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INFLUENCE OF MASONRY INFILLS ON THE DYNAMIC RESPONSE OF R/C FRAMED STRUCTURES

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Abstract

A three bay ten-story reinforced concrete building frame was analyzed under strong ground motion to quantitatively evaluate the effects of distribution of masonry infill panels in elevation on the seismic performance of the frame. The nonlinear dynamic analysis of the masonry infilled frame model was performed under the EL-Centro 1940 North-South earthquake component accelerogram using the computational platform IDARC2D version 4.0. Two practically relevant cases of distribution of masonry infill panels in the structural elevation were considered for the dynamic analysis. The peak ground acceleration that was considered corresponds to Richter scale magnitudes of 7.6. The study quantitatively shows that distribution of infill panels in the elevation of a framed building structure may be a crucial factor in deciding the survival or collapse of the structure in the event of a severe earthquake.

Key Words

Masonry infill, Soft story, Silt column, Dynamic analysis

1 Introduction

Significant experimental research has been performed in the last few decades to evaluate the contribution of the infill panels to the inelastic response of masonry infilled frames under simulated earthquake loading [Fiorato et al. (1970), Klingner and Bertero (1976), Bertero and Brokken (1983), Zarnic and Tomazevic (1990), Mander et al. (1994), Mehrabi and Shing (1996)]. Testing methodologies were designed to study the influence of a variety of governing parameters including properties of constituent materials, pattern and frequency of lateral loading (in case of cyclic loading), reinforcement content, relative beam and column strengths, frame-panel interface and the infill aspect ratio. An extensive review of research on testing and modelling of infilled frames through 1987 has been reported by Moghaddam and Dowling (1987). A comprehensive review of the relevant literature published subsequent to 1987 up to 1996 is presented by Madan et al. (1997).

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A particular configuration of engineered masonry infilled frame structure that was observed to suffer severe damage and in some cases complete collapse in the recent Bhuj earthquake was the one in which the masonry infill panels are discontinued at the base for reasons of functionality thus resulting in a structural configuration wherein the columns at the base act as stilts (stilt columns) and the entire building mass is supported on these stilt columns. While designing these buildings, the masonry panels were omitted at the base for functional purposes such as providing parking spaces at the ground level or basements below the ground level. The catastrophic experience of engineered masonry infilled frame structures with certain layouts of infill panels in the Bhuj earthquake has again underlined the importance of considering the influence of masonry infills on the seismic performance of building frames. However, the theoretical evaluation of seismic damage in practical masonry infilled frame structures presents a complex problem since a realistic assessment of structural damage due to strong motion, strictly speaking, requires a non-linear dynamic analysis of the entire structure. Moreover, the available numerical models for non-linear dynamic analysis of masonry infill panels are still in the experimental stages of development, as they have not been verified conclusively or exhaustively. The present study attempts to analytically investigate the effect of the layout of masonry infill panels in the elevation of masonry infilled frame structures on the seismic performance and the damage potential of the structure under strong ground motion using realistic and efficient computational models. The study focuses on the structural configurations of masonry infilled frames that are commonly constructed in the field and particularly vulnerable seismically, such as Infilled frame without infill panels in the first storey (soft first story or building supported on stilt columns). An important objective of the study is to rationally predict the seismic damage that can be suffered by the practical masonry infilled frame construction with seismically undesirable layout of the masonry panels in elevation when subjected to a high intensity earthquake.

2 Theoretical Evaluation of Seismic Response of Multi-Storey Masonry Infilled Frames

A three bay ten-story reinforced concrete building frame was analyzed under strong ground motion to evaluate the effects of distribution of masonry infill panels in elevation on the seismic performance of the frame. The present section of the paper includes the details of structural, element and material modeling, distributions of the masonry panels considered in the study and assumptions and parameters of dynamic analysis.

2.1 Structural Model

The structural model of the masonry infilled frame considered for evaluation is shown in Figure 1. The reinforcement details of the frame were obtained using the computer program STAAD Pro for elastic analysis and strength design in accordance with the standard criteria for earthquake resistant design. Table 1 presents the design reinforcement details for different structural frame members as well as the material properties assumed in the design.

2.2 Case Studies of Nonlinear Dynamic Analysis

The nonlinear dynamic analysis of the structure was performed under the El-Centro 1940 North-South earthquake component accelerogram using the computational platform IDARC2D version 4.0 [Valles et al. (1995)]. The peak ground acceleration considered corresponds to Richter scale magnitudes of 7.6.

