



Analysis of Diaphragm Force on Reinforced Concrete Building Structures with Horizontal Irregularities of Diaphragm Discontinuity

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ABSTRACT

The diaphragm plays a crucial role in distributing seismic forces within buildings during earthquakes, affecting both regular and irregular structures differently. This study investigates the seismic behavior of diaphragms in various building geometries resembling the letters I, T, L, and O, focusing on their influence on structural performance and reinforcement requirements. Using analytical methods, diaphragm seismic forces, slab shear stresses, and internal forces were calculated for a sample of buildings with different geometrical irregularities. The study reveals significant differences in diaphragm earthquake forces between regular and irregular buildings, with irregular geometries exhibiting distinct patterns of shear stress distribution. Particularly, the building with an L-shaped plan and concentrated stress points showed the highest maximum shear stresses in both orthogonal directions. Analysis of internal forces—axial, shear, and moment—highlighted varying reinforcement needs among the studied buildings. While axial and shear forces necessitated minimal additional reinforcement across all structures, moment forces indicated substantial reinforcement requirements, particularly in the L-shaped building. These findings underscore the importance of tailored diaphragm design strategies for buildings with irregular geometries to mitigate potential structural vulnerabilities during seismic events. The study contributes insights into optimizing diaphragm design practices and emphasizes the need for further research in this critical area of structural engineering.

Keywords: Diaphragms, Irregular, Shear Stress, Reinforcement.

INTRODUCTION

According to Bambang Budiono et al. (2016), in their research on the behavior of building structures with irregularities to earthquake loads, the performance of earthquake-sheltered buildings shows that irregular buildings, due to geometric variations that affect stiffness, have a deviant response compared to regular building structures. The combination of more than one irregularity in one of the floors reviewed gave the worst response compared to all the case studies conducted.

In their research, Mangesh S. et al. (2017) showed the effect of geometric irregularities through the collapse rate of reinforced concrete multi-story buildings, which were investigated based on non-linear static analysis, concluded that regular buildings were the last ones to collapse. Regular buildings are said to be more able to withstand earthquakes for a long time compared to irregular buildings with the shape of O, H and L plans which have the smallest resistance of all these forms. Therefore, if there is an increase in irregularities in buildings whose volume is fixed, the performance of the building will decrease (Mohsenian et al., 2020; Munni & Chandra Mohan Rao, 2022).

Research conducted by Annie Sweetlin et al. (2016), who compared the displacement of regular and irregular buildings due to earthquake forces, shows that irregular buildings with smaller dimensional directions provide greater displacement. In addition, the displacement of irregular buildings is lower than that of regular buildings because it is influenced by the structure's mass reduction.

Diaphragm analysis is closely related to the assumption of a given stiffness. In a study conducted by Alexander et al. (2018), the diaphragm on the floor of the building structure is classified into a flexible diaphragm on the upper floors and a semi-rigid diaphragm or a rigid diaphragm on the lower floors. A semi-rigid diaphragm stimulates stiffness in a way parallel to the true plane of the diaphragm. The flexibility in a semi-rigid diaphragm can affect the horizontal distribution of earthquake forces to vertical elements (Eivani et al., 2022; Tena-Colunga & Sabanero-García, 2023).

Research related to diaphragm floors in reinforced concrete multi-story buildings conducted by Jadhav Anupriya P, et al. (2017) presented the types of diaphragms assumed for buildings with and without sliding walls. Based on the results of the study, buildings without sliding walls indicate more accurately modelled rigid diagrams, while buildings with sliding walls give very different results because of the rigidity of the sliding walls. However, the result of a semi-rigid and flexible diaphragm is influenced by the irregular gemotriosis of the building.

The analysis of the diaphragm force is related to the diaphragm's role. Egan et al. (2018) analyzed the force and moment around the cord elements and collector beams due to the earthquake. The study's results show that the diaphragm functions as a buffer for gravity and lateral resistance. The cord element requires additional reinforcement in the tensile area, and some collector blocks require additional bending reinforcement (Janardhanraj et al., 2022; Rezaeian et al., 2020). The diaphragm itself is designed against shear forces and does not require additional reinforcement.

Prijasambada et al. (2018), in their research on the analysis of the diaphragm force of cords and collectors according to SNI 1726:2012, stated that buildings with sliding walls designed against diaphragm force require additional reinforcement of the diaphragm to the sliding wall as

friction shear reinforcement, collector element reinforcement and cord reinforcement. The amount of additional reinforcement depends on the irregular level of the building being analyzed (Massone et al., 2021).

