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Impact of Element Size and Material Grade Variations on Seismic Response of Multistorey Building Using Time History Method

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ABSTRACT

This article presents the three multi-story RCC buildings with varied element sizes, materials grades, and varying both sizes and grades that are analyzed through the nonlinear modal time history method using PGA data of past Elcentro 1940 earthquake through ETABS to conduct the analysis. This study focused on the impact of seismic behavior of multi-story buildings with varied element sizes, materials grades, and both, to evaluate displacement, drift, base shear, overturning moments, etc. The findings reveal that models with varied sizes exhibit the lowest maximum story displacement and drift, indicating enhanced stability and reduced lateral movement during seismic events. In terms of shear forces, the varied-size models demonstrate effective load distribution, resulting in lower values compared to the constant-size models. Additionally, both the varied size and grade models show similar overturning moments, while the constant size model experiences higher values due to increased mass. These results underscore the importance of optimizing element sizes and grades to improve structural performance, reduce material usage, and enhance resilience against seismic forces. Finally, it's concluded that a model with varied element sizes with constant grades is more suitable for construction practice due to its high strength, cost-effectiveness, and ease of execution.

KEYWORDS: *Non-linear Time History Analysis, Non-linear Modal History Analysis, Regular Building, Displacement, Story Shear, Base Shear, Story Drift, Overturning moments*

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INTRODUCTION

All over the world, there is a huge demand for the construction of high-rise buildings due to the increasing population. India is one of the countries where most of the structures are low rise, but migration towards cities leads to population increment in most of the cities. So, to accommodate these people in cities height of buildings should be increased to medium or high. The design and analysis of these structures are very complicated when these structures are present in a region of very high seismic activity. Improper design and construction of any residential building leads to the great destruction of structures across the globe. Designing of structure should be carried out while keeping in mind both safety and economy. The earthquake design of the structure is based on the specification of ground motion of previous earthquake results. So, earthquake-resistant design of any important structure according to the seismic frequency is essential to overcome damage. However, earthquake forces are different and unpredictable so the software tools need to be used for analyzing structures under any seismic forces. Earthquake develops different intensities at different locations and the damage induced in buildings at these locations is also different according to the type of structure. Therefore, it is necessary to study the seismic behavior of RC-framed buildings for different seismic intensities.

EARTHQUAKE

An earthquake can be understood as "Earth's surface shaking because of energy which is suddenly released by reasons of Earth's movement". This Earth's movement is a consequence of plate movement these plates are termed as tectonic plates. The crust of the earth is surrounded by a large number of very big-sized bodies called tectonic plates, they are constantly under motion concerning one another, due to their unexpected collision with one another leading to the releaseof energy that travels towards the earth's surface in the form of waves.

The recent past research works presented below given seismic design for multistorey buildings

1. **Patil and Kumbhar, 2013 [1]** analyzed the 10-storied buildings for different seismic intensities using SAP2000-15 software. Their study reported a similar variation pattern in seismic responses of base shear, and displacement for different intensities scales (V to X)

2. **Juni, Gupta and Patel, 2017 [2]** analyzed the 23-storied residential building considering 5 different intensities of time histories of (V, VI, VII, VIII, IX, and X) on Modified Mercalli's Intensity Scale (MMI) to develop the relationship between the seismic intensities and seismic responses using SAP 2000V.14.00 Software. Their study reported a similar variation pattern in seismic responses of base shear, and displacement for different intensities scales (V to X)

3. **Krishnasrinivas, Suresh and Reddy, et al. 2017 [3]** This journal deals with the study of seismic behavior of irregular building (G+5) subjected to different ground motions and analysis is performed using ETABS 2016 software. This study proved to prefer the plan irregularities to the distribution of the seismic lateral inertia force to various lateral load resisting systems in proportion to their lateral load resisting capacities.

4. **Abdul Ahad Faizan, et al. 2019 [4]** analyzed the 8-story building considering 3 different intensities of time histories of earthquake events such as the Landers earthquake 1992, Kobe earthquake 1995, and Chichi earthquake 1999 using ETABS software. This study reported that story shear decreased with an increase in height and Base shear, displacement, and drift increased with an increase in the intensity of an earthquake. Finally, this study concludes that the outcomes vary from time history to time history.

5. **Javed Ul Islam, et al. 2020 [5]** This journal deals is computing the story drift, and displacement for different models of G+9 & G+19 RC frames with and without shear wall & bracing system are taken into consideration using STAAD Pro. This study shows displacement reduces in the shear wall as compared to bracing and RC frame and base shear reduces in the braced frame compared to RC frame and shear wall

6. **Ramdev and Barbude, et al. 2021 [6]** analyzed the G+12 storied building with an equivalent static method, response spectrum method, and time history method. 4 different intensities of time histories of earthquake events such as the Bhuj, Chamba, Chamoli, and NE Myanmar earthquakes are considered using ETABS software. This study reported that equivalent static methods and response spectrum analyses are not sufficient for structures in higher seismically active regions. Time history analysis represents a seismic design method that avoids the approximations which leads to conservative results and is applied to any structure.

