International Journal of Architecture and Urbanism Vol. 08, No. 03 (2024) 463 – 478

International Journal of Architecture and Urbanism

Journal homepage: https://talenta.usu.ac.id/ijau

Seismic Performance Analysis of Regular and Irregular Buildings Based on SNI 1726:2019 Standards

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ARTICLE INFO

Article history:
Received 24-9-2024
Revised 22-10-2024
Accepted 14-11-2024
Available online 30-11-2024

E-ISSN: 2622-1640
P-ISSN: 2622-0008

How to cite:
Alfitra T.M.R, et.al. Seismic Performance Analysis of Regular and Irregular Buildings Based on SNI 1726:2019 Standards. International Journal of Architecture and Urbanism. 2024. 8(3):463-478.

http://doi.org/10.32734/ijau.v8i3.18258

ABSTRACT

This study analyzes the seismic performance of regular and irregular building structures according to the SNI 1726:2019 standards. Four building models were developed: one regular structure and three irregular structures, using data from the earthquake-prone Tarutung region in Sumatra. The analysis, conducted with ETABS software, focused on key seismic parameters including base shear, story shear, displacement, torsion, and column reinforcement. Results showed that regular buildings performed better under seismic loads, exhibiting lower base shear, story shear, and torsion due to their symmetrical configuration and uniform mass distribution. But the Country is such that where even less than irregular structures also faced more in seismic force and higher displacement at across the horizontal direction, torsional effects were seen much stronger especially with significant irregularities. This resulted in non-uniform distribution of forces and localized higher requirements for column reinforcement. These results underline how regular buildings, where developing countries have the most capacity to make improvements in construction quality and safety on a large scale, are actually quite resilient structures against seismic forces. This research demonstrates the significance of complying with seismic design codes and offers perspective which may assist engineers to develop irregular building structures that are more earthquake resistant.

Keywords: earthquake, irregular, regular, SRPMK, torsion

1. Introduction

Building design is a challenging aspect of modern construction because of seismic activities, especially those areas where earthquakes keep on arriving [1][2]. Because Indonesia has such a high level of seismic activity due to being a part of the Ring of Fire, it is common for tectonic events to occur which are capable of destroying buildings due to their structures. Situated in the Sumatera Fault Zone, the Tarutung region of Sumatera was badly affected in a 6.0 Mw earthquake, damaging a variety of infrastructure and building types with damage on scales from none through minor to severe. This underscores the need for earthquake-resilient buildings, even though earthquakes can never be predicted.

Changing the construction landscape with avant-garde design, irregular building structures are now a common feature in modern construction as the industry moves forward with aesthetic appeal and space challenges. Although these are aesthetically pleasing, they have implications in terms of seismic performance [3][4][5], [6][7]. There are two types of irregularities based on SNI 1726:2019 whether it is horizontal or vertical Irregularities in buildings [8]. A building structure has as a critical box to be inoperable effect of earthquakes

[9][10][11][12]. Irregular shapes can cause nonuniform deformation, high torsion and stress concentration, making the whole structure relatively weak with regard to earthquake failure [13][14][15][16][17].

Considering these facts, this study is about the seismic performance of regular and irregular buildings in accordance with SNI 1726:2019. The research investigates four buildings; three of them have irregular configurations and one has the regular configuration. Data are obtained from Tarutung but the seismic risks There which is very High. Base shear, story shear, displacement, torsion and column reinforcement are some key structural parameters analyzed that help in understanding the behavior of regular & irregular buildings during seismic events.

The seismic behavior of buildings varies significantly between regular and irregular structures. Irregular buildings, due to their non-uniform mass distribution and stiffness, are more susceptible to seismic damage, especially torsional forces [6][7][10][12]. The aim of this research is to perform a comparative analysis between regular and irregular buildings to assess their structural response under seismic conditions, as outlined by the SNI 1726:2019 standards.

The primary objective of this study is to evaluate and compare the seismic performance of four building models, focusing on base shear, story shear, displacement, torsion, and column reinforcement. This analysis will provide insights into the differences in seismic resilience between regular and irregular building structures, aiding in the design of safer and more earthquake-resistant buildings.

This research focuses on reinforced concrete structures, analyzing their seismic performance based on the SNI 1726:2019 standards. The study is limited to the Tarutung region in Sumatra, where the seismic data is collected. The structural analysis is conducted using ETABS software, and the findings are based on linear parameters such as base shear, story shear, displacement, and torsion.

The work presented in this study is a relevant contribution to the field of structural engineering, especially for earth-quake resistant design. This study helps to available important data about seismic performance of regular and irregular buildings which can support decision of engineers for designing the building in seismically active areas. These results will also be useful as benchmarks for future research on the seismic response of irregular buildings.

2. Method

2.1. Structural Modeling

Four building models were developed using the ETABS software, focusing on three irregular structures and one regular structure. The irregularities in these structures were based on horizontal and vertical configurations, following the classification in SNI 1726:2019. Each model was designed as a reinforced concrete structure, ensuring consistency in material properties and overall design. Each model can be seen in plan and perspective in Figures 1 and 2.

Regular Structure (Model 4). A standard, symmetrical building with consistent mass and stiffness distribution, Irregular Structures (Model 1-3), These buildings featured various irregularities such as asymmetry, re-entrant corners, and non-uniform mass distribution. Each model was designed to represent different real-world building designs commonly found in urban areas.

2.2. Seismic Input

The seismic data for the Tarutung region in Sumatra, which is located on the Sumatera Fault Zone, was used to simulate earthquake forces. The site classification was SE (soft soil), with response spectra generated from local seismic hazard data. The seismic analysis was conducted according to the response spectrum method outlined in SNI 1726:2019.

