Response of RC frames to Unconfined Surface Blast loads across Varied Structural Aspect Ratios

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Abstract
Urban sprawl in India leads to have more variety of buildings with different geometries, plan and structural aspect ratios and irregularities. Geometry (i.e. size and shape) is one of the perilous factors that affects the response of the structure against seismic and blast loads. It significantly affects the dynamic performance of the structure. Blast loads can cause catastrophic damage to the structures leading to huge life loss in addition to property loss. Hence, it is essential to understand the behavior of structures with different geometries and the influence of structural aspect ratio on the performance of structures subjected to explosive loads. The present study is focused on study of variation in the response of RC framed structures with varied structural aspect ratios against unconfined surface blast loads. Six different regular reinforced concrete frame models having structural aspect ratios (i.e. H/B) 0.25, 0.375, 0.5, 0.75, 1.0 and 1.5 are considered.

To meet the requirement of proposed structural aspect ratios, two different plinth areas of 576 sq.m. and 1296 sq.m. and three different numbers of stories of 3, 6 and 12 are taken. Response of these RC frame models is analyzed for three different blast load intensities having charge weights 500, 1500 and 2500kg TNT at a standoff distance of 10m. Time history analysis is performed on the above-mentioned RC frames using a computer software package. From the study, it is evident that low rise buildings are relatively more affected by unconfined surface blast loads. This impact will increase further with higher blast intensities.

Keywords: Blast loads, Low, mid and high-rise buildings, Storey drift, Structural aspect ratio, Time history analysis.

Introduction

Man-made disasters include chemical spills, hazardous material spills, explosions, chemical and biological attacks, nuclear blasts, rail accidents, airplane crashes, groundwater pollution and blasts. Crime, arson, civil unrest, terrorism, war, chemical and biological threats, cyberattacks and other man-made calamities are also other examples. As a major man-made disaster, blast loads offer serious threats to densely populated metropolitan areas, especially in cities with many high-rise buildings. These explosions create extremely high pressures that spread quickly, seriously damaging buildings. Reinforced concrete (RC) framed buildings are widely utilized in high-rise construction in urban areas due to their strength, durability and cost-effectiveness. Because of their exposed surfaces, these RC are particularly susceptible to these kinds of blast loads. The ensuing structural failure may cause a catastrophic collapse that puts people's lives and property in peril.

To strengthen disaster preparedness, protect urban infrastructures and increase resilience in high-risk metropolitan areas. It is imperative to comprehend how these frames behave under blast conditions. Furthermore, in recent years, the threat of explosions in urban environments has become a significant concern, prompting extensive research into the response of reinforced concrete (RC) framed buildings to such extreme loading scenarios. However, the behavior of RC framed buildings subjected to explosive loads remains a complex and challenging aspect of structural engineering. The structural aspect ratio, defined as the ratio of building height to its base dimensions, plays a crucial role in determining the response of RC framed buildings to explosive loads. Buildings with different aspect ratios exhibit distinct dynamic characteristics and failure modes when subjected to blast loading.

Understanding the influence of structural aspect ratio on the response of RC framed buildings to explosive loads is therefore paramount for enhancing their resilience and mitigating potential damage in urban environments. This study aims to investigate and to analyze the behavior of RC framed buildings with varying structural aspect ratios under unconfined ground explosive loading conditions. By conducting numerical simulations, the relationship between structural aspect ratio and blast resistance is established and can provide valuable insights for the efficient design and retrofitting of RC-framed structures to withstand explosive threats effectively.

Review of Literature

The absence of a comprehensive code of practice for designing structures subjected to blast loads highlights the necessity for research in this area. By reviewing existing literature and identifying research gaps, engineers and researchers can better understand the behavior of blast loads on structures, to develop more robust design guidelines and to outline further research to mitigate the risks associated with explosions.

Mvi et al[19] investigated the effects of stand-off distance on tall and slender structures of varying heights. Predicting explosion pressures accurately is crucial in explosion-resistant design and the distance from the blast to the structure significantly influences the intensity and duration of the blast loads. William et al[28] provided a synopsis and recommendations regarding the collapse of the A.P. Murrah Federal Building in Oklahoma City, USA. Through various studies, the authors proposed recommendations to mitigate progressive collapse in new and existing structures under extreme loading conditions. Alexander[2] explored methods for predicting explosion effects on buildings.

To obtain conservative estimates, simplified analytical techniques were used along with numerical methods such as Eulerian, Lagrangian, Euler-FCT, ALE and Finite Element Modeling for accurate blast load predictions. Bibiana et al [8] conducted analytical research on the failure of reinforced concrete (RC) structures under blast loads using AUTODYN software, comparing numerical results with photographs of actual explosion damage.

Alexander and Timothy[3] studied the importance of congestion effects between buildings under explosion loads and used numerical techniques to predict loads on buildings in an urban environment. Akhilesh et al[1] examined the potential effects of external explosions on the RC shell of a typical nuclear containment facility using suitable non-linear material models up to critical stages. The authors identified vulnerable points and corresponding design improvements. Krauthammer et al[16] developed a methodology to assess damage due to the progressive collapse of partially collapsed structures, aiming to improve the safety of inhabitants in structures subjected to extreme loads. Ngo et al[21] introduced methods to determine blast loads and structural responses, providing an overview of blast effects on a 52-story building.

Bing et al[7] observed that turbine buildings in nuclear power plants are often not designed to resist blast loads and conducted a numerical study on dynamic response of RC frames to distant surface explosions, considering the influence of claddings on frame structures. Assal[6] studied analytical methods for single-degree-of-freedom (SDOF) system analysis under explosion loads, focusing on displacement time history responses to understand SDOF system behavior.

Raparla et al[22] researched two-dimensional numerical modeling of progressive collapse in plane frames subjected to earthquakes, using Applied Element Method (AEM) to understand collapse responses.

Subin et al[24] used ANSYS finite element software to model RC and masonry buildings under explosion loads, determining explosion pressures on each wall face and roof based on charge weight and distance, conducting transient non-linear analysis for dynamic blast loading. Amy and Hojjat[4] studied the response of three earthquake-designed framing systems under blast loading, using AEM – a numerical simulation technique to analyze models with unconfined, free-air burst explosions.

