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Comparative Analysis of Two-Way Concrete Slabs using the Direct Planning Method with the Equivalent Frame Method

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Abstract— **The choice of method in planning the slab has regulated in the latest regulations on reinforced concrete in Indonesia. However, the selection of the most optimal process of utilization in the field needs to be examined to get a more efficient structural cost. The design of reinforced concrete slabs is base on applicable standards regulated in SNI 2847: 2013. Therefore, a two-way plate study is carried out using the direct design method and the equivalent frame method — the analysis to show on the Ultimate bending moment that results from loading. The results compared with using the Equivalent method. The results obtained are the value of the bending moment and area of reinforcement and the number of reinforcement. Based on the analysis, the equivalent skeletal method is superior in several factors. From the ultimate moment factor obtained by a deviation of 74.12%. From the ratio of rates has a deviation of 13.08% and is based on the number of reinforcement that is more or less simple.**

Keywords—Two-Way Concrete Plates, Direct Planning Method, Equivalent Frame Method

I. INTRODUCTION

In the slab design, SK SNI-2847-2013 requires using the direct planning method and equivalent framework in planning the two-way slabs[1]. The direct planning method has special requirements for its use. In direct planning, the required load is even, whereas in the equivalent order method, it can be used at any load by fulfilling the required assumptions. Because planning cannot yet know the most effective method, it is necessary to design that can facilitate planning. So in research will make a practical design of the plates with both methods. The practical design is made based on new regulations, namely SNI 2847: 2013, which will later produce a useful design table plate. This plate design will provide moments and the distance of reinforcement that will be used so that it is expected to be used and used as a reference in planning in the field.[2]

Direct design method

the spacing between the plates supporting the plates is also uniform or not much different. Apart from these two conditions, the direct planning method will not produce satisfactory results [3]. The immediate design method is a method used in determining the moments of the plan, in the calculation of two-way plates. But it must meet the following requirements:

a. There must be a minimum of three continuous ranges in each direction.

b. The panel plate must be square, with a ratio between the longer span and the shorter center to center of the pedestal in a pan no more significant than two.

c. The length of a sequence in the center to the center of the pedestal in each direction must not be different from more than a third of the longer span

d. The column position is permitted to experience a maximum offset as far as 10% of the span length (in the direction of shift) from either axes between successive column center lines are permitted.

e. The only calculated load is the gravity load and is distributed evenly across the entire plate panel. Unactured live load must not exceed twice the punctured dead load.

f. Panels with beams between supports on all sides, along with the equation that must be met for beams in two perpendicular directions.

Direct Planning Method

Equivalent Frame Method (EFM), formulated in SNI 2847: 2013 Article 13.7. The 3-dimensional building structure divided into several two-dimensional equivalents, the division is done by cutting along the centerline between the two columns. The skeletal structure is analyzed floor separately by floor in an elongated and transverse direction. The equivalent frame method is a method of calculating the moments in which can be used for a variety of two-way plates. So that it can be said that the technique is

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full. In this equivalent frame method, moment determination is done by analyzing the frame structure, for example, the moment distribution method.[4] The equivalent frame method is carried out by dividing the frame of the space portal into a 2-dimensional plane frame, which centered on the column line or pedestal line[5]. The resulting field frames are then analyzed separately in the longitudinal and transverse direction of the building and analyzed separately per building floor.[6]

II. METHODS

This research method is a literature study, namely structural modeling using direct planning methods that refer to existing rules, namely SNI 2847-2013[1]. In this plate design, the Microsoft Excel program is used and compares the results with the analysis results of the SAP 2000 Version 14[1].
Case study
The development of the engineering faculty building design is prioritize in the proposed classroom development area in areas A and B.

