EFFECT OF TIME PERIOD AND DAMPING COEFFICIENT ON SEISMIC PERFORMANCES OF OGS RC BUILDINGS

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ABSTRACT

*The ground floor kept opened is a common phenomenon in the of planning of both residential and commercial reinforced concrete (RC) buildings. Car parking, shops, open lawn etc. are the most common needs that may inspire the planning of such kind of open ground story (OGS) RC buildings. Due to absence of brick masonry walls in ground floor of these buildings, lateral stiffness becomes much reduced which may cause these buildings collapsed under seismic loading. The soft story phenomenon may also be an index property to explain this vulnerability. This study evaluates, through pushover analysis, the relation of few significant parameters that are relevant in the seismic performances of OGS RC buildings. The analysis shows that life safety (LS) and structural safety (*i.e. *Collapse prevention - CP) are depended on time period and damping coefficient at their performance points. The study shows that the increasing values of time period and damping coefficient are necessary to get performance points for OGS RC buildings considered in this study. The study indicates that the variation of ground floor stiffness might be a prior indicator of seismic performances of OGS RC buildings.*

Keywords: *Open ground story, soft story, seismic performance, time period, damping coefficient.*

1. INTRODUCTION

Seismic performance of OGS (open ground story) RC (reinforced concrete) buildings is now a matter of concern for structural engineers due to its structural vulnerability during past and recent earthquakes. Due to lack of brick masonry wall (BMW) in ground floor of these buildings, stiffness becomes reduced compared to its immediate upper floor. The upper floors act as a single mass like an inverse pendulum during earthquake. This could cause the whole building tilted at ground floor (Murty, 2005). Besides this, acceleration of ground is also a matter of concern in the seismic performances of these buildings. In addition, time period and damping coefficient are also significant indicators of their performances. To evaluate the relation of these indicators with life safety and structural safety of these buildings, pushover analysis has been performed using ETABS software.

2. MODELING OF OGS RC BUILDINGS

Four numbers of 8-story OGS RC building models have been taken in this study. The description of the models is shown in Table 1. The plan of the buildings is shown in Figure 1(a). Sections at C-C of the buildings are shown in Figures 1(b) through 1(f). The buildings are considered to be located in seismic zone-2 (Z = 0.15) as per code (BNBC, 2006) and intended for residential purpose.

Table 1: Description of the models

Model No.	Description
Model-1:	Open Ground Story with 5″ (127 mm) thick BMW in the upper stories [Figure 1(b)].
Model-2:	Bare frame with open ground story [Figure 1(c)].
Model-3:	Open ground story with 5″ (127 mm) thick BMW in the upper stories. In addition lintel beams are provided in ground story [Figure 1(d)].
Model-4:	Same as MODEL-3 with changing the earthquake hazard level [Figure 1(e)].
Model-5:	Open ground story with 5″ (127 mm) thick exterior BMW in the upper stories and no interior BMW [Figure 1(f)].