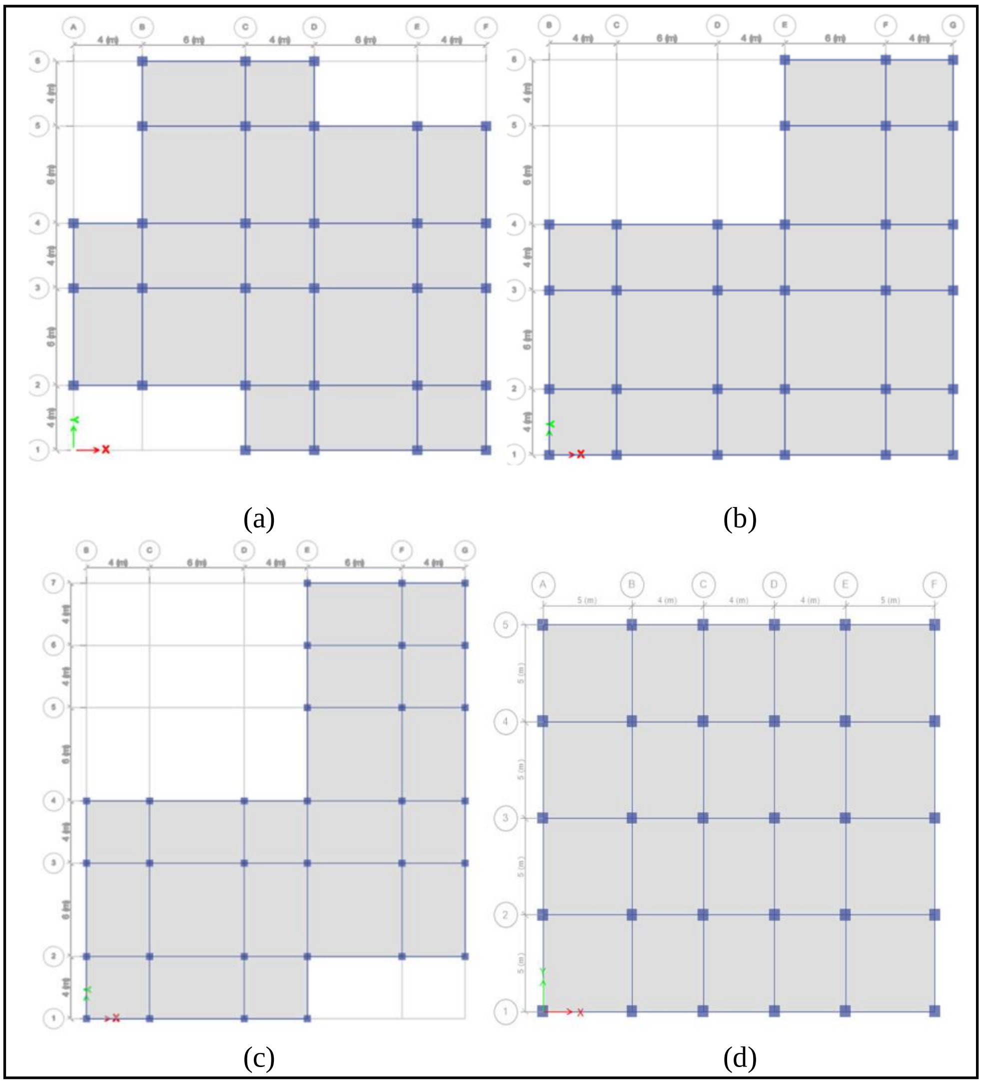

Figure 1 Building Plan (a) Model 1 (b) Model 2 (c) Model 3 (d) Model 4

2.3. Analysis Parameters

To evaluate the seismic performance of the building models, several key structural parameters were analyzed:

Base Shear the total horizontal force at the base of the building caused by seismic activity, Story Shear is the horizontal force present at each level of the building, Displacement the lateral movement of the building under seismic loading, measured at each story level, Torsion rotational forces induced by the asymmetrical mass and stiffness distribution in irregular buildings, Column Reinforcement the required reinforcement for columns to resist seismic forces, particularly in areas of high stress concentration.

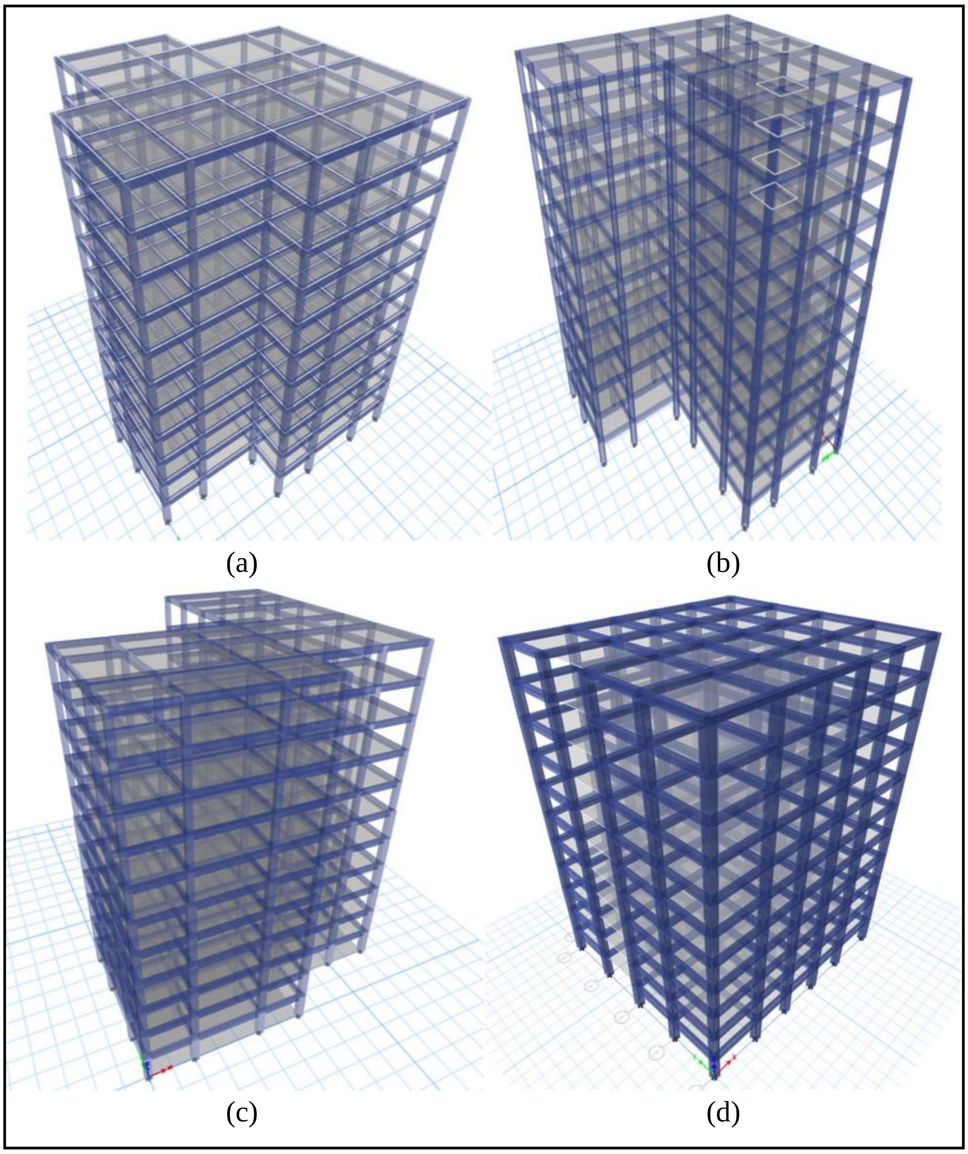

Figure 2 Building Perspective (a) Model 1 (b) Model 2 (c) Model 3 (d) Model 4

2.4. Seismic Design Code Compliance

The study strictly adhered to SNI 1726:2019 for all aspects of seismic design and analysis. This included the criteria for regular and irregular building classifications, as well as the specific response spectrum for the region. Additional guidelines from SNI 2847:2019 (reinforced concrete structures) and SNI 1727:2020 (loading standards) were incorporated into the structural design process.

