SEISMIC EVALUATION AND RETROFIT OF RC BUILDING, IN NEPAL

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ABSTRACT

The evaluation based on both site inspection and structural calculation to represent the seismic performance of building in terms of the seismic index of structure I_S and seismic index of nonstructural elements I_N is called seismic evaluation. The seismic performance is evaluated by checking its ultimate strength capacity and deformation capacity. There are three different levels of screening methods to find the seismic capacity of RC buildings in Japanese standard and guidelines. In this study, the first and the second level of screening methods are used to evaluate an existing RC building in Nepal. After the evaluation, it was found that the first and second floors are judged as unsafe in both directions. For retrofit, optimum techniques shall be adopted. In this case shear walls with two boundary columns are installed. After retrofitting, again, analysis is done by using STERA-3D software. The result is compared as the second screening versus push over static (before and after retrofit) and dynamic analysis (before and after retrofit). The criteria of seismic capacity based on Nepalese standard are proposed by comparing Japanese and Nepalese standards.

Keywords: Seismic Evaluation, Nonlinear Frame Analysis, Seismic Retrofit.

1. INTRODUCTION

Nepal is a mountainous country and it lies in Earthquake prone zone. The seismic record shows that major earthquakes strike the region in every 75-100 years period. The oldest record available of a major earthquake dates back to 1255 AD. Three major earthquakes occurred in Kathmandu valley in the 19th century in 1810, 1833 and 1866 AD. These earthquakes have devastated Kathmandu time and again by claiming lives and livelihoods of thousands of people. The earthquake that occurred in 1255 not only killed one third of the population of the city but also killed the then incumbent king – Abhaya Malla. Similarly, the earthquake occurred in 1934 was the largest earthquake in Nepal having magnitude 8.3 on the Richter scale. More than 8000 people were killed in that earthquake.

Many buildings, especially in urban areas are constructed without proper structural designs and supervision. It is necessary to check the seismic performance of such buildings. From the safety point of view, the safety of human life is a primary concern. The purpose of this study is to be able to check the seismic performance of such buildings and retrofit if necessary which is the main part of the disaster mitigation.

2. METHODOLOGY

English Version of the “Japanese Standard, Guidelines and Technical Manual for Seismic Evaluation and Seismic Retrofit of Existing Reinforced Concrete Buildings,2001” is used in this study. After evaluating and retrofitting by using this standard and guidelines, STERA 3D-V5.9 software is used for

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nonlinear analysis. There are three levels of screening procedure, the first, the second, and the third level screening. In the first level screening method, material strength and contribution of cross sectional areas of vertical members are considered. In the second level of screening method, the ductility or deformation capacity of vertical members as well as their strength are considered. The second method is more accurate than the first method. For the third level of screening method, the contribution of strength and ductility of beams and diaphragm wall areas are also considered. It is more detailed and accurate method than the second level. In all above mentioned methods, we have to find the seismic index (I_S) of the structure. The seismic index represents the seismic performance of the structure. This I_S index is compared with the seismic demand index I_{S0}. The seismic index of target structure shall be calculated by Eq. (1) at each story and in each principal horizontal direction of a building. The irregularity index S_D and the time index T may be used commonly for all stories and directions.
Basic seismic index of the structures (E_0) is a product of strength index C, ductility index F and story modification factor φ. Structural irregularity index (S_D) is to modify the basic seismic index of structure E_0 and time index (T) is also used to reduce the seismic index of the target structure.

$$I_S \quad = E_0.\ S_D\ T \tag{1}$$

The seismic demand index of structure I_{S0} should be calculated by Eq. (2)

$$I_{S0}. = E_S.Z.G.U \tag{2}$$

The basic seismic demand E_S is 0.8 for first screening and 0.6 for second and third screening level where Z is zone index, G is ground index and U is usage index.