The purpose of the study is to design a building structure system with irregularities with plans resembling I, T, L and O on the 2nd, 8th and 15th floors so that there is horizontal irregularity of diaphragm discontinuity according to SNI 1726:2012 reference, analyze the diaphragm force that occurs on one floor and the combination of earthquake force and analyze the shear stress of the floor plate and analyze the internal force and calculate the need for additional reinforcement due to the diaphragm force if Needed. With the results of the calculation of the additional reinforcement requirements of the floor slab, a more efficient design of building structure openings can be determined, especially based on the need for extra cord reinforcement.

RESEARCH METHODS

This study discusses regular and horizontal irregular buildings. Buildings with horizontal irregularities are assumed to have openings or voids with several schemes. They are designed with the same function, namely, an office building, and they have the same earthquake load.

The general data of the building structure analyzed are:

1. Function : Office Building
2. Number of Floors : 17 Floors + 1 Roof
3. Location : South Jakarta
4. Soil type : Soft soil
5. Building height : 63.7 m, with the floor height in the following table.

Table 1. Building Floor Height

It	Floor	Height Between Floors (m)
1	1st Floor	4,5
2	Floors 2-17	3,5
3	Roof floor	3,2

Structure plan

The structural plan is delineated following the preliminary structural plan to obtain openings in the floor plan under review (floors 2, 8, and 15) that conform to the requirements of the building with type 3 horizontal irregularities.

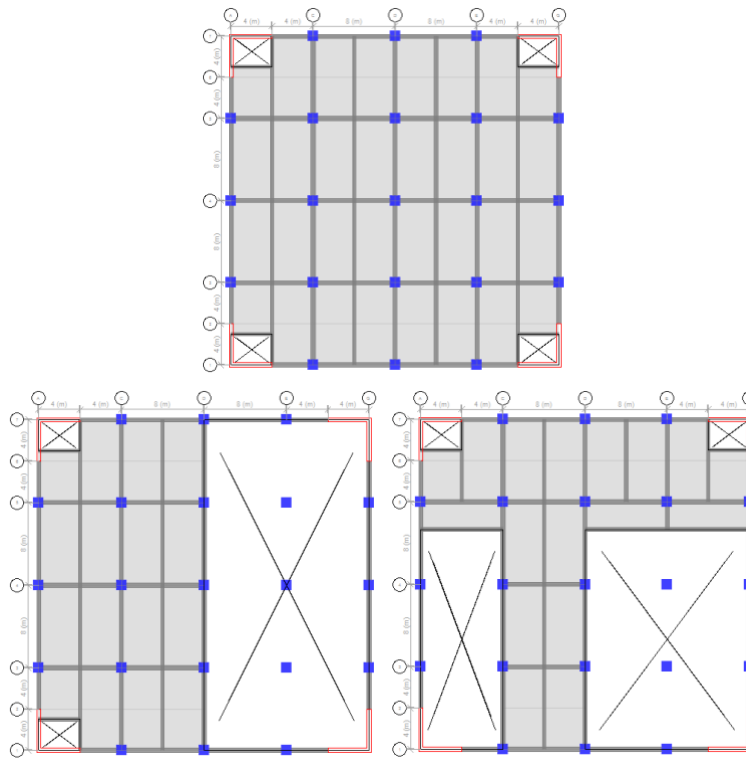


Figure 1. Floor Plans of 2,8 and 15 Regular Buildings

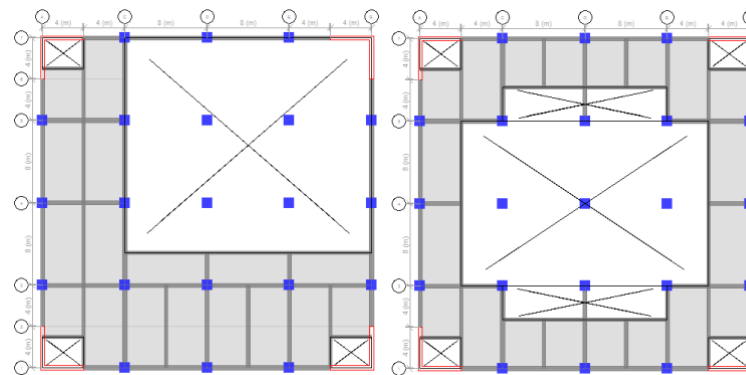


Figure 2. Floor Plans 2,8 and 15 Irregular Buildings

ETABS automatically calculates the loading data for the dead load itself. For additional dead loads, the SIDL for a typical office floor is 3.29 kN/m^2 , and the SIDL for a roof floor is 1.48 kN/m^2 . Living load is the burden given due to the function or use of the floor in the building. SNI 1727:2013 article 4.3.1 in table 4-1 has regulated the assumed cost of life. The living load for the office floor from the table is 2.4 kN/m^2 , while for the roof floor is 0.96 kN/m^2 . The preliminary design for the structural components of the building was carried out in accordance with the

requirements of the SNI 1726:2012 earthquake and SNI 2847:2013 reinforced concrete. So that it gets:

1. The typical beam dimensions for the parent beam are B40x70 and the daughter beam B30x50.
2. The thickness of the plates used for the design, H is 130 mm, and the roof plates are taken by 150 mm.
3. Column dimensions:
 - 12th – 17th floor: 600x600 mm.
 - Floor 6 – 11: 800x800 mm.
 - Floor 1 – 5: 1000x1000 mm.

This study uses a calculation method and comparison of several structural analyses with building modeling using ETABS v.16 software. Data collection is a software output that is processed with equations that have been determined by the rules of structural analysis. The calculation and checking of components also adjust to the limitations of the structure. Systematically, here is a picture of the research flow chart.

RESULTS AND DISCUSSION

Irregularity Checking

The irregularity examination was carried out limited to horizontal irregularity examination according to SNI 1726:2012 table 10. From the checks carried out, both regular and irregular buildings do not have irregularities in torque and excess torque (type 1a and 1b), irregularities in the inner corner (type 2), irregularities in transverse shifts to the plane (type 4) and irregularities in non-parallel systems (type 5). Regular buildings do not have type 3 horizontal irregularities, namely diaphragm discontinuities, while these irregularities are found in the following non-table buildings.

Table 2. Examination of diaphragm discontinuity irregularities

Building Type	Floors reviewed	Full Floor Area	Opening Area	Percentage of Opening Area	Check Irregular Continuity of Diaphragm Discontinuities
		(m)	(m)	(%)	
In the afternoon	Entire	1024	48	4.69	None
1st Irregular	2,8,15	1024	536	52,34	Exist
2nd Irregular	2,8,15	1024	536	52,34	Exist
3rd Irregular	2,8,15	1024	536	52,34	Exist
4th Irregular	2,8,15	1024	536	52,34	Exist

Diaphragm Earthquake Force

The diaphragm earthquake force for a certain floor is designed based on the equation contained in SNI 1726:2012 article 7.10.1.1. The calculation data is in the form of structural analysis results in ETABS software, such as diaphragm mass data, structural floor data and earthquake lateral force calculation data according to dynamic earthquake analysis.

This procedure requires that the structural elements' strength be adequate based on cross-sectional strength. This is done with concrete run-design in ETABS, and the results obtained show that all structural components are still safe based on cross-sectional strength with a combination of loading. Based on the existing data, the table shows the diaphragm's earthquake force design. These forces are assigned to each structural model for diaphragm analysis on the 2nd, 8th, and 15th floors.

Table 3. Diaphragm Earthquake Force

Floor	Regular Buildings		Irregular 1		Irregular 2		Irregular 3		Irregular 4	
	FPX-X	FPX-Y	1,25 FPX-X	1,25 FPX-Y	1,25 FPX-X	1,25 FPX-Y	1,25 FPX-X	1,25 FPX-Y	1,25 FPX-X	1,25 FPX-Y
	(kN)	(kN)	(kN)	(kN)	(kN)	(kN)	(kN)	(kN)	(kN)	(kN)
ROOF	1257,11	1256,97	1218,65	1215,02	1217,64	1212,33	1217,83	1217,98	1223,25	1221,99
Story 17	1266,41	1265,62	1241,67	1239,64	1243,27	1243,69	1241,81	1241,13	1245,24	1243,07
Story 16	923,14	923,17	926,08	923,40	926,85	922,00	926,31	926,53	929,64	926,94
Story 15	885,30	885,30	553,35	553,35	553,37	553,37	573,31	573,31	593,31	593,31
Story 14	495,59	496,37	477,69	481,18	478,39	483,41	477,63	478,15	475,50	479,18
Story 13	380,17	380,86	376,61	378,85	376,81	378,27	376,39	377,20	374,64	377,07
Story 12	313,99	314,49	320,10	322,85	320,26	324,04	320,03	320,61	317,05	319,55
Story 11	291,98	292,82	308,24	309,98	307,65	311,42	307,66	308,33	304,11	306,59
Story 10	296,51	296,76	320,44	321,36	319,91	321,11	320,29	320,78	317,75	318,78
Story 9	323,82	324,33	353,06	352,32	352,45	350,86	352,84	353,37	351,80	351,44
Story 8	885,36	885,36	553,39	553,39	553,41	553,41	573,35	573,35	593,36	593,36