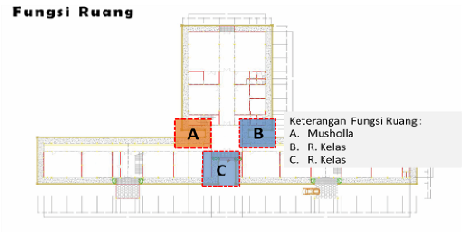

Fig. 1 1st Floor Development Location

Based on data in the 2016 civil accreditation forms, it located that the development of engineering buildings is the need for classrooms and prayer rooms. Therefore, in this case, plan. Mosque development located in area A, classroom development is located in area B, while for Main Entrance (Lobby Utama) development is located in area C. It is designing reinforcement for a panel in the two-way plate of 3 panels for each direction. The panel size is 4 x 4 m, the mounting column is 400 x 400 mm, with a column length of 3.6 m. live working load taken at 4.5 kN / m2, and additional dead load at 0.8 kN / m2, f'c = 20 MPa, fy = 400 MPa.

III. RESULT AND DISCUSSION

For the plate plan model used is a plate with a span of more than three that will be analyzed in the inner plate. Following is the calculation of one of the two-way plate design variations with the direct design method:

Plate thickness is 150 mm

Calculate the amount of factored load:

qd = 0.7 + plate weight = 0.7 + 0.2 (24) = 5.5 kN / m^2

qu = 1.2 (5.5) + 1.6 (4.5) = 13.8 kN / m^2

Shear strength is examined at the critical cross-section location, which is located d distance from the face of the beam, for a plate width of 1 m, with:

d = h - concrete blanket - db / 2 = 200 - 20-13 / 2 = 123.5 mm

Vu = qu (3.0 - ½ beam width - d) x 1 m = 36.2457 kN

Φ Vc = Φ (0.17 λ √f' c) bd = 98,9292 N = 98.93> Vu

Calculate total static moments in the long and short directions:

$$Mol = \frac{qu\, l_2\, l_n^2}{8} = 84.424 \text{ kN.m}$$

Calculate the plan moment in the long direction, l1 = 4.0 m

Distribution of total static moments in one plate panel:

Negative moment (Mn) = 0.65 Mol = -0.65 (89.424) = -58.126 kN.m

Positive moment (Mp) = 0.35 Mol = + 0.35 (89.424) = +31.2984 kN.m

Calculate the l2 / l1 ratio and the αf1 value:

$$\frac{l_2}{l_1} = \frac{4}{4} = 1 \quad \alpha f1 = \frac{E I_b}{E I_s} = 2{,}893$$

$$\alpha f1 = \frac{l_2}{l_1} = 4{,}34 > 1{,}0$$

• Negative moment distribution <Mn. The percentage of negative moments held by the column lane, using interpolation (for values of l2 / l1 = 1 and αf1 = 4.34) is 75%, then:

Column lane = 0.75Mn = -0.8 (58.1) = -43.59 kN.m

Middle lane = 0.25 Mn = -0.2 (58.1) = -14.53 kN.m

Because αf1 (l2 / l1)> 1.0, according to the regulations in SNI 2847: 2013 article 13.6.5, 85% of the moments in the column lane can be overturned, and the remaining 15% is borne by the plates in the column lane.

Beam = 0.85 (-43.6) = -37.06 kN.m

Column columns = 0.15 (-43.6) = -6,539 kN.m

Middle lane = -14.53 kN.m

• Positive moment distribution, Mp. The percentage of negative moments held by the column lane, using interpolation (for values of l2 / l1 = 1 and αf1 = 4.34) is 75%, then:

Column path = 0.75Mn = 0.8 (+31.3) = 23.47 kN.m

Middle lane = 0.25Mn = 0.2 (+31.3) = 7.82 kN.m

Because αf1 (l2 / l1)> 1.0, according to the regulations in SNI 2847: 2013 article 13.6.5, 85% of the moments in the column lane can be overturned, and the remaining 15% is borne by the plates in the column lane. Then:

Beam = 0.85 (23.5) = 19,953 kN.m

Column columns = 0.15 (23.5) = 3.5211 kN.m

Middle lane = 7.82 kN.m

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Calculate the plan moment in the long direction, l2 = 4.0 m

Distribution of total static moments in one plate panel:

Negative moment (Mn) = 0.65 MOS = -0.65 (89.42) = -58,126 kN.m

Positive moment (Mp) = 0.35 Mos = +0.35 (89.42) = +31.2984 kN.m

Calculate the l2 / l1 ratio, and the value of αf1:

l2 / l1 = 4/4 = 1 αf1 = Elb / Els = 2,893 αf1 = l2 / l1 = 4.34> 1.0

Negative moment distribution, Mn. The percentage of negative moments held by the column lane, obtained by interpolation (for values of l2 / l1 = 1 and αf1 = 4.34) is obtained at 75%, then:

Column lane = 0.75Mn = -0.8 (58.1) = -43.59 kN.m

Middle lane = 0.25 Mn = -0.2 (58.1) = -14.53 kN.m

Because αf1 (12/1)> 1.0, according to the regulations in SNI 2847: 2013 article 13.6.5, 85% of the moments in the column lane can be transferred to the beam, and the remaining 15% is borne by the plates in the column lane. Then:

Beam = 0.85 (-43.6) = -37.06 kN.m

Column columns = 0.15 (-43.6) = -6,539 kN.m

Middle lane = -14.53 kN.m

Distribution of positive moments, Mp. The percentage of negative moments held by the column lane, obtained by interpolation (for values of l2 / l1 = 1.2 and αf1 = 2.976) is obtained at 75%, then:

Column path = 0.75Mn = 0.8 (+31.3) = 23.47 kN.m

Middle lane = 0.25Mn = 0.2 (+31.3) = 7.82 kN.m

Because αf1 (12 / l1)> 1.0, according to the regulations in SNI 2847: 2013 article 13.6.5, 85% of the moments in the column lane can be overturned, and the remaining 15% is borne by the plates in the column lane. Then:

Beam = 0.85 (23.5) = 19,953 kN.m

Column columns = 0.15 (23.5) = 3.5211 kN.m

Middle lane = 7.82 kN.m

Table 1. Reinforcement of the long direction plate

Direction length	Lane column		Middle Lane	
	Negative	Positive	Negative	Positive
Mu (kN.m)	6.53913	3.52107	14.53	7.82
Strip width, b (mm)	2000	2000	2000	2000
Efektif height, d (mm)	129.4	129.4	129.4	129.4
Ru (=Mu/bd^2, Mpa)	0.19526	0.10514	0.43392	0.23365
Reinforcement ratio, ρ (%)	0.0864	0.0463	0.1447	0.0774
As = ρbd (mm^2)	223.6032	119.8244	374.4836	200.3112
As min= 0.0018 bh (mm^2)	792	540	540	540
Reinforcement bar D12	3	3	5	3
The distance between reinforcement	667	667	400	667
Maximum distance. 2h	300	300	300	300
Installed distance, mm	300	300	300	300

2. Analysis Equivalent Frame Methods

1. Plate thickness: 150 mm.

2. Determine the stiffness of the Ks:

$$Ks = K\frac{EIs}{Is}$$

Where K is a factor of stiffness, and

$$Is = \frac{I_2 hs^3}{12} = \frac{4000 \ x \ 150^3}{12} = 1125x10^6 \ mm^4$$

If the moment of inertia of the Is plate is considered as a reference and is considered as 1.0 unit, then the commercial moment between the axis of the column to the column face is:

$$\frac{1,0}{\left(1\frac{c2}{l2}\right)^2} = \frac{1,0}{\left(1-\frac{400}{4000}\right)^2} = 1,235$$

The width of the analogy column varies with 1 / L, that is equal to (1 / 1.235) = 0.81

$$K = I^1 = \left(\frac{1}{Aa} + \frac{Mc}{Ia}\right)$$

With:

Aa = analytical column cross-sectional area = 4000 + 2 (200) (0.81) = 4724

Ia = the commercial moment of the analogy column.