2.1. First level Screening Method:

The basic seismic index of structure E_0 shall be calculated by using the following Eqs. (3) and (4) based on approximate evaluation of the strength index C, the ductility index F, and the effective strength factor α. The larger value is taken as E_0 of the structure. If the story consists of extremely short columns E_0 value shall be taken only by equation (4).

$$E_0 = \frac{n+1}{n+i}\ (C_W + \alpha_1.C_C)\ F_W \tag{3}$$

$$E_0 = \frac{n+1}{n+i}\ (C_{SC} + \alpha_2.C_W + \alpha_3.C_C).F_{SC} \tag{4}$$

Then, irregularity index (S_D) and time index (T) are calculated with the standard guidelines. After that, the seismic index of the target structure (I_S) is compared with seismic demand index of the target building (I_{S0}). If I_S value is larger, the seismic performance of the building is judged as safe and we have to evaluate it by the second screening method if the value is less than the demanded I_{S0} value.

2.2. Second level Screening Method:

In this method, the axial force in the columns, reinforcement of the columns and shear walls are considered to calculate the strengths and ductility of the vertical members. The vertical elements are classified into five different categories. The shear force at ultimate flexural capacity (Q_{mu}) and ultimate shear capacity of columns and walls (Q_{su}) are calculated, and then their results were compared.
Ductility dominant basic seismic index of structure is calculated as:
Vertical members shall be classified by their ductility indices F into three groups or less defined as the first, the second, and the third group. The basic seismic index, $\boldsymbol{E_0}$ is calculated as the following:

$$E_0 = \frac{n+1}{n+i}\sqrt{E_1^{\,2}+E_2^{\,2}+E_3^{\,2}} \tag{5}$$

Strength-dominant basic index of structure is calculated as:
The effective strength factor α in the second and higher groups should be calculated considering the effects of yield deformations and clear heights of vertical members on the relationships between the story shear forces and the drift angles. The minimum effective strength factor of the vertical members should be used in each group. The basic seismic coefficient is calculated as:

$$E_0 = \frac{n+1}{n+i}\left(C_1 + \sum_j \alpha_j C_j\right)F_1 \tag{6}$$

The strength index C is calculated by dividing the ultimate load-carrying capacity of the vertical members in the story concerned by the weight of the building including live load for seismic calculation supported by the story concerned. Q_u is the minimum of Q_{mu} and Q_{su}.

$$C = \frac{Q_u}{\sum W} \tag{7}$$

In this method we have to check the $C_{TU}*S_D$ index which should be greater or equal to $0.3*Z*G*U$. If we supposed the value of Z, G and U is unity than $C_{TU}*S_D \geq 0.3$.

2.3. Nonlinear frame analysis by STERA 3D:

Nonlinear static push over analysis and dynamic analysis were carried out by using STERA 3D software. After the analysis of the target building with STERA 3D, the results are compared as second screening versus push over static analysis before and after retrofit and dynamic analysis (nonlinear earthquake response analysis) before and after retrofit. In dynamic analysis El Centro earthquake was used as input ground motion.

3. CASE STUDY OF EXIXTING BUILDING IN NEPAL

3.1. Introduction of the Target Building

The target building in this study is the Alapot Health Post Building. This health post building is situated at Alapot V.D.C., which is very near to Kathmandu Metropolitan City. It is a RC frame structure with infill brick wall and was built in 2007. It represents the majority of the existing building quality of Nepal. The size of the column is 230 mm * by 230 mm and beam size is 230 mm.* by 340 mm. The thickness of the slab is 110mm. The characteristic strength of concrete, f_{ck} =20 N/mm^2 and yield strength of steel,

σ_y=415 N/mm^2. The following Figs. 1 and 2 show picture of the building and first floor plan respectively.

