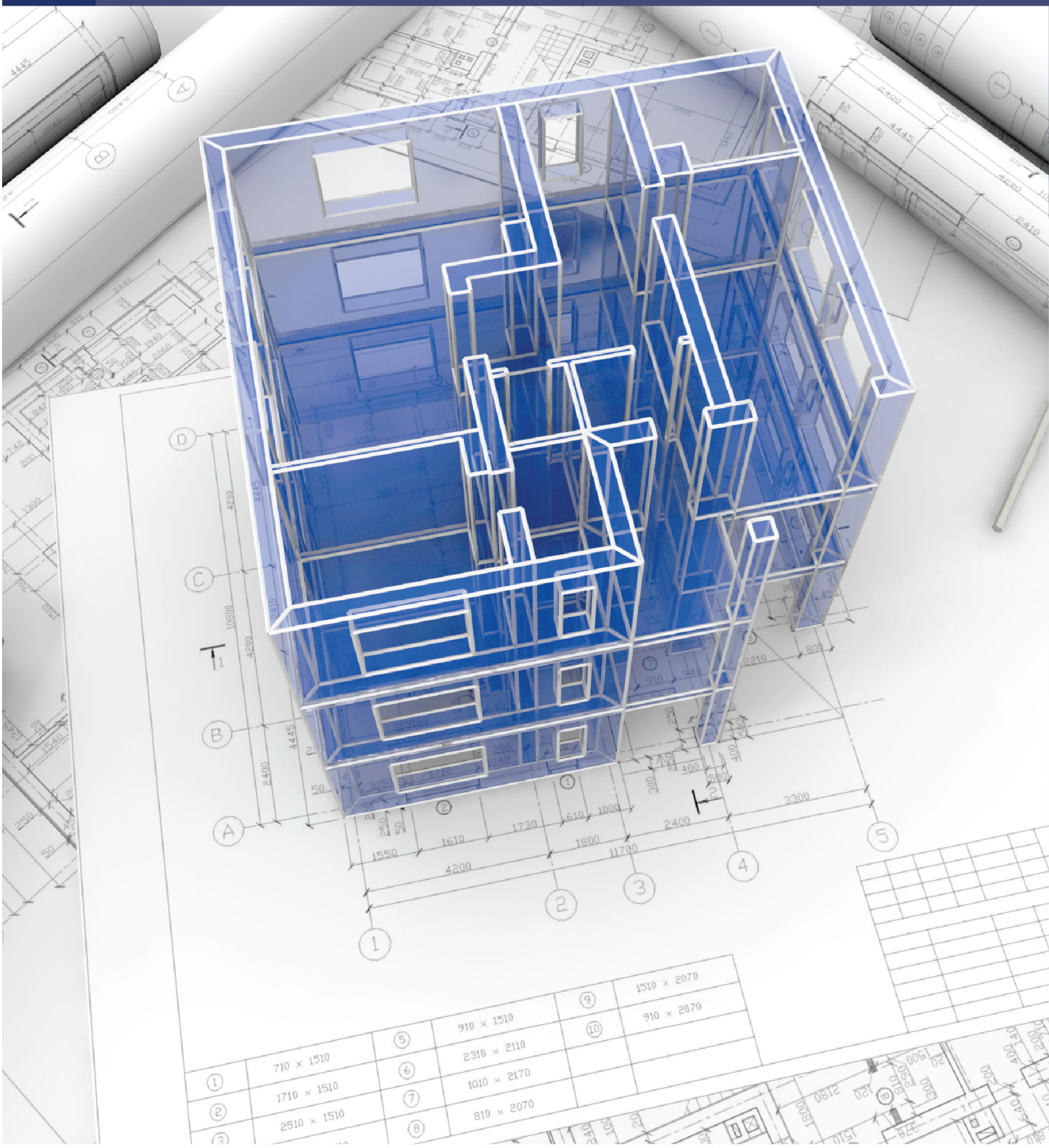
STRUCTURE INSIGHT

VOL.04

Structural Design Guide for Flat Slab



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Structural Design Guide for Flat Slab

VOL. 04
STRUCTURE INSIGHT

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Flat Slab Modeling

Chapter 1

Flat Slab Modeling

What is a Flat Slab?

