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Design of Reinforced Concrete Structural Elements of Archive Building with the Diaphragm Discontinuity Irregularity

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ABSTRACT: The archive building is a building that serves as archive storage and an office. The layout of the archive building is designed to follow the standards of the National Archives of the Republic of Indonesia. This research aims to analyze and design the elements of the structure of a 4-story archive building with diaphragm discontinuity irregularity of structure. The building structure designed has 4 working floors with a building length of 25 m, a width of 18 m, and a height of 21.17 m. Based on the results of the sondir test or Cone Penetration Test (CPT), the type of soil is classified as medium soil site class (SD) and indicates that the system of structures belongs to the seismic design category (SDC) "D". The designed structural elements which are beams, columns, and slabs, have a concrete quality (f'c) of 30 MPa, a longitudinal reinforcement quality (fy) of 420 MPa, and a transverse reinforcement (fyt) of 280 MPa. To obtain structural elements that are rigid, strong, and ductile, structural elements are designed to withstand moment and shear forces. Based on the results of analysis and design, the dimensions of the structural elements for main beams are 300 x 500 mm; secondary beams are 250 x 350 mm; columns are 550 x 550 mm; and thick slabs are 130 and 150 mm and had fulfilled the requirements of "Strong Columns Weak Beams."

KEYWORDS: design structures, archive building, reinforced concrete, irregularity, earthquake

1. INTRODUCTION

1.1 Background

The archive building is a building that serves as archive storage and an office. The archive room provides protection and preservation for archive storage. The layout of the archive building is designed to follow the standards of the National Archives of the Republic of Indonesia.

According to SNI 1727:2020 on Minimum Loads and Related Criteria for Buildings and Other Structures, it is stated that archive and computer rooms must be designed for heavier loads. In this case, one of the facilities used is a cabinet made of metal or iron, where the floor loading of 150 psf (7.18 kN/m^2) applies to the installation of filing cabinets[2]. This condition shows a large load.

Indonesia is one of the countries that has a high earthquake risk. Design the structural elements for an archive building, it must provide the rigidity, strength, and ductility of the structures.

The 4th floor plan of the archive building will be designed with a wide opening for more space. The irregular or asymmetric shape of the building has a point mass that is not located in the middle of the building. This is very influential when building structures receive earthquake loads[5]. This condition indicates that the structural elements must provide a safe design and meet the requirements of "Strong Columns Weak beams".

1.4 Formulation of the Problem

This research will discuss the earthquake-resistant building structural elements design of an archive building with diaphragm discontinuity irregularity that can withstand vertical and horizontal loads and fulfill the safety standards.

1.2 Problem Statement

The limits of the problem in this design are:

1. The structure of the multi-story building under review is a 4-story building with reinforced concrete construction.
2. Designing structural elements, namely, beams, columns, plates, and column-beam joints.
3. Structural element design uses analysis referring to SNI 2847:2019 on Structural Concrete Requirements for Buildings.
4. Earthquake force analysis using the spectral response analysis method based on SNI 1726: 2019 on Earthquake Resistance Designing Procedures for Building and Non-building Structures.
5. Calculation of loading based on SNI 1727:2020 on Minimum Design Loads and Related Criteria for Buildings and Other Structures.
6. The loads to be reviewed are dead loads, live loads, and earthquake loads.
7. The steel structure is only assumed to be mass. The design of the steel structure is not discussed.
8. Building design includes only structural analysis and the design of structural elements.

1.5 Scope and Goals of the Research

The purpose of this research is to see the effect of discontinuity diaphragm irregularity on the design of reinforced concrete structural elements of the archive building that are resistant to earthquakes.

1.6 Research Significance

This research can provide information and references to analyze and design reinforcement concrete structural elements with discontinuity diaphragm irregularity.

1.7 Diaphragm Discontinuity Irregularity

According to SNI 1726:2019, Diaphragm discontinuity irregularity is defined as existing if there is a diaphragm that has discontinuity or sudden variation in stiffness, including having a open area greater than 50% of the gross diaphragm area closed or a change in effective diaphragm stiffness of more than 50% from one level to the next. Or, in other words, if there is an open area greater than 50% of the gross diaphragm area, the area is closed [3].