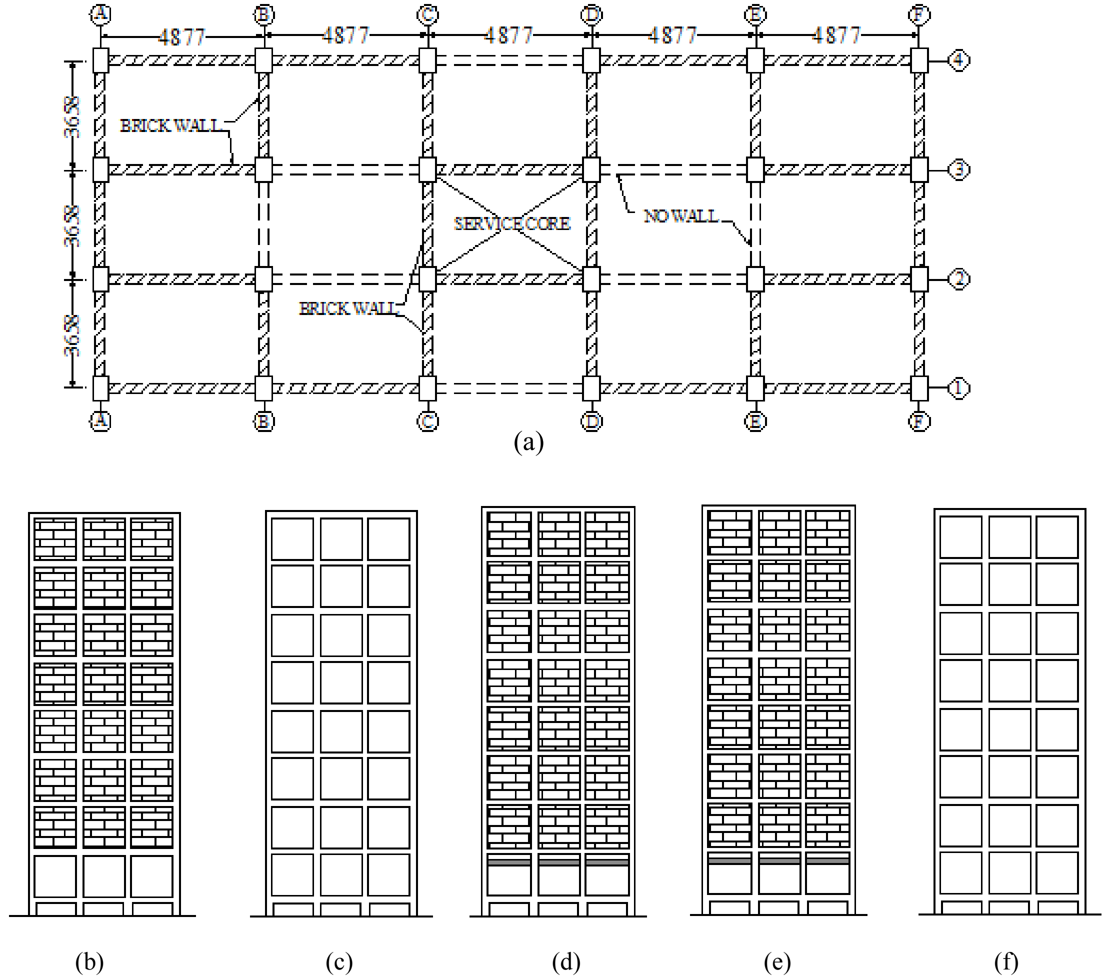

Figure 1: Plan and sections of the buildings: (a) Plan, (b) Section C-C of MODEL-1, (c) Section C-C of MODEL-2, (d) Section C-C of MODEL-3, (e) Section C-C of MODEL-4, (f) Section C-C of MODEL-5. All dimensions are in mm.

The typical panel size is assumed as 3658 mm by 4877 mm (Figure 1). Elastic moduli of concrete and brick masonry are assumed as 2.5×10^4 N/mm^2 and 3.5×10^3 N/mm^2 respectively. The unit weight of concrete and masonry are taken as 2.3×10^{-5} N/mm^3 and 1.88×10^{-5} N/mm^3 respectively. The live loads and floor finish are considered as 1.9 kN/m^2 and 1.2 kN/m^2 respectively. Size of beams and columns are taken as 254×406 mm and 305×508 mm respectively. Three percent (3%) rebar is taken for columns. Slab thickness is taken as 127 mm. In seismic load calculation, 25% of live load is considered. For pushover analysis seismic parameters are considered as shown in Table 2 followed by codes (BNBC, 2006; ATC-40, 1996; FEMA-356, 2000).

Table 2: Seismic Parameters

Parameters	**Values**
Seismic zone:	Z = 0.15 (Zone – 2)
Earthquake hazard level:	E = 1 for Design Earthquake (DE)
Seismic source type:	A ≥15 km
Near source factor:	N = 1
Soil profile type:	S_E (soft soil, penetration value <15)
Type of structure:	B (for new structure and consideration of long duration of ground shaking)

BMW has been modelled based on the theory of diagonal strut modelling (Holmes, 1961). Default hinges are considered as P-M-M for columns, V2 and M3 for beams and 'P' for strut for simplicity (Habibullah, 1995). Location of hinges is considered according to the literature (ATC-40, 1996; Inel & Ozmen, 2006).

3. EVALUATION OF STORY STIFFNESS

Story stiffness is a basic index property for evaluating the vulnerability of OGS buildings. From this view point, ground floor story stiffness of the models in terms of their immediate upper stories under equivalent linear static loading in long direction (*i.e.* EQX) has been analyzed according to literature (Chopra, 2002; Clough & Penzien, 1993). Their values in percentages are shown along the ordinate in Figure 2.