Nebojsa et al[20] examined the effect of transverse steel on the perforation capability of RC slabs under hard missile impact, concluding that transverse steel does not significantly influence the perforation capacity of concrete slabs subjected to rigid missile impact. Amr et al[5] experimentally studied the dynamic response of RC beams under blast loads, finding that the failure mechanism varies significantly with blast distance and the magnitude of longitudinal reinforcement.

Yasser et al[29] observed that most structures at risk from blasts are not designed for blast load safety. The authors evaluated the performance of RC frames under blast loading through comprehensive finite element analyses using ABAQUS, improving blast response by altering external columns' design, particularly using concrete-filled steel tube sections.

Madisetti et al[17,18] studied the performance of symmetric and vertical irregular RC buildings under seismic and unconfined surface blast loads, performing nonlinear time history analysis using AEM based software. Ithamsetti et al[11] conducted nonlinear dynamic analysis on regular framed buildings with different plan aspect ratios to study blast response, applying a blast load of 2500 kg TNT at a standoff distance of 10 meters as a time history function using ETABS software. After conducting a thorough review of over 70 research findings published over the previous 40 years.

Vincent et al[26] came to the conclusion that the majority of the researchers looked at how RC frames subjected to blast loads are affected by charge weight, standoff distance, structural orientation, geometric irregularities and mass irregularities. The authors also recommended specific guidelines for blast resistant structure design. Vincent et al[27] studied the blast response of a G+11 storied reinforced concrete framed building against various unconfined surface blast load intensities considering SSI effects and concluded that for both rigid and flexible bases, the ground floor is the most vulnerable to collapse.

It is clear from the literature evaluation that the behavior of RC-framed buildings with different structural aspect ratios exposed to unconfines surface blast loads has not been comprehensively researched. This has served as one of the driving forces for the authors to treat this as a research problem.

Material and Methods

Three, six and twelve-story reinforced concrete framed structures with plinth areas of 576 sq. m. and 1296 sq. m. were selected to assess the blast performance of RC framed structures across six varied structural aspect ratios: 0.25, 0.375, 0.5, 0.75, 1.0 and 1.5. To simplify the explosive load calculations and the complex methodology of defining time history functions in the numerical tool, an interior plane (2D) frame of the buildings is considered for evaluating the blast response. Unconfined surface explosive loads of three different charge weights (500 kg, 1500 kg and 2500 kg TNT) at a standoff distance of 10 m were applied to the structures. Blast wave parameters were evaluated using the technical manual TM-5-1300[25].

The positive phase of the blast wave curve is considered while defining the blast load. Time history analysis is performed on the specified R.C plane frames using the software package ETABS[9].

Hypothetical Case Studies: In the current work, six case studies are analysed against three different blast load scenarios to understand the influence of structural aspect ratio on the performance of structures under explosive loads. Table 1 presents the case studies considered in this study.

Geometric Details: The geometric details of the building models RFA and RFB considered in the present study are shown in table 2. The geometric views of the building models RFA and RFB are shown in figures 1 and 2 respectively.

Properties of Structural Elements: The considered building model was initially analyzed and designed for gravity and seismic loads in accordance with relevant Indian codes. The sectional properties of the various structural elements obtained from the design are presented in table 3.

Material Properties: A reinforced concrete structural framing system is adopted for the building model. Table 4 shows the material properties of the structural framing systems used in the present study.

Details of Loads: First, the considered building model is analyzed and designed for gravity (dead and live) and seismic loads according to the relevant Indian codes. Blast loads are then applied to this designed frame (as per IS: 456-2000[12]) to study the response of the structure.

Dead and Live Load [IS: 875 (Part1 and 2)][13,14]: Refer to table 5 for the dead and live loads acting on the structure. Figures 2 and 3 show the interior plane (2D) frames of RFA and RFB respectively.

Seismic Load [IS: 1893 (Part1)-2016][15]: Refer to table 6 for the Earthquake load parameters adopted in the present study.

Blast Loads: For the present study, unconfined surface explosive loads with three different charge weights: 500 kg TNT, 1500 kg TNT and 2500 kg TNT at a standoff distance of 10 m were considered to assess the response of the structures. Table 7 presents the blast load cases considered for this work. Blast parameters were evaluated using the technical manual TM-5-1300[25]. A summary of the blast loads acting on RFA6 for BC1 is shown in table 8.

Verification / validation of model for a Case Study on Impulsive Loads

In the present study, structural software package of ETABS[9] was used to analyze all the considered structural models against blast loads. Blast load is defined as a triangular time history function. Single bay single storey SDOF structure subjected to different triangular impulsive loads (Refer figure 4 and Table 9) is taken to verify the results obtained from the time history impulsive load analysis by ETABS with manual methods. Model details adopted for the verification problem are presented as follows.

Details of Model for validation:

Bay Length = 4 m

Storey height = 3.6 m

Beam size = 0.3m × 0.3 m

Column size = 0.3m × 0.3 m

$I_b = \frac{bd^3}{12} = 6.75 \times 10^{-4}\ m^4$; $I_c = \frac{bd^3}{12} = 6.75 \times 10^{-4}\ m^4$;

$f_{ck} = 25$ MPa; $E_c = 5000\sqrt{fck} = 25000$ MPa or 25×10^6 kPa.