7. **Pyla Shanti Swaroop, et al. 2017 [7]** analyzed the G+12 storied building subjected to seismic, dead, and live loads using ETABS software. This study aims to compare the results of seismic zones of 3,4 & 5. The behavior of high-rise structures clearly shows that lateral displacements, drifts, and story shears are higher in Zone 5 compared to zones 4 & 3.

From the above analyses, it was noticed that no one has studied the "Impact of Element Size and Material Grade Variations on Seismic Response of Multistorey Building Using the Time History Method" Hence in this view, I would like to analyze the multistoried building with varied element sizes and grades considering the different nonlinear modal time history analysis using ETABS software. The results of this study show the displacement, drift, story shear, and overturning moments of all three models. The maximum story displacement is at a higher level, the maximum story shear and overturning moments are at the base level and the maximum story drift is on the mid-floor levels of the building in all the cases.

OBJECTIVES

1. To analyze a multistoried RC framed building (10 Stories) with varied element sizes using the time history method considering the Zone III response spectrum matched to past PGA data of the El Centro earthquakes.

2. To analyze a multistoried RC framed building (10 Stories) with varied element grades using the time history method considering the Zone III response spectrum matched to past PGA data of the El Centro earthquakes.

3. To analyze a multistoried RC framed building (10 Stories) with varied both element grades and sizes using the time history method considering the Zone III response spectrum matched to past PGA data of the El Centro earthquakes.

4. To compare the impact of seismic behavior of multistoried RC framed buildings (10 Stories) of varied element sizes, element grades, and varied both element grades and sizes for El Centro earthquakes in terms of various responses such as Story Displacement, Story Drift, Storey shears and overturning moments.

METHODOLOGY

An R.C.C. framed structure is an assembly of slabs, beams, columns, and foundations interconnected to each other as a unit. The load transfer mechanism in this structure is from slabs to beams, from beams to columns, and ultimately from columns to the foundation, which in turn passes the load to the soil.