M = moment in the middle of the plate due to the load of 1 unit in the outer fiber cross section of the analogy column

$$c = \frac{l1}{2} = \frac{5500}{2} = 2750 \quad = 1,0 \ x \frac{l1}{2} = 1,0 \ x \ \frac{4000}{2} = 2000$$

So that:

$$K = I_1\left(\frac{1}{Aa} + \frac{Mc}{Ia}\right) = 4000\left(\frac{1}{4724} + \frac{2000 x 2000}{8812626667}\right) = 2,66$$

Whereas the plate stiffness is:

$$Ks = K\frac{EIs}{Is} = 2,6623E\ \frac{1125x106}{4000} = 748776.598 \ E$$

3. Determine column stiffness, Kc:

$$Kc = K'\frac{EIs}{Is} \ x \ 2$$

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$Ic = \frac{400^4}{12} = 2133333333$

Stiffness factor, K′ is determined as follows:

$K' = Ic\left(\frac{1}{Aa} + \frac{Mc}{Ic}\right)$

With:

Ic = column length = 3600 mm.

C = Ic / 2 = 3500/2 = 1800 mm.

Aa = Ic - plate thickness = 3600 - 150 = 3450 mm.

$Ia = \frac{c(Ic - ks)^3}{12} = \frac{(3450)^3}{12} = 3421968750$

M = 1.0 (Ic / 2) = 1750 mm.

$K' = Ic\left(\frac{1}{Aa} + \frac{Mc}{Ic}\right) = 3.600\left(\frac{1}{3450} + \frac{2133333333}{3.500}\right) x2 = 4,452$

So that:

Determine the torsional stiffness, Kt, from the plate side of the column:

$Kt = \sum \frac{9EcsC}{12\left(1 - \frac{c2}{l2}\right)}$ dengan $C = \sum \left(1 - 0,63\frac{x}{y}\right)\left(\frac{x^3 y}{3}\right)$

In this case x = 110 mm T plate thickness on the side of the column:

$$c = \left(1 - \frac{0,63 x 150}{400}\right)\left(\frac{3,375000^3 x 400}{3}\right) = 343687500$$

$$Kt = \frac{9E \ x \ 343687500}{4000\ (1 - 400/4000)} = 859\,218.75\,E$$

For inner plates, two plates are close together, so that:

Kt = 2 (859218.75 E) = 1718437.5 E

Calculate the equivalent column stiffness, Kec

Kec = 1296270.801

Calculates the moment distribution factor (DF).

$$\frac{1}{kec} = \frac{1}{\sum Kc} + \frac{1}{Kt} = \frac{1}{1671709,76E} + \frac{1}{195996,83E} =$$

0,000003149, s o Kec = 1296270.801

$Dfcolumnm = \frac{Kec}{Ks + Kec} = = 0,63$

$Dfslab = \frac{Kc}{Ks + Kec} = = 0,37$

Because the columns at the top and bottom of the plate have the same dimensions, the DF value is divided equally into the second to the two columns, so the DF value = 0.32

For the interior (interior):

$$c = \left(1 - \frac{0,63 x 150}{400}\right)\left(\frac{3,375000^3 x 400}{3}\right) = 343687500$$

$Df\ slab = \frac{Ks}{2Ks + Kec} = 0,27$

$Df\ column = \frac{Kec}{2Ks + Kec} = 0,46$

Because the columns above and below the plate have the same dimensions, the DF value is equally divided into the two columns, so the value of Df = 0.232

Calculate fixed end moments:

qu = 1,2 (0.8) +1,6 (4,5) = 8,16 kN / m2

$$= \frac{1}{12}\, qu\, .\, l2.(l1)^2 = -\frac{1}{12}.\ 8,16\ .\ 4.\ (4)^2 = -$$

43,52

Equivalent order analysis is then carried out by using the moment distribution method or often known as the cross method.

Table2. Equivalent Frame Methods

Direction length	Lane column		Middle Lane	
	Negative	Positive	Negative	Positive
Mu (kN.m)	3.5503	2.59449	3.76	2.99
Strip width, b (mm)	2000	2000	2000	2000
Efektif height, d (mm)	117.4	129.4	129.4	129.4
Ru (=Mu/bd^2, Mpa)	0.23722	0.10514	1.30176	0.23365
Reinforcement ratio, ρ (%)	0.0751	0.0403	0.1620	0.0867
As = ρbd (mm^2)	176.3348	104.2964	419.256	224.3796
As min= 0.0018 bh (mm^2)	792	540	540	540
Reinforcement bar D12	3	2	4	4
The distance between reinforcement	667	1000	400	667
Maximum distance. 2h	300	300	300	300
Installed distance, mm	300	300	300	300