$m = \frac{30 \times 4 \times 10^3}{9.81} = 12232.42$ kg

(Self-weight of the portal frame is not considered)

Validation:

Lateral stiffness of single bay and single storied frame with rigid supports $= \frac{\frac{24EI_c^2}{h^4} + \frac{144EI_cI_b}{h^3 l}}{\frac{4I_c}{h} + \frac{6I_b}{l}} = 5910.17$ kN/m

Natural Period $T = 2\pi\sqrt{\frac{m}{k}} = 2\pi\sqrt{\frac{12232.42}{5910170}} = 0.286$ Sec

Ratio of impulse period to natural periods are as follows:

$\frac{t}{T} = \frac{0.05}{0.286} = 0.175$ for TIL – 1 and 2

$\frac{t}{T} = \frac{0.1}{0.286} = 0.350$ for TIL – 3 and 4

From figure 4, $R_{max} = 0.49$ for TIL – 1 and 2

$R_{max} = 0.90$ for TIL – 3 and 4

$\delta_{max} = Rmax\langle\frac{p_o}{k}\rangle$

$= 0.49\langle\frac{500}{5910.17}\rangle = 0.04145m$ for TIL – 1

$= 0.49\langle\frac{1000}{5910.17}\rangle = 0.08290m$ for TIL – 2

$= 0.90\langle\frac{500}{5910.17}\rangle = 0.07614m$ for TIL – 3

$= 0.90\langle\frac{1000}{5910.17}\rangle = 0.15220m$ for TIL – 4

Table 10 presents the comparison of analysis results against triangular impulsive loads between manual and ETABS analysis. The response of a single bay, single-story SDOF structure subjected to various impulsive load situations as determined by hand calculations suggested by Ray and Penzien[23] is in satisfactory agreement with the results of the ETABS.

Results and Discussion

Blast Response of Regular R.C Frame Buildings with different Aspect Ratios: Based on the results from the time history analysis, the responses of structures with various aspect ratios to different blast load cases are represented in graphs showing inter storey drift, velocity and acceleration.

Table 1
Description of the Hypothetical Case studies on regular RC frames

S.N.	Designation	Plinth Area	No. of storey(s)	Size of Building (L × B × H)	Structural Aspect Ratio (H/B)
1.	RFA3	1296 sq. m.	3	36m × 36m × 9m	0.25
2.	RFB3	576 sq. m.	3	24m × 24m × 9m	0.375
3.	RFA6	1296 sq. m.	3	36m × 36m × 18m	0.5
4.	RFB6	576 sq. m.	6	24m × 24m × 18m	0.75
5.	RFA12	1296 sq. m.	6	36m × 36m × 36m	1.0
6.	RFA12	576 sq. m.	6	24m × 24m × 36m	1.5

Table 2
Geometric details of RFA and RFB

S.N.	Parameter	Dimensions of RFA	Dimensions of RFB
1.	Plan Dimensions	36 m × 36 m	24 m × 24 m
2.	Typical Bay Dimensions	6 m × 6 m	6 m × 6 m
3.	Typical Storey Height	3.00 m	3.00 m
4.	Depth of Foundation	2.00 m	2.00 m
5.	No. of Stories	3, 6 and 12 Stories	3, 6 and 12 Stories
6.	H/B Ratio	0.25, 0.5 and 1.0	0.375, 0.75 and 1.5

Table 3
Cross Sectional Properties of Structural Components

Structural Component	Size of the component		
	For 3 Storied	For 6 Storied	For 12 Storied
Column	375 mm × 375 mm	450 mm × 450 mm	600 mm × 600 mm
Plinth Beam	300 mm × 600 mm	300 mm × 600 mm	300 mm × 600 mm
Floor Beam	300 mm × 600 mm	300 mm × 600 mm	300 mm × 600 mm
Slab Thickness	150 mm	150 mm	150 mm

Table 4
Material Characteristics of Structural RC Frames

S.N.	Material	Grade of Material	Characteristic Strength	Young's Modulus
1.	Concrete	M30	30 MPa	27386.13 MPa
2.	Reinforcement	Fe500	500 MPa	2×10^5 MPa

Table 5
Dead and Live Loads

S.N.	Details	Load Intensity		
1.	Dead Load on Slab	Own-weight of slab	$0.15 \times 25 = 3.75$ kN/m^2	$\rho_{r.c.c} = 25$ kN/m^3
		Floor Finish Load	1.00 kN/m^2	Assumed
		Unexpected Load	1.00 kN/m^2	Assumed
		Total Dead Load	$5.75 \approx 6.00$ kN/m^2	Sum
2.	Wall Load	$0.23 \times (3 - 0.6) \times 20 = 11.04 \approx 12$ kN/m	$\rho_{brick} = 20$ kN/m^3	
3.	Live Load on Slab	3.00 kN/m^2		As per IS:875 - (Part 2)[14]

