STOREY SEISMIC CAPACITY OF LOW-RISE RC BUILDING

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ABSTRACT

This study presents a simplified method of storey seismic capacity evaluation for low-rise reinforced concrete buildings. As a case study, four-storey RC school buildings will be evaluated by using two methods that available in the previous literature. The objective of this case study is to evaluate the accuracy of both methods in prediction the storey capacity of the buildings. Both methods are based on the allowable average shear stress of vertical member section at storey as the main factor in the calculation method. First method is based on the Japan Building Standard Law (JBSL). The second method, as the proposed method, uses the Softened strut-and-tie principle as the model for the prediction of the shear strength of the vertical members. The comparison of both methods shows that the methods can indicate the insufficient capacity of the buildings. However, in this study, the calculated result of proposed method is more conservative than the JBSL method in prediction of the first storey capacity.

Keywords: evaluation, storey capacity, seismic, reinforced concrete, low-rise
1. INTRODUCTION

Many post earthquake investigation reports showed that the low-rise reinforced concrete buildings were prone to the earthquake damages (ABRI, 1999, and Bali, et al., 2006). This evidence indicates that the remain low-rise RC buildings in earthquake prone area need to be evaluated its seismic capacity and retrofitted if the seismic capacity is insufficient.

This paper proposes an analytical study of a simplified method of storey seismic capacity evaluation for low-rise reinforced concrete buildings. For the case study, four-storey RC school buildings as the typical compulsory school buildings in the urban area of Taiwan, are evaluated using two methods that available in the literature. Both methods are based on the allowable average shear stress of vertical member section at storey as the main factor in the calculation method. The first method is based on the Japan Building Standard Law (JBSL). The second method, as the proposed method, uses the Softened strut-and-tie principle as the model for the prediction of the shear strength of the vertical members.

The objective of this case study is to evaluate the accuracy of both methods in prediction the storey capacity of the low-rise RC buildings in earthquake prone area. As the base data to compare the both methods, it is provided the building capacity as the load-deflection curve of the building that is calculated using a simplified pushover analysis.

2. METHODS

The Shiga’s simplified method of storey capacity evaluation was reported by Watanabe and Sumi (2006). The method was adopted in the Seismic Design Requirement of Japan Building Standard Law (JBSL) 1981 (Watanabe and Sumi, 2006). To evaluate the storey capacity of building, the low-rise buildings designed by this simplified method should not exceed the height of 20 meters and satisfy the condition given as follows (Watanabe and Sumi, 2006).

\[ 25\Sigma A_w + 7\Sigma A_c \geq ZW_iA_i \]  

where \( \Sigma A_w \) is total horizontal sectional area of structural walls which are effective to lateral load direction (cm\(^2\)), \( \Sigma A_c \) is total sectional area of columns of lateral system and nonstructural walls which are connected to main frames at top and bottom of them, \( Z \) is seismic zone factor (0.7 \( \leq Z \leq 1.0 \)), \( W_i \) is weight above i-th storey, and \( A_i \) is lateral storey shear distribution factor which depend on \( \alpha = W_i / W \) where \( W \) is total weight of building above ground level, and \( T \) is natural period of a building.

In Eq. (1), the allowable average shear stress of wall section and column section at the storey collapse are assumed to be 25 kgf/cm\(^2\) and 7 kgf/cm\(^2\), respectively. Eq. (1) is based on the investigation on the past earthquake damage to building.

The lateral storey shear distribution factor \( A_i \) can be determined using Fig. 1. In order to determine the value of \( A_i \), the value of \( \alpha \) and \( T \) should be calculated in advance. The value of \( T \) may be approximated from the following equation (UBC, 1997), \( T = C_i(h_i)^{3/4} \), where \( C_i = 0.030 \) for reinforced
concrete moment-resisting frames, and $h_n$ is height above the base to level $n$ (in meter).

According to the calculation of the average ultimate stress of the wing walls and the columns of the four-storey RC school buildings, Bali (2007) proposed the modification of the Shiga’s method and it can be expressed as the equation for the evaluation of storey capacity as follows,

$$20\Sigma A_w + 9\Sigma A_c \geq ZW/A_i$$  \hspace{1cm} (2)

where the average shear stress of wing wall and column sections are assumed to be 20 kg/cm$^2$ and 9 kg/cm$^2$ respectively.