For the sake of brevity, the paper presents only the following salient practically relevant and theoretically representative cases that considered for nonlinear dynamic time history analysis:

a) Completely infilled frame.
b) Infilled frame without infill panels in the first storey (soft first story or building supported on stilt columns).
c) Bare Frame without any infill panels (hypothetical case considered for comparison).

The effect of seismic actions is based on the damage indices developed by Park (1986).

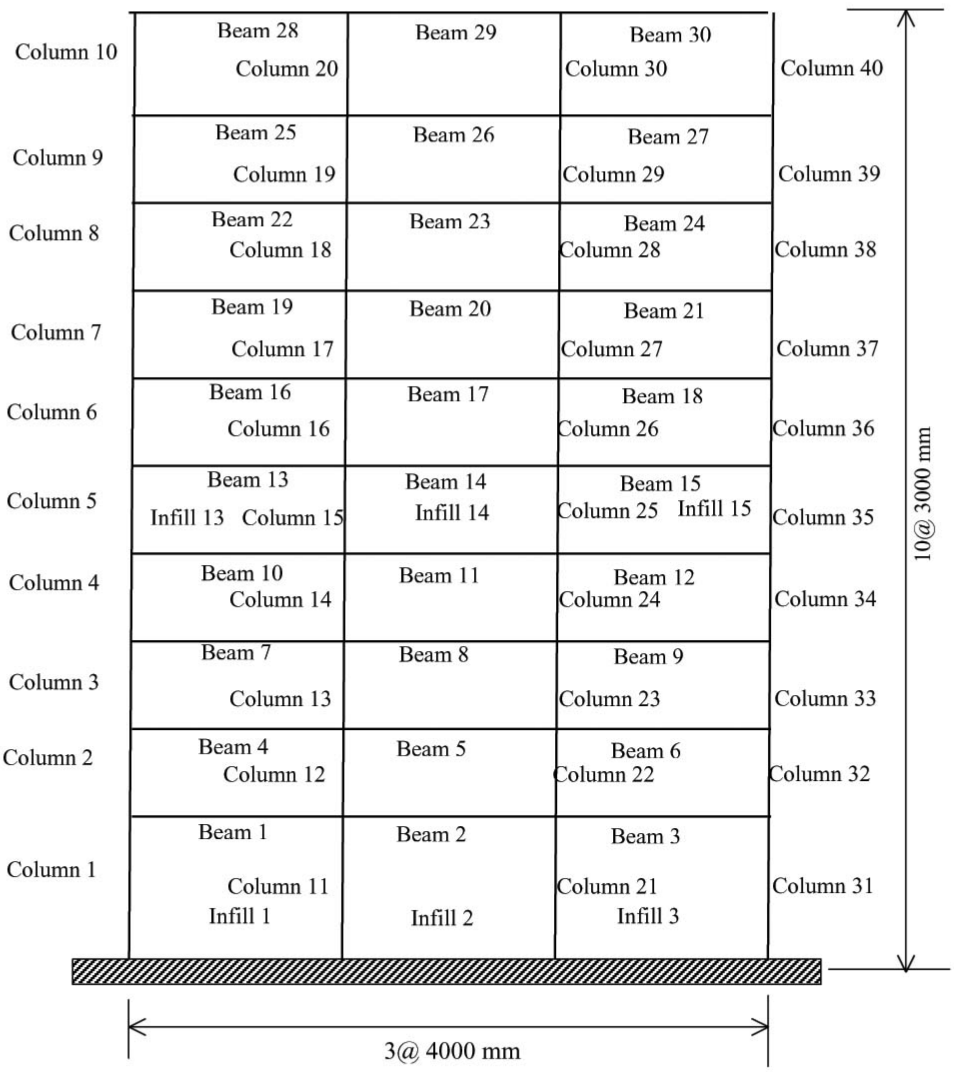


Figure 1 Structural model of masonry infilled frame for nonlinear dynamic analysis

