

The Effect BOF Mainshock- Aftershock in Successive Earthquake on RC Building

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Abstract -Earthquakes are highly destructive natural hazards that can cause significant damage to structures and infrastructure. While the mainshock typically results in major damage, strong aftershocks can further weaken structures and increase the risk of failure. In this study, a G+8 building is analyzed under mainshock–aftershock sequences, considering infill and bare frame configurations as well as horizontal and vertical seismic components. Time-history analysis is performed using the El Centro earthquake record. The results indicate that aftershocks significantly increase structural damage compared to the mainshock alone, particularly across different damage states ranging from slight to collapse. Infill frames exhibit greater damage than bare frames, and horizontal seismic components have a more pronounced effect on structural response than vertical components.

Key Words: optics, photonics, light, lasers, templates, journals

1. INTRODUCTION

An earthquake is the sudden shaking of the Earth's surface caused by the release of energy within the Earth's crust, producing seismic waves. Most earthquakes occur along geological faults due to the movement and slipping of rock masses. The point where an earthquake originates is called the focus (hypocenter), while the point directly above it on the Earth's surface is known as the epicenter. Earthquakes can occur through different fault movements, including strike-slip, normal, and reverse faulting. They are among the most destructive natural hazards and can cause significant damage to structures, especially high-rise buildings. Earthquake events are generally classified into mainshocks and aftershocks. The mainshock is the largest and most damaging earthquake, while aftershocks are smaller tremors that follow and gradually decrease in frequency and magnitude. The seismic waves generated during an earthquake are mainly of two types: body waves and surface waves.

2. LITERATURE REVIEW

Massumi et al. (2021) [2] investigated 6- and 10-story RC moment-resisting frame buildings subjected to mainshock–aftershock sequences. Using fragility curves, the study demonstrated that previous earthquake damage and vertical

ground-motion components significantly increase inter-story drift and collapse probability.

Oyguc et al. (2018) [3] analyzed irregular reinforced concrete structures under the Tohoku earthquake sequence using nonlinear numerical models. The results showed that multiple earthquake excitations and structural irregularities lead to greater damage accumulation and reduced structural capacity. Hosseinpour and Abdelnaby (2017) [5,8] developed fragility curves and performed dynamic response analyses for RC buildings under multiple earthquakes. Their findings revealed that prior damage, earthquake direction, structural irregularity, and vertical ground-motion components considerably influence seismic performance.

Morfidis and Kostinakis (2017) [7] examined the response of infilled RC buildings subjected to seismic sequences and concluded that masonry infills increase structural damage compared with bare-frame structures.

Hatzivassiliou and Hatzigeorgiou (2015) [11] studied regular and irregular RC buildings under successive earthquakes and emphasized the importance of considering multiple seismic events for reliable seismic design.

Song et al. (2014) [14] investigated the collapse risk of damaged structures under aftershocks and reported that longer-duration and lower-frequency aftershocks significantly increase the fragility of post-mainshock buildings.

Ruiz-García et al. (2014) [15] evaluated RC buildings subjected to soft-soil seismic sequences and found that the interaction between the structural period and aftershock frequency content plays a crucial role in the seismic response. Zhai et al. (2013) [16] developed damage spectra for mainshock–aftershock sequences and demonstrated that aftershocks contribute significantly to cumulative structural damage and should be considered in seismic assessment procedures.

3. METHODOLOGY

Problem Statement and Methodology

This study investigates the seismic performance of a G+8 reinforced concrete (RC) building subjected to mainshock–aftershock earthquake sequences. Three cases are considered: (i) bare frame under mainshock and aftershock loading, (ii) comparison of bare and infill frames, and (iii) effects of horizontal and vertical earthquake components. The building is located in Seismic Zone IV on medium-stiff soil and has an overall height of 28.8 m. Material properties considered are M20 concrete and Fe415 steel.

Structural Modeling

The building was modeled in SAP2000 as a special moment-resisting frame (SMRF) with a response reduction factor of 5 and an importance factor of 1. The plan consists of 5 m bays, and the beam size is 230 mm × 525 mm. Infill walls were modeled using the equivalent diagonal strut approach as per codal recommendations. The equivalent strut widths were calculated as 735 mm for exterior walls and 766 mm for interior walls.

Time-History Analysis

Nonlinear time-history analysis was performed using recorded ground-motion data from the 1940 Imperial Valley (El Centro) earthquake. The mainshock record (Mw 6.9) and aftershock record (Mw 5.8) were applied sequentially to capture cumulative damage effects. Both horizontal and vertical components were considered. The structural response was evaluated in terms of storey displacement, drift, acceleration, and internal forces.

Pushover Analysis

Pushover analysis was conducted to assess the nonlinear behavior and seismic capacity of the structure. Plastic hinge formation and performance levels, namely Immediate Occupancy (IO), Life Safety (LS), and Collapse Prevention (CP), were evaluated. Capacity curves were used to determine yield and ultimate displacements.

Fragility Assessment

Fragility curves were developed to estimate the probability of exceeding different damage states under seismic loading. Four damage states were considered: Slight Damage, Moderate Damage, Extensive Damage, and Collapse. The assessment was based on spectral displacement obtained from pushover analysis and was used to evaluate the vulnerability of the structure under mainshock–aftershock sequences.