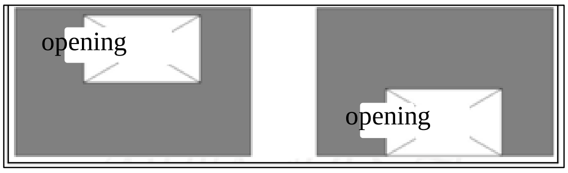

Fig.1. Diaphragm Discontinuity Irregularity (Source: SNI 1726:2019)

2.1 Methodology

1. Building Parameters

- Building function = Archive room and offices
- Number of stories = 4 stories
- Elevation of structure = ± 21.17 meters
- Elevation stories = 4.2 m (story 1) and 4 m (story 2 to 4)
- Building length = ± 25 m (x-axis)
- Building width = ± 18 m (y-axis)
- Material = Concrete

2. Material Parameters

- Concrete quality (f'c) = 30 MPa
- Specific gravity (γ) = 2400 kg/m^3
- Modulus of elasticity of concrete (E_c) = 25742,9602 MPa
- Quality of main reinforcement steel (f_y) = 420 MPa (BjTS 420A)
- Quality of stirrups steel (f_{ys}) = 280 MPa (BjTP 280)
- Modulus of elasticity of steel (E_s) = 200000 MPa

3. Load Parameters

The design loads consist of dead loads (the own weight of the structure and additional loads), live loads of area per m^2, which are reviewed based on the function of the building based on SNI 1727:2020, and earthquake loads analyzed based on SNI 1726: 2019

4. 4-story plan with diaphragm discontinuity irregularity

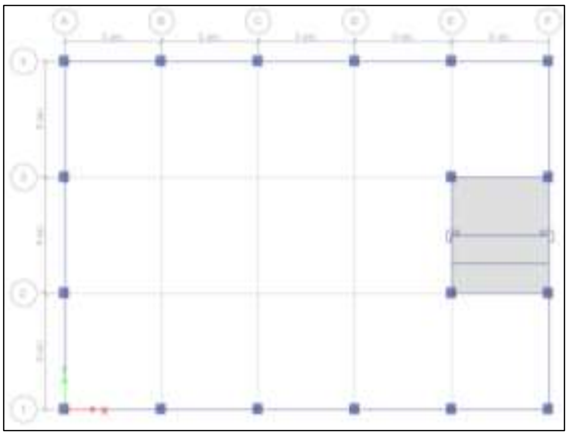

Fig.2. 4th Story Plan

3. RESULTS AND DISCUSSION

3.1 Load Design

1. Dead Loads

- Self-weight of reinforced concrete structural elements (Dead Load) determined under the program = 24 kN/m^3
- Additional load/Super Imposed Dead Load (SIDL) = 1.2 kN/m^3

2. Live Loads

- Vital static archive room = 7.18 kN/m^2
- Record center room = 7.18 kN/m^2
- Control room = 4.79 kN/m^2
- Lobby and corridor (first floor) = 4.79 kN/m^2
- Lobby and corridor (above first floor) = 3.83 kN/m^2
- Archival restoration and maintenance = 4.79 kN/m^2
- Data collection and maintenance room = 4.79 kN/m^2
- Sorting room = 4.79 kN/m^2
- Transit room = 4.79 kN/m^2
- Training/workshop room = 4.79 kN/m^2
- Server room = 4.79 kN/m^2
- Meeting room = 4.79 kN/m^2
- Administrative room = 2.4 kN/m^2
- Reading room/public information = 2.87 kN/m^2
- Diorama/visualization room = 2.4 kN/m^2
- Control room = 2.4 kN/m^2
- Warehouse = 6 kN/m^2
- Pantry = 1.92 kN/m^2
- Toilet = 1.92 kN/m^2
- Live roof load = 0.96 kN/m^2

3. Earthquake Load

Earthquake load using dynamic analysis of spectral response based on SNI 1726:2019.

- Earthquake acceleration parameters

Ss = 1.0608 g

S_1 = 0.4722 g

- Risk category II and earthquake priority factor (Ie) is 1.0
- Site class/soil type = SD (medium soil)
- Spectral response parameters

SDS = 0.7607 g ≥ 50

SD1 = 0.5754 g ≥ 20

Based on the value of SDS and SD1, the structure includes seismic design category (SDC) and a selected Special Moment Frames (SMF).