2.5. Evaluation Criteria

The evaluation of the building models focused on determining comparison of base shear and story shear across all models, analysis of maximum displacement values for both regular and irregular structures., assessment of torsional forces in irregular structures and their impact on overall stability, and examination of column reinforcement requirements in critical areas, particularly in irregular models where stress concentrations were highest.

3. Results and Discussion

3.1. Base Shear

The base shear represents the total horizontal seismic force acting on the base of the structure. The analysis shows that the base shear values vary significantly between the regular and irregular building models (see Table 1 and Figure 3). The regular structure (Model 4) exhibited a more uniform distribution of base shear compared to the irregular models are called Model 1, Model 2, and Model 3. Irregular structures displayed higher base shear values, especially in areas where irregularities such as asymmetrical configurations were present. This indicates that irregular structures are more prone to larger seismic forces due to their uneven distribution of mass and stiffness.

Model 4 (Regular Structure), the base shear was relatively uniform due to the symmetry in the building's geometry and mass distribution. Model 1-3 (Irregular Structures), these models experienced higher base shear values, particularly in the direction of the irregularities. The lack of symmetry caused localized increases in shear forces, highlighting the vulnerability of irregular buildings to seismic loads.

Table 1 Base Shear

Structure	Base Shear	
	X-Direction	Y-Direction
	kN	kN
Model 1	1446,2814	1443,8556
Model 2	1556,4323	1556,4324
Model 3	1430,2491	1475,1051
Model 4	1518,1397	1411,124

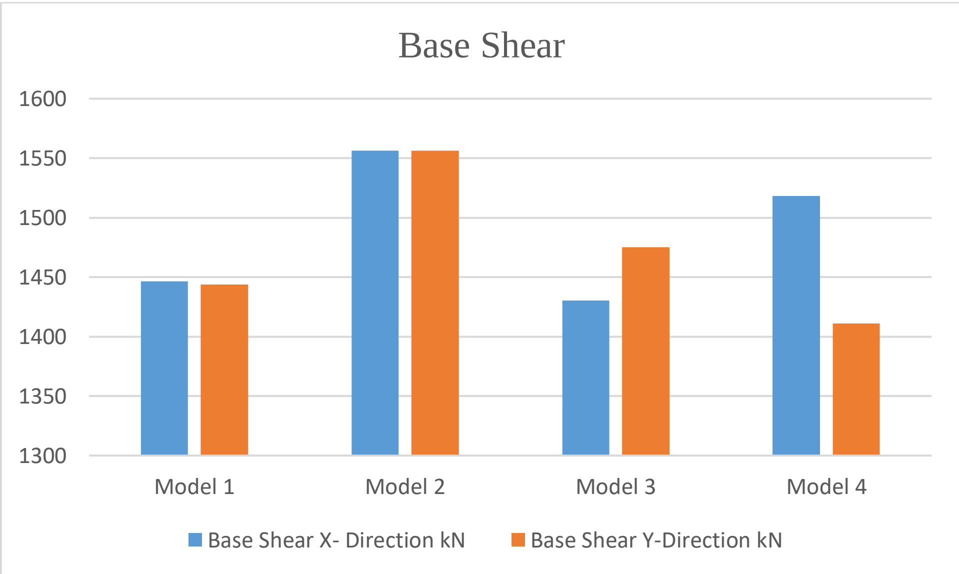

Figure 3 Base Shear Graph

3.2. Story Shear

Story shear refers to the horizontal seismic forces acting at each story level. Similar to base shear, story shear values were higher in the irregular structures compared to the regular building. The irregularities in mass distribution and geometry caused an uneven distribution of shear forces across the height of the buildings (see Tables 2-5 and Figures 4-9).

Model 4 demonstrated a gradual and predictable increase in story shear from the base to the top of the structure, indicating a stable and controlled response to seismic forces. Model 1-3 exhibited sharp variations in story shear, particularly at the levels where the irregularities were most pronounced. This uneven distribution of forces increases the potential for damage at specific floors during an earthquake.

Table 2 Model 1 Story Shear

	Story Shear	
	X-Direction	Y-Direction
	kN	kN
11	222,463	222,298
10	444,243	443,699
9	639,273	638,305
8	812,888	811,546
7	966,713	965,053
6	1101,19	1099,27
5	1216,45	1214,34
4	1310,92	1308,66
3	1382,86	1380,51
2	1429,08	1426,69
1	1446,28	1443,86