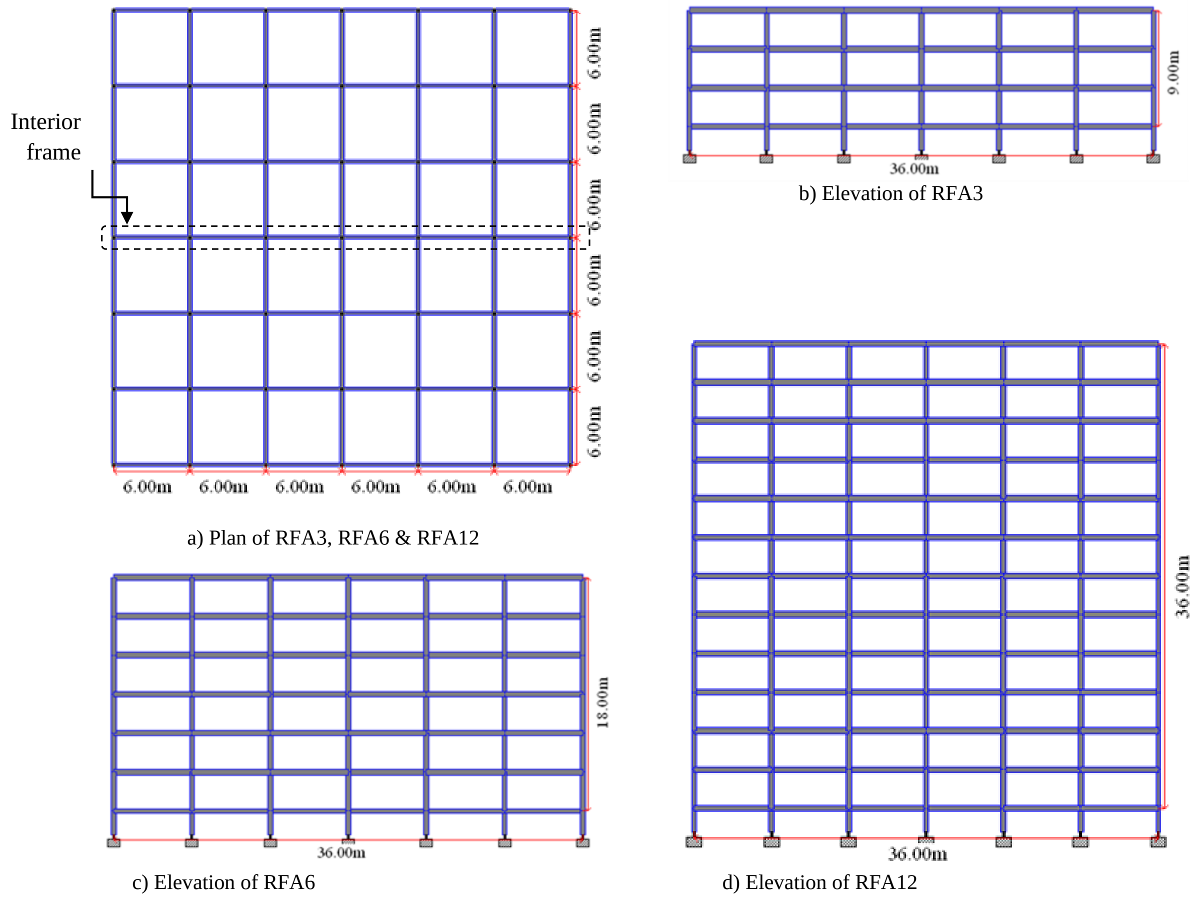

Fig. 1: Geometric Views of Regular Frame – RFA

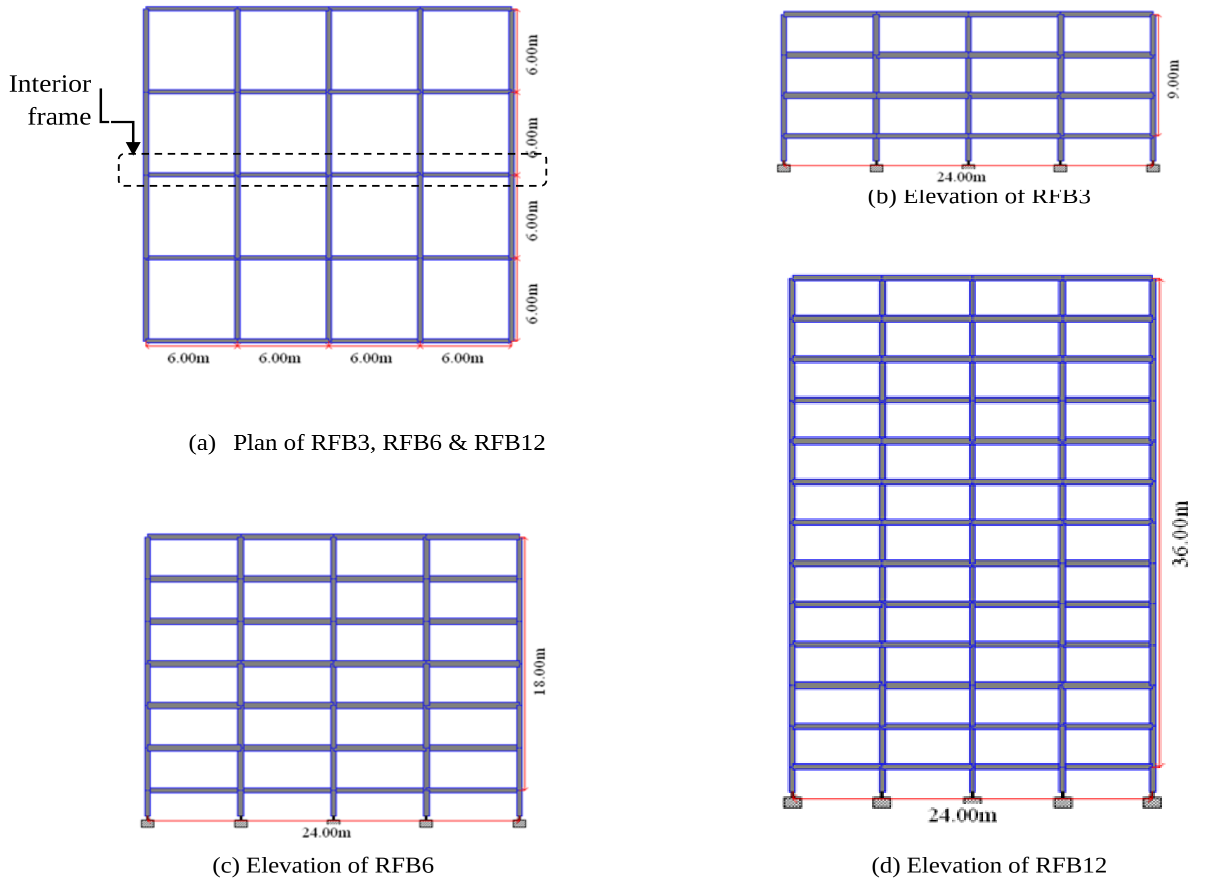

Fig. 2: Geometric Views of Regular Frame – RFB

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Table 6
Earthquake Load parameters (IS: 1893 (Part1)-2016[15])

S.N.	Parameter	Factor	Remarks
1.	Seismic Zone Factor (Z)	0.1	Zone – II
2.	Importance Factor (I)	1.5	Important Buildings
3.	Response Reduction Factor (R)	3.0	OMRF
4.	Soil type	-	Type I, II and III
5.	Percentage of Imposed Load	25%	For 3.0 kN/m^2

Table 7
Blast load cases considered for the present work

S. N.	Designation of Blast load case	Description of Blast load case
1.	BC1	Charge weight 500 kg TNT at a Stand- off distance of 10 m
2.	BC2	Charge weight 1500 kg TNT at a Stand- off distance of 10 m
3.	BC3	Charge weight 2500 kg TNT at a Stand- off distance of 10 m