The following is a comparison table of Ultimate Moment values from Direct Planning to Equivalent frame methods Reaction Ratio

Table 3. Comparison table of Ultimate Moment values from Direct Planning to Equivalent Frame methods Reaction Ratio

Mu (kN.m)	Lane column		Middle Lane	
	Positive	Negative	Positive	Negative
Direct Planning Method	6.53913	3.52107	14.53	7.82
Equivalent Frame Method	3.5503	2.59449	3.76	2.99
Difference	45.71%	26.31%	74.12%	45.71%

From the results of the moment analysis using the direct planning method and the equivalent order in the elongated direction, a maximum deviation of 74.12% is obtained at the negative middle lane moment whereas the minimum difference is 26.31% at the moment of the positive column lane. This result proves that using equivalent framework results in a lower ultimate moment compared to the direct planning method.

The following is a comparison table of the value of the Retirement Ratio from Direct Planning to Equivalent Frame methods

Table 4. Comparison table of the value of the Retirement Ratio from Direct Planning to Equivalent Frame methods

Reinforcement ratio ρ (%)	Lane column		Middle Lane	
	Positive	Negative	Positive	Negative
Direct Planning Method	0.0864	0.0463	0.1447	0.0774
Equivalent Frame Method	0.0751	0.0403	0.1620	0.0867
Difference	13.08%	12.96%	11.95%	13.07%

From the results of the moment analysis using the direct planning method and equivalent order in the elongated direction, a maximum deviation of 13.08% is obtained in the negative column lane moments. Whereas the minimum difference is 11.95% at negative middle lane moments. This result proves that using equivalent framework results in a lower ultimate moment compared to the direct planning method.

The following is a comparison table of the amount of reinforcement used in the Direct Planning Equivalent Frame methods.

Table 5. Comparison table of the amount of reinforcement used in the Direct Planning Equivalent Frame methods.

Installed distance	Lajur Kolom		Lajur Tengah	
	Negatif	Positif	Negatif	Positif
Direct Planning Method	3 D12	3 D12	5 D12	3 D12
Equivalent Frame Method	3 D12	2 D12	4 D12	4 D12

From the results of the moment analysis with the direct planning method and the equivalent order in the elongated direction, the number of reinforcement is more than the equivalent order method compared to the direct planning method. This result proves that using equivalent framework results in a lower ultimate moment compared to the direct planning method.

IV. CONCLUSIONS

Based on moment ultimate, quantifier of reinforcements, and the ratio of reinforcement, the equivalent frame method is superior. the ultimate moment obtained by a deviation of 74.12%. The ratio of reinforcement has a difference of 13.08%. based on a quantifier of reinforcement that is more similar.

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REFERENCES

[1] Agus Setiawan, *Perancangan Struktur Beton Bertulang Berdasarkan SNI 2847-2013*, 1st ed. Jakarta: Erlangga, 2016.

[2] W. Apriani, F. Lubis, and M. Angraini, "IOP Conference Series : Earth and Environmental Science Experimental Study of Axially Tension Cold Formed Steel Channel Members Experimental Study of Axially Tension Cold Formed Steel Channel Members," pp. 0–5, 2017.

[3] A. Setiawan, *Perencanaan Struktur Baja dengan Metode LRFD*, 2nd ed. Jakarta: Erlangga, 2008.

[4] Yovi Surya Futariani, "Kajian Struktur Baja sebagai Alternatif Review Design Struktur Beton Bertulang (Studi Kasus pada Gedung LPTK FT UNY)," Universitas Negeri Yokyakarta, 2017.

[5] W. T. Segui, *Aisc 2005*. 2005.

[6] J. I. Kadir, S. Tudjono, D. T. Sipil, F. Teknik, U. Diponegoro, and K. Desain, "EVALUASI DESAIN STRUKTUR GEDUNG TRAINING CENTRE II," *J. Karya Tek. Sipil*, vol. 6, no. 1, pp. 428–437, 2017.