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Assessment of Earthquake Vulnerability in RC Frames Featuring Varied Masonry Infill Patterns

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INTRODUCTION & AIM

Reinforced concrete (RC) frame buildings with masonry infills have been widely used to construct commercial, residential and industrial buildings. Such buildings have been mostly designed and constructed following different specifications and construction codes without ac counting for the interaction between RC frames and the infill panels. Even though the infill panels were not intended to be a part of the structural system, interactions between RC frame and infill panels in crease the lateral stiffness of the structure. Consequently, these interactions not only cause significant damage to the infills, which constitute a substantial portion of the building's value, but can also result in undesirable failure mechanisms, such as short column effects or brittle shear failure. Consequently, the assessment of seismic performance of RC frames, including the effect of infills, has been of great interest to researchers over the past seven decades
This study presents a comprehensive numerical analysis aimed at assessing the effect of infill distribution patterns on the seismic vulnerability of various 2D frames. A reliable finite element modelling approach was adopted to simulate several RC buildings with different infill distributions. Incremental dynamic analysis was conducted using.

METHOD

Description of the building structure

To study the effect of the infill spatial configurations along other infill configurations, the residential building shown in Fig. 1 was selected as a representative case study, which consists of 6 storeys, and the columns have a size of 30 cm × 30 cm. This column size reflects typical design practices for mid-rise buildings in seismic zones such as Algeria.
The building chosen has the plan dimensions of 13.1 m x 17.4 m, which consists of 4.3 × 4.3 m modules (i.e., in x and y directions, respectively). The floor heights were kept constant at (3) meters over the entire height of the building. The edge frame at vertical axis 5–5 be¬ tween horizontal axes A and D was selected to generate the 2D models. The structures were designed for gravity loads to simulate a design sit¬ uation where no seismic actions are included. A global vertical load of 5.25kN/m2 plus a variable load of 2 kN/m2 were considered. Six storeys were chosen as a representative case for mid-rise buildings.

Infill Wall Configurations

The selected infill wall configurations represent typical and realistic building layouts. Common cases include soft-storey (SF) frames found in buildings with open ground floors, and partially infilled (PF) frames with door and window openings. Discontinuous infill patterns (e.g., RF, MF, 2RLF) simulate variations from architectural design or retrofitting. Other configurations (3SF, UF, 2MF, MHF, DF, SDF) illustrate less common but possible vertical irregularities due to large openings. This diversity ensures that both practical and theoretical scenarios are represented for broader applicability

Description of the numerical model

Nonlinear dynamic analyses were performed using OpenSees due to its computational efficiency and flexibility in defining structural components. The RC frame elements (beams and columns) were modeled as beam–column elements with fiber sections, integrated using the Modified Radau method with six points per element. The plastic hinge length (Lp) was computed following Paulay and Priestley:

$$L_p = 0.08 l_e + \quad 0.022 d_b f_y$$

The fiber sections included three materials: unconfined concrete (Concrete01) for cover, confined concrete (Concrete01 with Kent and Park confinement), and reinforcing steel (Steel02) modeled with isotropic hardening.

