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Seismic Performance Evaluation of an RC Building with Brick Walls in Nepal
Part 2 Seismic Performance Evaluation of the Building

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Masonry wall Nonlinear analyses Nonstructural wall
Reinforced concrete Seismic performance Strut replacement

1. Introduction

Compressive tests of masonry prisms have been conducted to clarify the properties of brick walls, as explained on Part 1. This part analytically investigates the contribution of brick walls to the seismic performance of the target building.

2. Parametric Analyses of the Building with/without Brick Walls

Three analytical cases are considered herein, as shown in **Table 1**.

2.1 Modeling of the Building

The target building was modeled as a space frame. The assumptions of modeling are shown as follows:

1) The five-story superstructure without basement was represented by line elements. The footing beams were assumed to be rigid and foundations were replaced by pin supports under the footing beam elements. The columns and beams were replaced by line elements, whose rigid zones were set up to D/4 from the member critical section (D: depth of each member). The restoring force characteristics of the columns and beams were evaluated based on inelastic and elastic models shown in **Table 2**.
2) The elastic moduli and compressive strengths obtained from the tests on Part 1 were used in modeling of brick walls.
3) The building was modeled in three cases. In Case A, the weight of the building was assumed to be the weight of the frame only. In Cases B and C, the weight of brick walls was also considered in weight of the building.
   For Case C, the stiffness and strength of brick walls were also considered. Each brick wall was replaced by a line (strut) element with pins at both ends. The restoring characteristics of the strut was represented by a bilinear model linking the origin to yield point. The width of strut was calculated by Equation (1) given by Smith & Carter [1], which was used to evaluate the stiffness of brick walls. On the other hand, the strength of strut was evaluated as per the width by Equation (2) given by Mainstone [2]. The strength of strut is obtained according to the following equation: the strength of strut = compressive strength × width × thickness. In Case C, compressive strength of material was reduced so that the strength of strut having the width obtained by Equation (2) was equal to that having the width obtained by Equation (1).

$$w = 0.58\left(\frac{1}{H}\right)^{-0.445}\left(\lambda_h H'\right)^{0.335 d_z \left(\frac{1}{H}\right)^{0.064}} \tag{1}$$

$$w = 0.175 d_z \left(\lambda_h H'\right)^{-0.4} \tag{2}$$

Symbols in the equations are referred to references.

The analytical models based on the above assumptions are shown in **Figure 1**.

Table 1 Analyses cases

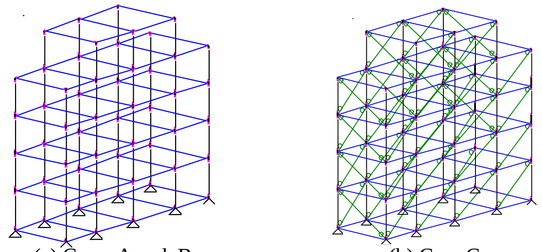
Analyses case	Consideration of brick walls	
Case A		
Case B	weight	
Case C	weight	Stiffness and Strength

Table 2 Modeling for restoring force characteristics of column and beam

member	Bending	Shear and Axis
Column	Multi spring model	Uniaxial elastic spring
Beam	Uniaxial inelastic spring	Uniaxial elastic spring

Table 3 Comparison of natural period

Natural period (s)		Measured value	Analyses value		
			Case A	Case B	Case C
Span direction	1st	0.33~0.34	0.498	0.646	0.268
	2nd	0.15~0.16	0.168	0.216	0.082
Ridge direction	1st	0.11~0.13	0.420	0.546	0.138



(a) Cases A and, B (b) Case C

Figure 1 Analytical modeling

2.2 Analytical Results

Eigenvalue analyses were conducted for all three cases. **Table 3** compares the analytical results with the natural periods obtained by the past observation [3]. The natural periods of Case C considering the stiffness and strength of brick walls had the closest value to the measurements.

Pushover analyses were conducted in the ridge direction. Loading was applied from the northeast to southwest direction up to a maximum story drift of 0.05 rad. **Figure 2** compares the base shear coefficient versus ground floor story drift angle among three cases.

Case C with the struts representing brick walls, had the highest yield strength among three cases: 1.7 times higher than that of Case A, and 2.4 times higher than that of Case B. It indicated that the strength of the building significantly increased when the brick walls were taken into account as Case C.