STRUCTURAL MODELING AND ANALYSIS DETAILS

1. Details of Buildings

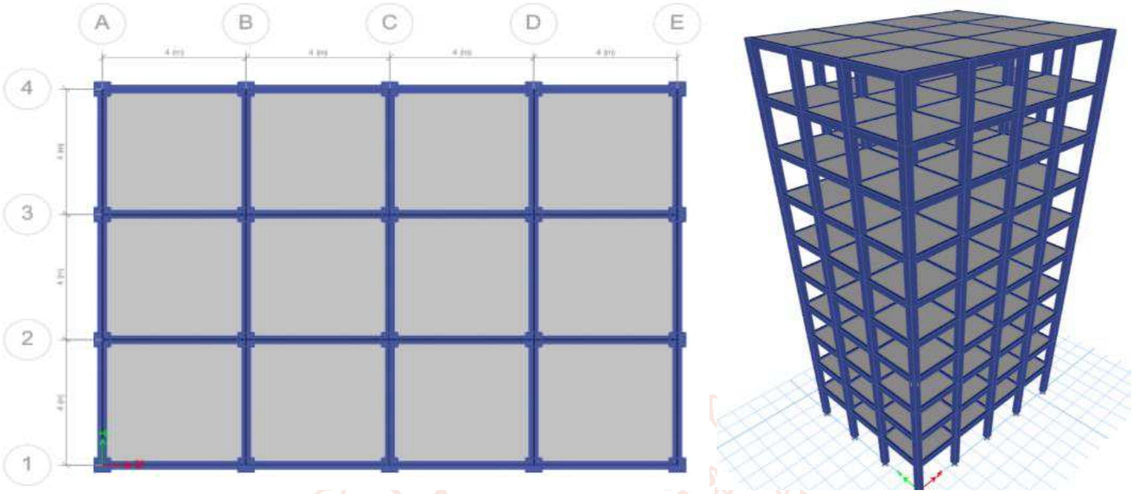


Fig 1: Plan & 3D View of Building

Table 1: Details of Building Models

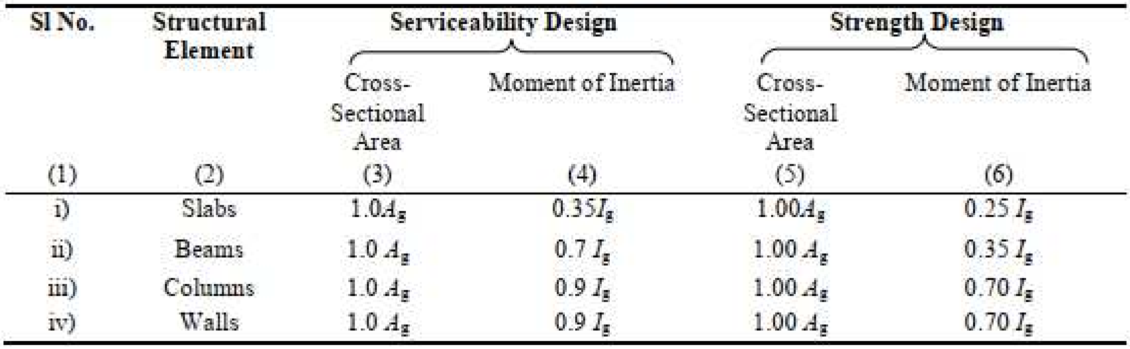
Model Details		Grade Change	Size Change	Changing Both
Numberofstories		10	10	10
StructureType		Office	Office	Office
Bottom StoryHeight		4 m	4 m	4 m
Each StoryHeight		3.5 m	3.5 m	3.5 m
Heightof thebuilding		35.5 m	35.5 m	35.5 m
X-direction Bay Width		4 m c/c	4 m c/c	4 m c/c
Y-direction Bay Width		4 m c/c	4 m c/c	4 m c/c
No. of Grids in X-direction		5	5	5
No. of Grids in Y-direction		4	4	4
Thickness of the Main Wall		230 mm	230 mm	230 mm
Thickness of Partition and Parapet Wall		150 mm	150 mm	150 mm
Height of Parapet Wall		1000 mm	1000 mm	1000 mm
Column	(Base to 4thfloor)	0.5 m x 0.5 m	0.5 m x 0.5 m	0.5 m x 0.5 m
	(5thto 7thfloor)	0.5 m x 0.5 m	0.45 m x 0.45 m	0.45 m x 0.45 m
	(8thto 10thfloor)	0.5 m x 0.5 m	0.4 m x 0.4 m	0.4 m x 0.4 m
Beam		0.23 m x 0.45 m	0.23 m x 0.45 m	0.23 m x 0.45 m
Materials Grade	(Base to 4thfloor)	M-30 & Fe 550	M-30 & Fe 500	M-30 & Fe 550
	(5thto 7thfloor)	M-25 & Fe 500	M-30 & Fe 500	M-25 & Fe 500
	(8thto 10thfloor)	M-20 & Fe 415	M-30 & Fe 500	M-20 & Fe 415

2. Table 3: Material Properties

Table 2: Material Properties [8]

Densityofconcrete	25 kN/m3
Density of wall	18 kN/m3
Modulus of Elasticity for Concrete	27.386 x103 Mpa
Modulus of Elasticity for Steel	2x105 Mpa

3. Defining Stiffness modifiers as per [9]



Sl No.	Structural Element	Serviceability Design		Strength Design	
		Cross-Sectional Area	Moment of Inertia	Cross-Sectional Area	Moment of Inertia
(1)	(2)	(3)	(4)	(5)	(6)
i)	Slabs	1.0A_g	0.35I_g	1.00A_g	0.25 I_g
ii)	Beams	1.0 A_g	0.7 I_g	1.00 A_g	0.35 I_g
iii)	Columns	1.0 A_g	0.9 I_g	1.00 A_g	0.70 I_g
iv)	Walls	1.0 A_g	0.9 I_g	1.00 A_g	0.70 I_g

Fig 2: Stiffness Modifiers

4. Loads Considered Common to Buildings

A. Static Loads

Table 3: Static Loads considered[10]

Dead Load	Self-Weight
Liveload on floors	2.5 kN/m2
Liveload on the terrace	1.5 kN/m2
Floor finish	1 kN/m2
Main Wall	12.627 kN/m
Partition Wall	8.235 kN/m
Parapet Wall	3 kN/m

B. Dynamic Loads

- **Response Spectrum**

Table 4: Seismic properties [11]

Zonefactor	0.36
Soil type	Mediumstiff
Building type	SMRF
Responsereductionfactor	5
Importancefactor	1
Target Spectrum	Zone III
Damping ratio	5%

- **Time History**

Table 5: Adopted Earthquake Records

Earthquake	Country	Year	PGA (g)	Mw (R)	Duration (s)	Type	Hypo. distance
Elcentro	U S	1940	0.281	6.9	53.72	Near-field	12.2 km