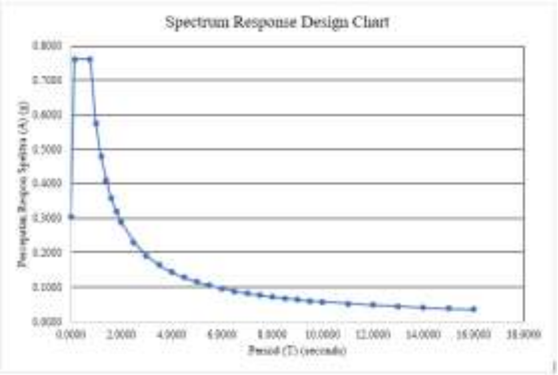

Fig.2. Spectrum Response Design

4. Loads Combination

The combination of loads under the impact of seismic loads, along with the combination of base loads. The load combination used is a combination of the ultimate method, or LRFD (Load and Resistance Factor Design), based on SNI 1727:2020 article 4.2.2. For the combination of load that has been calculated plus the seismic impact.

3.2 Preliminary Design

1. Preliminary Design of Beams
- Primary beams (B1, B2, B3) = 300 x 500 mm
- Secondary beams (BA)= 250 x 350 mm
2. Preliminary Design of Columns
   Columns (K1 and K2) = 550 x 550 mm
3. Preliminary Design of Slabs
- Main slabs = 130 mm (2nd, 3rd, and lift machine floor) and 150 mm (4th floor)

The thickness of the 4th floor slab is designed to be thicker than the 2nd and 3rd floors because, based on the analysis, the force of the factored moment that occurs as a result of the lives load of the archive room on the 4th floor is quite large. Therefore, the 4th floor slab is designed to be 150 mm thick in order to make the slab more rigid, and the moment that occurs will decrease[12]. At the time of reinforcement calculation, the reinforcement ratio needs not to cross the maximum reinforcement ratio limit, and the reinforcement design distance is greater.

3.3 Analysis Results

The results of the analysis can be seen in the following table:

Table 1. Beams Bending Moment Result Analysis (End Section)

Story	Beams	Beams Length (mm)	Mu- (kN) (End)
4	B1 30/50	5000	60.521
	BA 25/35	5000	30.748
3	B1 30/50	5000	67.776
	B2 30/50	6000	84.590
	B3 30/50	6000	162.982
	BA 25/35	5000	46.336
2	B1 30/50	5000	106.391
	B2 30/50	6000	140.416
	B3 30/50	6000	158.855
	BA 25/35	5000	71.260
1	B1 30/50	5000	106.358
	B2 30/50	6000	142.684
	B3 30/50	6000	145.291
	BA 25/35	5000	65.223

Table 2. Beams Bending Moment Result Analysis (Middle Section)

Story	Beams	Beams Length (mm)	Mu+ (kN) (Middle)
4	B1 30/50	5000	33.106
	BA 25/35	5000	17.501
3	B1 30/50	5000	63.210
	B2 30/50	6000	137.236
	B3 30/50	6000	158.456
	BA 25/35	5000	41.651
2	B1 30/50	5000	91.910
	B2 30/50	6000	149.408
	B3 30/50	6000	146.006
	BA 25/35	5000	68.125
1	B1 30/50	5000	92.767
	B2 30/50	6000	144.428
	B3 30/50	6000	125.239
	BA 25/35	5000	67.660

Table 3. Beams Shear Forces Result Analysis

Story	Beams	Beams Length (mm)	V (kN)
4	B1 30/50	5000	70.660
	BA 25/35	5000	26.345
3	B1 30/50	5000	88.048
	B2 30/50	6000	134.542
	B3 30/50	6000	185.134
	BA 25/35	5000	30.850

2	B1 30/50	5000	131.534
	B2 30/50	6000	138.441
	B3 30/50	6000	197.174
	BA 25/35	5000	72.677
1	B1 30/50	5000	126.866
	B2 30/50	6000	140.204
	B3 30/50	6000	216.077
	BA 25/35	5000	43.504