Story 7	394,5 1	394,6 1	371,4 7	371,1 7	372,0 1	372,5 9	371,3 5	371,2 9	373,1 9	373,3 6
Story 6	424,7 7	424,3 1	412,2 8	410,9 9	413,0 0	410,1 3	412,7 3	412,5 3	415,5 1	414,0 5
Story 5	434,7 1	434,4 6	428,8 3	426,9 1	428,8 4	426,5 9	428,8 1	428,6 2	431,2 3	429,6 0
Story 4	408,6 7	408,3 6	405,6 9	403,6 0	406,1 4	402,8 9	405,9 7	405,6 7	408,8 1	406,6 1
Story 3	349,3 4	348,6 9	346,6 5	344,8 4	346,7 9	344,3 2	346,7 9	346,3 7	348,7 9	347,0 6
Story 2	885,4 2	885,4 2	553,4 4	553,4 4	553,4 7	553,4 7	573,4 1	573,4 1	593,4 3	593,4 3
Story 1	131,9 2	130,7 9	119,8 3	119,7 9	119,9 4	121,0 5	119,8 5	119,2 1	120,3 8	120,1 3

Based on the calculation of the diaphragm earthquake force for regular buildings, the design earthquake force does not need to be increased by 25% of the diaphragm earthquake force.

Diaphragm Shear Voltage Analysis

The stage of modelling the structure with the input of the floor diaphragm force into a load case is carried out to check the diaphragm structure. The first analysis is to check the shear stress of the plate. It should be noted to limit the minimum thickness of the plate designed as a diaphragm plate by not taking into account the sliding reinforcement. The shear stress limitations that occur in diaphragm plates are:

$$\sigma_u \geq \frac{5}{6} \sqrt{fc'}$$

The quality of the concrete floor slab in the 1st irregular building is $fc' = 30$ MPa, then:

$$\sigma_{ijin} = \frac{5}{6} \sqrt{fc'} = \frac{5}{6} \sqrt{30} = 4.56 \text{ N/mm}^2$$

Based on modelling with ETABS v.16 in a building with an aura and irregularity, the shear stress that occurs on the plate (S12) due to the diaphragm design earthquake load case (Fpx) for the floors reviewed is less than the allowable voltage limit that can occur on the plate from both directions reviewed. The following is a table of plate shear stresses.

Table 4. Shear Tension Diaphragm Plate Floors 2,8 and 15

Floor	Regular Buildings		Irregular 1		Irregular 2		Irregular 3		Irregular 4	
	Directi on X	Directi on Y	Directi on X	Directi on Y	Directi on X	Directi on Y	Directi on X	Directi on Y	Directi on X	Directi on Y

	(N/m m2)	(N/m m2)	(N/m m2)	(N/m m2)	(N/m m2)	(N/m m2)	(N/m m2)	(N/m m2)	(N/m m2)	(N/m m2)
Stor y2	2,27	2,81	1,64	1,19	1,94	0,55	3,79	3,93	1,14	0,68
Stor y8	3,04	3,08	1,94	1,34	2,25	0,6	4,03	4,11	1,46	0,85
Stor y15	3,27	3,34	2,05	1,38	2,42	0,66	4,24	4,32	1,51	0,92

From the table above, the plate's shear stress due to the diaphragm's earthquake force is still below the allowable shear stress. Therefore, the thickness of the building slabs for the 2nd, 8th, and 15th floors is still sufficient (**OK**).

Force Analysis in Diaphragm

The next analysis to determine the influence of the design's lateral force is to analyze the internal force that occurs in the diaphragm plate. According to the plate's identification as a cord diaphragm, the internal force is moment, axial force, and shear force.

Style capture in the diaphragm using section-cut tools provided by the ETABS v.16 program. The location of the section cut is taken based on the identification of the cord diaphragm according to each orthogonal direction due to the earthquake force of the diaphragm design (Fpx-X and Fpx-Y).

Based on the section cut made on the floor plate, the force in F11, F22 and M. F11 is the force value in the direction of the force being reviewed, so it is the shear force on the diaphragm plate. Meanwhile, F22 is the axial force of attraction or compression on the diaphragm plate, and M is the bending moment that occurs due to the lateral force of the diaphragm.

Section cut analysis was carried out for the 2nd, 8th and 15th floors of regular and irregular buildings according to the cord diaphragm's location and the section's position according to the initial identification. The following are the results of the deep style from the section-cut analysis.

