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INFLUENCE OF STOREY NUMBER AND NUMBER OF BAYS ON THE STRUCTURAL RESPONSE OF FRAME SYSTEMS

Summary: This paper presents a parametric numerical study on the influence of the number of storeys and number of bays on the structural response of planar reinforced concrete frame systems. Numerical models with one to six storeys and bays were analyzed under symmetric and asymmetric loading conditions. The frames were subjected to uniformly distributed loads of 10 kN/m and concentrated loads of 10 kN. Both regular loading applied to each storey and bay and randomly distributed loading patterns were considered. The analysis reveals clear trends in the redistribution of bending moments and shear forces in beams and columns caused by changes in structural configuration. In order to isolate the influence of geometric parameters and externally applied loads, the self-weight of structural members was neglected. The obtained results were compared with characteristic examples and recommendations reported in relevant structural engineering literature.

Keywords: frame structures, parametric analysis, number of storeys, number of bays, internal force distribution

UTICAJ BROJA SPRATOVA I BROJA POLJA NA STATIČKI ODZIV RAMOVSKIH SISTEMA

Rezime: U radu je izvedena parametarsku numerička analiza uticaja broja etaža i broja polja na odgovor armiranobetonskih okvirnih sistema. Analizirani su numerički modeli formirani od jedne do šest etaža i sa jednim do šest polja pri simetričnim i asimetričnim uslovima opterećenja. Okviri su opterećeni ravnomerno raspodeljenim opterećenjem intenziteta 10 kN/m i koncentrisanim opterećenjem od 10 kN. Razmatrani su kako slučajevi pravilnog opterećivanja svake etaže i svakog polja, tako i slučajevi nasumično raspoređenih opterećenja. Analiza pokazuje jasne trendove u preraspodeli momenata savijanja i transverzalnih sila u gredama i stubovima usled promena u konfiguraciji konstrukcije. Kako bi se izolovao uticaj geometrijskih parametara i spoljnih opterećenja, sopstvena težina konstruktivnih elemenata nije uključena u analizu. Dobijeni rezultati upoređeni su sa karakterističnim primerima i preporukama navedenim u relevantnoj stručnoj i naučnoj literaturi iz oblasti građevinskih konstrukcija.

Ključne reči: okvirne konstrukcije, parametarska analiza, broj spratova, broj polja, raspodela unutrašnjih sila

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1. INTRODUCTION

Frame systems are widely used in civil engineering practice due to their ability to efficiently resist both vertical and horizontal loads while providing considerable architectural flexibility. Their structural response depends not only on material properties and member dimensions but also on geometric characteristics, among which the number of storeys and the number of bays play a significant role in determining stiffness, internal force distribution, and displacement behaviour [1].

The number of storeys is one of the key parameters used to characterize buildings, as it is directly related to their geometry, height, volume, and other structural properties [2]. In general, increasing the number of storeys leads to higher axial forces and larger global displacements, whereas increasing the number of bays affects the redistribution of internal forces and may result in increased bending moments and shear forces in structural members. Consequently, geometric configuration represents an important aspect of structural design.

Numerical methods based on the stiffness approach are commonly employed in the analysis of frame systems because they enable accurate determination of internal forces and nodal displacements under various loading conditions [3]. Although numerous studies have investigated frame behaviour, most research has focused on seismic response, dynamic effects, or structural optimization. Comparatively fewer studies have examined the isolated influence of fundamental geometric parameters, such as the number of storeys and the number of bays, on the static response of frame systems.

Therefore, the objective of this study is to investigate the influence of storey number and bay number on the structural response of planar frame systems through a parametric numerical analysis. Several frame configurations were analyzed under symmetric and asymmetric distributed loads, as well as concentrated vertical and horizontal loads. Particular attention was devoted to the variation of bending moments, shear forces, axial forces, and displacements in order to identify general behavioural trends relevant to preliminary structural design.

2. STRUCTURAL MODEL AND LOADING

The analyzed structural systems are planar reinforced concrete frames with rigid beam–column connections. All structural elements were modeled using constant rectangular cross-sections of 25 x 25 cm for both beams and columns. Linear-elastic material behaviour was assumed throughout the analysis.

