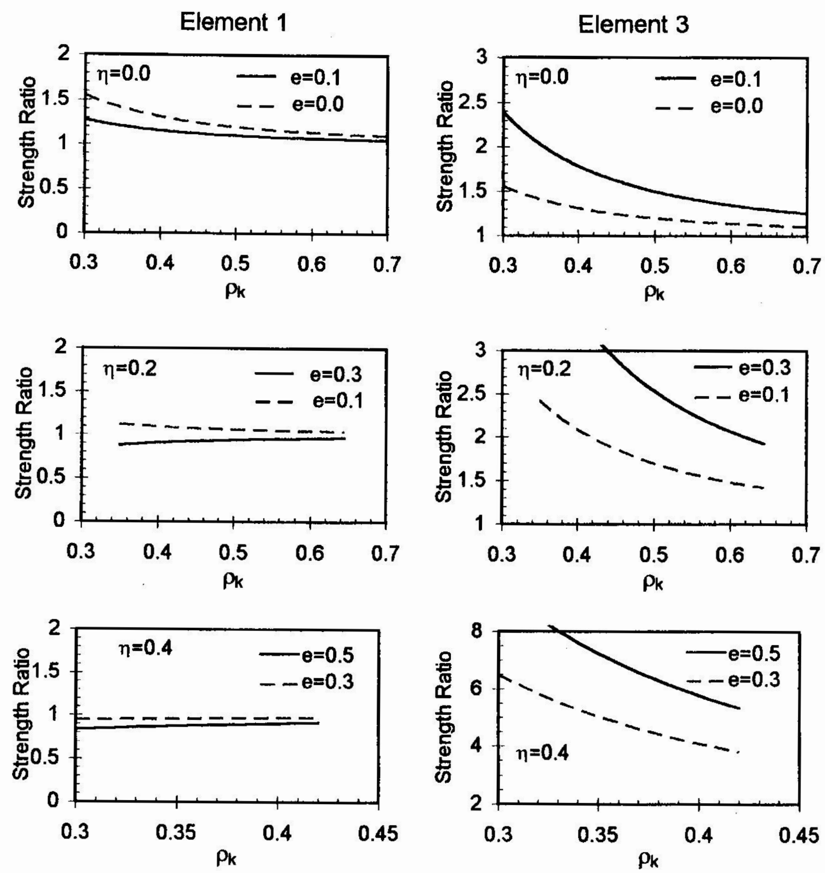

Fig. 2 Strength ratios of longitudinal edge elements

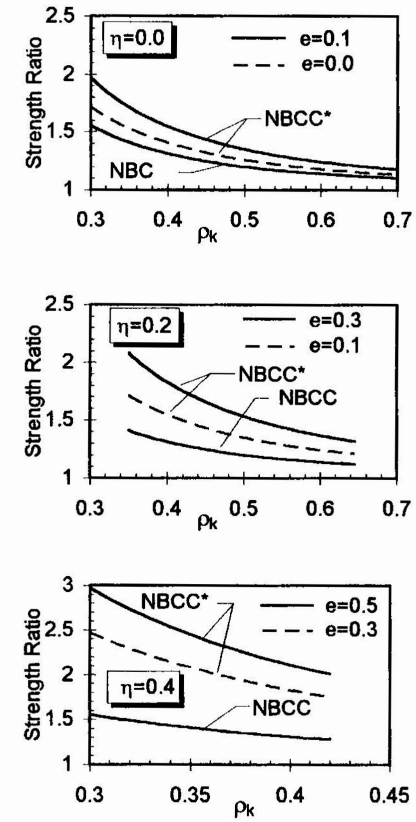

Fig. 3 Strength ratios of transverse edge elements

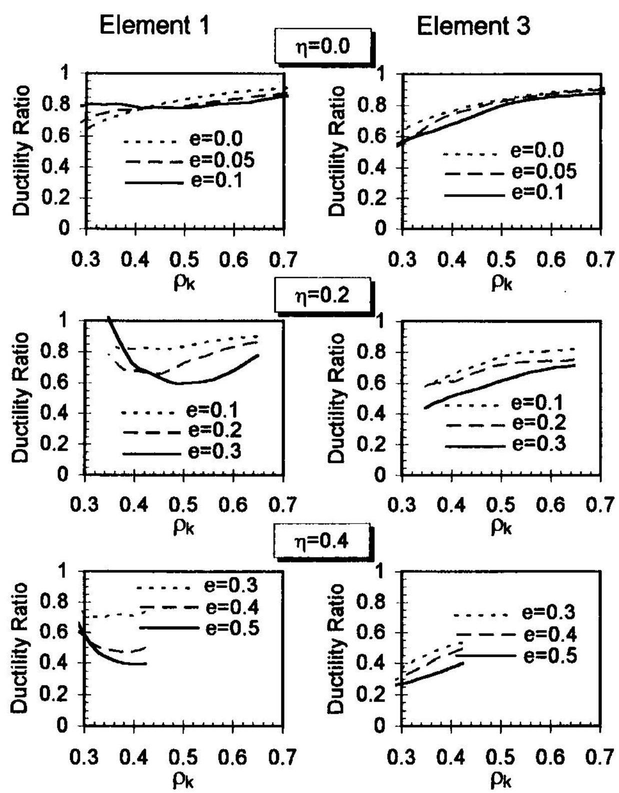

Fig. 4 Ductility ratios for elements 1 and 3 for systems designed using NBCC

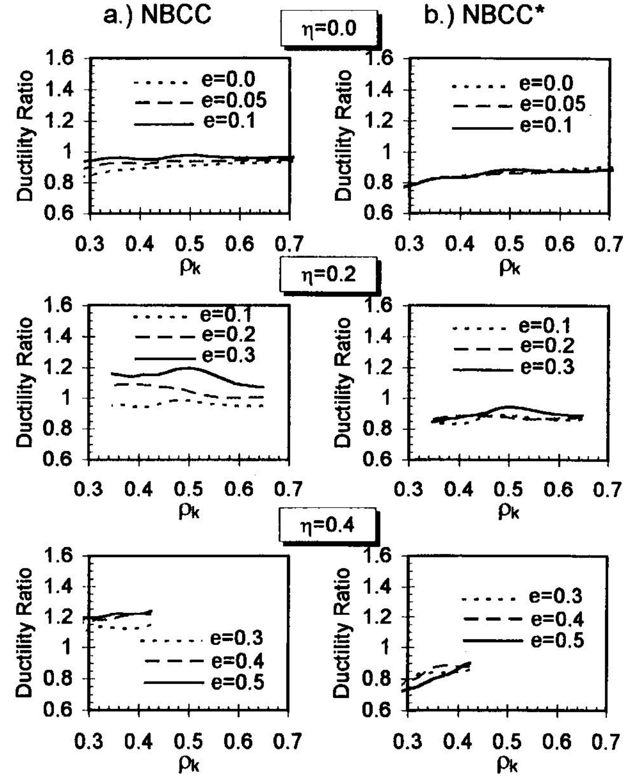

Fig. 5 Ductility ratios for element 4 for systems designed using a.) NBCC and b.) modified NBCC