Table 5. Summary of Styles in Regular Building Plates

Floor	Section Cut	Axial Force	Sliding Force	Momen
		kN	kN	kNm
Floor2	SCut-A	0	153,8	2078,4
	SCut-B	0	112,7	2436,1
Floor8	SCut-A	0	145,2	3146,0
	SCut-B	0	98,2	3634,1
Floor15	SCut-A	0	167,8	4303,3
	SCut-B	0	117,0	4901,8

Table 6. Summary of Styles in 1st Irregular Building Slabs

Floor	Section Cut	Axial Force	Sliding Force	Momen
		kN	kN	kNm
Floor2	SCut-A	27,7	67,4	789,7
	SCut-B	0	70,4	1280,5
Floor8	SCut-A	48,8	72,8	1091,2
	SCut-B	0	49,7	1767,7
Floor15	SCut-A	60,7	97,1	1541,1
	SCut-B	0	70,8	2342,5

Table 7. Summary of Styles in 2nd Irregular Building Slabs

Floor	Section Cut	Axial Force	Sliding Force	Momen
		kN	kN	kNm
Floor2	SCut-A	26,75	144,75	213,37
	SCut-B	146,83	210,55	668,28
	SCut-C	28,45	109,58	174,43
	SCut-D	31,86	79,08	266,39
Floor8	SCut-A	29,1	164,15	266,39
	SCut-B	157,62	202,37	813,52
	SCut-C	32,69	102	189,61
	SCut-D	43,44	70,19	220,71
Floor15	SCut-A	38,81	175,51	329,28
	SCut-B	168,22	211,64	873,08
	SCut-C	47,54	144,89	283,19
	SCut-D	61,45	94,44	386,34

Table 8. Summary of Styles in 3rd Irregular Building Slabs

Floor	Section Cut	Axial Force	Sliding Force	Momen
		kN	kN	kNm
Floor2	SCut-A	175,3	102,7	809,3
	SCut-B	389,2	97,2	1257,5
Floor8	SCut-A	168,2	97,6	761,5
	SCut-B	415,3	131,8	1122,3
Floor15	SCut-A	162,4	106,2	711,3
	SCut-B	434,9	177,7	810,5

Table 9. Summary of the Force in the 4th Irregular Building Plate

Floor	Section Cut	Axial Force	Sliding Force	Momen
		kN	kN	kNm
Floor2	SCut-A	198,5	58,5	206,9

	SCut-B	19,7	46,1	167,5
	SCut-C	48,3	32,0	121,8
	SCut-D	48,6	31,4	119,8
Floor8	SCut-A	71,3	52,0	125,9
	SCut-B	48,0	5,7	114,7
	SCut-C	52,1	9,9	125,5
	SCut-D	52,0	10,5	130,1
Floor15	SCut-A	14,2	123,1	230,0
	SCut-B	7,3	28,2	110,4
	SCut-C	61,7	9,8	171,0
	SCut-D	61,7	9,8	172,3

Diaphragm Plate Auxiliary Reinforcement

The floor slab was initially analyzed based on the gravity load according to the floor function. In this study, the burden given is for office buildings with a special load, namely the burden of the office lobby. The thickness of the floor slab is $t = 130$ mm, and the reinforcement installed based on the combination of gravity loads is D10-200 for both positive reinforcement and negative reinforcement in both directions.

Furthermore, the plate is designed with a lateral force diaphragm, and according to the section-cut analysis that has been carried out, the internal force of the plate is used as a parameter for calculating the rebar requirement. In the literature review, equations have been presented to obtain the nominal strength value of the structural components. The calculation is in the form of nominal axial force (ϕT_n), nominal shear force (ϕV_n) and nominal cord moment (ϕM_n).

The deep force analysis was carried out on all pieces of each floor reviewed for regular and irregular buildings. This analysis shows that the internal force in the form of axial and shear does not exceed the nominal strength provided by the concrete and the rebar attached to the gravity loading plate. However, the force in the moment in some pieces exceeds the nominal capacity of the plate, so it is necessary to add reinforcement, namely the moment reinforcement of the cord. The summary of the results of the force analysis on the diaphragm floor plate is as follows:

Table 10. Summary of Force Analysis in Regular Building Slabs

Floor	Section Cut	Check Axial Force			Check Sliding Force			Check the Cord Moment		
		Your	T_n	Chequ e	V_u	ϕV_n	Chequ e	In the	ϕM_n	Chequ e
		kN	kN		kN	kN		kNm	kNm	
Floor2	SCut-A	64,95	1336,3	OK	0	4308,6	OK	0	3848,6	OK