The investigated configurations range from a single-storey frame (P) to a six-storey frame (P+5). The ground-floor height was 3.8 m, while all upper storeys were 3.0 m high. To examine the influence of bay number, frames with one to six equal bays were analyzed. The bay width was fixed at 4.8 m for all configurations. Material properties, cross-sectional dimensions, and storey heights remained unchanged in all models.

Column bases were assumed to be fully fixed. The self-weight of structural members was neglected in order to isolate the effects of geometric parameters and externally applied loads.

Several static loading cases were considered, including uniformly distributed and concentrated loads acting on beams and columns. The numerical investigation included variations in the number of storeys (Figure 1) and the number of bays (Figure 2) and comprised the following loading cases (a–h):

- uniformly distributed load acting on beams, with an intensity of 10 kN/m (a);
- asymmetric uniformly distributed load acting on beams, 10 kN/m (b);
- asymmetric uniformly distributed load acting on columns, 10 kN/m (c);
- concentrated horizontal load applied at each storey level, 10 kN (d);
- concentrated vertical load applied at the midspan of the beam, 10 kN (e);
- concentrated load with variation in the loaded storeys, 10 kN (f);

- uniformly distributed load with variation in the loaded storeys, 10 kN/m (g);
- concentrated load with variation in the loaded storeys, 10 kN (h).

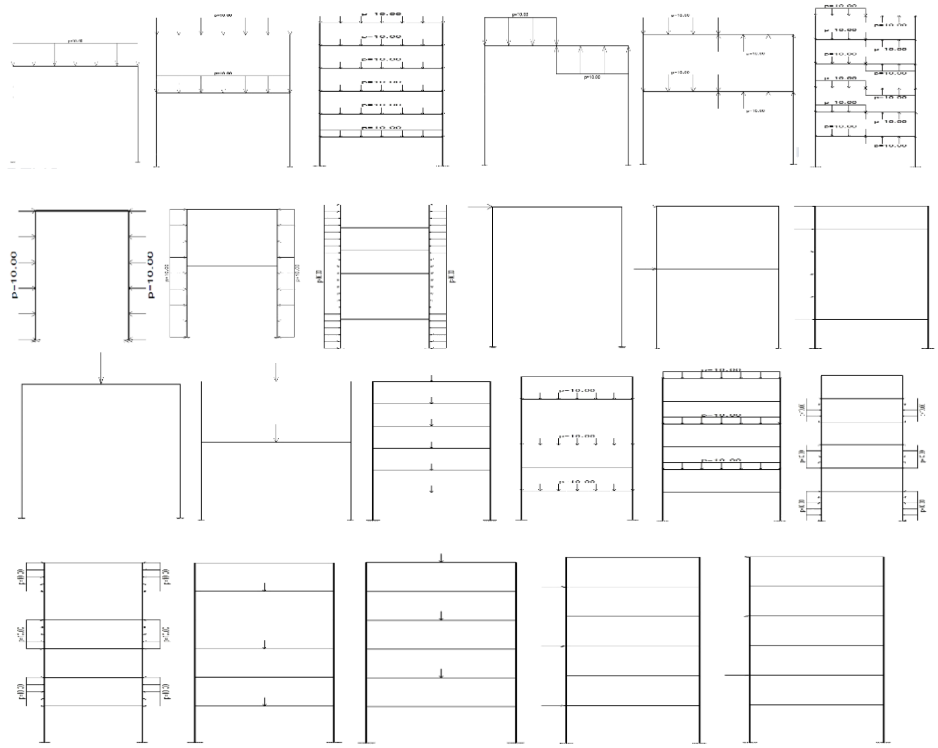


Figure 1: Loading cases considered for reinforced concrete frame models with variation in the number of storeys