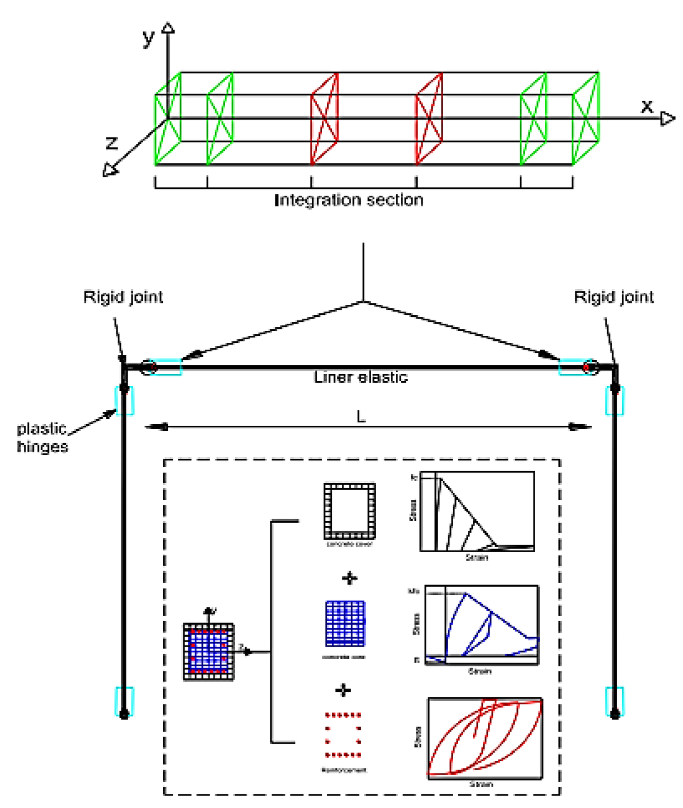

Fig. 1. Adopted strategy for modelling RC elements.

Seismic Vulnerability and Fragility Curves

The seismic vulnerability of RC buildings is evaluated through fragility curves, which express the probability of exceeding a given damage state under a specific seismic intensity measure (IM). Damage states—such as cracking, spalling, or collapse—are related to structural engineering demand parameters (EDP) like global drift.
In this study, analytical fragility curves were derived from nonlinear time-history analyses of numerical models. The selected seismic records were scaled to match the Algerian seismic code (RPA99/2003) to ensure realistic representation of local seismic conditions

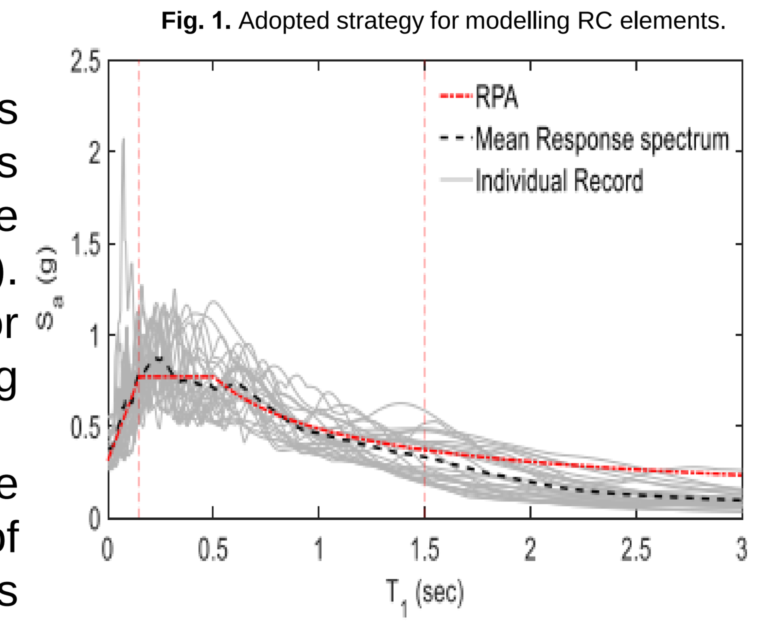

Fig. 5. Scaled response spectra for the twenty-five ground motions with their mean response spectrum and the target elastic response spectrum for Zone III according to the Algerian Seismic Regulations RPA 99/2003

RESULTS & DISCUSSION

Using the procedures described earlier, datasets corresponding to each damage-state threshold were obtained. Table 6 presents their mean and standard deviation values. Several statistical distributions were tested to model the empirical data; however, the lognormal cumulative distribution provided the best fit [59]. Its parameters—ln(θ̂) (mean) and β̂ (standard deviation)—were estimated using the Maximum Likelihood Estimation (MLE) method. Accordingly, the fragility function is expressed as:

$$P(D \leq C|IM) = \Phi\left[\frac{\ln(IM) - \ln(\widehat{\theta})}{\widehat{\beta}}\right]$$

Table 1

Statistical parameters of the fragility datasets for different structures and different limit states.

