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The design of the flat slab system with drop panel in the Sukawati market building

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ABSTRACT

Sukawati Market Building has 4 floors and 1 basement with a total building area of 1136.16 m2. It was designed to use a flat slab structure system with the addition of drop panels that maintained the height or story clearance while reducing total building height by eliminating the interior beams. The structure was designed follow the Indonesian Standard for reinforced concrete building design guideline and assessed through finite element simulation. The shear capacity of the flat slab was determined by the strength of the concrete and its dimensions. The reinforcing bar of flat slabs with drop panels is determined in the same way as the reinforcing bar of concrete slabs. Based on the results, the design efficiently resists the forces demand while meeting the deflection requirement, reflecting the structure system's safety and serviceability. The structure system also maintains the total height of the building in order to comply with local high-limit regulation.

Keywords: drop panel; dynamic analysis; flat slab; structure system

1 Introduction

Dimensions of reinforced concrete structure elements used in the building must adhere to the concept of earthquake resistance design [1], [2], which considers the safety factor used in reinforced concrete design [3], [4] as well as element deflection [5], [6]. Following the standard design procedure usually results in beams that are deeper than the slab thickness. The depth of the beam will reduce the effective height of the story. This effective height or story clearance is critical when designing the market building for human psychology and goods circulation inside.

Using conventional design to meet Sukawati market building demand capacity results in total height limitation exceedance, which allows only 15m height according to Bali Regional Building Regulation [7]. Frequently, it was necessary to address this architectural issues and local regulation when designing multi-story buildings in addition to maintaining structural strength and capacity. The use of a flat slab system is one innovation that can overcome these kinds of challenges. The effective height or story clearance can be maintained while the total height of the building is reduced by eliminating the interior beams and the slab directly supported by columns [8], [9]. They are simple to construct and formwork quickly. The slab's underside can be directly covered with the architectural finish. Low story heights are made possible by this, which reduces the cost of vertical items.

However, the punching shear capacity of flat slab systems is questionable and can sometimes lead to the structure's progressive failure. To overcome these drawbacks, it is necessary to add drop panels to the system. The drop panel placed around the perimeter of the column is intended to distribute the load that occurs on the plate to the column, resulting in a slight thickening and reinforcing of the plate in the column perimeter[10].

This paper describes the flat slab with drop panel design application in reinforced concrete structure, the Sukawati Market building, which was evaluated using theoretical formulation and finite element modeling.

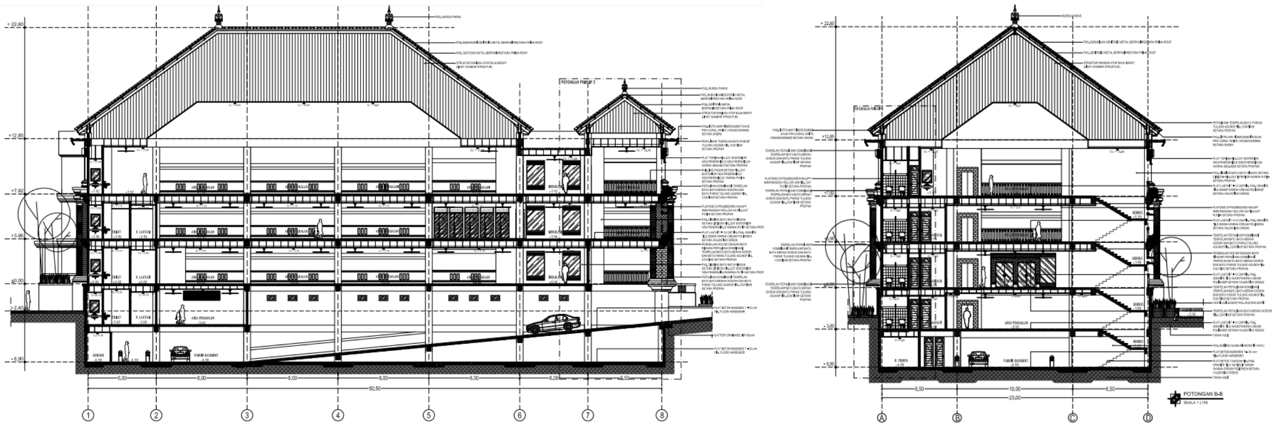

Figure 1. The design plan of the Sukawati Market Building.