From Fig. 2 it can be seen that the ground floor stiffness of MODEL-1, MODEL-3, MODEL-4, and MODEL-5 lie within 17% to 20% only in terms of their immediate upper story stiffness which are much lower than 70% of the code limit (BNBC, 2006). This may be due to lack of BMW in ground floors of these models. It was further noticed that these stiffness were not increased even though the lintel beams were provided in ground floor of MODEL-3 and MODEL-4. Besides this, MODEL-2 shows its ground floor stiffness much higher than the code limit. This may be due to bare frame in which there is no chance of higher stiffness of immediate upper floor than that of its ground floor.

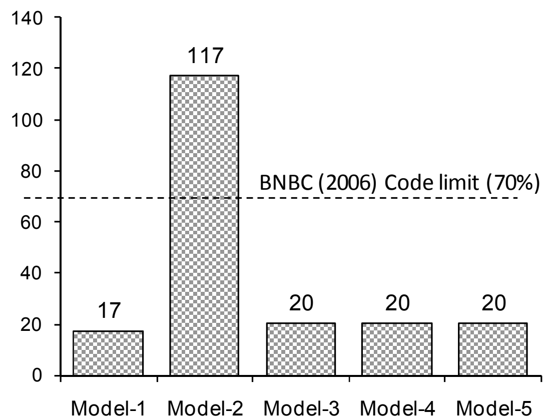

Figure 2: Ground floor story stiffness in terms of its immediate upper story (%)

4. SEISMIC PERFORMANCES

Seismic performances were determined in acceleration displacement response spectrum (ADRS) format through pushover analysis as shown in Figure 3. The analysis result is shown under the load case of PUSHX (*i.e.* nonlinear static pushover loading in long direction 'X'). In this figure $\bar{e}_p$(M1), $\bar{e}_p$(M2), $\bar{e}_p$(M4) and $\bar{e}_p$(M5) denote the performance points of MODEL-1, MODEL-2, MODEL-4, and MODEL-5. Performance point was not found in case of MODEL-3. Each capacity curve of the models intersects with different demand curve (*i.e.* ground motion) and time period. In this figure the performance point $\bar{e}_p$(M2) for MODEL-2 indicates the lowest performance as it lies in the highest roof displacement (D) of 248 mm among the models considered in this study. Moreover, its performance point, $\bar{e}_p$(M2) intersects with a demand curve of 28% damping and a time period ($T_{eff.}$) of 2.88 sec. which are the highest values among the models (Figure 3 and Table 3).

On the other hand, the point $\bar{e}_p$(M4) for MODEL-4 indicates the highest performance as it lies with the lowest roof displacement (D) of 44 mm among the models considered in this study. In addition, its performance point, $\bar{e}_p$(M4) was intersected with a demand curve of 15% damping and a time period ($T_{eff.}$) of 0.88 sec. which are the lowest among the models. Besides this, the performance points $\bar{e}_p$(M1) and $\bar{e}_p$(M5) for MODEL-1 and MODEL-5 lie within the range of MODEL-2 and MODEL-4 in terms of their roof displacements (Fig. 3 and Table 3). The time period and damping coefficients of these two models (MODEL-1 and MODEL-5) were found within the range of MODEL-2 and MODEL-4 as well. It may be mentioned here that MODEL-3 does not show any performance point under earthquake hazard level of DE (design earthquake). By changing this level from DE to SE (serviceability earthquake), this model (*i.e.* MODEL-3) shows its performance point. This model is represented as MODEL-4 in this study.