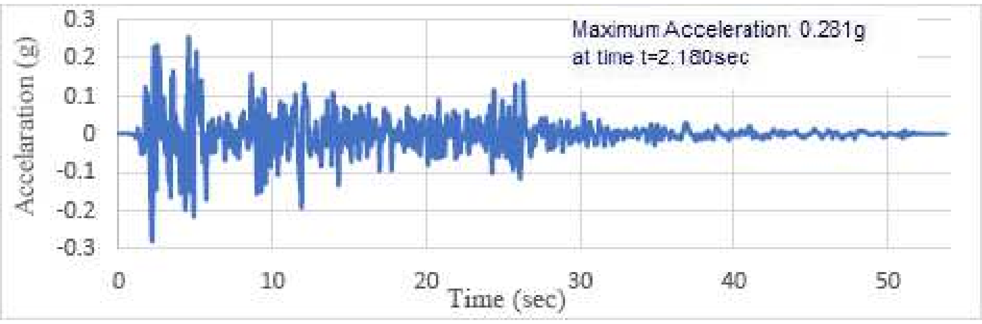
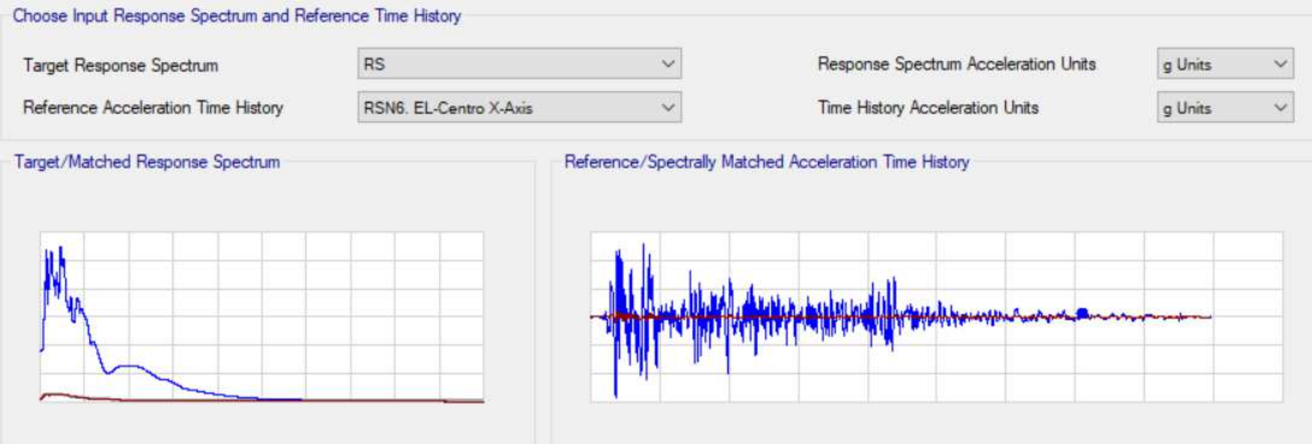


Fig 3: Defining TH Function (El Centro)

C. Matching Time History to Target Spectrum

Matching the El Centro earthquake to the Zone-III target spectrum code guidelines, to accurately predict a structure's response to an earthquake, it's essential to match the time history to the response spectrum of the specific region. An unknown earthquake cannot be directly applied to any geological area; it must be scaled to reflect the local seismic conditions. This ensures that the seismic input aligns with the expected earthquake characteristics, leading to reliable and realistic structural analysis.



Choose Input Response Spectrum and Reference Time History

Target Response Spectrum: RS

Reference Acceleration Time History: RSN6. EL-Centro X-Axis

Response Spectrum Acceleration Units: g Units

Time History Acceleration Units: g Units

Fig 4: Time History Matching to zone-III Target spectrum

5. Load Combinations

Table 6: Load combinations considered[12]

Combination-1	1.5(DL+LL)
Combination-2	1.5(DL±THX/Y)
Combination-3	0.9DL±1.5THX/Y)
Combination-4	1.2(DL+LL±THX/Y)

6. Base Shear Scaling (As per IS1893 Cl. 6.4.2)

Load Case	Base Shear, kN		Load Case	Base Shear, kN
EQX	774		EQY	670
THX-Unscaled	173		THY-Unscaled	184

Scale factor considered in X direction is = 4.460

Scale factor considered in Y direction is = 3.635

According to [11] clause 6.4.2, if the base shear from dynamic analysis is lower than that from static analysis, it should be scaled up to match the static base shear. This ensures that the seismic design forces are not underestimated. The above scaling table is done for the model with varied element size, similarly the same process do for remaining two models to meets safety requirements.