3 Seismic Performance Evaluation Based on Equivalent Single Degree of Freedom System

3.1 Replacement to Equivalent Single Degree of Freedom System

The results of pushover analyses in Section 2 were replaced to the performance curves (S_a-S_d relationships) in the equivalent single degree of freedom systems. Furthermore, each performance curve

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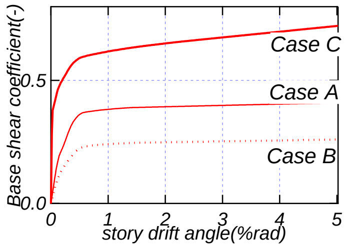

Figure 2 Comparison of strength

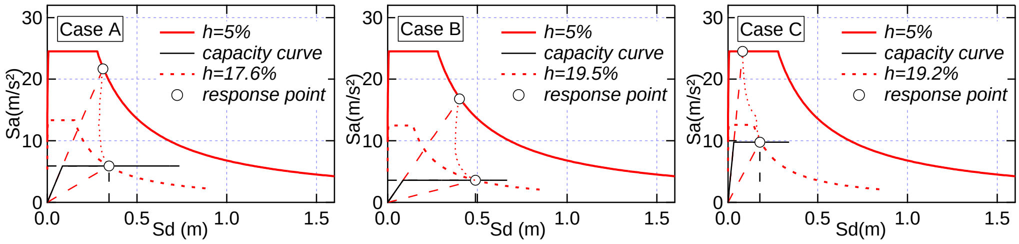

Figure 3 Comparison of response point

was idealized by a bilinear curve so that the bilinear curve had the equivalent energy dissipation capacity to that of the performance curve.

3.2 Design response spectrum used in Nepal

Before the introduction of Nepal National Building Code (NBC) in 1994, structural design in Nepal was done by referring Indian Standards (IS), which is the origin of NBC [4]. Thus, an acceleration response spectrum was calculated for the target building according to IS.

3.3 Comparison of seismic performance

Figure 3 shows the response points of three analytical cases evaluated by overlaying the bilinear curve on the design spectrum curve in IS [5].

Case A having only RC frame responded 0.34 m in displacement and 4.05 in ductility factor which was defined as a ratio of the displacement response divided by the yield displacement. Case B considering the weight of brick walls attained 0.48 m in displacement and 5.65 in ductility factor higher than those of Case A. Case C in which brick walls were replaced by struts showed the lowest value of 0.18 m in displacement. These results show the response displacement of the building is reduced by considering brick walls as Case C. Buildings in Nepal are designed neglecting brick walls as nonstructural elements. However, it is needed to design buildings based on the fact that brick walls can change the structural performance and earthquake responses

4. Analyses with Increasing/Decreasing the Number of Floors

As mentioned in Part 1, this target building was three-story building in the design phase, and extended to five-story building in the construction phase. In order to investigate the effects of such extension on the seismic performance of building, additional pushover analyses and seismic performance evaluations were conducted in the same manner as Sections 2 to 3 using building models with increasing/decreasing the number of floors: three-story building in design, and four to eight-story buildings, because 1, 2, or 3 floors extension after construction was popular in the surrounding areas of the building site.

Table 4 compares the story drift angle of the ground floor at the response point among all analytical cases.

The five-story building corresponding to the real building responded

Table 4 Comparison of story drift angle of the ground floor at response point

Rank	Drift angle of Ground Floor (%rad)
3 story (in design)	1.59
4 story	3.11
5 story (actual)	2.80
6 story	2.84
7 story	3.00
8 story	3.12

approximately 1.76 times larger than the three-story building in the design phase. The eight-story building assuming 3 floors extension attained approximately 1.11 and 1.96 larger than the five-story and three-story buildings, respectively.

5. Conclusions

Experiments and analyses were conducted to investigate the effects of brick walls on the seismic performance of a typical RC building in Kathmandu, Nepal.

The major findings can be summarized below.

(1)The building was replaced by a space frame model. Pushover analyses and response evaluations were conducted to three cases: Only RC frame, RC frame considering the weight of brick walls, and RC frame considering the weight, stiffness, and strength of brick walls, which were modeled based on the experiments reported in Part 1. It was observed that the brick walls significantly reduced the earthquake response of the building by considering not only the weight but also the stiffness and strength.

(2)In Nepal, currently, brick walls are neglected as nonstructural elements. However, it should be noted the brick walls significantly affect the structural performance of typical buildings in Nepal.

(3)Floor extension of Nepalese buildings increased the inter-story drift response, resulting in significant decrease of the seismic performance.

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