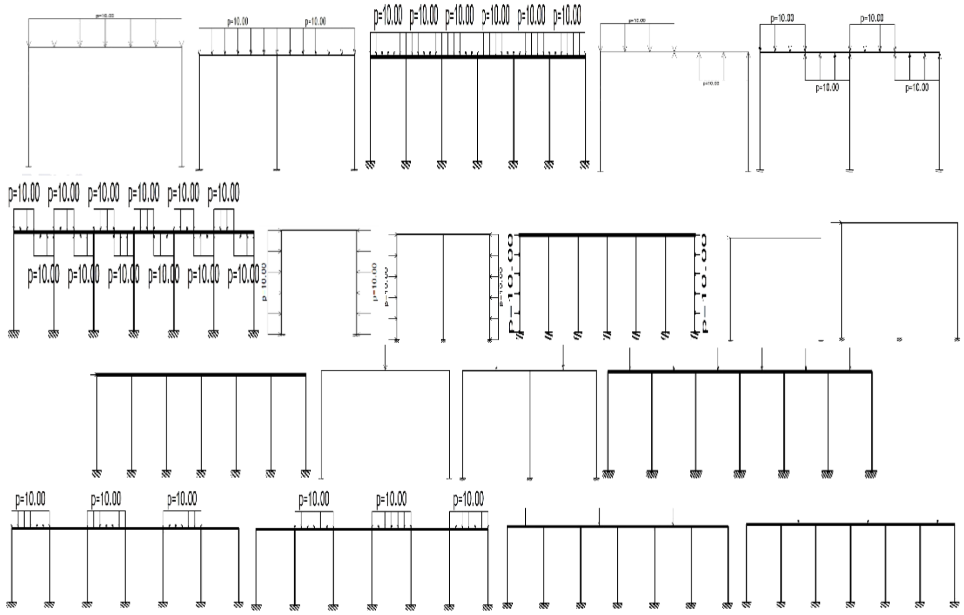


Figure 2: Loading cases considered for reinforced concrete frame models with variation in the number of bays

All numerical analyses were conducted using the structural analysis software Tower 8 Demo, based on the matrix stiffness method.

3. NUMERICAL ANALYSIS

The numerical analysis was conducted to evaluate the influence of storey number and bay number on the structural response of planar frame systems. For each analyzed configuration, internal forces and displacements were determined for beams and columns. The obtained results were organized in tabular and graphical form to facilitate the identification of trends associated with geometric parameter variation.

All loading cases shown in Figures 1 and 2 were analyzed. Due to space limitations, only representative results corresponding to load cases (a–e) are presented in the following tables and diagrams. The remaining load cases (f–h) exhibited similar behavioural trends and were considered in the overall evaluation of structural response.

3.1. VARIATION OF STOREY NUMBER

The influence of storey number was investigated through the analysis of frame configurations ranging from a single-storey frame (P) to a six-storey frame (P+5). Maximum and minimum values of internal forces and displacements obtained for the analyzed models are summarized in Table 1.

Table 1: Internal force values in beams and columns for different numbers of storeys under loading cases

	[illegible]			
	[illegible]	[illegible]	[illegible]	[illegible]
P	[illegible]		[illegible]	
P+1	[illegible]	[illegible]	17,21	[illegible]
P+2	[illegible]	[illegible]	16,90	[illegible]
P+3	[illegible]	[illegible]	16,70	[illegible]
P+4	[illegible]	[illegible]	16,70	[illegible]
P+5	[illegible]	[illegible]	16,71	[illegible]

(a)

	[illegible]		
	[illegible]	[illegible]	[illegible]
P	[illegible]		6,78
P+1	5,01	2,74	2,50
P+2	6,54	0,77	3,25
P+3	6,19	1,06	3,28
P+4	6,27	0,99	[illegible]
P+5	6,25	1,00	[illegible]

(a)

	Трансверзалне силе стубова приземља	
	Трансвезалне силе у стубу (kN)	Промена вредности (%)
P	5,39	
P+1	1,98	2,72
P+2	2,57	0,77
P+3	2,44	1,05
P+4	2,47	0,99
P+5	2,46	1,00

(a)

	Нормалне силе греда приземља	
	Нормалне силе греда (kN)	Промена вредно
P	5,39	
P+1	7,19	0,75
P+2	3,38	2,13
P+3	4,24	0,80
P+4	4,06	1,04
P+5	4,1	0,99

(a)

	[illegible]			
	[illegible]	[illegible]	[illegible]	[illegible]
P	[illegible]		[illegible]	
P+1	[illegible]	[illegible]	[illegible]	[illegible]
P+2	[illegible]	[illegible]	[illegible]	[illegible]
P+3	[illegible]	[illegible]	[illegible]	[illegible]
P+4	[illegible]	[illegible]	[illegible]	[illegible]
P+5	[illegible]	[illegible]	[illegible]	[illegible]