Table 3. Slabs Bending Moment Result Analysis

Story	Strip	Direction	Mu (kN.m)
Story 4	Column Strip	X	-3.1260
			1.3729
		Y	-2.5516
			1.0898
	Middle Strip	X	-5.0096
			2.1637
		Y	-10.3764
			5.8489
Story 3	Column Strip	X	-35.1640
			12.6626
		Y	-40.9337
			17.0054
	Middle Strip	X	-37.2561
			26.7430
		Y	-46.3008
			24.8766
Story 2	Column Strip	X	-12.7736
			3.9383
		Y	-13.4813
			4.8825
	Middle Strip	X	-13.4809
			7.8235
		Y	-26.7573
			13.3293
Story 1	Column Strip	X	-12.6046
			3.7609
		Y	-13.1598
			4.8258
	Middle Strip	X	-14.1247
			6.8655
		Y	-26.9071
			13.4386

3.4 Reinforcement Design

The internal forces are used to calculate reinforcement beams, columns, and slabs. The design of reinforcements for structural elements used the standards of SNI 2052:2017 and SNI 2847:2019.

1. Beams Reinforcement Design

Beams reinforcement design includes bending, shear, and torsion/side reinforcement. The results of calculating the beam reinforcement can be seen in the following table.

Table 4. Recapitulation of Beams Bending Reinforcement

Story	Beams	Dimension (mm)	Tension	Compression
4	B1	300 x 500	4D16	3D16
			4D16	3D16
	BLIFT	250 x 350	3D16	2D16
			3D16	2D16
3	B1	300 x 500	4D16	3D16
			4D16	3D16
	B2	300 x 500	5D16	3D16
			5D16	3D16
	B3	300 x 500	6D16	3D16
			6D16	3D16
	BA	250 x 350	4D16	2D16
			4D16	2D16
2	B1	300 x 500	4D16	3D16
			4D16	3D16
	B2	300 x 500	5D16	3D16
			5D16	3D16
	B3	300 x 500	6D16	3D16
			6D16	3D16
	BA	250 x 350	4D16	2D16
			4D16	2D16
1	B1	300 x 500	4D16	3D16
			4D16	3D16
	B2	300 x 500	5D16	3D16
			5D16	3D16
	B3	300 x 500	6D16	3D16
			6D16	3D16
	BA	250 x 350	4D16	2D16
			4D16	2D16
Sloof	TB	300 x 500	6D19	6D19
			6D19	6D19

Torsion reinforcements beams have a design diameter of 2-S13 for beams B1 and B2, 2-S16 for beams B3, and 2-S10 for secondary beams (BA).

Table 5. Recapitulation of Beams Shear Reinforcement

Story	Beams	Dimension (mm)	Sections	Shear Reinforcement Design
4	B1	300 x 500	End	3D10-95
			Middle	3D10-200
	BLIFT	250 x 350	End	2D10-70
			Middle	2D10-140
3	B1	300 x 500	End	3D10-95
			Middle	3D10-200
	B2	300 x 500	End	3D10-95
			Middle	3D10-200
	B3	300 x 500	End	3D13-95
			Middle	3S13-200
	BA	250 x 350	End	2D10-70
			Middle	2D10-140
2	B1	300 x 500	End	3D10-95
			Middle	3D10-200
	B2	300 x 500	End	3D10-95
			Middle	3D10-200
	B3	300 x 500	End	3D13-95
			Middle	3S13-200
	BA	250 x 350	End	2D10-70
			Middle	2D10-140
1	B1	300 x 500	End	3D10-95
			Middle	3D10-200
	B2	300 x 500	End	3D10-95
			Middle	3D10-200
	B3	300 x 500	End	3D13-95
			Middle	3S13-200
	BA	250 x 350	End	2D10-70
			Middle	2D10-140
Sloof	TB	300 x 500	End	3D10-100
			Middle	3D10-200