Table 1 Properties and reinforcement details of structural elements

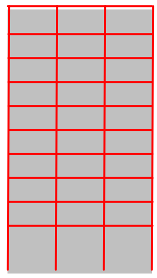
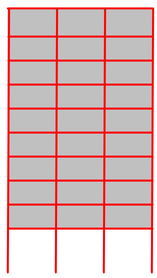
Section	Longitudinal Reinforcement (Each face for columns)	Transverse Reinforcement
Beam B1 (Typical)	3 # 16 & 2 #12	# 8 @ 200 mm
Column C1	4 # 25	# 8 @ 200 mm
Column C2	4 # 25	# 8 @ 200 mm
Column C3	4 # 20	# 8 @ 200 mm
Column C4	4 # 20	# 8 @ 200 mm
Column C5	4 # 16	# 8 @ 200 mm
Column C6	4 # 16	# 8 @ 200 mm
Column C7	4 # 16	# 8 @ 200 mm
Column C8	4 # 12	# 8 @ 200 mm
Column C9	4 # 12	# 8 @ 200 mm
Column C10	5 # 25	# 8 @ 200 mm
Column C11	5 # 25	# 8 @ 200 mm
Column C12	4 # 25	# 8 @ 200 mm
Column C13	4 # 25	# 8 @ 200 mm
Column C14	4 # 20	# 8 @ 200 mm
Column C15	4 # 20	# 8 @ 200 mm
Column C16	4 # 20	# 8 @ 200 mm
Column C17	4 # 16	# 8 @ 200 mm
Column C18	4 # 16	# 8 @ 200 mm

3 Results and Interpretation

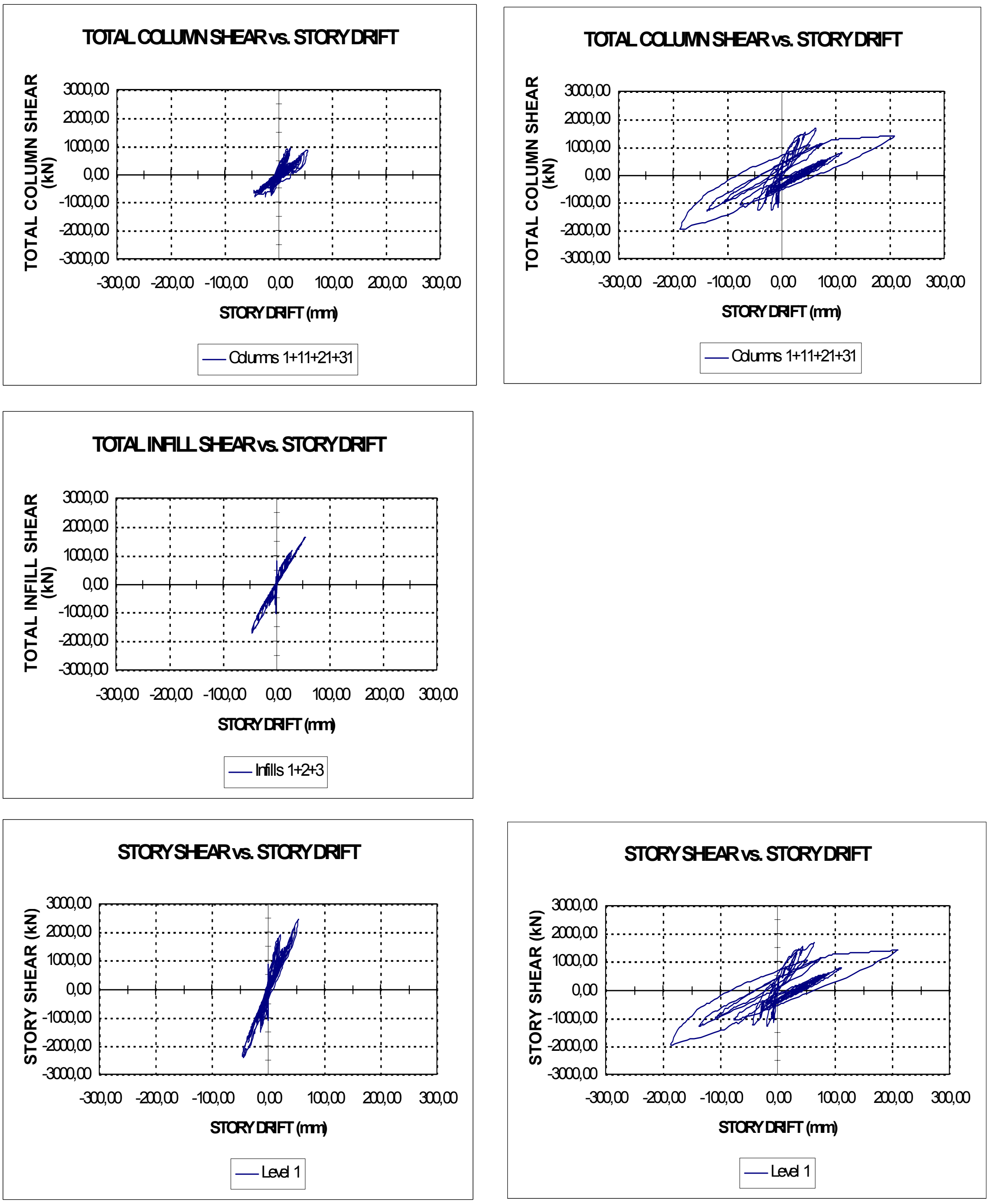
Table 2 presents a summary of the results of the non-linear dynamic analysis of the frame model for various cases considered in the study. The results of the nonlinear dynamic response for various cases are also illustrated graphically in Figure 2. The Table 2and Figure 2provide the results of analysis for the Imperial Valley earthquake (May, 1940) ground motion accelerogram (north-south component) recorded at the El-Centro terminal substation that measured 7.6 on the Richter scale. A corresponding analysis was also carried out for El- Centro ground motion scaled to a Richter scale magnitude of 7.1 for comparison. The tabulated results include the quantitative indices of cumulative damage in the frame members as well as the overall damage in the frame. A brief inspection of the Table 1 and Figure 2 reveals that the seismic performance of the frame that is completely infilled with masonry panels is much better than the hypothetical case of the bare frame, which has no infill panels at all. The damage indices included in Table 2 indicate that the overall frame damage in a bare frame is almost four times that of the damage in the completely infilled frame under the ground motion corresponding to Richter scale magnitude of 7.6. In fact, the completely infilled frame is practically undamaged based on the interpretation of overall damage index provided by Table 2. Therefore, the presence of infill in all the panels of the frame reduces the seismic damage in the frame members considerably. The chronology of structural events included in Table 3 indicates that cracking in structural frame elements (beams and columns) initiates at a