Table 8
Summary of Blast Loads acting on RFA6 for BC1

Storey Level	Peak positive incident pressure Pso [psi]	Time of arrival ta [ms]	Fictitious positive phase duration tof [ms]	ta+tof [ms]	Peak reflected pressure Prα [psi]	Prα [kN /m^2]	Blast Force [kN]
0 m	32.39	28	14.8	42.8	111.03	765.64	6656
3 m	32.39	28	14.8	42.8	108.98	751.5	13036
6 m	31.12	28.9	15.1	44	101.78	701.85	12351
9 m	29.93	29.7	15.5	45.2	95.22	656.61	11449
12 m	27.74	31.7	16.2	47.9	85.32	588.35	10416
15 m	25.79	33.6	16.9	50.5	77.24	532.63	9360
18 m	23.23	36.6	18	54.6	68.28	470.84	4422

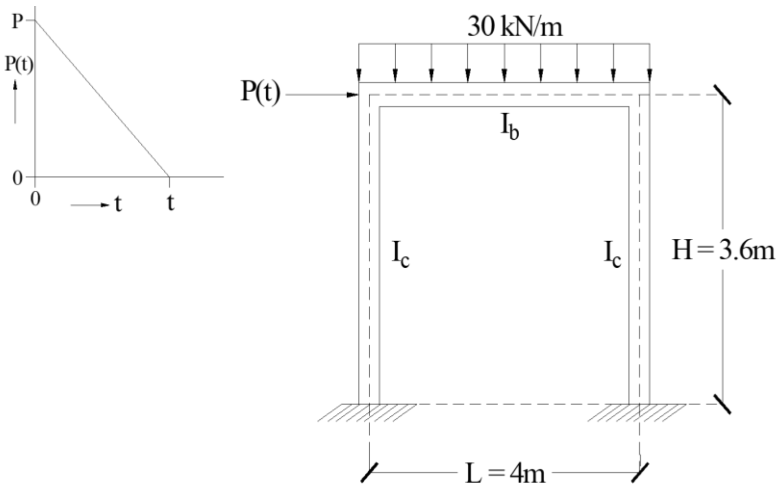

Fig. 3: SDOF Structure subjected to Triangular Impulsive load

Table 9
Triangular Impulsive Load Cases Considered for Verification

Load Case	P (kN)	t (Sec)	t /T
TIL- 1	500	0.1	0.175
TIL- 2	1000	0.1	0.175
TIL- 3	500	0.2	0.350
TIL- 4	1000	0.2	0.350

Table 10
Results

S.N.	Parameter	ETABS	Manual	% difference
1	T (Sec)	0.288	0.286	+ 0.70%
2	δ_{max} (mm) for TIL – 1	40.69	41.45	- 1.83%
3	δ_{max} (mm) for TIL – 2	81.39	82.90	- 1.83%
4	δ_{max} (mm) for TIL – 3	75.86	76.14	- 0.37%
5	δ_{max} (mm) for TIL – 4	151.7	152.28	- 0.38%

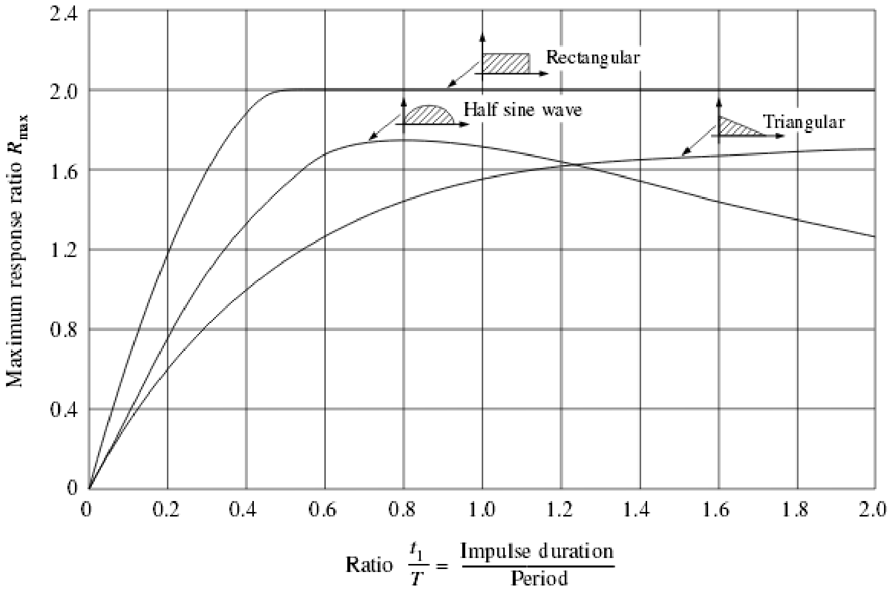

Fig. 4: Displacement – response spectra for three types of impulse (Clough and Penzien[23], 1993)

Inter Storey Drift: The inter storey drift is a crucial parameter for assessing structure's performance under dynamic loads. The permissible inter-storey drift ratio (PD) for seismic loads, specified as 0.4% in IS: 1893 (Part 1) – 2016[15], is used. Structural performance levels outlined in FEMA 356[10] (2000)—Immediate Occupancy (IO) at 1%, Life Safety (LS) at 2% and Collapse Prevention (CP) at 4%—are employed to evaluate the structure's performance.

Figures 5 to 7 illustrate the storey drift variations of RC frames with different aspect ratios when subjected to surface blast loads ranging from BC1 to BC3. The results show that the maximum inter-storey drift occurs at lower storey levels across all building models with varying aspect ratios under different blast intensities. In contrast to buildings subjected to seismic loads, those with lower aspect ratios (i.e. three-story buildings) exhibit higher inter-storey drift while buildings with higher aspect ratios (i.e. twelve-story buildings) show lower drift under all unconfined surface blast load scenarios. For any given 'n' storied building (n = 3, 6 and 12), an increase in the aspect ratio results in a noticeable rise in storey drift due to the decreased lateral stiffness of the frames.

Structural Performance Levels: The structural performance levels of various building models under different blast load intensities are illustrated in bar charts as shown in figures 8 to 10. Almost all building models, regardless of aspect ratio, exceeded the performance limit of 0.4% inter-storey drift ratio for the blast load cases considered. For the lowest blast intensity (BC1), only the RFB3 model, which falls under the LS (Life Safety) performance level, differed; all other models with various aspect ratios remained in the IO (Immediate Occupancy) performance level.