(b)

	Моменти стубова приземља	
	Моменти у стубу (kNm)	Промена вредности (%)
P	1,23	
P+1	1,24	0,99
P+2	1,22	1,02
P+3	1,19	1,03
P+4	1,16	1,03
P+5	1,14	1,02

(b)

	[illegible]		
	[illegible]	[illegible]	[illegible]
P	11,49		12,51
P+1	11,57	0,99	12,43
P+2	11,57	1,00	12,43
P+3	11,57	1,00	12,43
P+4	11,57	1,00	12,43
P+5	11,57	1,00	12,43

(b)

	Моменти греде приземља	
	Моменти у греди (kNm)	Промена вредно
P	3,41	
P+1	0,27	12,63
P+2	0,79	0,34
P+3	0,68	1,16
P+4	0,17	4,00
P+5	0,70	0,24

(c)

	[illegible]					
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
P	[illegible]		[illegible]		[illegible]	
P+1	11,15	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
P+2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
P+3	10,17	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
P+4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
P+5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

(c)

	[illegible]		
	[illegible]	[illegible]	[illegible]
P	[illegible]		[illegible]
P+1	[illegible]	[illegible]	[illegible]
P+2	[illegible]	[illegible]	[illegible]
P+3	[illegible]	[illegible]	[illegible]
P+4	[illegible]	[illegible]	[illegible]
P+5	[illegible]	[illegible]	[illegible]

(c)

	Нормалне силе греда приземља	
	Нормалне силе греда (kN)	Промена вредности (%)
P	15,60	
P+1	36,67	0,43
P+2	33,45	1,10
P+3	34,18	0,98
P+4	34,02	1,00
P+5	34,06	1,00

(c)

	[illegible]		
	[illegible]	[illegible]	[illegible]
P	[illegible]		[illegible]
P+1	[illegible]	[illegible]	[illegible]
P+2	[illegible]	[illegible]	[illegible]
P+3	[illegible]	[illegible]	[illegible]
P+4	[illegible]	[illegible]	[illegible]
P+5	[illegible]	[illegible]	[illegible]

(d)

	[illegible]			
	[illegible]	[illegible]	[illegible]	[illegible]
P	7,84		11,29	
P+1	148,05	0,05	222,33	0,05
P+2	[illegible]	[illegible]	35,67	[illegible]
P+3	[illegible]	0,77	48,20	[illegible]
P+4	[illegible]	0,81	[illegible]	[illegible]
P+5	[illegible]	[illegible]	[illegible]	[illegible]

(d)

	Трансверзалне силе греда приземља	
	Трансвезалне силе греда (kN)	Промена вредност
P	3,26	
P+1	82,13	0,04
P+2	13,92	5,90
P+3	19,78	0,70
P+4	25,68	0,77
P+5	31,58	0,81

(d)

	Трансверзалне силе стубова приземља	
	Трансвезалне силе стубова (kN)	Промена вредности (%)
P	5,01	
P+1	100,09	0,05
P+2	15,01	6,67
P+3	20,01	0,75
P+4	25,01	0,80
P+5	30,01	0,83

(d)

	Нормалне силе греда приземља	
	Нормалне силе греда (kN)	Промена вреднос
P	4,99	
P+1	49,87	0,10
P+2	4,99	9,99
P+3	4,99	1,00
P+4	4,99	1,00
P+5	4,99	1,00

(d)

	Нормалне силе стубова приземља	
	Нормалне силе греда (kN)	Промена вреднос
P	3,26	
P+1	124,13	0,03
P+2	27,65	4,49
P+3	49,09	0,56
P+4	76,77	0,64
P+5	110,7	0,69

(d)

	[illegible]		
	[illegible]	[illegible]	[illegible]
P	[illegible]		[illegible]
P+1	[illegible]	[illegible]	[illegible]
P+2	[illegible]	[illegible]	[illegible]
P+3	[illegible]	[illegible]	[illegible]
P+4	[illegible]	[illegible]	[illegible]
P+5	[illegible]	[illegible]	[illegible]

(e)