Floor	Section Cut	Check Axial Force			Check Sliding Force			Check the Cord Moment		
		Your	Tn	Chequ	Vu	φVn	Chequ	In the	φMn	Chequ
		kN	kN	e	kN	kN	e	kNm	kNm	e
Floor8	SCut-B	76,13	1336,3 2	OK	112.7 0	4308,6 7	OK	2436.1 0	3848,6 0	OK
	SCut-A	98,31	1336,3 2	OK	145.2 0	4308,6 7	OK	3146.0 0	3848,6 0	OK
	SCut-B	113,5 7	1336,3 2	OK	98.20	4308,6 7	OK	3634.1 0	3848,6 0	OK
Floor15	SCut-A	134,4 8	1336,3 2	OK	167.8 0	4308,6 7	OK	4303.3 0	6841,9 6	OK
	SCut-B	153,1 8	1336,3 2	OK	117.0 0	4308,6 7	OK	4901.8 0	6841,9 6	OK

Table 11. Summary of Force Analysis in 1st Irregular Building Slab

Floor	Section Cut	Check Axial Force			Check Sliding Force			Check the Cord Moment		
		Your	Tn	Chequ	Vu	φVn	Chequ	In the	φMn	Chequ
		kN	kN	e	kN	kN	e	kNm	kNm	e
Floor2	SCut-A	49,3 6	668,16	OK	67, 4	2017,6 2	OK	200,44 8	962,15	OK
	SCut-B	40,0 2	1336,3 2	OK	70, 4	4308,6 7	OK	400.90	3848.6 0	OK
Floor8	SCut-A	68,2 0	668,16	OK	72, 8	2017,6 2	OK	200.45	962.15	Chequ e
	SCut-B	55,2 4	1336,3 2	OK	49, 7	4308,6 7	OK	400.90	3848.6 0	OK
Floor15	SCut-A	96,3 2	668,16	OK	97, 1	2017,6 2	OK	200.45	962.15	Chequ e
	SCut-B	73,2 0	1336,3 2	OK	70, 8	4308,6 7	OK	400,90	3848,6 0	OK

Table 12. Summary of Force Analysis in 2nd Irregular Building Slabs

Floor	Section Cut	Check Axial Force			Check Sliding Force			Check the Cord Moment		
		Your	Tn	Chequ	Vu	φVn	Chequ	In the	φMn	Chequ
		kN	kN	e	kN	kN	e	kNm	kNm	e
Floor2	SCut-A	26,6 7	334,08 0	OK	144,7 5	803,74	OK	213,3 7	240,5 4	OK

Floor	Section Cut	Check Axial Force			Check Sliding Force			Check the Cord Moment		
		Your	Tn	Cheque	Vu	ϕVn	Cheque	In the	ϕMn	Cheque
		kN	kN		kN	kN		kNm	kNm	
	SCut-B	63,05	442,66	OK	210,55	1064,96	OK	668,28	422,29	Cheque
	SCut-C	16,46	442,66	OK	109,58	1064,96	OK	174,43	422,29	OK
	SCut-D	25,13	442,66	OK	79,08	1064,96	OK	266,39	422,29	OK
Floor8	SCut-A	33,30	334,08	OK	164,15	803,74	OK	266,39	240,54	Cheque
	SCut-B	76,75	442,66	OK	202,37	1064,96	OK	813,52	422,29	Cheque
	SCut-C	17,89	442,66	OK	102	1064,96	OK	189,61	422,29	OK
	SCut-D	20,82	442,66	OK	70,19	1064,96	OK	220,71	422,29	OK
Floor15	SCut-A	41,16	334,08	OK	175,51	803,74	OK	329,28	240,54	Cheque
	SCut-B	82,37	442,66	OK	211,64	1064,96	OK	873,08	422,29	Cheque
	SCut-C	26,72	442,66	OK	144,89	1064,96	OK	283,19	422,29	OK
	SCut-D	36,45	442,66	OK	94,44	1064,96	OK	386,34	422,29	OK

Table 13. Summary of Force Analysis in 3rd Irregular Building Slabs

Floor	Section Cut	Check Axial Force			Check Sliding Force			Check the Cord Moment		
		Your	Tn	Cheque	Vu	ϕVn	Cheque	In the	ϕMn	Cheque
		kN	kN		kN	kN		kNm	kNm	
Floor2	SCut-A	101,16	334,08	OK	102,7	803,74	OK	809,3	240,54	Cheque
	SCut-B	118,63	442,66	OK	97,2	1064,96	OK	1257,5	422,29	Cheque
Floor8	SCut-A	95,19	334,08	OK	97,6	803,74	OK	761,5	240,54	Cheque