3. CASE STUDY

A type of cantilever corridor building with the structure of open frame system is selected in this case study. This building as a prototype model of four-storey RC classroom building/Building I (Chen, 2006) is selected in this study in order to represent the typical compulsory schools in the urban area of Taiwan (Fig. 2). The total weight of each floor and roof are 3601 kN and 3001 kN, respectively. The material properties of columns are concrete strength $f_c' = 17.2$ MPa, reinforcement yielding strength $f_y = 275$ MPa and elasticity modulus of steel $E_s = 200056$ MPa.

There are three other buildings as the retrofitted building (Fig. 3) that will be calculated in this study i.e. the 1~2F retrofitted building (Building II), the 1~3F retrofitted building (Building III), and the 1~4F retrofitted building (Building IV). The height of floor to floor of the buildings is 360 cm.

The simplified pushover analysis method was used for seismic evaluation of the four buildings (Bali, 2007). In the simplified pushover analysis, the seismic capacity of the buildings is estimated by superposing the load-displacement response of vertical members in the storey. The characteristic of this method is simply superposing the load-deflection response without considering the
arrangement of columns. In this study, the shear strength of the shear walls and columns is estimated using simplified procedure of Softened strut-and-tie model (Hwang and Lee, 2002). The shear strength can be expressed as 

\[ V_s = K \zeta f_c A_{nt} \cos \theta, \]

where \( K \) is the strut-and-tie index and \( K = (K_s + K_r - 1) \), \( f_c \) is compressive strength of a standard concrete cylinder (MPa), \( A_{nt} \) is the effective area of the diagonal strut, and the softening coefficient \( \zeta \) is approximated as \( \zeta = 3.35 / \sqrt{f_c} \leq 0.52 \) (Hwang and Lee, 2002).

The load-deflection response for each floor of the buildings is presented in Fig. 4, Fig. 5, Fig. 6, and Fig. 7. The seismic capacity and the corresponding deflection of Building I are 6428 kN and 6.1 cm (Fig. 8) respectively. This building is expected failure in the first floor. Building I has the existing seismic capacity lower than the required capacity (Bali, 2007). The analysis of Building II indicates that the third floor of the building as the weakest floor. This evidence is found in the distribution of base shear at the third floor which the distributed base shear is larger than maximum capacity of the third floor. It means that the third floor of this building type will collapse firstly. In this case, the third floor will control the seismic capacity of the building. The seismic capacity and the corresponding deflection are 8570 kN and 5.1 cm respectively (Fig. 8). The maximum point of load-deflection curve of Building IV has seismic capacity.
of 12079 kN, and the corresponding deflection of the building of 5.4 cm (Fig. 8). The Building IV is expected failure in the first floor. The seismic capacity and the corresponding deflection of the 1~3F retrofitted building are 12079 kN and 6.4 cm respectively (Fig. 8), and the building failure is expected in the first floor.

4. RESULTS AND DISCUSSION
Both JBSL [Eq. (1)] and proposed method [Eq. (2)] can indicate the insufficient capacity at 1~3 floor of Building I (Fig. 9). For Building II, the third floor failure of the building can be predicted also by the both methods (Fig. 10). However, the Eq. (2) also notes first floor failure of the Building II, III, and IV (Fig. 10, Fig. 11, and Fig. 12). The low results of the Eq. (2) are due to the simplified pushover analysis based on strength and ductility concern, but the force equation \( (ZW/A_i) \) is possible too conservative for ductility. According to this evidence, for future study, a broad range of analysis data is needed in order to set a good empirical equation.

![Figure 4. Load-deflection curve of floors for Building I (Bali, 2007)](image)

![Figure 5. Load-deflection curve of floors for Building II (Bali, 2007)](image)
Figure 6. Load-deflection curve of floors for Building III (Bali, 2007)

Figure 7. Load-deflection curve of floors for Building IV (Bali, 2007)

Figure 8. The load-deflection curves of the buildings (Bali, 2007)
Figure 9. Evaluation of storey capacity for Building I (Bali, 2007)

Figure 10. Evaluation of storey capacity for Building II (Bali, 2007)

Figure 11. Evaluation of storey capacity for Building III (Bali, 2007)
Figure 12. Evaluation of storey capacity for Building IV (Bali, 2007)

5. CONCLUSION

This study presents a simplified method of storey seismic capacity evaluation for low-rise reinforced concrete buildings. Based on the results and discussion of the case study, it can be concluded that JBSL and proposed method can predict the storey capacity of the buildings. However, the calculated result of proposed method is more conservative in prediction of the first storey of the buildings. For future study, a broad range of analysis data is needed in order to set a good empirical equation of the proposed method.

REFERENCES


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