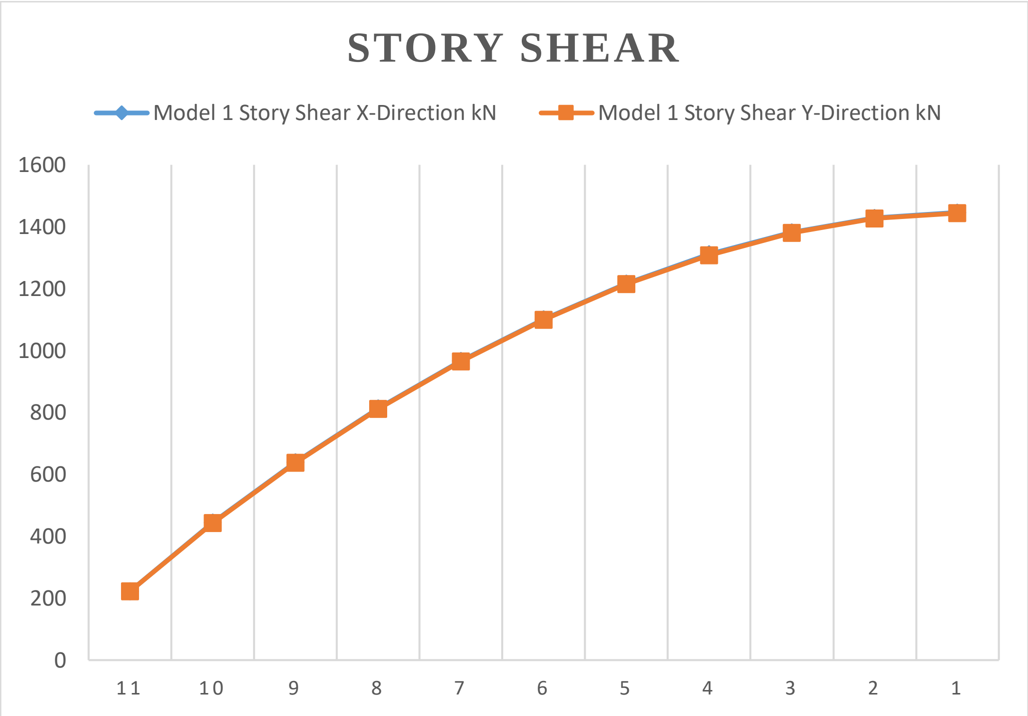

Figure 4 Model 1 story shear graph

Table 3 Model 2 Story Shear

	Story Shear	
	X-Direction	Y-Direction
	kN	kN
11	237,895	237,895
10	476,338	476,339
9	686,545	686,542
8	873,861	873,861
7	1039,93	1039,93
6	1185,1	1185,1
5	1309,4	1309,4
4	1411,14	1411,14
3	1488,46	1488,46
2	1538,01	1538,01
1	1556,43	1556,43

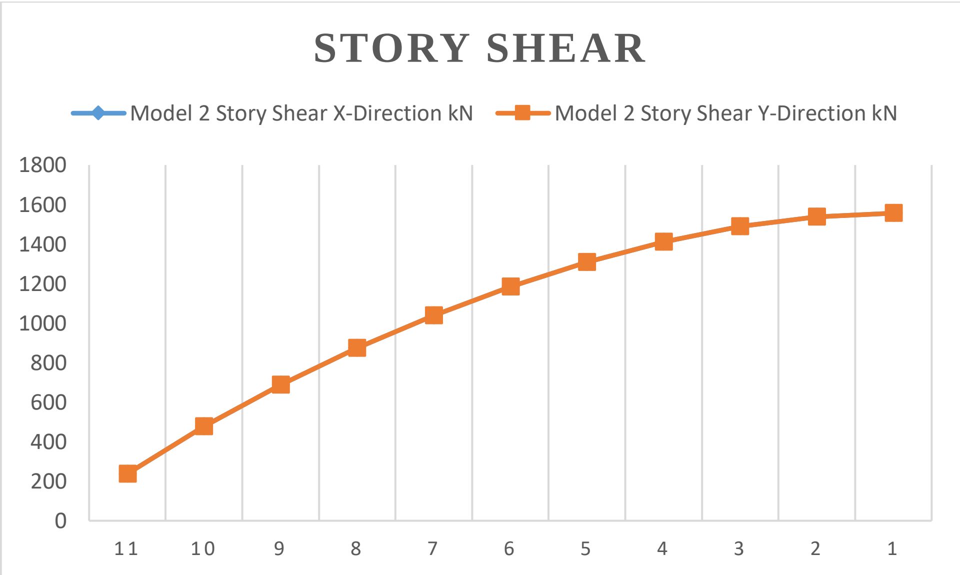

Figure 5 Model 2 story shear graph

Table 4 Model 3 Story Shear

	Story Shear	
	X-Direction	Y-Direction
	kN	kN
11	219,375	223,576
10	439,244	449,271
9	632,476	648,74
8	804,426	826,804
7	956,73	984,851
6	1089,81	1123,04
5	1203,75	1241,25
4	1297,02	1337,82
3	1367,93	1411,02
2	1413,39	1457,77
1	1430,25	1457,11

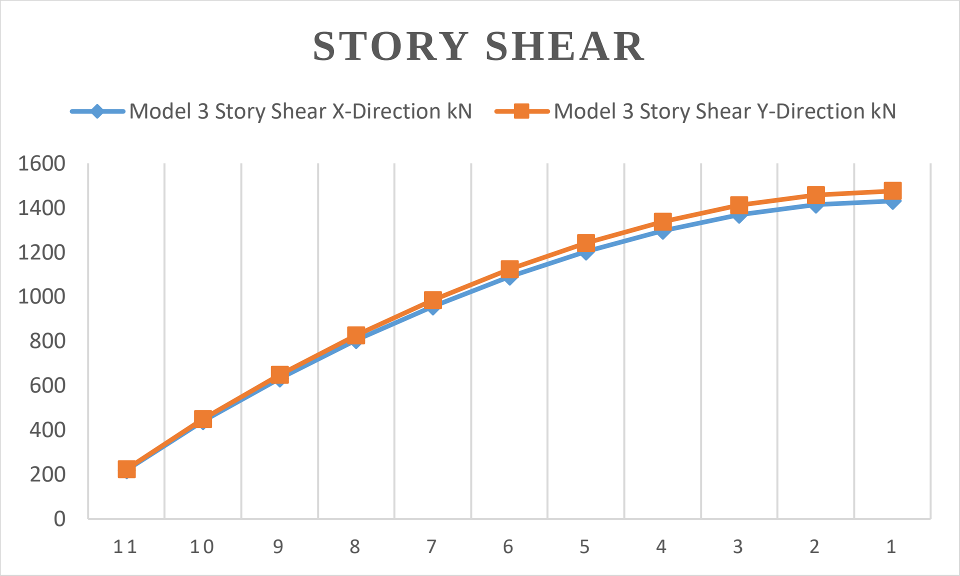

Figure 6 Model 3 story shear graph

Table 5 Model 4 Story Shear

	Story Shear	
	X-Direction kN	Y-Direction kN
11	225,86	215,716
10	455,70	431,459
9	660,71	621,54
8	844,84	791,202
7	1008,99	941,832
6	1152,84	1073,66
5	1275,85	1186,65
4	1376,19	1279,14
3	1452,00	1349,44
2	1500,23	1394,46
1	1518,14	1411,12