2 Data and Methods

Sukawati Market, located on Jl. Raya Sukawati, Sukawati District, Gianyar, Bali, will have 4 floors and 1 basement with a total building area of 1136.16 m^2 and will be designed with a flat slab structure system with drop panels. Using this structure system on the building, the total height of the structure can be as high as 12.85m measured from the ground level, with story heights of 3.96m and 4.93m, respectively, for the typical and top story. The flowchart for the design were shown in figure 2.

2.1 Flat Slab Design

The thickness of the slab is the first consideration in flat slab design. According to the design guidelines, a non-prestressed plate with no interior beams stretching between the supports on all sides and a maximum long span to short span ratio of 2 must meet the limitations in Table 1 and cannot be less than the following values [11]:

1. without a 125mm drop panel.
2. with a 100mm drop panel.

Aside from thickness, the reinforcing bar will be generated proportionally to the forces encountered in the slabs. The density of reinforcing bars will be higher in column lanes, which are defined as areas connecting columns with a width of approximately 25% of column to column span on each column side. The area formed between the column lanes is further defined as the middle lane.

2.2 Drop Panel Design

The design of the drop panel is arranged as follows:

1. Drop panel thickness

$$h_{\text{drop panel}} \geq \frac{1}{4} \text{h slab} \quad (1)$$

2. Drop panel width

$$L_{\text{drop panel}} \geq \frac{1}{6} \text{Column to column span} \quad (2)$$

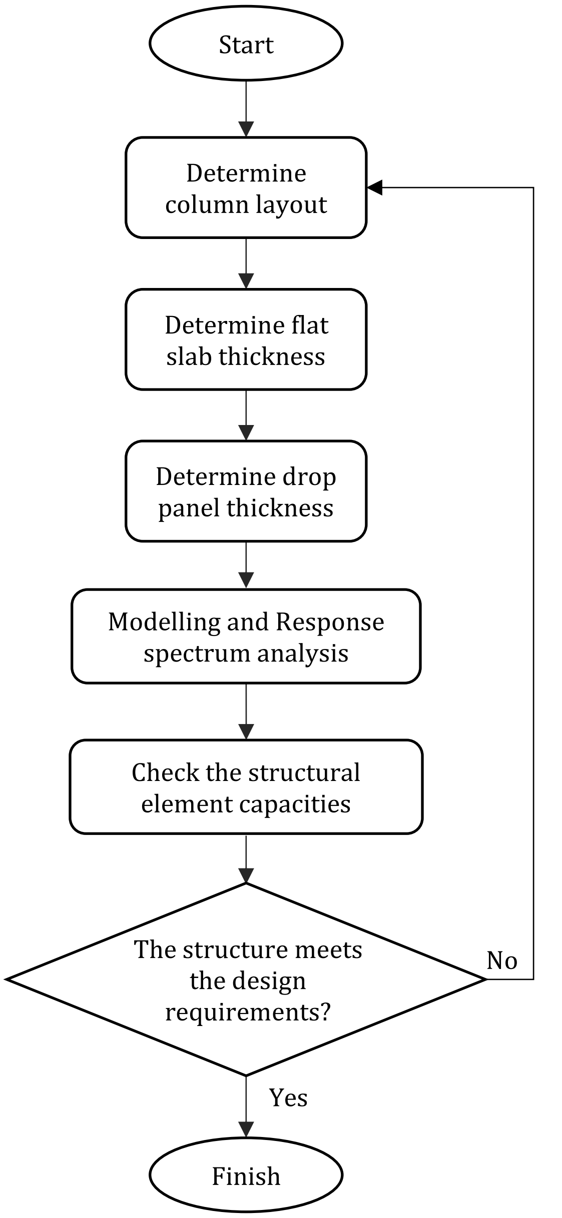

Figure 2. The flowchart for the design of a flat slab with a drop panel structure.

Table 1. Minimum Thickness of Non-Prestressed Two-Way Plates Without Interior Beams[11]

f_y, MPa [(2)]	No *drop panel*[(3)]			With *drop panel*[(3)]		
	Exterior panels		Panel interior	Exterior panels		Panel interior
	No edge beams	With edge beams [(4)]		No edge beams	With edge beams [(4)]	
280	$l_n/33$	$l_n/36$	$l_n/36$	$l_n/36$	$l_n/40$	$l_n/40$
420	$l_n/30$	$l_n/33$	$l_n/33$	$l_n/33$	$l_n/36$	$l_n/36$
520	$l_n/28$	$l_n/31$	$l_n/31$	$l_n/31$	$l_n/34$	$l_n/34$

(1) l_n is the net distance in the longitudinal direction, measured from the face to the face of the fulcrum (mm).
(2) For f_y with the intermediate values given in the table, the minimum thickness should be calculated by linear interpolation.
(3) *Drop panel* according to 8.2.4
(4) Plates with beams between the columns along the edges of the exterior. Exterior panels should be considered without edge beams if a_f is less than 0.8. The value of a_f for the edge beam should be calculated according to 8.10.2.7.