RESULTS AND DISCUSSIONS

1. MAXIMUM STORY DISPLACEMENT:

Table 7: Maximum Story Displacement (in mm)

Story No.	X- Direction in mm			Y-Direction in mm		
	Size	Grade	Both	Size	Grade	Both
Terrace	115.275	116.686	123.881	114.558	117.633	117.112
9th floor	113.866	115.496	120.395	108.449	111.452	112.466
8th floor	111.473	112.936	114.49	103.098	104.865	106.277
7th floor	106.807	107.861	108.15	94.536	95.422	96.132
6th floor	99.277	99.697	98.684	83.187	83.581	83.468
5th floor	87.194	87.369	84.308	68.525	69.685	67.933
4th floor	70.115	71.153	65.765	53.046	54.061	51.487
3rd floor	50.669	52.409	47.558	37.649	37.798	37.686
2nd floor	30.782	32.337	29.907	22.941	22.475	23.027
1st floor	12.364	12.937	12.085	9.195	8.966	9.215
Base	0	0	0	0	0	0

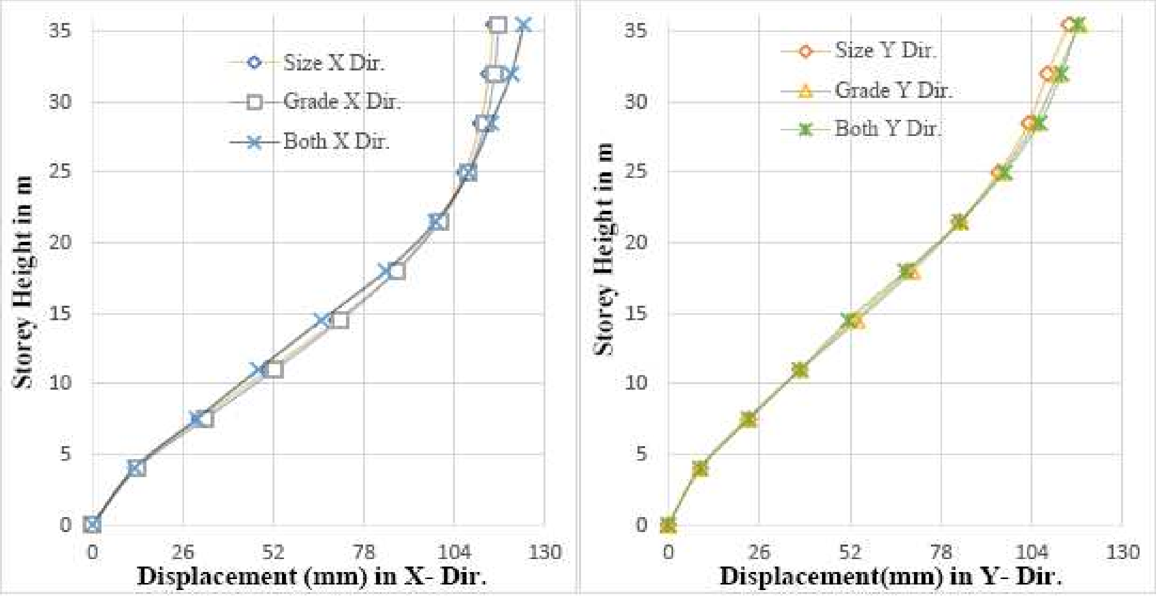


Fig 5: Maximum Story Displacement

The above table and graph illustrate the maximum story displacements for the G+10 three building models analyzed using the Time History Method, adopting the PGA data from the El Centro earthquake. The graph (Fig. 5) shows the trend of displacement concerning the story height in millimeters (mm). The terrace experienced the highest displacements, while the base had zero displacements, as expected. The model with constant sizes along varied grades and constant grades along varied sizes has slightly the same displacements, while the model with varied grades and sizes shows the max. displacement in terrace level.

This suggests that varied element sizes offer better strength by reducing displacements effectively, making it economical by optimizing element sizes can save material quantities. Constant element sizes enhance rigidity and reduce lateral displacement. A combination of varied sizes and grades shows the importance of optimizing both parameters to achieve a balance between flexibility and rigidity in earthquake-resistant building design, leading to the largest displacements, but displacements are well within permissible limits, confirming the stability of the structure under the given loading conditions.

2. MAXIMUM STORY DRIFT:

Table 8: Maximum Story Drift (in %)

Story No.	X-Direction (in %)			Y-Direction (in %)		
	Size	Grade	Both	Size	Grade	Both
Terrace	0.001726	0.001997	0.002097	0.002044	0.002302	0.002358
9th floor	0.002666	0.002834	0.003124	0.003343	0.003297	0.003843
8th floor	0.003448	0.003534	0.003959	0.004002	0.003918	0.004609
7th floor	0.003713	0.004046	0.00381	0.0041	0.004212	0.004463
6th floor	0.003955	0.004216	0.004168	0.004331	0.004492	0.0048
5th floor	0.004989	0.004951	0.005322	0.004886	0.004641	0.005166
4th floor	0.005557	0.005689	0.00551	0.004766	0.004778	0.00471
3rd floor	0.005824	0.005916	0.005489	0.004438	0.004581	0.004298
2nd floor	0.005306	0.005562	0.005099	0.003959	0.003938	0.003996
1st floor	0.003091	0.003234	0.003021	0.002299	0.002241	0.002304
Base	0	0	0	0	0	0