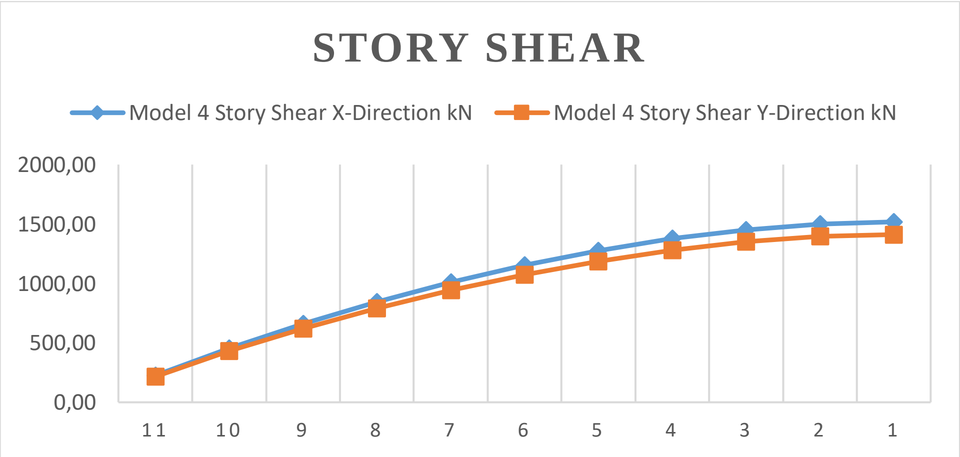

Figure 7 Model 4 story shear graph

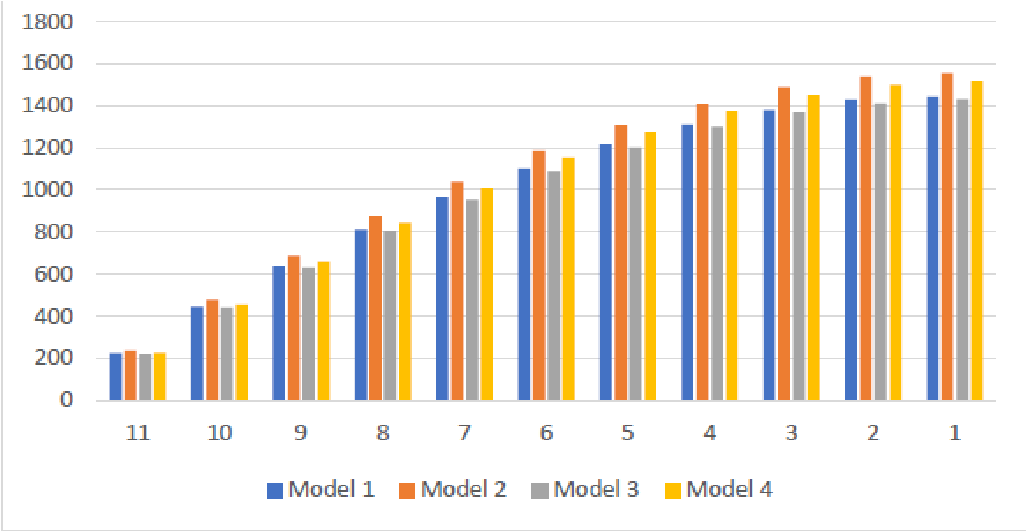

Figure 8 Comparison Chart of X-Direction Story Shear

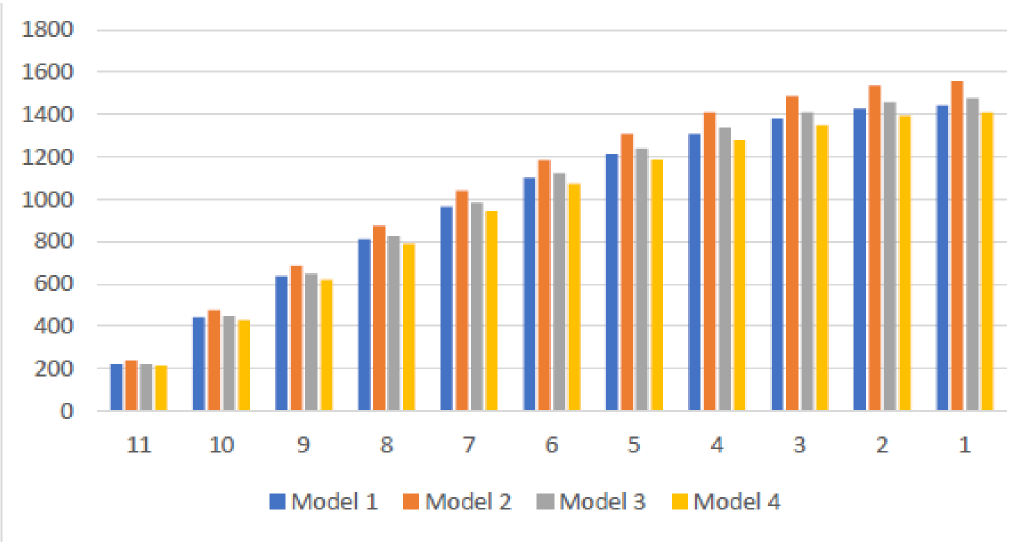

Figure 9 Comparison Chart of Y-Direction Story Shear

3.3. Displacement

The lateral displacement of the structures was another key parameter in the analysis. Displacement values indicate how much the building moves laterally during an earthquake. Regular buildings, such as Model 1, showed smaller and more uniform displacement values across all stories. In contrast, the irregular structures experienced larger displacements, particularly at the points of irregularities (see Tables 6-9 and Figures 10 and 11).

Model 4 maintained a controlled displacement pattern, which is critical for minimizing structural damage during seismic events. Model 1-3 displayed larger displacements, especially at stories with irregular configurations. These larger displacements can lead to increased damage to non-structural elements, such as walls and partitions, as well as structural failure in extreme cases.

Table 6 Model 1 Structure Displacement

Story	*Displacement*		*Elastic Drift*		*h*	*Inelastic Drift*		*Drift Limit*	*Cek*
	δe_X	*δe_Y*	*δe_X*	*δe_Y*		*Δ_X*	*Δ_Y*		
	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	
11	43.973	46.188	1.477	1.518	3000	8.123	8.349	46.154	OK
10	42.496	44.67	2.168	2.249	3000	11.924	12.370	46.154	OK
9	40.328	42.421	2.943	3.070	3000	16.187	16.885	46.154	OK
8	37.385	39.351	3.693	3.868	3000	20.312	21.274	46.154	OK
7	33.692	35.483	4.376	4.595	3000	24.068	25.273	46.154	OK
6	29.316	30.888	4.964	5.225	3000	27.302	28.738	46.154	OK
5	24.352	25.663	5.434	5.728	3000	29.887	31.504	46.154	OK
4	18.918	19.935	5.727	6.042	3000	31.499	33.231	46.154	OK
3	13.191	13.893	5.704	6.017	3000	31.372	33.094	46.154	OK
2	7.487	7.876	4.983	5.248	3000	27.407	28.864	46.154	OK
1	2.504	2.628	2.504	2.628	3000	13.772	14.454	46.154	OK