Buildings ID	Slight		Light		Moderate		Extensive		Partial collapse		Collapse	
	μ[g]	σ[g]	μ[g]	σ[g]	μ[g]	σ[g]	μ[g]	σ[g]	μ[g]	σ[g]	μ[g]	σ[g]
BF	0.0166	0.0045	0.0266	0.0072	0.1028	0.0285	0.4167	0.1435	1.0401	0.3825	1.5312	0.5222
PF	0.0193	0.0036	0.0309	0.0058	0.1205	0.0191	0.4549	0.0705	1.0063	0.3309	1.3203	0.4264
FF	0.0207	0.0039	0.0331	0.0062	0.1377	0.0308	0.4766	0.0645	1.0409	0.2852	1.3538	0.3656
SF	0.0126	0.0026	0.0201	0.0041	0.0742	0.0144	0.2949	0.0790	0.6368	0.2122	0.8567	0.3004
DF	0.0149	0.0029	0.0238	0.0046	0.0871	0.0169	0.3158	0.0758	0.7206	0.2402	0.9998	0.3598
MHF	0.0142	0.0044	0.0227	0.0070	0.0849	0.0254	0.3309	0.1089	0.8030	0.2970	1.1654	0.4453
RLF	0.0173	0.0036	0.0277	0.0057	0.1095	0.0279	0.4342	0.1407	1.0656	0.3738	1.5347	0.5323
SDF	0.0149	0.0031	0.0239	0.0049	0.0893	0.0190	0.3118	0.0724	0.7290	0.2529	0.9804	0.3822
MF	0.0189	0.0033	0.0302	0.0053	0.1192	0.0199	0.4390	0.0854	1.0856	0.3661	1.4166	0.4805
RF	0.0204	0.0037	0.0326	0.0059	0.1295	0.0198	0.4406	0.0750	1.0970	0.3436	1.4512	0.5108
UF	0.0118	0.0028	0.0188	0.0045	0.0696	0.0146	0.2775	0.0672	0.6752	0.1724	1.0412	0.3283
2MHF	0.0135	0.0034	0.0215	0.0054	0.0809	0.0200	0.3010	0.0877	0.7619	0.2990	1.0917	0.4485
2RLF	0.0183	0.0042	0.0294	0.0067	0.1162	0.0306	0.4648	0.1632	1.1141	0.3947	1.5406	0.5068
3SF	0.0148	0.0053	0.0238	0.0085	0.0905	0.0332	0.3865	0.1736	0.8962	0.3837	1.3400	0.5696

Figure 8 illustrates the resulting fragility curves. Some curves intersect, especially among configurations with different infill patterns, indicating that relative vulnerability varies across damage states.
The fully infilled frame (FF) shows a significant reduction in exceedance probabilities compared to the bare frame, confirming previous findings on the beneficial role of infills in increasing stiffness and delaying collapse. Nevertheless, since this study focuses on in-plane effects, the inclusion of out-of-plane failure could lessen the observed advantages .
Structures with soft-storey configurations exhibit higher probabilities of slight and moderate damage but may delay collapse, unlike stiffer systems that fail more brittly. These intersections highlight the importance of assessing multiple limit states to capture the complex seismic behavior.
In general, cases with continuous infills (e.g., RF, MF, 2RLF, RLF) perform better than those with discontinuities. Moreover, having two consecutive bare stories improves energy dissipation compared to alternating bare and infilled floors, as greater flexibility allows the structure to absorb vibrations without severe damage