At medium blast intensity (BC2), the RFB3 model was categorized as CP (Collapse Prevention) while RFA3 and RFB6 fell under LS and the rest of the models remained in the IO level. For the highest blast intensity (BC3), RFB3 was classified as CP. RFA3, RFA6, RFB6 and RFB12 were classified as LS and RFA12 was in the IO performance level. The structural performance levels of building models with different aspect ratios against all the considered blast load cases are summarized in table 12.

The results clearly indicate that low-rise buildings (three stories) generally demonstrated poorer structural performance compared to mid and high-rise buildings under the same blast load cases. Additionally, buildings with higher aspect ratios exhibited lower structural performance. Among the models studied, the three-story RFB3 with an aspect ratio of 0.375 had the highest inter-storey drift ratio and thus the lowest structural performance whereas the twelve-story RFA12 with an aspect ratio of 1.0 had the lowest inter-storey drift ratio and the highest structural performance.

Velocity Response: The variations in roof velocity of the R.C frames with different aspect ratios subjected to blast loads BC1 to BC3 are shown in figures 11 to 13. From the velocity response, it is observed that the maximum roof velocity is experienced by RFB3 and the minimum by RFA12 across all blast load cases. Low-rise buildings, such as three-story buildings, experience higher velocities because they are stiffer compared to mid- and high-rise buildings. The time required to reach peak velocities increases with the number of stories. Peak roof velocities increase with higher blast load intensities but occur at the same time steps for all blast load cases due to the very short duration and close proximity of the defined blast load intensities.

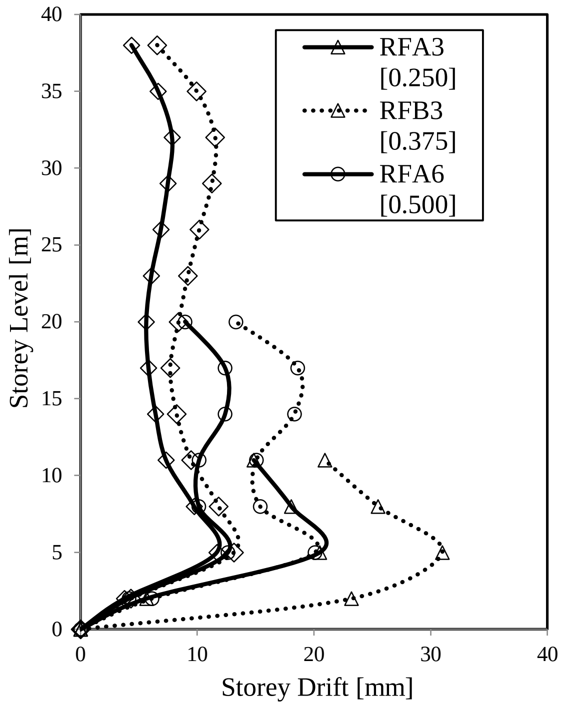

Fig. 5: Inter Storey Drift of RC Frames with different Aspect Ratios subjected to Surface Blast Load BC1

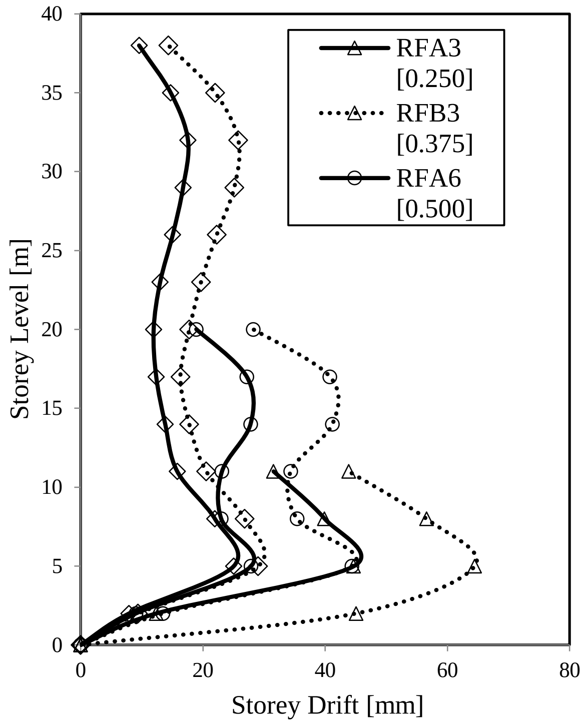

Fig. 6: Inter Storey Drift of RC Frames with different Aspect Ratios subjected to Surface Blast Load BC2

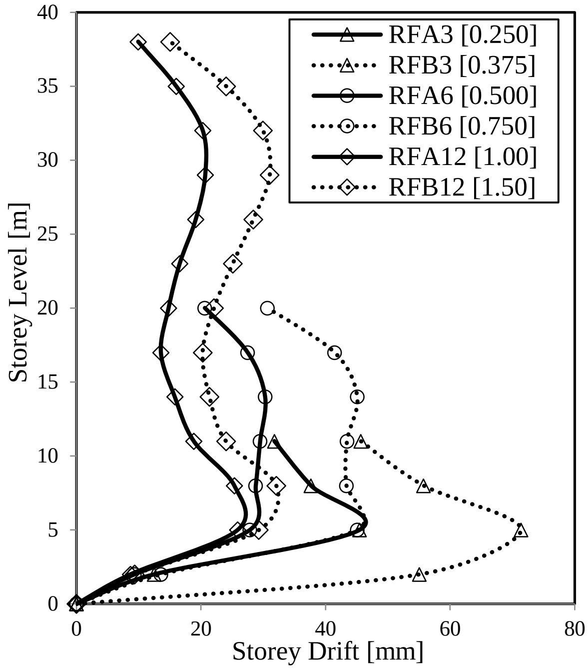

Fig. 7: Inter Storey Drift of RC frames with different Aspect Ratios subjected to Surface Blast Load BC3