Figure 1. Alapot Health Post Building

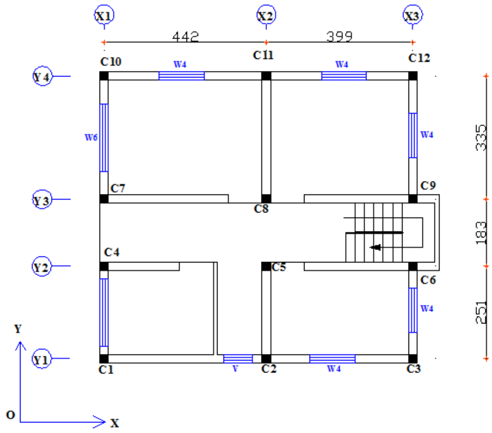

Figure 2. First floor plan(dimensions are in cm).

3.2. Seismic Evaluation Results

The building is evaluated by considering brick wall as spandrel wall and without considering brick wall. In first screening level the building was judged as unsafe in all floors in both cases in both directions. After that the building was evaluated by the second screening method. Tables 1 and 2 show the results of seismic evaluation for original building by the second screening. In this method the building was judged as safe in third story only in all conditions. Therefore, retrofit is needed in both direction and four shear walls (two in each direction) in first floor and three shear walls (two in X direction and one in Y direction) in second floor were installed. The seismic evaluation results of the target building before and after retrofit (the second screening method) are shown in Tables 1 and 2. As shown in Tables 1 and 2, the retrofitted building was judged as safe in all floors in both directions.

Table 1. X- Direction

Condition	Story	Before retrofit			After retrofit		
		I_s	Calculated $C_{TU*}S_D$	Judgement	I_s	Calculated $C_{TU*}S_D$	Judgement
with wall	3	1.32	0.41	Safe	1.32	0.41	Safe
	2	0.72	0.28	Unsafe	1.44	1.44	Safe
	1	0.67	0.26	Unsafe	0.88	0.88	Safe
without wall	3	1.32	0.41	Safe	1.32	0.41	Safe
	2	0.68	0.21	Unsafe	1.43	1.43	Safe
	1	0.50	0.16	Unsafe	0.83	0.83	Safe

Table 2. Y- Direction

Condition	Story	Before retrofit			After retrofit		
		I_s	Calculated $C_{TU*}S_D$	Judgement	I_s	Calculated $C_{TU*}S_D$	Judgement
with wall	3	1.32	0.41	Safe	1.32	0.41	Safe
	2	0.48	0.33	Unsafe	0.85	0.77	Safe
	1	0.46	0.17	Unsafe	0.91	0.91	Safe
without wall	3	1.32	0.41	Safe	1.32	0.41	Safe
	2	0.57	0.17	Unsafe	0.93	0.84	Safe
	1	0.41	0.13	Unsafe	0.84	0.84	Safe

3.3. STERA 3D Results

The nonlinear static pushover analysis was conducted by assuming the lateral loading condition as A_i distribution. Before retrofit, the yielding at the exterior ends of the beams and both ends of the columns was observed in the first story, but there was no yielded member in the second and the third stories in both directions. After retrofit, the strength of the first and the second stories were larger than the third story, although the third story had a large I_S value. The large value of I_S for the third story was due to the slender columns having large F values. Therefore, being the third story as the weakest story, the columns were started to yield from the third story in the STERA 3D analysis and these results were also in similar pattern with second screening method.
Nonlinear earthquake response analysis was conducted by applying the strong ground motion of the El Centro Earthquake. The results of the dynamic analysis with the El Centro earthquake ground motion are shown in the Figures. 3 and 4.

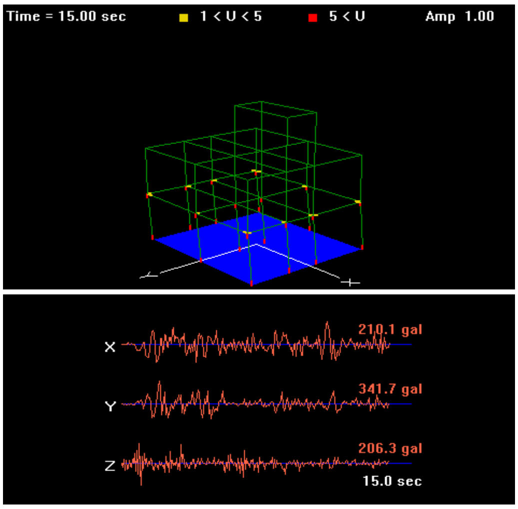

Figure 3. Nonlinear dynamic analysis with El Centro earthquake ground motion (before retrofit).