Table No.3.1 Schedule of Columns for G+8 Building Model

Column No.	Floor	Size of Column	Reinforcement
C1, C5, C21,C25	Groundto4th Floor	300x750	12nos. -16 mmΦ
	5thto 6th Floor	300x600	10 nos. -16 mm Φ
	7thto 8th Floor	300x525	4 nos. -16 mm Φ 6 nos. 12 mm Φ
C2, C4, C22,C24	Groundto4th Floor	300x750	4 nos. -20 mm Φ 10 nos. 16 mm Φ
	5thto 6th Floor	300x600	10 nos. -16 mm Φ
	7thto 8th Floor	300x525	8 nos. -16 mm Φ
C3, C6, C10,C23	Groundto4th Floor	300x750	6 nos. -20 mm Φ 10 nos. 16 mm Φ
	5thto 6th Floor	300x600	10 nos. -16 mm Φ
	7thto 8th Floor	300x525	8 nos. -16 mm Φ
C7,C8, C9	Groundto4th Floor	300x750	6 nos. -20 mm Φ 10 nos. 16 mm Φ
	5thto 6th Floor	300x600	12 nos. -16 mm Φ

	7thto 8th Floor	300x525	4 nos. -16 mm Φ 6 nos. 12 mm Φ
C11, C15, C16,C17, C18, C19,C20	Groundto4th Floor	300x750	6 nos. -20 mm Φ 10 nos. 16 mm Φ
	5thto 6th Floor	300x600	10 nos. -16 mm Φ
	7thto 8th Floor	300x525	8 nos. -16 mm Φ
C12,C13, C14	Groundto4th Floor	300x750	6 nos. -20 mm Φ 10 nos. 16 mm Φ
	5thto 6th Floor	300x600	10 nos. -16 mm Φ
	7thto 8th Floor	300x525	8 nos. -16 mm Φ

4. RESULT

4.1 Storey Displacement

Storey displacement for horizontal component shows the maximum storey displacement of the horizontal component under mainshock and aftershock conditions. The maximum displacement is 45.97 mm during the mainshock and 39.96 mm during the aftershock. According to IS 1893:2016, the allowable displacement limit is 115.2 mm (0.004 times the storey height), indicating that the building displacement is within the permissible limit.

Story displacement for vertical component illustrates the maximum storey displacement of the vertical component. The displacement is 15.00 mm during the mainshock and 17.81 mm during the aftershock, showing a slightly higher displacement during the aftershock.

Story displacement for infill frame presents the maximum storey displacement of the infill frame. The displacement is 27.07 mm during the mainshock and 25.42 mm during the aftershock. With the diagonal strut used as the infill wall, the displacement remains within the allowable limit.

4.2 Pushover Curve

Pushover Curve for Horizontal Component shows the pushover curve of the bare frame for the horizontal component under mainshock and aftershock conditions. The building reaches collapse at a displacement of 0.338 m with a base shear of 11,358.71 KN during the mainshock, while in the aftershock it fails at a higher displacement of 0.358 m and a base shear of 11,813.66 KN, indicating greater displacement and strength demand.

Pushover Curve for Infill Frame shows the pushover curve of the infill frame for the horizontal component under mainshock and aftershock conditions. The frame fails at displacements of 0.024 m and 0.028 m with base shears of 17,465.04 KN and 19,148.36 KN, respectively, indicating significantly lower displacement and higher lateral resistance compared to the bare frame.

Pushover Curve for Vertical Component shows the pushover curve of the bare frame for the vertical component under both mainshock and aftershock conditions. The building reaches failure at a displacement of 0.088 m with a base shear of 2729.32 KN in both cases, indicating lower displacement

and damage potential compared to the horizontal component due to the dominance of gravity loads in the vertical direction.

4.3 Plastic Hinges Formation

Plastic Hinges	IO	LS	CP
Mainshock Horizontal Component	132	6	67
Aftershock Horizontal Component	136	4	69
Mainshock Vertical Component	2	0	0
Aftershock Vertical Component	2	0	0
Infill Frame (Mainshock)	12	0	17
Infill Frame (Aftershock)	1	0	10

5. CONCLUSIONS

This study investigated the seismic behavior of a G+8 storey building subjected to mainshock–aftershock sequences using time-history analysis. A comparative assessment was carried out between bare and infill frames, as well as between horizontal and vertical earthquake components.

Key conclusions:

Buildings experience significant damage during the mainshock, and subsequent aftershocks further increase the level of damage.

Infill frames exhibit greater damage than bare frames under both mainshock and aftershock conditions, indicating lower seismic performance.

Horizontal earthquake components cause substantially more damage than vertical components.

Compared to the mainshock, aftershocks increase damage probabilities in the slight, medium, extensive, and collapse states by 11.37%, 9.50%, 1.98%, and 0.34%, respectively.

Infill frames show considerably higher damage than bare frames in all damage states during both mainshock and aftershock events.

Horizontal components result in higher slight and medium damage, whereas vertical components show slightly higher extensive and collapse damage due to marginally greater spectral displacement.

6. REFERENCES

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