	[illegible]			
	[illegible]	[illegible]	[illegible]	[illegible]
P	[illegible]		[illegible]	
P+1	[illegible]	[illegible]	[illegible]	[illegible]
P+2	[illegible]	[illegible]	[illegible]	[illegible]
P+3	[illegible]	[illegible]	[illegible]	[illegible]
P+4	[illegible]	[illegible]	[illegible]	[illegible]
P+5	[illegible]	[illegible]	[illegible]	[illegible]

(e)

	Трансверзалне силе стуба приземља	
	Трансвезалне силе стуба (kN)	Промена вредности (%)
P	1,68	
P+1	0,62	2,71
P+2	0,80	0,78
P+3	0,76	1,05
P+4	0,77	0,99
P+5	0,77	1,00

(e)

	Нормалне силе греда приземља	
	Нормалне силе греда (kN)	Промена вредности (%
P	1,68	
P+1	2,25	0,75
P+2	1,06	2,12
P+3	1,32	0,80
P+4	1,27	1,04
P+5	1,28	0,99

(e)

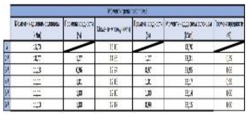
The percentage values represent the ratio of the corresponding response quantity to the value obtained for the reference single-storey frame. Selected results from Table 1 are illustrated in Figure 3.

Figure 3: Comparison diagrams for selected load cases (variation in the number of stoteys)

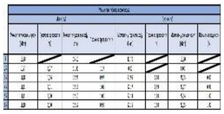
3.2. VARIATION OF BAY NUMBER

The influence of span number was investigated through the analysis of frame configurations with one to six equal bays. Maximum and minimum values of internal forces and displacements obtained for the analyzed models are summarized in Table 2.

Table 2: MTN values in columns and beams for load cases a-h (bay case)



(a)



(a)

(a)

Трансверзалне силе стубова првог поља

	Леви стуб		Десни стуб	
	Трансверзалне силе (kN)	Промена вредности (%)	Трансверзалне силе (kN)	Промена вредности (%)
λ	5,39		5,39	
2-λ	4,23	1,27	0,00	
3-λ	4,39	0,96	0,78	0,00
4-λ	4,36	1,01	0,67	1,16
5-λ	4,36	1,00	0,69	0,97
6-λ	4,35	1,00	0,70	0,99

(a)

Нормалне силе греда првог поља

	Нормалне силе греда (kN)	Промена вредности (%)
λ	5,39	
2-λ	4,23	1,27
3-λ	4,39	0,96
4-λ	4,36	1,01
5-λ	4,36	1,00
6-λ	4,35	1,00

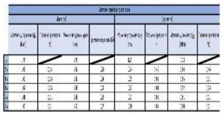
(a)

Нормалне силе стубова првог поља

	Леви стуб		Десни стуб	
	Нормалне силе (kN)	Промена вредности (%)	Нормалне силе (kN)	Промена вредности (%)
λ	24,00		24,00	
2-λ	21,35	1,12	53,22	0,45
3-λ	21,76	0,98	50,24	1,06
4-λ	21,70	1,00	50,70	0,99
5-λ	21,70	1,00	50,63	1,00
6-λ	21,70	1,00	50,65	1,00

(a)

(b)



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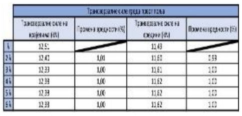

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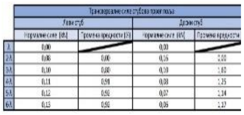
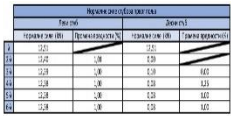


(b)

Нормалне силе греда првог поља

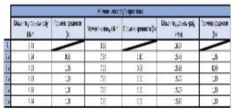
	Нормалне силе греда (kN)	Промена вредности (%)
λ	0,00	
2-λ	0,08	0,00
3-λ	0,10	0,80
4-λ	0,11	0,91
5-λ	0,12	0,92
6-λ	0,13	0,92

(b)



(b)

(c)



(c)

(c)

Моменти греде првог поља

	Моменти у греди (kNm)	Промена вредности (%)
λ	0	
2-λ	1,63	0,00
3-λ	1,38	0,85
4-λ	1,40	0,99
5-λ	1,38	1,01
6-λ	1,36	1,01