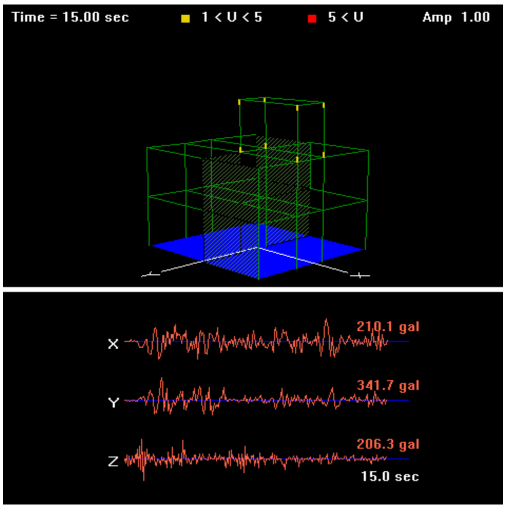

Figure 4 Nonlinear dynamic analysis with El Centro earthquake ground motion (after retrofit).

Before retrofit, the yielding at both ends of the first floor columns and yielding at the exterior end of the beams were observed in the first story. After retrofit, the first and second stories became stronger and no damage occurred, but the third story suffered by the yielding of all columns because it became weak as compared to the other two stories. In fact, the pattern of the result was similar as in case of the static analysis.

4. COMPARISON OF JAPANESE STANDARD WITH NEPALESE STANDARD

In Japanese standard, $C_{TU}*S_D$ shall be larger than $0.3*Z*G*U$, where 0.3 corresponds to structural characteristic factor (D_s) and base shear coefficient (C_0) corresponding to high ductile structure for second phase design. In the same way, in Nepalese standard, the value corresponding to structural performance factor K (which is 1 for high ductile structure) and basic seismic coefficient C (which is 0.08), will be 0.08. Therefore for Nepalese standard $C_{TU}*S_D \geq 0.08*Z*I$ should be appropriate.

Seismic demand index I_{S0} = 0.6 in Japanese standard which is very close to basic seismic index E_0 which is calculated by $C*F*\varphi$. In the same way E_0 for Nepalese standard is 0.12 to 0.256. Therefore the suitable value for demand index I_{S0} will be 0.25. But it needs a lot of theoretical and practical investigations to finalize the demand indices and it is the most challenging job.

5. CONCLUSION AND RECOMMENDATIONS

In the first screening method the building was judged as unsafe in all stories in both directions whereas in the second screening the third story was judged as safe. After retrofit, it was safe in all the stories in both directions. In the static push-over analysis and dynamic analysis by STERA 3D with the El Centro Earthquake ground motion yielding of columns is started in the third floor. It is because, after retrofit, the first and the second stories become very strong than the third story and failure was started from the weakest part.

On the basis of this study the following are some recommendations to increase the efficiency and accuracy of this standard.

- It is recommended to consider the contribution of non-structural elements like brick walls, hollow concrete blocks etc.
- The demand value of I_{S0} and $C_{TU}*S_D$ index in Japan may be slightly larger in case of Nepal due to its low seismicity. Therefore, further study to get accurate value of demand indexes is strongly recommended.
- There is no any provision in case of the foundation which is one of the very important parts of any structure. Therefore, a further study is strongly recommended towards the foundation.

ACKNOWLEDGEMENTS

Foremost, I would like to express my sincere gratitude to my supervisor Dr. Masanori TANI, research engineer from IISEE for the continuous support to my master paper. His useful comments, remarks, motivation and engagement through the learning process helped me in all aspects. Furthermore, I would like to thank my advisor Dr. Koichi MORITA, chief research engineer from IISEE for introducing me to the topic as well for his support to my individual study.

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