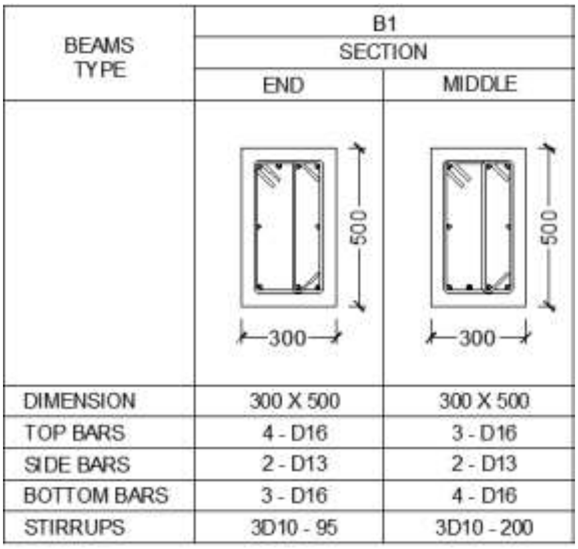

Fig.3. Details of Beam (B1) Reinforcement

2. Columns Reinforcement Design

- Center columns and edge columns of X direction (K2)
  Longitudinal reiforcement = 12-S22
  Shear reinforcement
  Plastic joints area (Io) = 650 mm
  End/plastic joints area = 5D13 – 100
  Middle/outside the plastic joints area
  = 5D13 – 125
- Corner columns and edge columns of Y direction (K1)
  Longitudinal reinforcement = 16-S22
  Shear reinforcement
  Plastic joints area (Io) = 650 mm
  End/plastic joints area = 5D13 – 100
  Middle/outside the plastic joints area
  = 5D13 – 125

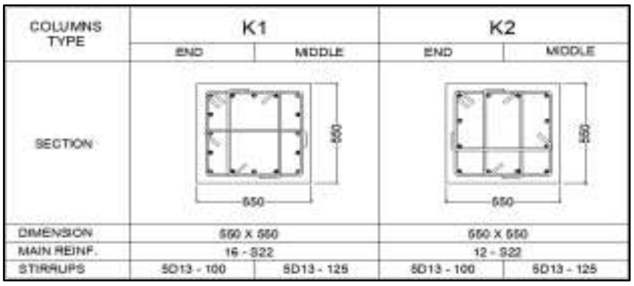

Fig.4. Details of Columns Reinforcement

3. Slabs Reinforcement Design

Table 6. Recapitulation of Slab Reinforcement in X direction

Number of floor	Strip	Dimension (mm)	Main reinforcement
			X-direction

Machine room (Type A)	Column	130	D13-300
	Middle		D13-300
4 (Type B)	Column	150	D13-150
	Middle		D13-150
3(Type A)	Column	130	D13-300
	Middle		D13-300
2 (Type A)	Column	130	D13-300
	Middle		D13-300
1/*Base*	Column	-	M8-150
	Middle		M8-150

Table 7. Recapitulation of Slab Reinforcement in Y direction

Number of floor	**Strip**	**Dimension (mm)**	**Main reinforcement**
			Y-direction
Machine room (Type A)	Column	130	D13-300
	Middle		D13-300
4 (Type B)	Column	150	D13-100
	Middle		D13-100
3(Type A)	Column	130	D13-300
	Middle		D13-150
2 (Type A)	Column	130	D13-300
	Middle		D13-150
1/*Base*	Column	-	M8-150
	Middle		M8-150

Shrinkage reinforcements slabs have a design diameter of P10-200 for main slab.