much later time during the ground motion in case of the completely inflled frames than in case of the bare frame. Further, the presence of masonry infill panels in an infilled frame prevents the yielding of beams and columns that is detected in case of the bare frame.

Table 2. Summary of Results of Dynamic Analysis under El-Centro Ground Motion for 35 seconds duration (PGA = 0.945 g, I = 7.6 on Richter scale)

Analysis case	**Story Number**	**Maximum Drift ratio %**	**Maximum Story Shear (kN)**	**Beam Slab Damage**	**Column Damage**	**Overall Frame Damage**	**Schematics**	**Remarks**
Completely Infilled Frame	10	0.18	1133.91	0.014	0.000	**0.32**		Cracking in Beam 6 at 0.849 sec, Yielding in Beam 3 at 1.46 sec, Cracking in Column 1 (bottom) at 1.523 sec, Yielding in Column 31 (bottom) at 6.042 sec
	9	0.45	1347.03	0.029	0.009			
	8	0.74	1396.85	0.077	0.004			
	7	1.01	1638.45	0.122	0.004			
	6	1.36	1827.11	0.165	0.000			
	5	1.60	1966.12	0.209	0.000			
	4	1.75	1998.76	0.240	0.000			
	3	2.01	2185.68	0.268	0.000			
	2	2.32	2354.68	0.312	0.000			
	1	1.81	2486.04	0.126	**0.408**			
Infilled Frame without infill panels in First Story	10	0.12	1126.96	0.000	0.000	**1.23 (Colla-pse)**		Cracking in Beam 1 at 0.630 sec, Yielding in Beam 1 at 0.863 sec, Cracking in Column 31 (bottom) at 0.819 sec, Yielding in Column 1 (bottom) at 1.553 sec
	9	0.26	1326.57	0.007	0.028			
	8	0.49	1299.04	0.039	0.003			
	7	0.72	1368.09	0.073	0.005			
	6	1.00	1467.41	0.107	0.000			
	5	1.29	1651.78	0.136	0.000			
	4	1.54	1757.83	0.170	0.000			
	3	1.82	1762.92	0.200	0.000			
	2	2.45	1739.95	0.122	0.353			
	1	6.99	1969.77	0.073	**1.526**			

The examination of results presented in Table 2 as well as the lateral force-deformation hysteresis curves illustrated in Figure 2 offers an interesting interpretation. The overall frame damage indices provided in Table 2 suggest that the masonry infilled frame with a soft story at level 1 (ground level or first story) may collapse due extensive or severe damage in case of a strong earthquake of intensity 7.6 on the Richter scale, since the damage index larger than 1.0 signifies the structure or collapse of the frame [Table 3]. The schematics shown in Figure 3 illustrate the final state of the frame at collapse with the location of cracks and yield zones. Thus, a masonry infilled frame structure resting on stilt columns at the ground level is an extremely vulnerable structural configuration in a seismic event. The hysteresis curves presented in Figure 2 corroborate this finding as the lateral force-deformation curves for the columns at the first story (level 1) display excessive hysteretic energy dissipation in case there are no infill panels in that story (i.e. stilt columns at level 1).