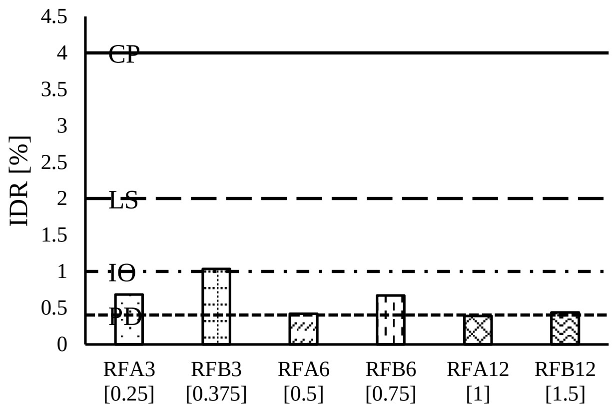

Fig. 8: Inter Storey Drift Ratios of R.C Frames with different Aspect Ratios subjected to BC1

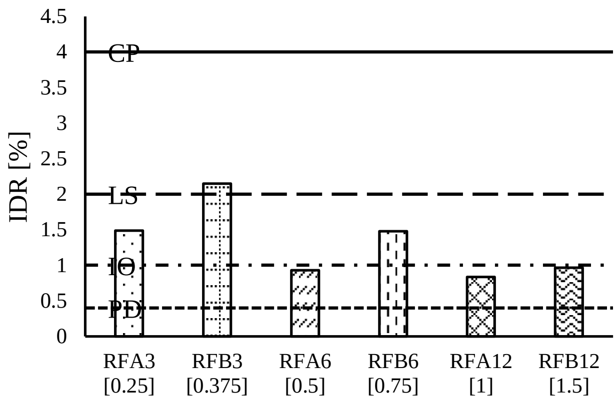

Fig. 9: Inter Storey Drift Ratios of R.C Frames with different Aspect Ratios subjected to BC2

Figures 11 and 12 show that the roof velocities of RFA3, RFB3, RFA6, RFB6, RFA12 and RFB12 increase by 117%, 120%, 117%, 118%, 123% and 119% respectively for blast load case BC2 compared to BC1. Figures 11 and 13 reveal that the roof velocities of RFA3, RFB3, RFA6, RFB6, RFA12 and RFB12 increase by 127%, 135%, 116%, 115%, 161% and 148% respectively for blast load case BC3 compared to BC1.

Table 12
Structural performance levels of buildings with various aspect ratios against different blast loads

Frame Designation	Blast Load Cases		
	BC1	**BC2**	**BC3**
RFA3 (O.250)	IO	LS	LS
RFB3 (0.375)	LS	CP	CP
RFA6 (0.500)	IO	IO	LS
RFB6 (0.750)	LS	LS	LS
RFA12 (1.00)	PD	IO	IO
RFB12 (1.50)	IO	IO	LS

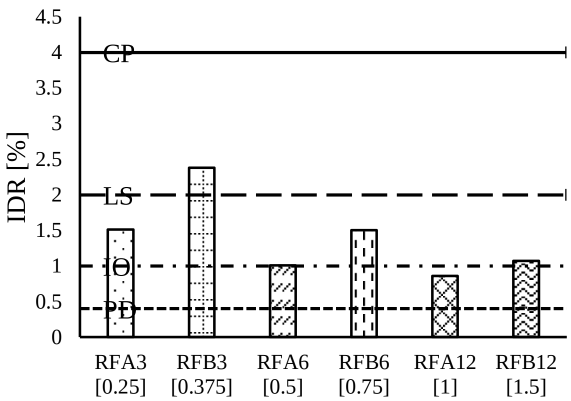

Fig. 10: Inter Storey Drift Ratios of R.C Frames with different Aspect Ratios subjected to BC3

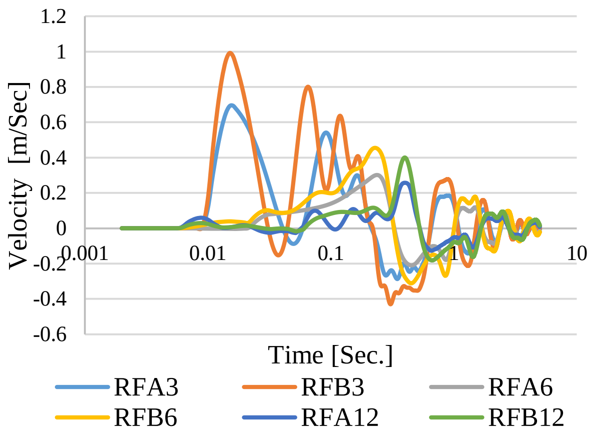

Fig. 11: Roof Velocity of R.C Frames with different Aspect Ratios subjected to BC1

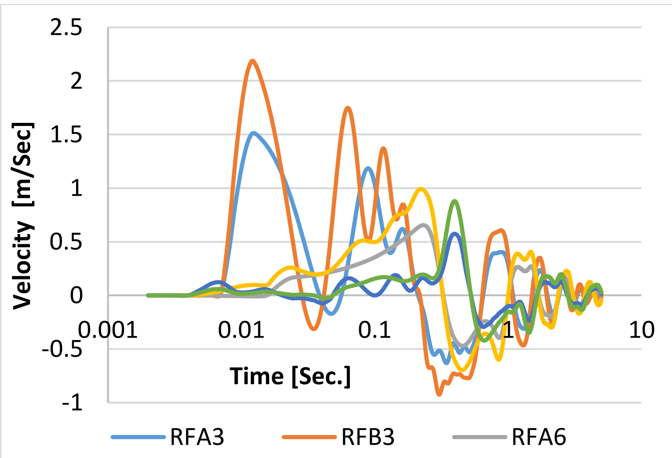

Fig. 12: Roof Velocity of R.C Frames with different Aspect Ratios subjected to BC2

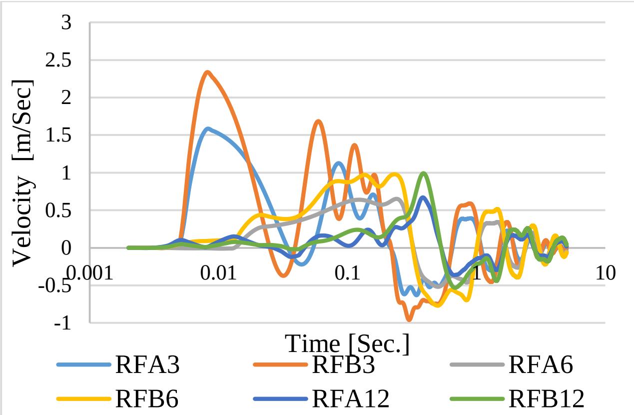

Fig. 13: Roof Velocity of R.C Frames with different Aspect Ratios subjected to BC3