2.3 Modeling and Loading

The structure of the Sukawati Market building was modelled with the structural analysis software, ETABS [12], [13], as show in figure 3 and figure 4. The reinforced concrete material used in the simulation for this particular building has strengths of 30 MPa, 280 MPa, and 420 MPa, respectively.

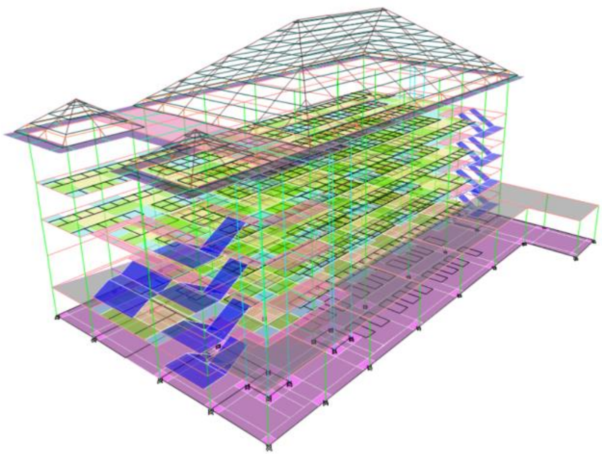

Figure 3. The 3D model of Sukawati Market Building.

The primary external loads: dead load, live load, rain load, and wind load were applied to the structure. The impact of Earthquake load was also considered since studied structure is situated in a seismically active region, which constructed on class D site and designed with the third risk category (Market Building). The spectral acceleration for the maximum considered earthquake (MCER) is 0.963g and 0.395g for S_S and S_1, respectively. The design is following Indonesian standard guidelines, such as SNI 2847: 2019 [11] for guidelines in reinforced concrete structures design, SNI 1727: 2020 [14] and SNI 1726: 2019 [15] in structure design loading. In accordance with SNI 1727:2020, all of the factored loads were applied to the structural models in various combinations to produce the corresponding internal forces (M_u, V_u, and P_u).

2.4 Flat Slab Shear Capacity

The shear capacity of the flat slab was governed from the concrete material strength and its dimensions, showing the conservativeness of the design. The two-way shear capacity is determined by the smallest value of the following equation:

$$V_{c1} = 0{,}33 \cdot \lambda \cdot \sqrt{f'_c} \cdot b_o \cdot d \quad (3)$$

$$V_{c2} = 0{,}17 \cdot \left(1 + \frac{2}{\beta}\right) \cdot \lambda \cdot \sqrt{f'_c} \cdot b_o \cdot d \quad (4)$$

$$V_{c3} = 0{,}083 \cdot \left(2 + \frac{a_s \cdot d}{b_o}\right) \cdot \lambda \cdot \sqrt{f'_c} \cdot b_o \cdot d \quad (5)$$

By circumference of the critical cross section can be calculated based on the area on the drop panel, as follows:

1. For the middle column

$$b_o = 2(B + d) + 2(H + d) \quad (6)$$

2. For corner columns

$$b_o = (0{,}5d + B) + 2(0{,}5H + d) \quad (7)$$

3. For edge columns

$$b_o = 2(0{,}5d + H) + 2(d + B) \quad (8)$$

In which:

V_c = nominal shear strength provided by concrete.
f'_c = quality of concrete (MPa).
b_0 = critical cross-sectional circumference.
d = effective thickness of the plate.
b = width of the critical cross section.
β = the ratio of column width to column length.
a_s = 40 (interior column).
a_s = 30 (edge column).
a_s = 20 (corner column).

The value of the two-way shear strength on the allowable plate ($\emptyset V_c$) must be greater than the factored shear force (V_u) so that the plate does not experience two-way shear failure, $\emptyset V_c \geq V_u$, with $\emptyset = 0.75$.