Table 7 Model 2 Structure Displacement

Story	*Displacement*		*Elastic Drift*		*h*	*Inelastic Drift*		*Drift Limit*	*Cek*
	δe_X	*δe_Y*	*δe_X*	*δe_Y*		*Δ_X*	*Δ_Y*		
	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	
11	45.83	45.83	1.512	1.512	3000	8.316	8.316	46.154	OK
10	44.318	44.318	2.238	2.238	3000	12.309	12.309	46.154	OK
9	42.08	42.08	3.051	3.051	3000	16.781	16.781	46.154	OK
8	39.029	39.029	3.838	3.838	3000	21.109	21.109	46.154	OK
7	35.191	35.191	4.553	4.553	3000	25.042	25.042	46.154	OK
6	30.638	30.638	5.173	5.173	3000	28.452	28.452	46.154	OK
5	25.465	25.465	5.668	5.668	3000	31.174	31.174	46.154	OK
4	19.797	19.797	5.980	5.980	3000	32.890	32.890	46.154	OK
3	13.817	13.817	5.964	5.964	3000	32.802	32.802	46.154	OK
2	7.853	7.853	5.221	5.221	3000	28.716	28.716	46.154	OK
1	2.632	2.632	2.632	2.632	3000	14.476	14.476	46.154	OK

Table 8 Model 3 Structure Displacement

Story	*Displacement*		*Elastic Drift*		*h*	*Inelastic Drift*		*Drift Limit*	*Cek*
	δe_X	*δe_Y*	*δe_X*	*δe_Y*		*Δ_X*	*Δ_Y*		
	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	
11	50.34	45.406	1.758	1.478	3000	9.669	8.129	46.154	OK
10	48.582	43.928	2.520	2.209	3000	13.860	12.150	46.154	OK
9	46.062	41.719	3.398	3.019	3000	18.689	16.605	46.154	OK
8	42.664	38.7	4.259	3.802	3000	23.425	20.911	46.154	OK
7	38.405	34.898	5.041	4.517	3000	27.726	24.844	46.154	OK
6	33.364	30.381	5.715	5.134	3000	31.433	28.237	46.154	OK
5	27.649	25.247	6.246	5.627	3000	34.353	30.949	46.154	OK
4	21.403	19.62	6.564	5.934	3000	36.102	32.637	46.154	OK
3	14.839	13.686	6.497	5.912	3000	35.734	32.516	46.154	OK
2	8.342	7.774	5.603	5.166	3000	30.817	28.413	46.154	OK
1	2.739	2.608	2.739	2.608	3000	15.065	14.344	46.154	OK

Table 9 Model 4 Structure Displacement

Story	*Displacement*		*Elastic Drift*		*h*	*Inelastic Drift*		*Drift Limit*	*Cek*
	δe_X (mm)	δe_Y (mm)	δe_X (mm)	δe_Y (mm)	(mm)	Δ_X (mm)	Δ_Y (mm)	(mm)	
11	43.676	47.330	1.276	1.474	3000	7.018	8.107	46.154	OK
10	42.400	45.856	1.995	2.232	3000	10.973	12.276	46.154	OK
9	40.405	43.624	2.801	3.093	3000	15.406	17.012	46.154	OK
8	37.604	40.531	3.584	3.936	3000	19.712	21.648	46.154	OK
7	34.020	36.595	4.302	4.708	3000	23.661	25.894	46.154	OK
6	29.718	31.887	4.930	5.381	3000	27.115	29.596	46.154	OK
5	24.788	26.506	5.441	5.920	3000	29.926	32.560	46.154	OK
4	19.347	20.586	5.780	6.257	3000	31.790	34.414	46.154	OK
3	13.567	14.329	5.810	6.229	3000	31.955	34.260	46.154	OK
2	7.757	8.100	5.135	5.412	3000	28.243	29.766	46.154	OK
1	2.622	2.688	2.622	2.688	3000	14.421	14.784	46.154	OK

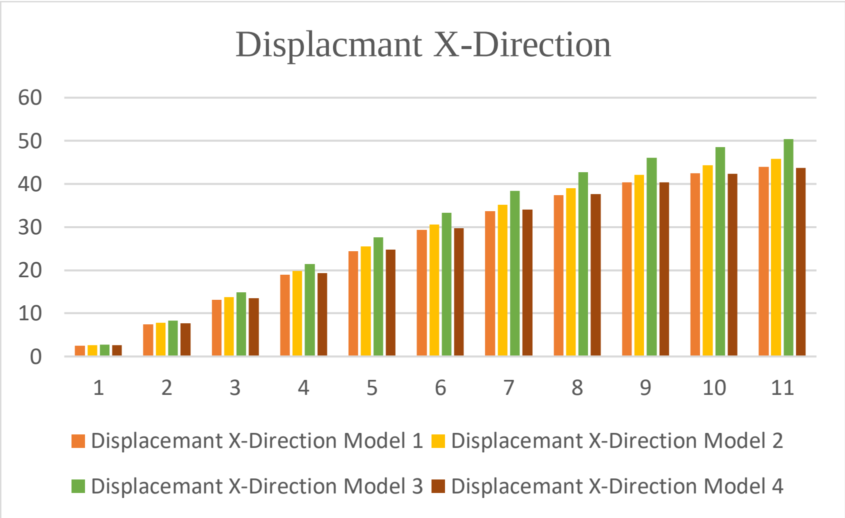

Figure 10 X-Direction Displacement Comparison Chart

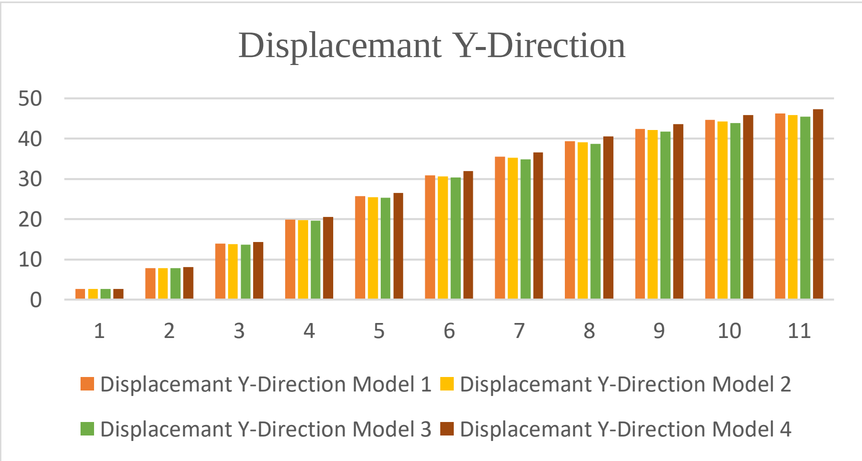

Figure 11 Y-Direction Displacement Comparison Chart

3.4. Torsion

Torsion describes the rotating forces that occur when a building's center of mass does not coincide with its center of rigidity. This mismatch causes the structure to rotate during seismic activity (see Table 10 and Figure 12). Model 4 experienced minimal torsion due to its symmetrical design, which ensured that the center of mass and center of stiffness were closely aligned. Model 1-3, on the other hand, exhibited higher torsional forces, especially in areas where there were significant irregularities in the layout. This torsion can cause excessive stress concentrations, leading to localized failures in the building structure.