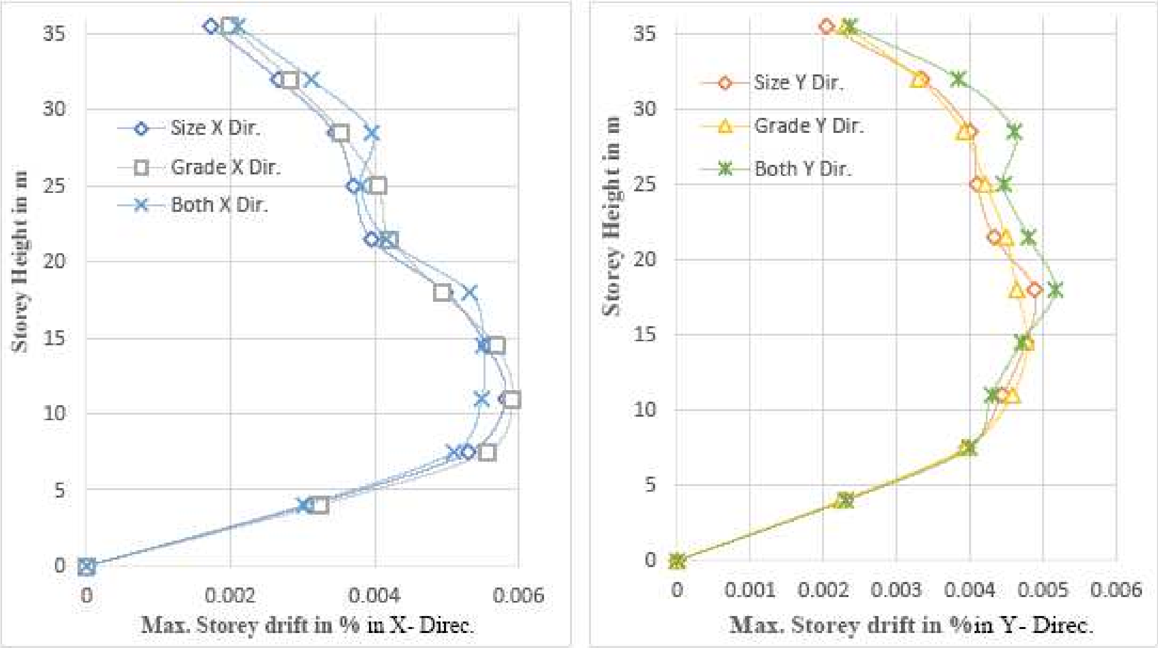


Fig 6: Maximum Story Drift

The table and graph above illustrate the maximum story drift for the G+10 building models, graph (Fig. 6) shows that the maximum story drift occurs in between the 3rd to 5th floors. The model with varied element sizes shows the least maximum drift, with a value of 0.00557 in the X direction at the 4th floor, which is 11.8% lower compared to the model with varied grades (0.00632). The model with both size and grade varied exhibits the highest drift, with values of 0.00632 in the X direction and 0.00517 in the Y direction at the 4th and 5th floors, respectively. This indicates that the model with both size and grade varied has even higher drift values, highlighting that optimizing the size of elements plays a crucial role in reducing lateral deformation. Moreover, optimizing sizes can achieve a stronger and more economical structure, while varying both sizes and grades can lead to increased flexibility, which may not be favorable for controlling drift under seismic loads. The results emphasize the need to focus on element size for achieving better performance and economy in earthquake-resistant design.

3. MAXIMUM STORY SHEARS

Table 9: Maximum Story Shear (in kN)

Story No.	X-Direction (in kN)			Y-Direction (in kN)		
	Size	Grade	Both	Size	Grade	Both
Terrace	277.1278	311.8749	287.6528	278.4432	264.0511	269.5836
9th floor	543.5321	583.9222	532.8596	590.095	582.6637	559.3211
8th floor	627.5567	672.4734	607.4926	674.1044	715.5126	675.9856
7th floor	724.0367	798.0247	669.0618	747.8792	776.0735	778.0885
6th floor	760.6411	833.3258	743.4004	802.4479	877.1892	826.9221
5th floor	977.0923	1026.9122	1008.497	928.0667	896.1257	941.3151
4th floor	1189.5836	1246.252	1173.5166	969.9595	974.735	948.6857
3rd floor	1287.3292	1318.5196	1197.6176	909.6381	949.9482	888.8534
2nd floor	1318.4942	1383.7569	1290.95	963.5466	936.7227	948.0871
1st floor	1394.8354	1461.6032	1375.8652	1008.1442	992.199	1014.9381
Base	0	0	0	0	0	0