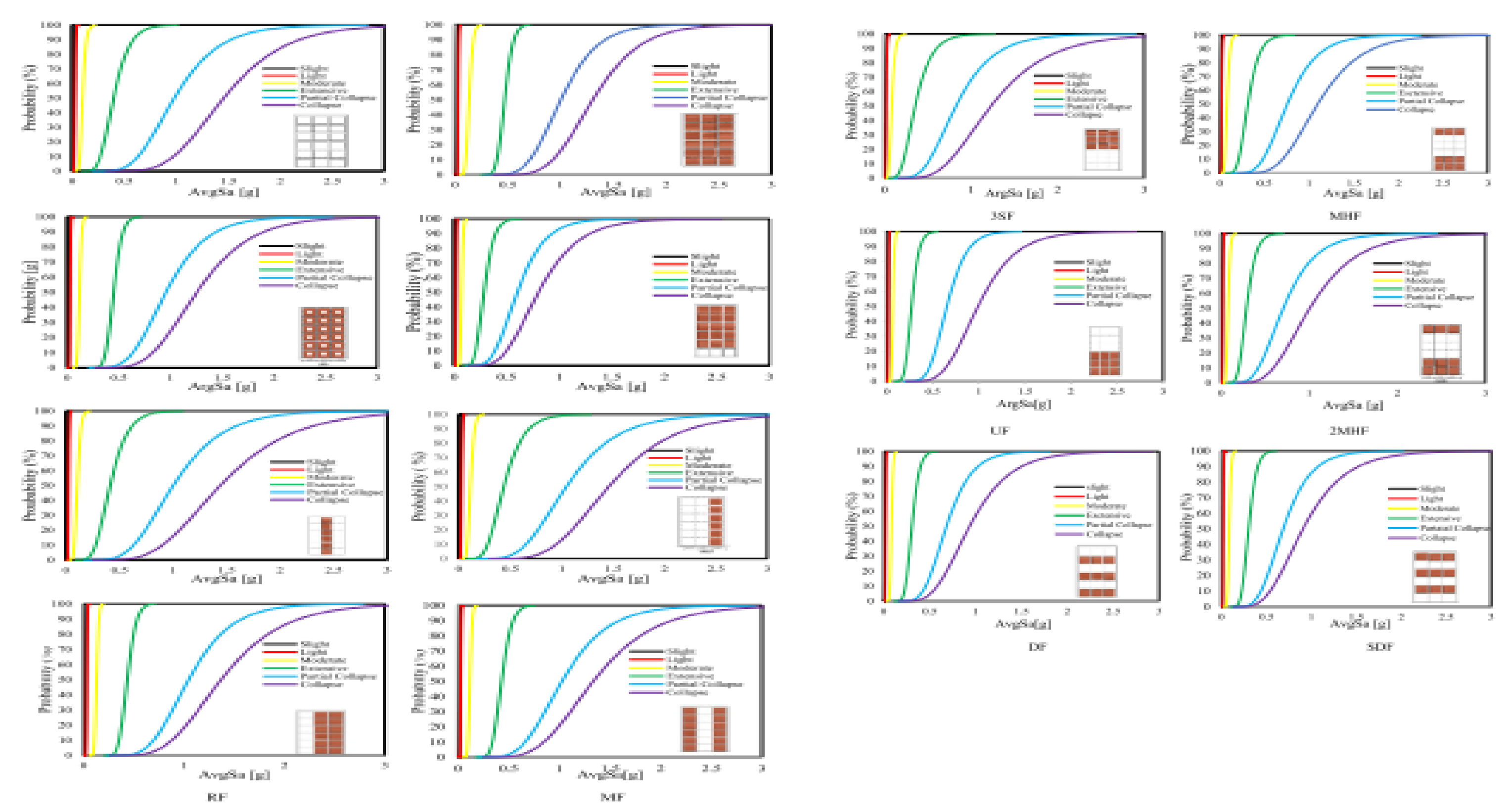

Fig. 3. The obtained fragility functions for the considered case of studies

CONCLUSION

It is important to state that the present study focuses on the in-plane response of masonry infill walls, however, it is acknowledged that out-of-plane forces induced by seismic ground motion can critically affect infill wall stability. Under strong seismic load, slender or poorly anchored infills may suffer out-of-plane failure, thereby eliminating their contribution to in-plane stiffness and strength. This interaction can significantly alter the sequence and mode of failure in RC frames, especially in configurations where IP contribution is critical to prevent soft-story mechanisms.

FUTURE WORK / REFERENCES

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