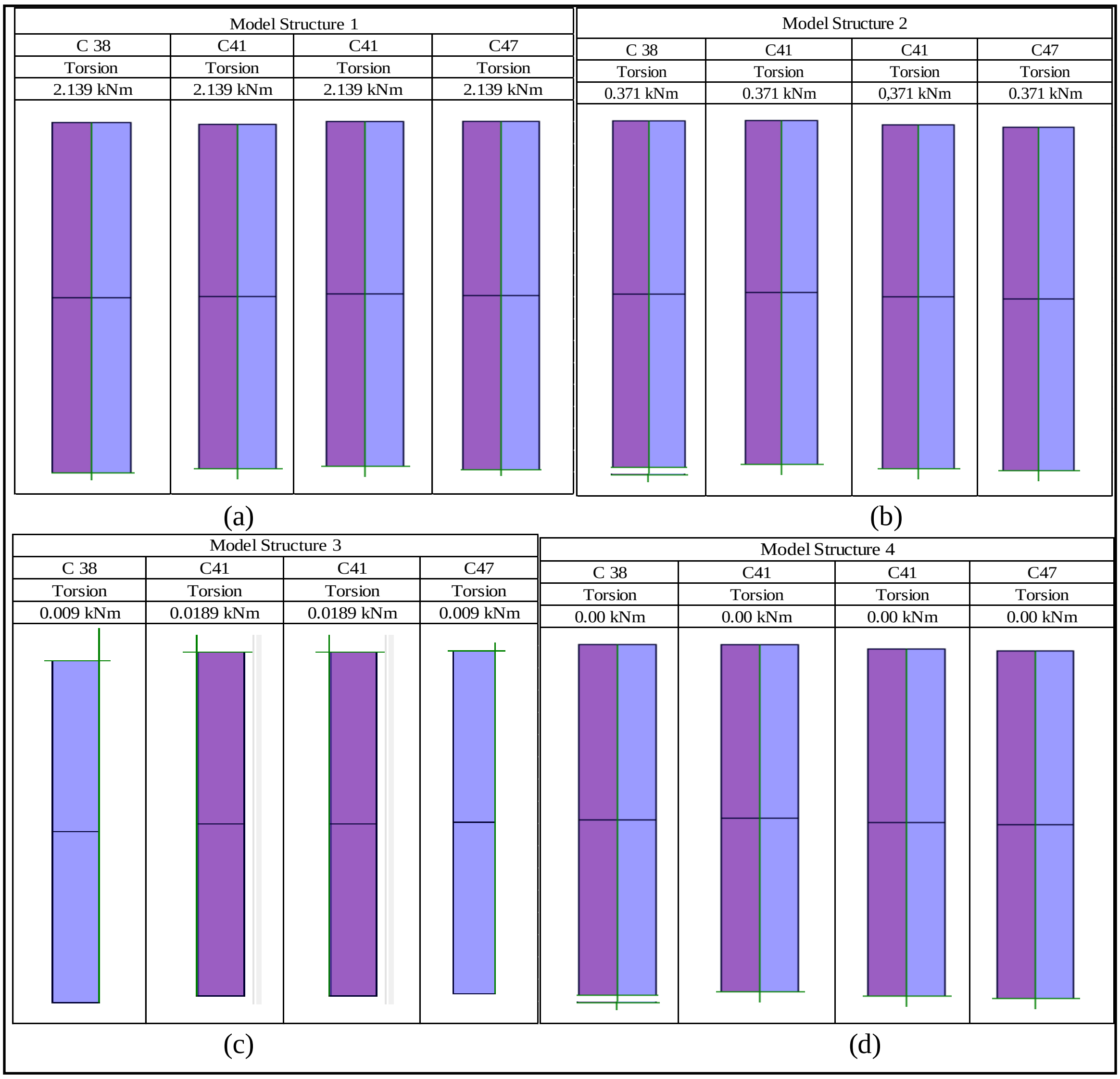

Figure 12 Column torsion in (a) structure Model 1 (b) structure Model 2 (c) structure Model 3 (d) structure Model 4

Table 10 Torsion on Column

	Model 1	Model 2	Model 3	Model 4
	kNm	kNm	kNm	kNm
Story11	0.871	0.4223	0.1585	0
Story10	1.3016	0.5094	0.2827	0
Story9	1.7883	0.6254	0.3249	0
Story8	2.2588	0.7438	0.3081	0
Story7	2.6857	0.8507	0.2756	0
Story6	3.0538	0.9376	0.2361	0
Story5	3.3449	0.9966	0.1902	0
Story4	3.5206	1.0145	0.1382	0
Story3	3.4874	0.9651	0.0833	0
Story2	3.0093	0.7932	0.0605	0
Story1	2.138	0.3713	0.0189	0

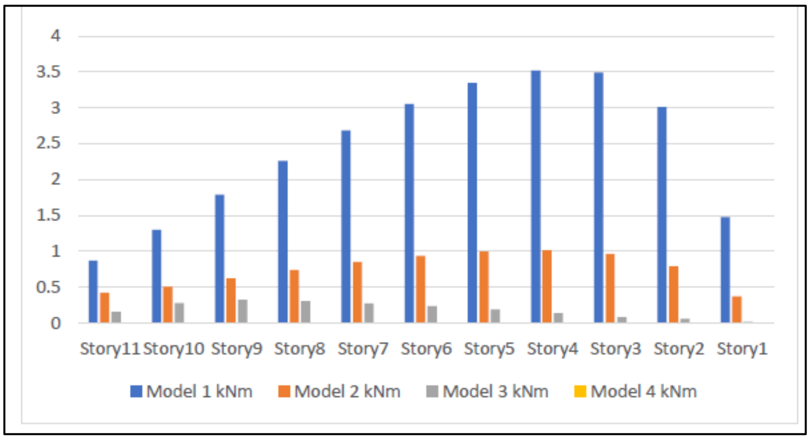

Figure 13 Torsion comparison chart

3.5. Column Reinforcement

The amount of reinforcement required for columns was also analyzed, as it directly relates to the building's ability to withstand seismic forces. In regular structures, the reinforcement was more evenly distributed, reflecting the uniform seismic load distribution. However, in irregular buildings, certain columns required significantly more reinforcement due to the higher forces acting on them, particularly in areas with large displacements and torsion.