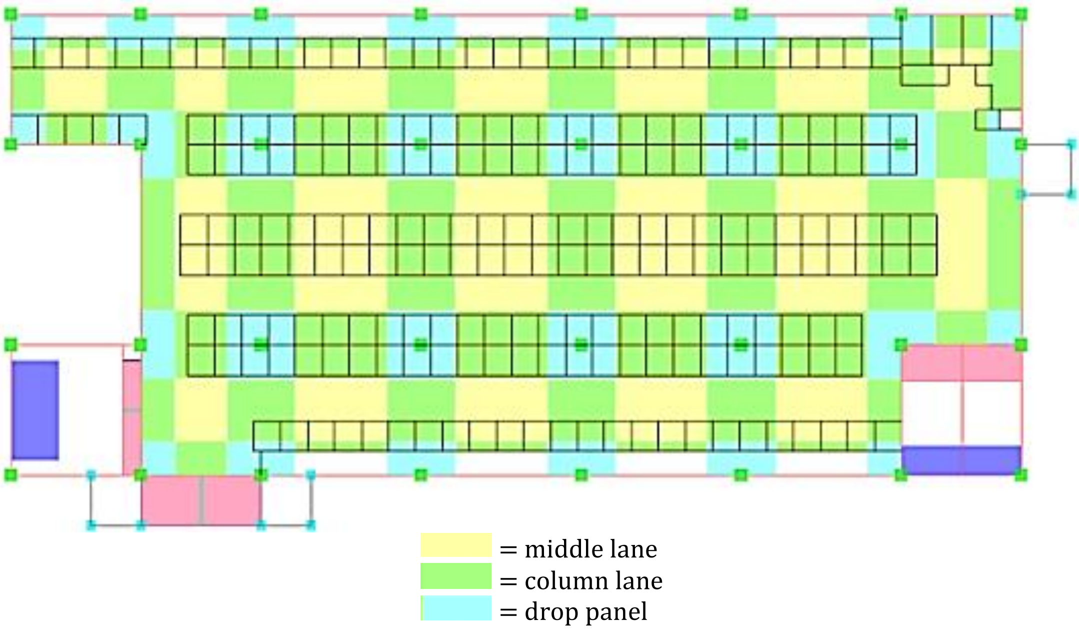

Figure 4. Typical floor plan of the structure.

2.5 Flat Slab Bending Capacity with the Addition of Drop Panels

Based on SNI 2847:2019, the reinforcing bar of flat slabs with the addition of drop panels is determined the same as the reinforcing of concrete slabs, namely:

$$\emptyset M_n \geq M_u \quad (9)$$

$$M_n = A_s \cdot f_y (d - \frac{a}{2}) \quad (10)$$

In which:

M_n = Nominal moment
M_u = Ultimate moment
$\emptyset$ = Reduction factor (0.75 – 0.80)

3 Results and Discussion

3.1 Flat slab with drop panel performance

Following the design method mentioned in section 2, the flat slab thickness was 275mm and 75mm drop thickness measured from bottom surface of the flat slab, therefore the total high of drop panel and 350mm. Furthermore, the width of the drop panel was 3400mm for longitudinal and transversal directions, as depicted in figure 4. By these dimensions and assigned loading in the structure mentioned in section 2, the ultimate shear occurred in perimeter of the columns and the shear capacities of the drop panels were both listed in table 2.

Table 2. Shear demand and capacity of drop panels

Column Location	b_o	a_s	V_u	$\emptyset V_c$
	mm		kN	kN
Interior	3824	40	1277	1586
Edge	2562	30	470	1062
Corner	1606	20	281	666

The comparisons demonstrated that the dimensions of the drop panels were sufficient to resist the effect of punching shears occurred near the column's perimeters.

Table 3. Moment demand of flat slab and drop panels

Strip	Part	Base	1st Floor	2nd Floor	3rd Floor
		M_u	M_u	M_u	M_u
		kN.m	kN.m	kN.m	kN.m
Column lane-x	End	158,1	157,7	157,2	156
	Mid	48,9	43,2	43	42,3
Column lane-y	End	216	214,4	209,5	211,5
	Mid	76,6	71,3	72,3	72,7
Middle lane-x	End	35,8	36	36	35,2
	Mid	44,6	39	39	42,5
Middle lane-y	End	43,4	36,7	36,7	36,6
	Mid	58,3	59,5	59,5	62,6

Furthermore, ultimate moment demand was obtained from of 1.2D + 1.6L loading combination as shown in table 3 and depicted in figure 5. In figure 5, it is obvious that the moment demand in drop panel and column lane area were higher than that in middle lane (higher demand visualized by brighter color). Following Eq. (9) and (10) the reinforcing rebar of flat slabs and drop panels can obtained and ensure the bending capacity of the flat slab with drop panel resisting moment demand. The reinforcing rebar listed in table 4, and applied for ground floor, 1st, 2nd, and 3rd story, respectively, and can be visualized in figure 6.