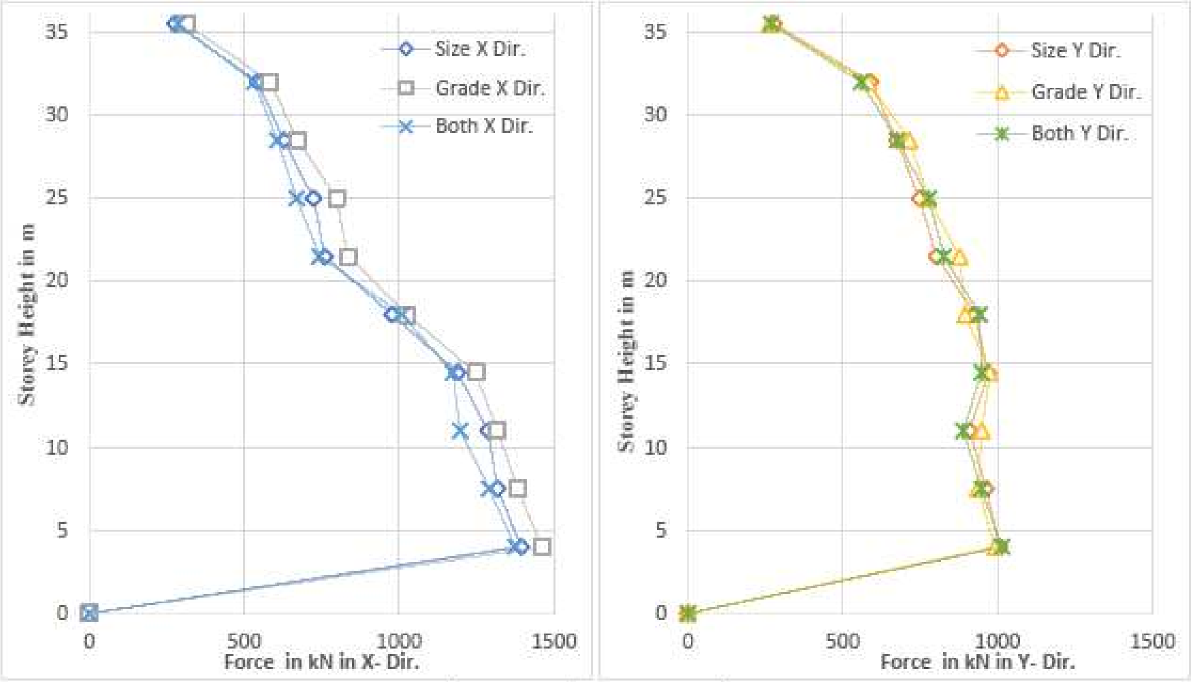


Fig 7: Maximum Story Shear

The table and graph above present the maximum story shear values. In terms of shear force distribution, the base levels experienced the highest shear forces, with the model having varied grades showing the highest values. At the 1st floor, the model with grade variation has a shear force of 1461.63 kN in the X direction, which is about 4.8% greater compared to the model with only size variation. For mid-levels, such as the 4th floor, the model with both size and grade variation exhibited a shear force of 1197.617 kN in the X direction, while the size-only model showed a similar value with a difference of 1.5%. Overall, the structure with grade variation tends to experience greater shear forces, indicating that material grade changes affect the lateral force distribution more significantly compared to size variation alone.

4. STORY OVERTURNING MOMENT

Table 10: Story Overturning Moment (in kN-m)

Story No.	X-Direction in kN-m			Y-Direction in kN-m		
	Size	Grade	Both	Size	Grade	Both
Terrace	14908.2049	14836.0347	14908.2047	19877.6066	19781.3797	19877.6062
9th floor	43955.4939	45228.2351	43955.4932	58607.3252	60304.3135	58607.3243
8th floor	73002.7829	75620.4355	73002.7817	97337.0439	100827.2474	97337.0423
7th floor	102013.987	106012.636	102013.9853	136018.6493	141350.1812	136018.6471
6th floor	131694.3684	136404.836	131694.3662	175592.4912	181873.1151	175592.4883
5th floor	161374.7499	166797.037	161374.7471	215166.3331	222396.0489	215166.3295
4th floor	191019.0463	197189.237	191019.0433	254692.0618	262918.9831	254692.0577
3rd floor	221411.2469	227581.438	221411.2439	295214.9959	303441.9172	295214.9919
2nd floor	251803.4476	257973.639	251803.4445	335737.9301	343964.8514	335737.926
1st floor	282195.6482	288365.839	282195.6451	376260.8643	384487.7856	376260.8602
Base	286694.3198	292864.511	286694.3167	382259.0931	390486.0144	382259.089