(c)

(c)

Трансверзалне силе десног стуба првог поља

	Трансверзалне силе стуба (kN)	Промена вредности (%)
2-λ	0	
3-λ	0,45	0,00
4-λ	0,34	1,32
5-λ	0,32	1,06
6-λ	0,28	1,14

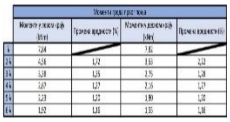
(c)

Нормалне силе греда првог поља

	Нормалне силе греда (kN)	Промена вредности (%)
λ	15,60	
2-λ	16,30	0,96
3-λ	16,17	1,01
4-λ	16,16	1,00
5-λ	16,13	1,00
6-λ	16,10	1,00

(c)

(c)



(d)

(d)

Трансверзалне силе греда првог поља

	Трансверзалне силе греда (kNm)	Промена вредности (%)
λ	3,26	
2-λ	1,69	1,93
3-λ	1,28	1,32
4-λ	1,01	1,27
5-λ	0,84	1,20
6-λ	0,72	1,17

(d)

(d)

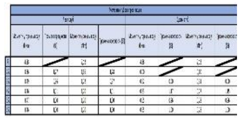
Нормалне силе греда првог поља

	Нормалне силе греда (kN)	Промена вредности (
λ	4,99	
2-λ	6,98	0,71
3-λ	7,77	0,90
4-λ	8,24	0,94
5-λ	8,53	0,97
6-λ	8,73	0,98

(d)

(d)

(e)



(e)

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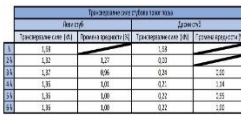
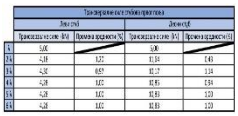


(e)

Нормалне силе греда првог поља

	Нормалне силе греда (kN)	Промена вредности (%)
λ	1,68	
2-λ	1,32	1,27
3-λ	1,37	0,96
4-λ	1,36	1,01
5-λ	1,36	1,00
6-λ	1,36	1,00

(e)



(e)

The percentage values represent the ratio of the corresponding response quantity to the value obtained for the reference single-bay frame. Selected results from Table 2 are illustrated in Figure 4.

Figure 4: Comparison diagrams for selected load cases (variation in the number of bays)

4. COMPARATIVE DISCUSSION OF PARAMETER INFLUENCE

4.1. CASE OF INCREASE IN STOREY NUMBER

For loading cases acting on beam elements, increasing the number of storeys generally resulted in higher bending moments in the lower-storey beams. At the same time, bending moments in the columns decreased, while axial forces increased significantly and became the dominant internal action in these members.

Shear forces exhibited relatively small variations and were generally highest in the uppermost storey. Exceptions were observed for uniformly distributed loads acting on beams and for concentrated loads applied at beam midspan, where beam shear forces remained unchanged regardless of storey number.

The displacement response was non-uniform. Vertical deflections decreased only in the beam directly below the newly added storey, while deflections in the remaining lower-storey beams increased. The most pronounced reduction occurred when the number of storeys increased from one to two, whereas further increases produced comparatively smaller changes. As expected, the overall horizontal displacement increased with structural height.

For loading cases applied directly to the columns, increasing the number of storeys reduced bending moments at the column end sections and near the column mid-height of the preceding storey, while higher bending moments developed in the upper column region at the support level of the added storey.

Under column loading, shear forces in the columns increased, whereas beam shear forces remained equal to zero. Axial forces in the columns remained negligible, while axial forces in the beams increased with increasing storey number. Deflection trends were similar to those observed for beam loading, with substantially higher values in single-storey frames and progressively smaller differences between taller configurations. In some cases, uplift of beam elements occurred, resulting in positive deflection values according to the adopted sign convention.

4.2. CASE OF INCREASE IN BAY NUMBER

The analysis showed that increasing the number of bays significantly influences the redistribution of internal forces within the frame system. For loading cases acting on beam elements, the addition of new spans reduced bending moments in the columns and beam regions of the preceding bay, while higher bending moments developed in the newly added bay. Consequently, the maximum beam bending moment gradually shifted toward the support zones.