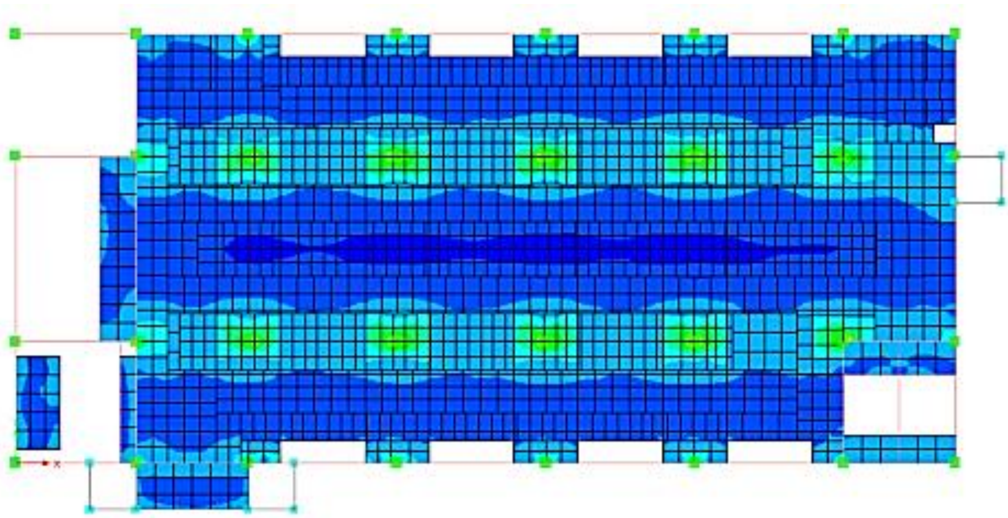

Figure 5. Typical moment demand ($M_{2\text{-}2}$) on the flat slab with drop panel.