Floor	Section Cut	Check Axial Force			Check Sliding Force			Check the Cord Moment		
		Your	Tn	Cheque	Vu	ϕVn	Cheque	In the	ϕMn	Cheque
		kN	kN		kN	kN		kNm	kNm	
	SCut-B	105,88	442,66	OK	131,8	1064,96	OK	1122,3	422,29	Cheque
Floor15	SCut-A	88,91	334,08	OK	106,2	803,74	OK	711,3	240,54	Cheque
	SCut-B	76,46	442,66	OK	177,7	1064,96	OK	810,5	422,29	Cheque

Table 14. Summary of Force Analysis in 4th Irregular Building Slabs

Floor	Section Cut	Check Axial Force			Check Sliding Force			Check the Cord Moment		
		Your	Tn	Cheque	Vu	ϕVn	Cheque	In the	ϕMn	Cheque
		kN	kN		kN	kN		kNm	kNm	
Floor2	SCut-A	51.73	167.04	OK	58.5	401.87	OK	206.9	60.13	Cheque
	SCut-B	41.88	167.04	OK	46.1	401.87	OK	167.5	60.13	Cheque
	SCut-C	25.64	198.36	OK	32.0	477.22	OK	121.8	84.80	Cheque
	SCut-D	25.22	198.36	OK	31.4	477.22	OK	119.8	84.80	Cheque
Floor8	SCut-A	31.48	167.04	OK	52.0	401.87	OK	125.9	60.13	Cheque
	SCut-B	28.68	167.04	OK	5.7	401.87	OK	114.7	60.13	Cheque
	SCut-C	26.42	198.36	OK	9.9	477.22	OK	125.5	84.80	Cheque
	SCut-D	27.39	198.36	OK	10.5	477.22	OK	130.1	84.80	Cheque
Floor15	SCut-A	57.50	167.04	OK	123.1	401.87	OK	230.0	60.13	Cheque
	SCut-B	27.60	167.04	OK	28.2	401.87	OK	110.4	60.13	Cheque
	SCut-C	36.00	198.36	OK	9.8	477.22	OK	171.0	84.80	Cheque
	SCut-D	36.27	198.36	OK	9.8	477.22	OK	172.3	84.80	Cheque

Based on the table above, only the force in the chord moment requires additional reinforcement. The additional reinforcement requirements for the required floors are based on the regular and irregular building sections-cuts in the following table.

Table 15. 1st Irregular Building Auxiliary Reinforcement

Floor	Section Cut	Additional Reinforcement	Additional Tonnage
			Kg
8th Floor	SCut-A	D10 - 400	429
15th Floor	SCut-A	D10 - 400	429

Table 16. 2nd Irregular Building Auxiliary Reinforcement

Floor	Section Cut	Additional Reinforcement	Additional Tonnage
			Kg
2nd Floor	SCut-B	D10 - 400	216
8th Floor	SCut-A	D10 - 400	118
8th Floor	SCut-B	D10 - 400	216
15th Floor	SCut-A	D10 - 400	118
15th Floor	SCut-B	D10 - 400	216

Table 17. 3rd Irregular Building Auxiliary Reinforcement

Floor	Section Cut	Additional Reinforcement	Additional Tonnage
			Kg
2nd Floor	SCut-A	D10 - 200	326
2nd Floor	SCut-B	D10 - 200	471
8th Floor	SCut-A	D10 - 200	326
8th Floor	SCut-B	D10 - 400	235
15th Floor	SCut-A	D10 - 200	326
15th Floor	SCut-B	D10 - 400	235

Table 18. 4th Irregular Building Auxiliary Reinforcement

Floor	Section Cut	Additional Reinforcement	Additional Tonnage
			Kg
2nd Floor	SCut-A	D10 - 200	155
2nd Floor	SCut-B	D10 - 300	104
2nd Floor	SCut-A	D10 - 400	92
2nd Floor	SCut-B	D10 - 400	92
8th Floor	SCut-A	D10 - 400	78
8th Floor	SCut-B	D10 - 400	78

8th Floor	SCut-A	D10 - 400	92
8th Floor	SCut-B	D10 - 400	92
15th Floor	SCut-A	D10 - 200	155
15th Floor	SCut-B	D10 - 400	78
15th Floor	SCut-A	D10 - 400	92
15th Floor	SCut-B	D10 - 400	92

The reinforcement for the cord moment is installed like the repetition of the bending moment of a typical plate. The length of the rebar installed corresponds to the cut diaphragm's length and the cord plate's width.