Shear forces generally increased with increasing bay number in both beams and columns, reflecting the increased participation of structural members in load transfer. The influence on axial forces was less pronounced. Beam axial forces exhibited relatively small variations, whereas column axial forces showed a consistent tendency to increase with increasing bay number.

The displacement response was more complex than the corresponding force response. Beam and column deflections increased in some regions and decreased in others depending on the number of spans and member position. In several configurations, uplift of beam elements occurred, resulting in both positive and negative deflection values according to the adopted sign convention.

For loading cases applied directly to the columns, increasing the number of bays produced higher bending moments and shear forces in both beams and columns, while axial forces exhibited moderate increases. Local regions with zero shear force remained consistent with the applied loading pattern.

Unlike the increase in storey number, which predominantly affected axial forces and global displacement behaviour, the increase in bay number primarily influenced the redistribution of bending moments and shear forces. The results indicate that bay number is one of the key geometric parameters governing the internal force distribution in planar frame systems.

4.3. COMPARISON WITH PREVIOUS STUDIES

The observed trends are generally consistent with findings reported in previous investigations. Šperac [4] demonstrated that variations in storey number and bay configuration significantly affect the distribution of internal forces and deformation patterns in frame systems. Similar tendencies were identified in the present study, particularly regarding the redistribution of bending moments and the increase in axial force demands associated with increasing structural height. Likewise, Lahri and Garg [5] reported that changes in the geometric configuration of frame structures influence stiffness characteristics and consequently modify internal force distribution, which is in agreement with the present results.

Tafheem et al. [6] investigated reinforced concrete buildings with three, six, and nine storeys and reported increased reinforcement demand in beams and columns with increasing building height. Although their study considered gravity, wind, and seismic loading, the reported increase in structural demand is consistent with the higher axial force levels and force redistribution observed in the present investigation.

The influence of bay-related geometric parameters observed in this study is also consistent with the optimization-based investigation of Boito and Kripka [7], who showed that larger bay configurations lead to less favourable structural solutions and higher structural costs. While their work focused on economic optimization rather than internal force redistribution, both studies confirm the significant influence of bay configuration on the overall structural performance of reinforced concrete frame systems.

An additional contribution of the present study lies in the simultaneous consideration of both storey number and bay number within a unified numerical framework. While previous investigations have commonly focused on individual geometric parameters or specific design objectives, the present analysis enables a direct comparison of their relative influence on internal force redistribution and displacement behaviour. The results indicate that these parameters affect different components of structural response and should therefore be considered separately during the preliminary design stage.

Overall, the comparison with previous studies indicates that storey number predominantly affects axial force development and global displacement behaviour, whereas bay number primarily governs the redistribution of bending moments and shear forces. The present study complements existing research by providing a systematic comparison of these effects under a range of static loading conditions and by highlighting the distinct roles of storey and bay variation in the structural response of planar frame systems. The obtained results are also consistent with fundamental principles of structural analysis, according to which frame stiffness and internal force distribution are strongly governed by structural geometry, member arrangement, and load-transfer paths [1].

5. CONCLUSION

This study investigated the influence of storey number and bay number on the structural response of reinforced concrete frame systems through a parametric numerical analysis. The results confirmed that changes in structural geometry significantly affect the distribution of internal forces and deformation patterns.

Increasing the number of storeys primarily influenced axial force development and global displacement behaviour. Beam bending moments increased in the lower storeys, while axial forces in the columns became more pronounced and gradually emerged as the dominant internal action. In contrast, increasing the number of bays mainly affected the redistribution of bending moments and shear forces within the frame system, while axial force variations remained comparatively moderate.

A direct comparison of the investigated parameters indicates that storey number and bay number govern different aspects of structural behaviour. Storey number predominantly affects axial forces and global displacements, whereas bay number primarily controls the redistribution of bending moments and shear forces.

The comparison with previous studies confirmed the general consistency of the observed trends and highlighted the importance of geometric configuration as one of the governing factors affecting frame behaviour. The present investigation contributes to existing research by providing a systematic comparison of the influence of storey and bay variation under a range of static loading conditions. The obtained results may serve as a useful basis for preliminary structural design and for future analytical and parametric investigations of reinforced concrete frame systems.

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