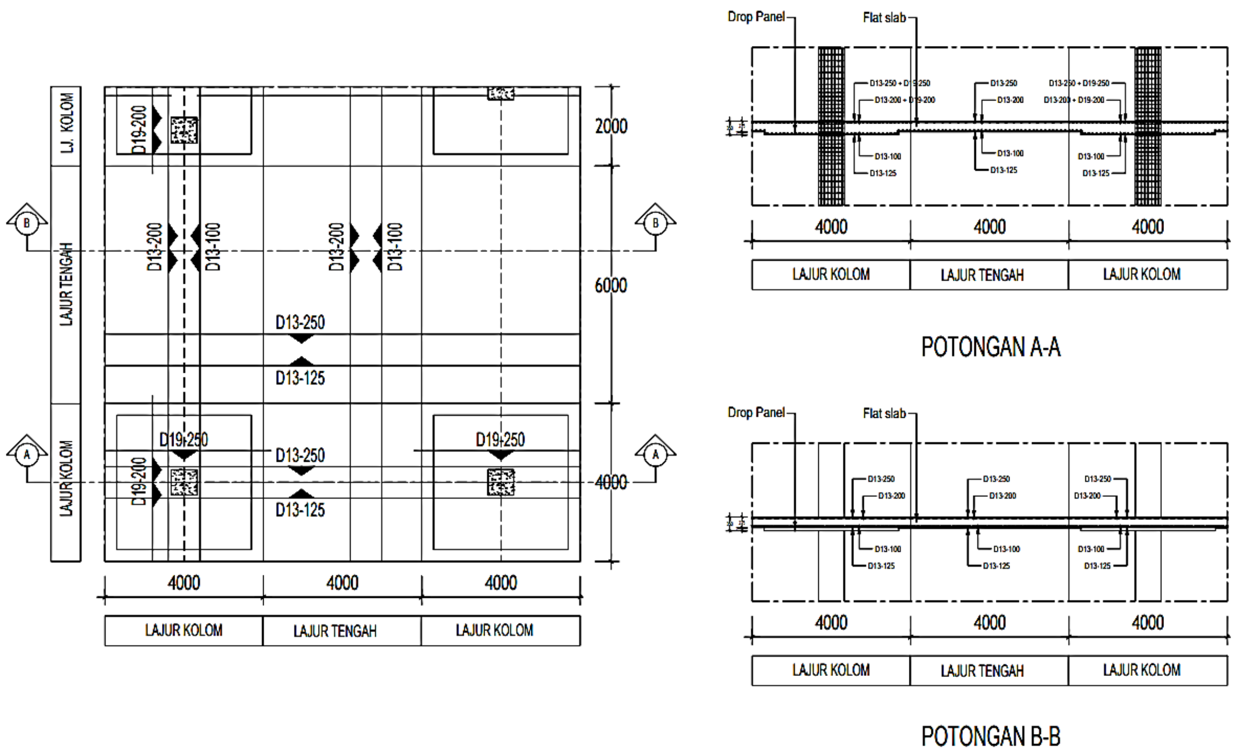

Figure 6. Details of flat slab with drop panels.

Table 4. Reinforcing rebar for flat slab with drop panel.

Strip	Part	Tensile rebar	Compression rebar
Column lane-x	End	D13-250	D13-125
	Drop Panel	D19-250	
	Mid	D13-125	D13-250
Column lane-y	End	D13-200	D13-100
	Drop Panel	D19-200	
	Mid	D13-100	D13-200
Middle lane-x	End	D13-125	D13-250
	Mid	D13-125	D13-250
Middle lane-y	End	D13-100	D13-200
	Mid	D13-100	D13-200

3.2 Deflection assessment

Aside from investigating the safety demand through design capacity, controlling deflection is a critical factor in ensuring the structure's comfortability, stability, and integrity. The allowable vertical deflection of the slabs, $L_{allowable}$, were calculated according the design guideline as $L_{allowable}=L/240$, resulting in 41.67mm. In which L is the span of the slabs. Compared to the analysis results shown in figure 7, the maximum vertical deflection occur on the flat slab were 16.2mm, which is within or lower than allowable vertical deflection, reflecting the applicability of the slab element.

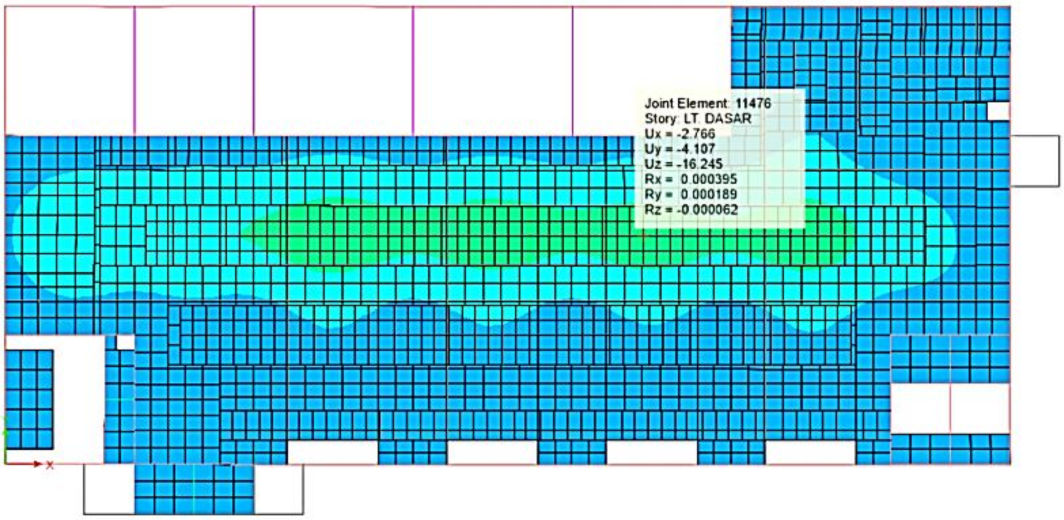

Figure 5. Slab's overall maximum deflection found at ground floor of building.

4 Conclusion

This study focused on the application of flat slab with drop panel in Sukawati Market Building. The dimensions of the structure system designed following the Indonesian guideline based on the loading combination correspond to the construction site and its functionality.

Based on the results and discussion above, it can be concluded that the design efficiently resists the forces demand. Further assessment showed that the flat slab system meets the design requirement in term of vertical deflection, reflects the serviceability of the structure system. The structure system also maintains the total high of the building to comply the local regulation on high limitation.

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