(a) 1st Story Response of infilled frame (b) First Story Response of soft story frame

Figure 2 Comparison of Dynamic Response of the Completely Infilled Frame vs Infilled Frame with Soft Story (No Panels) at Level 1 under ElCentro ground motion (PGA = 0.95g), Richter Scale Magnitude 7.6

The results suggest the discontinuation of infill panels in the first story (level 1) may Result in the collapse of the structure in the event of a strong earthquake with intensity 7.6 while the presence of a single infill panel in the first story may prevent the collapse.

Table 3: Interpretation of Overall Damage Index (Park et al. 1986)

Limit State Damage Index (DI)	Degree of Damage	Usability	Appearance
0.00	None - Slight	Usable	Undeformed/ uncracked
0.20 – 0.30	Slight - Minor	Temporarily unusable	Moderate – severe cracks
0.50 – 0.60	Moderate - severe	Temporarily unusable	Spalling of concrete
> 1.0	Collapse	Unusable	Loss of shear/axial stress

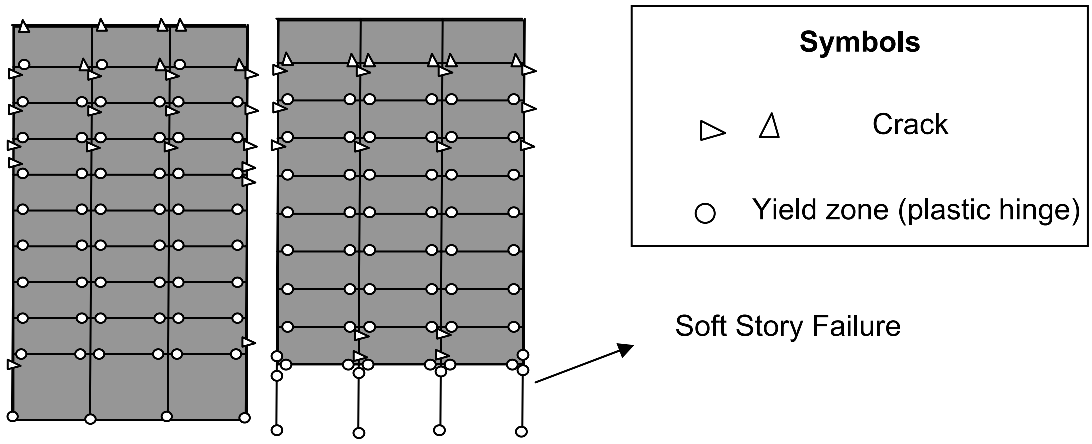


Figure 3: Final States of the Masonry Infilled Frames at the end of the Seismic Event due to ElCentro ground motion (PGA = 0.95 g), Richter Scale magnitude = 7.6

4 Conclusions

The A three bay ten-story reinforced concrete building frame was analysed under strong ground motion to quantitatively evaluate the effects of distribution of masonry infill panels in elevation on the seismic performance of the frame. The nonlinear dynamic analysis of the masonry infilled frame model was performed under the EL-Centro 1940 North-South earthquake component accelerogram using the computational platform IDARC2D version 4.0 [Valles et al. (1996)]. Various practically relevant cases of distribution of masonry infill panels in the structural elevation were considered for the dynamic analysis. Two different peak ground accelerations were considered corresponding to Richter scale magnitudes of 7.1 and 7.6 respectively. The results of the non-linear dynamic analysis quantitatively demonstrate the following facts:

(a) The seismic performance of the frame that is completely infilled with masonry panels is much better than the corresponding bare frame without any infill panels. The presence of infill in all the panels of the frame reduces the seismic damage in the frame members considerably.

(b) The seismic performance of a masonry infilled frame is adversely and significantly affected if the infill panels are discontinued in the first story (soft story at level 1), which results in a structural configuration wherein the entire building mass is resting on stilt columns.

(c) The discontinuation of infill panels in the first story (level 1) may result in the collapse of a masonry infilled frame structure in the event of a strong earthquake.

Thus, the study quantitatively shows that distribution of infill panels in the elevation of a framed building structure may be a crucial factor in deciding the survival or collapse of the structure in the event of a severe earthquake.

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