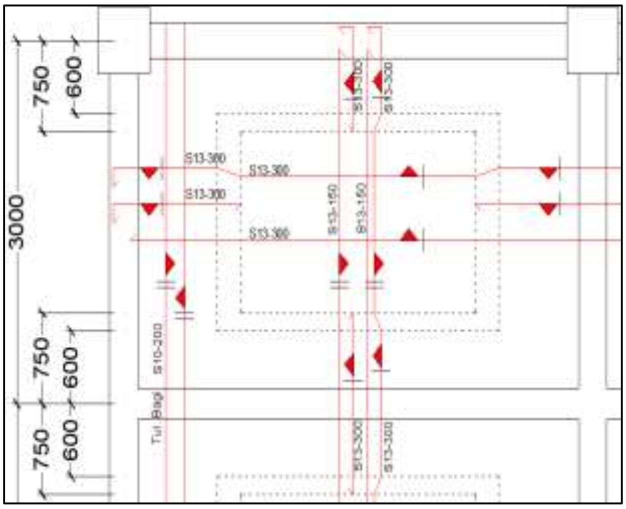

Fig.5. Details of Slabs (Type A) Reinforcement

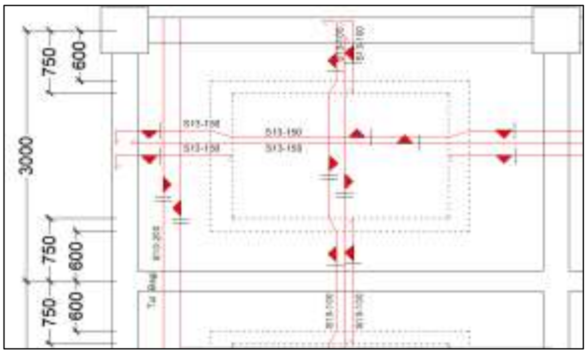

Fig.6. Details of Slabs (Type B) Reinforcement

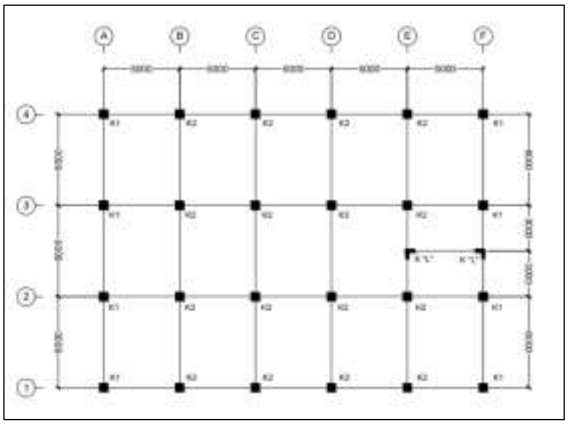

Fig.7. 1st = 2nd = 3rd Story Columns Plan

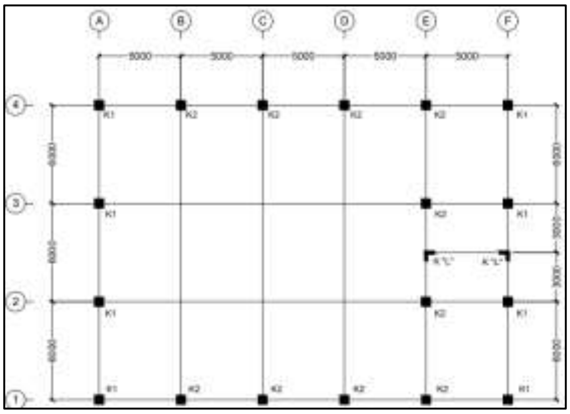

Fig.8. 4th Story Columns Plan(Diaphragm Discontinuity Irregularity)