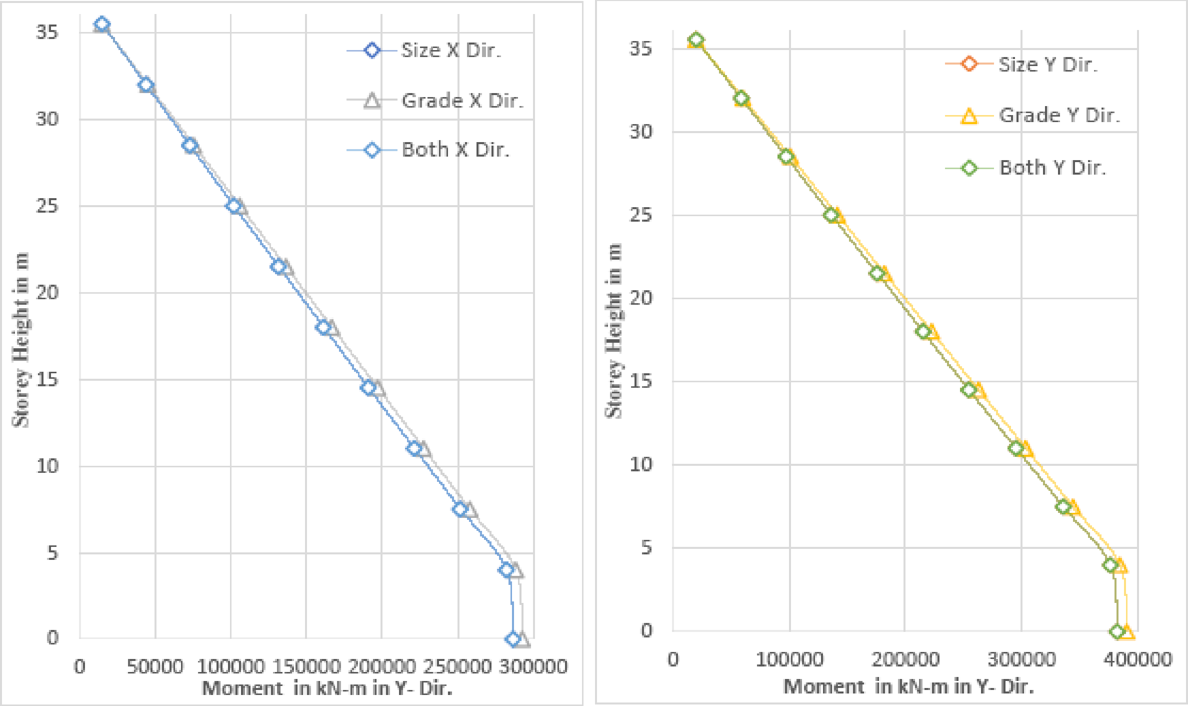


Fig 8: Story Overturning Moment

The table and graphs presented for the story overturning moment illustrate how different models respond to lateral forces at varying story levels. The model with varied sizes and varied both size and grade modifications demonstrate nearly identical moment distribution throughout the structure. In contrast, the model with a constant size but varied grade exhibits higher overturning moments due to the increased mass associated with higher-grade materials, which enhances the stiffness but also elevates the forces experienced by the structure. This increased overturning moment reflects a higher demand for the foundation and structural stability. Thus, adopting an approach that optimizes both element size and grade leads to a more balanced distribution of moments, improving overall structural performance and reducing potential risks during seismic events.

CONCLUSION

1. Th mode wit varie size showe th leas maximu stor displacement indicatin enhance latera stability an i constant-siz mode wit varie grade ha highe displacement du t increase mass whil th mode wit varie bot size an grade show th importanc o optimizin bot parameter t achiev a balanc betwee flexibilit an rigidit i earthquake-resistan buildin design leadin t th larges displacements
2. Varie siz model exhibite superio performanc i stor drift reinforcin th benefit o optimizin elemen sizes
3. Stor Shear wer lowe i model wit varie size compare t constant-siz models highlightin effectiv loa distribution
4. Bot th varie siz an grad model displaye simila overturnin moments whil th constan siz mode ha elevate values emphasizin th significanc o mas distributio i design
5. Fro thi analysi i suggest tha varyin elemen size wit constan grad offe bette strengt b reducin displacement effectively makin i economica b optimizin elemen size ca sav material an i i a mos practice metho o constructio tha i practicall possible An mode wit constan elemen size wit varie elemen grade enhance rigidit an reduce latera displacement bu thi metho i no preferabl fo constructio practice

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