Model 4 required consistent column reinforcement throughout the structure, indicating a balanced distribution of seismic forces. Model 1-3 showed increased reinforcement needs in specific areas where irregularities caused higher stress concentrations. This indicates the need for careful design and additional reinforcement in irregular buildings to prevent structural failure during earthquakes. Based on the analysis results, the column reinforcement in the four models can be seen in Figure 14.

4. Conclussion

The seismic performance of the regular and irregular building structure based on SNI 1726:2019 has been discussed completely in this study. This analysis of the four models—three with irregular behaviour and one with regular behaviour indicated that there are significant differences in their seismic force resistance. Aesthetically pleasing properties, those with symmetric geometry and uniform mass quantity showed a more structured response to seismic activities in terms of lower base shear, story shear, displacement and torsion. However, the performance of these buildings under earthquake loading was more predictable and stable, with uniformly distributed seismic forces and uniform requirements for column reinforcing.

In contrast, the irregular structures displayed higher susceptibility to seismic forces. The irregularities in their layout—such as asymmetrical mass distribution and geometric configurations—led to increased base shear and story shear forces, particularly in areas where the irregularities were most pronounced. These irregularities also resulted in larger displacements and higher torsional forces, contributing to the increased vulnerability of these structures. Torsional effects, in particular, played a significant role in amplifying stress concentrations in certain areas of the buildings, further emphasizing the structural challenges posed by irregular designs.

Moreover, the irregular shaped buildings have also demanded more concentrated column reinforcement in areas of greater vulnerability to mitigate the unequal force distribution. Irregular structures are special cases because their seismic performance is more unpredictable compared to regular buildings, and this means that it needs careful design considerations.

To sum up, the results of this study emphasize the necessity to design irregular structure following seismic design codes. Modern architectural trends tend towards such irregular designs for reasons of aesthetics and space, but such designs lead to higher seismic risks, results of this study say. They should adopt extra reinforcement strategies and seismic analysis for irregular buildings in earthquake-prone regions to maintain the stability. In the end, this work delivers valuable information on how irregular buildings behave in an earthquake and guidelines for reducing seismic risk of these kind of structures.

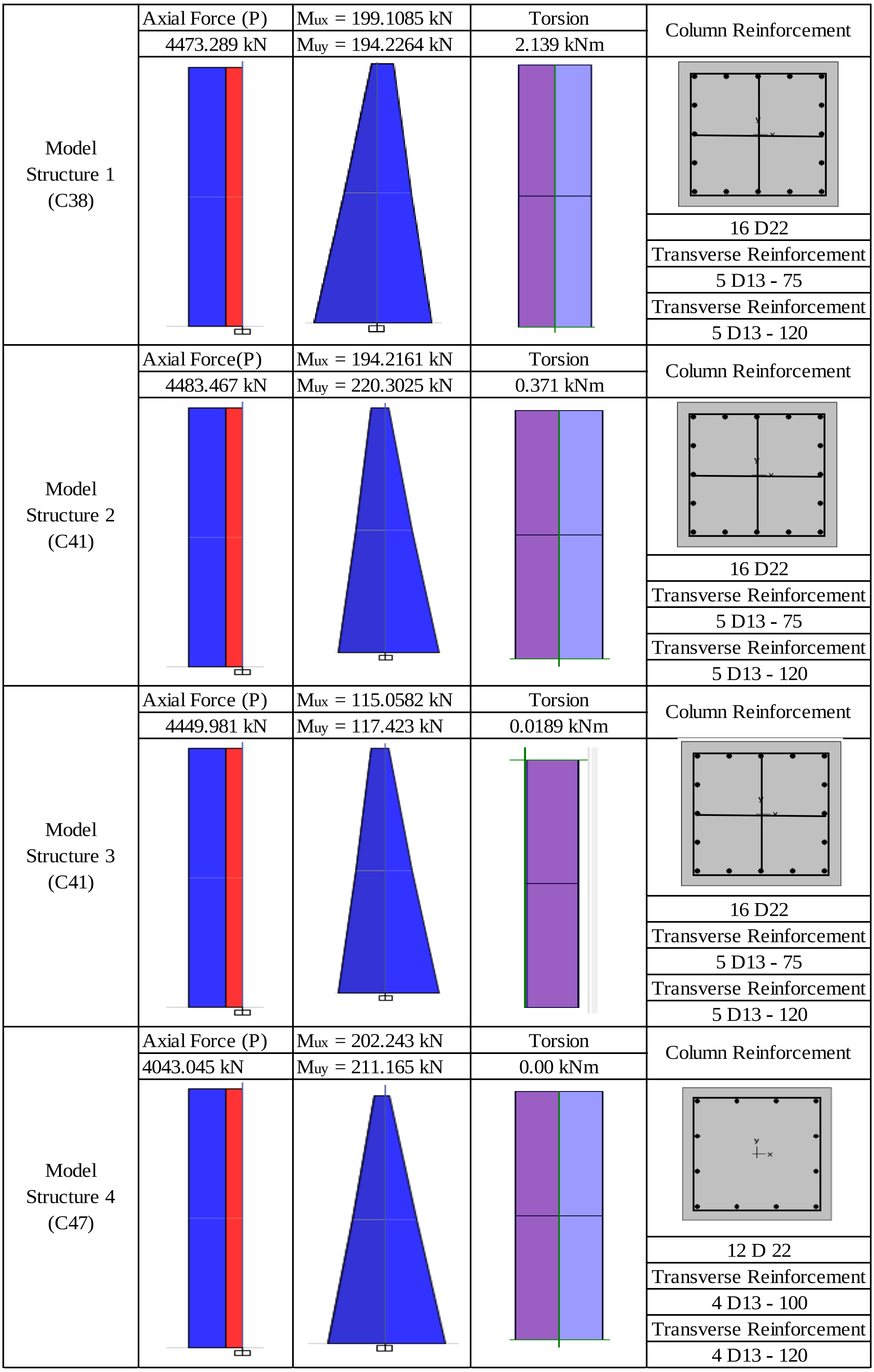

Figure 14 Column reinforcement recapitulation

5. Acknowledgements

The purpose of this study is to obtain and apply SNI 1726 2019 from the results of a comparison of four structural models. Three models with irregular structures and one model with a regular structural plan. With earthquake data taken from the Tarutung area of North Sumatra. The results compared from the four structural models are Base shear, Story shear, Displacement, Torsion, Column reinforcement.

6. Conflict of Interest

The authors listed below confirm that the manuscript does not contain any conflicts of interest.

TM Rezaka Alfitra

This statement is signed with all the above information is true and correct (a photocopy of this form may be used if there are more than 10 authors):

Author's name	Author's signature	Date
TM Rezaka Alfitra		22 october 2024

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