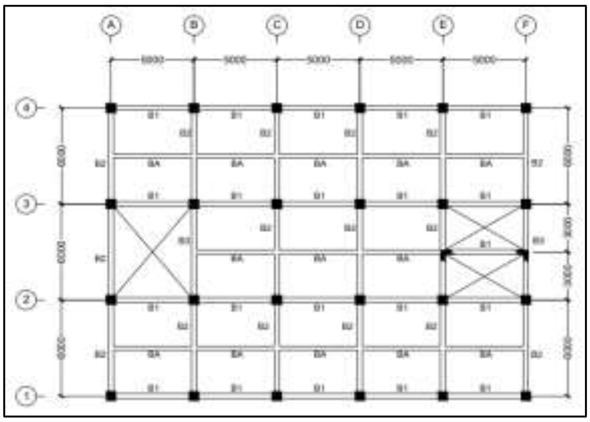

Fig.9. 1st = 2nd = 3rd Story Beams Plan

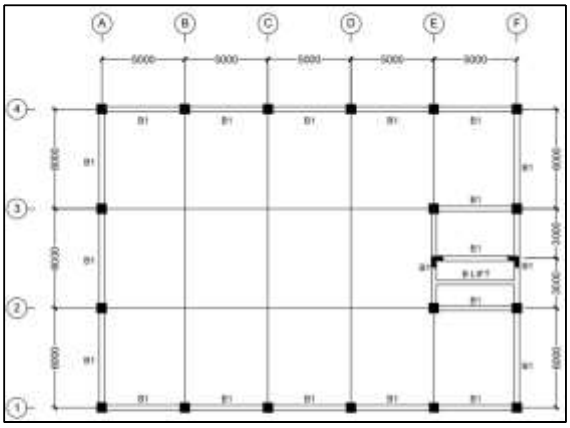

Fig.10. 4th Story Beams Plan

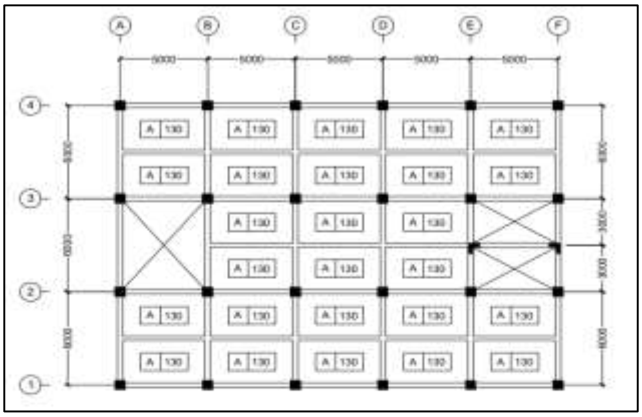

Fig.11. 1st = 2nd = 3rd Story Slabs Plan

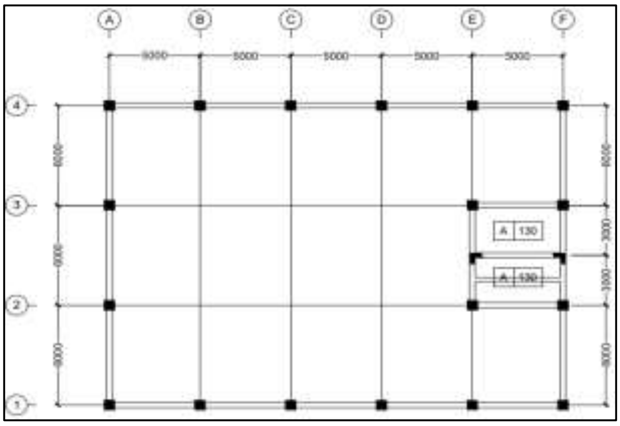

Fig.12. 4th Story Slabs Plan (Diaphragm Discontinuity Irregularity)

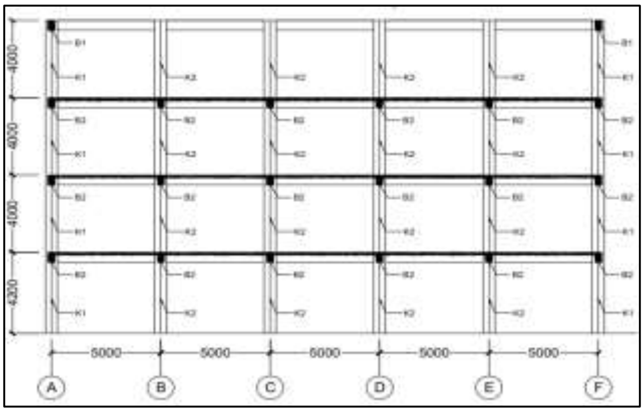

Fig.13. Portal As-1 = As-4 Section

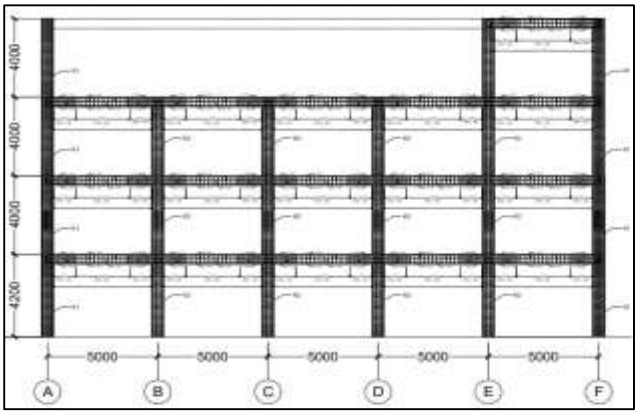

Fig.15. Portal As-2 = As-3 Section (Diaphragm Discontinuity Irregularity)