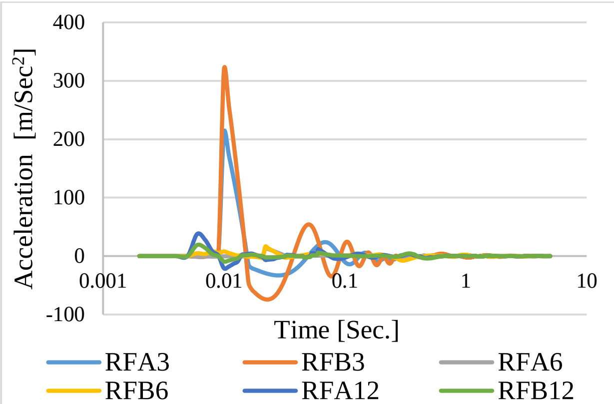

Fig. 14: Roof Acceleration of R.C Frames with different Aspect Ratios subjected to BC1

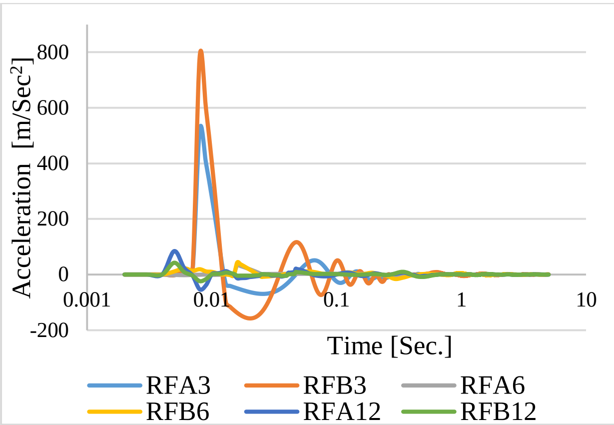

Fig. 15: Roof Acceleration of R.C Frames with different Aspect Ratios subjected to BC2

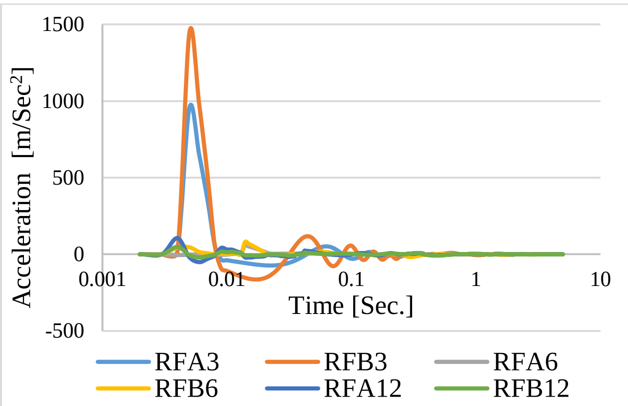

Fig. 16: Roof Acceleration of R.C Frames with different Aspect Ratios subjected to BC3

Acceleration Response: The variations in roof acceleration of the R.C frames with different aspect ratios subjected to blast loads BC1 to BC3 are shown in figures 14 to 16. From the acceleration response, it is observed that the maximum roof acceleration is experienced by RFB3 and the minimum by RFA12 across all blast load cases. Low-rise buildings, such as three-story buildings, experience higher accelerations because they are stiffer compared to mid- and high-rise buildings. The time required to reach peak accelerations increases with the number of stories. Peak roof accelerations increase with higher blast load intensities but occur at the same time steps for all blast load cases due to the very short duration and close proximity of the defined blast load intensities.

Figures 14 and 15 show that the roof accelerations of RFA3, RFB3, RFA6, RFB6, RFA12 and RFB12 increase by 147%, 147%, 151%, 167%, 124% and 124% respectively for blast load case BC2 compared to BC1. Figures 14 and 16 reveal that the roof accelerations of RFA3, RFB3, RFA6, RFB6, RFA12 and RFB12 increase by 354%, 356%, 328%, 391%, 181% and 157% respectively for blast load case BC3 compared to BC1.

By studying the blast response of the building with varied aspect ratios, low-rise buildings experienced more storey drift, velocity and acceleration compared to mid and high-rise buildings when subjected to unconfined surface blast loads. This phenomenon occurs for several reasons:

Lower Mass: Low-rise buildings have less mass compared to mid- and high-rise buildings. This means they have less inertia to resist the forces from a blast, resulting in greater displacements.

Stiffer Structures: While low-rise buildings are often stiffer than taller buildings, this stiffness can lead to higher accelerations and forces during a blast event, translating into higher storey drifts.

Foundation Interaction: Low-rise buildings are usually more directly coupled to the ground, meaning they absorb more of the blast energy. In contrast, taller buildings might have more flexibility and damping mechanisms that dissipate energy better.

Structural Redundancy: High-rise buildings often have more structural redundancy and complex load paths that can better distribute and absorb blast forces, reducing localized damage and storey drift.

Conclusion

The following are the major conclusions derived by studying the dynamic response of regular R.C frames with various structural aspect ratios against unconfined surface blast loads.

1) Buildings with lower aspect ratios exhibit higher inter-storey drift while buildings with higher aspect ratios show lower drift under all the considered unconfined surface blast load scenarios.

2) For any given 'n' storied building (n = 3, 6 and 12), an increase in the aspect ratio results in a noticeable rise in storey drift due to the decreased lateral stiffness of the frames.

3) Low-rise buildings mostly demonstrated poorer structural performance compared to mid and high-rise buildings under the same blast load cases.

4) Low-rise buildings, such as 3-story buildings, experience higher velocities and accelerations as they are stiffer compared to mid and high-rise buildings.

5) Low-rise buildings experienced more storey drift, velocity and acceleration compared to mid and high-rise buildings when subjected to unconfined surface blast loads due to lower mass, stiffer structure, better foundation interaction and higher structural redundancy.

6) So, particularly for explosive loads, it is evident that low rise buildings are more prone to unconfined surface blast loads. This impact will increase further with higher blast intensities.

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