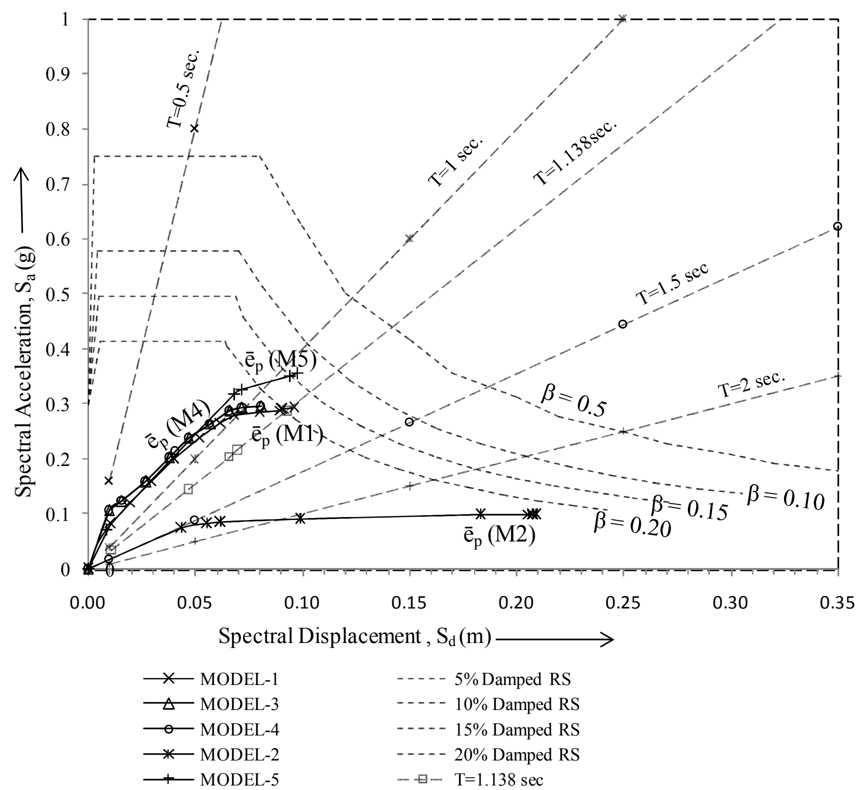

Figure 3: Seismic performances of the models in ADRS format

Table – 3: Effect of time period and damping coefficient on life and structural safety

Model No.	Base shear, V (kN)	Roof Displ., D (mm)	Time period, $T_{eff.}$ (sec.)	Damping coefficient $\beta_{eff.}$	Hinge formed status*			
					B-IO	IO-LS	LS-CP	CP-E
MODEL-1	4842	101	1.14	0.19	61	32	72	2
MODEL-2	903	248	2.88	0.28	102	88	144	2
MODEL-3	No performance point found							
MODEL-4	3330	44	0.88	0.15	71	54	14	0
MODEL-5	4757	96	1.02	0.16	40	37	75	2

* B: End of Elastic Stiffness, IO: Immediate Occupancy, LS: Life Safety, CP: Collapse Prevention, C: Collapse, D: Damage, E: Energy Lost

On the other hand, in case of MODEL-4, its hinge formed status was found the best with showing the least amount of hinges formed within LS-CP (life safety to collapse prevention) level and no hinges formed after this level (ATC-40, 1996; FEMA-356, 2000). In this case, the time period and damping coefficient were determined as the lowest. But in case of MODEL-2, the hinges formed was determined as the highest within LS-CP even though two more hinges formed towards most hazard level (CP-E) where the value of time period and damping coefficient were the highest. The other two models (MODEL-1 and MODEL-5) show their hinge formed status gradually lower in terms of their higher value of time period and damping coefficient. This phenomenon indicates that the lower is the stiffness of the ground story of the building, the higher are the required time period and damping coefficient for getting acceptable performance points.

Story drift is another important indicator in the seismic performances of OGS buildings. The ground floor drift ratios of all the models considered in this study were found exceeded the code limits (BNBC, 2006; ATC-40, 1996). This effect was also observed in the case of the hinge formed status where no models were found within LS level (Table 4).

Table 4: Ground floor drift ratio of the models

Model No.	Drift ratio	BNBC (2006) limitation	ATC-40 (1996) limitation
MODEL-1	0.024	0.004	0.005
MODEL-2	0.010	0.004	0.005
MODEL-3	0.097	0.004	0.005
MODEL-4	0.018	0.004	0.005
MODEL-5	0.020	0.004	0.005

5. CONCLUSIONS

Due to lack of brick masonry wall (BMW) in ground floor of the models, story stiffness was found inadequate except in case of bare frame model. This stiffness may serve as an index property of OGS buildings. However, it could not ensure the adequacy of seismic performance of a model as in the case of MODEL-2 which shows the worst performance in spite o its adequate stiffness in its ground floor. Besides this, the analysis based on performance phenomenon, like pushover analysis may predict the more real and a unique presentation of structural condition. In this respect, seismic performances in ADRS format found performance points where the capacity curves met with demand curves or in other words ground motion with specific damping coefficients. Time period at performance points were predicted as well. The analysis results show that the lowering of performance point in terms of roof displacements demand higher time period and damping coefficient (MODEL-4, MODEL-1, MODEL-5 and MODEL-2). Hinge formed status were also found to comply with this relation. This phenomenon may explain that the lower is the stiffness of ground floor of OGS RC buildings, the higher are the required time period and damping coefficient for getting a performance point. These time period and damping coefficients may be controlled by some means like changing story stiffness (shear wall, larger section for column), using damper and so on.

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