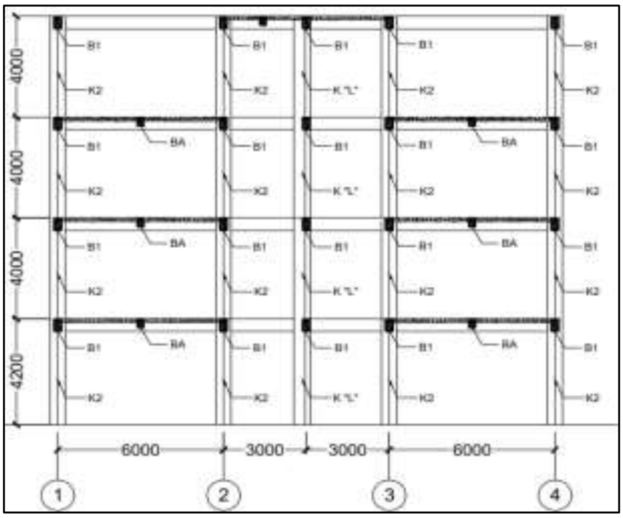

Fig.16. Portal As-E Section

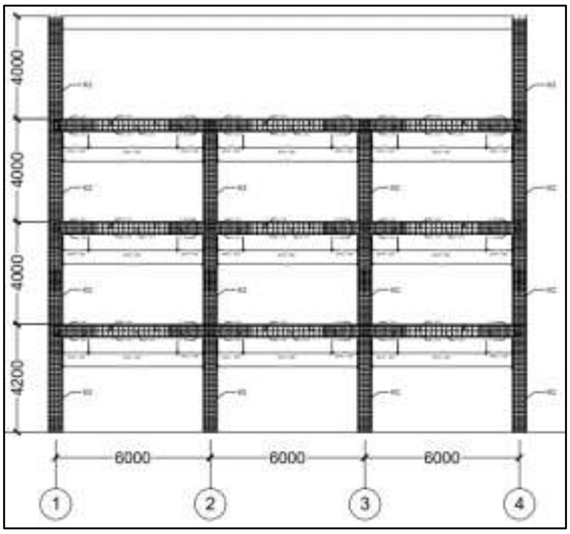

Fig.17. Portal As-C = As-D Section (Diaphragm Discontinuity Irregularity)

4. CONCLUSIONS

Based on the results of the earthquake-resistant building structure design of an archive building with diaphragm discontinuity irregularity are:

1. Building structures have horizontal irregularity structures that are examined based on SNI 1726:2019 on earthquake resistance design procedures for building and non-building structures, as follows:
   Diaphragm discontinuity irregularity occurs due to the fact that the opening area on the 4th story (420 m2) is more than 50% of the floor area surrounding it (450 m2), with a percentage of 93% of the opening area. Building structures with horizontal irregularities have undergone additional repair steps according to SNI 1726: 2019 procedures.
2. Main beams (B1, B2, B3) and Sloof design are 300 x 500 mm and secondary beams (BA) are 250 x 350 mm. The beams are designed with different amounts of bending and shear reinforcement.
3. Columns (K1, K2) dimension design are 550 x 550 mm. The columns are divided into corner columns, center columns, x-direction edge columns, and y-direction edge columns. The dimensions of the columns are typical from the 1st to the 4th floor, with a different amount of reinforcement.
4. The elements of the slabs are designed to be two-way slabs, with the following dimensions:
   2nd and 3rd floors (Type A slab) are 130 mm, 4th floor (Type B slab) are 150 mm.
5. The structural element designs have met the requirements of "Strong Column, Weak Beam" in the special moment frames (SMF) according to SNI 2847:2019, namely that the joints between beams and columns meets the condition of $\Sigma Mnc \geq 1{,}2\ \Sigma Mnb$. This shows that the nominal bending strength of the columns is greater than the nominal bending strength of the beams.

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