Comparison of Calculation Results

The results of the analysis of the shear stress and force in the diaphragm plate are very verifiable. The relatively same diaphragm seismic force loading input for an irregular building provides a maximum shear stress value that tends to differ in the two directions reviewed (Akelyan et al., 2020). Likewise, the value of force in the diaphragm, where there is additional reinforcement due to the moment of the chord. The following is a comparison of the variables of the calculation results.

Table 19. Comparison of Diaphragm Force, Shear Tension, Cord Moment and Additional Reinforcement Calculation Results

Floor	Building Type	Fpx-Design		Fair. Geser-Max		Momen Kord-Max		Additional Reinforcement
		FPX-X (kN)	FPX-Y (kN)	FPX-X (kN/m ²)	FPX-Y (kN/m ²)	Direction X (kNm)	Direction Y (kNm)	
2	Regular	885.42	885.42	2.27	2.81	2078.4	2436.1	0
2	1st Irregular	553.44	553.44	1.64	1.19	789.7	1280.5	0
	2nd Irregular	553.47	553.47	1.94	0.55	668.3	266.4	216
	3rd Irregular	573.41	573.41	3.79	3.93	809.3	1257.5	613
	4th Irregular	593.43	593.43	1.14	0.68	206.9	121.8	422

Floor 8	Regular	885.3 6	885.3 6	3.04	3.08	3146.0	3634.1	0
	1st Irregular	553.3 9	553.3 9	1.94	1.34	1091.2	1767.7	429
	2nd Irregular	553.4 1	553.4 1	2.25	0.60	813.5	220.7	364
	3rd Irregular	573.3 5	573.3 5	4.03	4.11	761.5	1122.3	433
	4th Irregular	593.3 6	593.3 6	1.46	0.85	125.9	130.1	324
Floor 15	Regular	997.1 0	996.9 6	3.27	3.34	4303.3	4901.8	0
	1st Irregular	553.3 5	553.3 5	2.05	1.38	1541.1	2342.5	429
	2nd Irregular	553.3 7	553.3 7	2.42	0.66	873.1	386.3	364
	3rd Irregular	573.3 1	573.3 1	4.24	4.32	711.3	810.5	433
	4th Irregular	593.3 1	593.3 1	1.51	0.92	230.0	172.3	398

From the table above, it can be seen that based on the calculation results, regular buildings are given the largest diaphragm force because regular buildings have a full floor plan without voids that are >50% of the total area of a floor plan. Meanwhile, the earthquake force of the irregular building diaphragm has a relatively similar value. The difference is due to the arrangement and beams of different floor plans. The order from the largest is the 4th, 3rd, 2nd and 1st irregular buildings for all floors. The diaphragm shear voltage is still below the allowable shear stress. The order for X Direction of the largest is that the 3rd, 2nd, 1st and 4th irregular buildings are consistent for all floor zones. For the Y direction, the order is the 3rd, 1st, 4th and 2nd buildings.

The force in the plate presented is the value of the moment of the cord, where the greatest value occurs in a regular building because the width of the cut diaphragm covers the entire plan.

For irregular buildings, the moment of the cord is very varied, considering the width of the diaphragm or the length of the section cut, which is different according to the floor plan. The need for additional reinforcement is required based on the moment the cord occurs. Overall here is the total need for additional reinforcement.

Table 20. Total Reinforcement Needs

Building Type	Additional Reinforcement
	(kg)
In the afternoon	0
1st Irregular	858
2nd Irregular	944
3rd Irregular	1479
4th Irregular	1144

CONCLUSION

Based on the results of analysis and calculations, the researcher concluded that the regular and irregular buildings with horizontal discontinuities of diaphragms (letter plans I, T, L, O) on the 2nd, 8th, and 15th floors, which are given lateral loads in the form of diaphragm force show the need for additional details on the diaphragm cord plates. The shear stress shows a large value in irregular buildings L, and the greatest chord moment reinforcement is produced with the deep force used for the calculation. However, there are factors such as the geometry of the building that also influence it. The calculation of diaphragm force in irregular buildings shows relatively the same value but produces very varied internal forces. Forces in axial and shear plates do not require additional repetition details, while cord moments require additional reinforcement. This deep force analysis shows the number of reinforcement requirements, where the largest total requirement is a regular building with an L plan, and then O, T, I, and regular buildings do not require additional reinforcement. The researcher suggests that the next research study should review the irregularities of other buildings and/or buildings with more than 1 irregularity. In addition, it is necessary to develop other structural variables, such as the distribution and rigidity of the structure due to diaphragm earthquake forces.

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First publication right:

Asian Journal of Engineering, Social and Health (AJESH)

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