A flat slab is a two-way reinforced concrete slab that usually does not have beams and girders, and the loads are transferred directly to the supporting concrete columns.

The flat plate is a two-way reinforced concrete framing system utilizing a slab of uniform thickness, the simplest of structural shapes. The flat slab is a two-way reinforced structural system that includes either drop panels or column capitals at columns to resist heavier loads and thus permit longer spans.

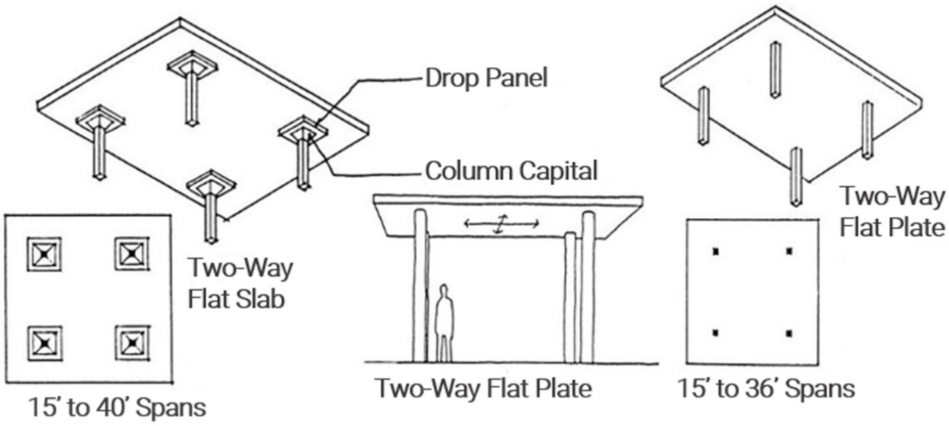


Figure 1. Flat Slab Model

1.1. Advantages of Flat Slab

1. Flexibility in room layout.
   - Partition walls can be placed anywhere.
   - Offers a variety of room layout to the owner.
   - False ceilings can be omitted.
2. Reinforcement placement is easier.
   - As reinforcement detailing of flat slab is simple, it is easier to place.
3. Ease of Framework installation.
   - Big table framework can be used in flat slab.
4. Building height can be reduced.
   - As no beam is used, floor height can be reduced and consequently the building height will be reduced.
   - Approximately 10% of the vertical member could be saved.
   - Foundation load will also reduce.
5. Less construction time.
   - Use of big table framework helps to reduce construction time.
6. Prefabricated welded mesh.
   - Standard sizes.
   - Less installation time.
   - Better quality control.
7. Auto sprinkler is easier.

1.2. Column Capital & Drop Panel

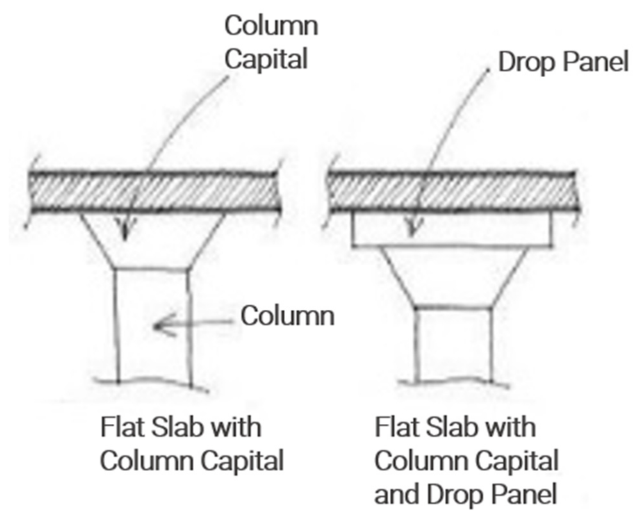


Figure 2. Column Capital and Drop Panel

Uses of column heads (Capital)

Shear strength of flat slab is increased by using column heads.

Column heads reduce the clear or effective span, and therefore, reduce the moment in the flat slab floor.

Uses of drop panels

Drop panels increase the shear strength of flat slab floor.

Drop panels increase flat slab's negative moment capacity.

Drop panels reduce deflection by stiffening the flat slabs.

1.3. How to Create Flat Slab in nGen

1.3.1 Determine the thickness of the flat slab

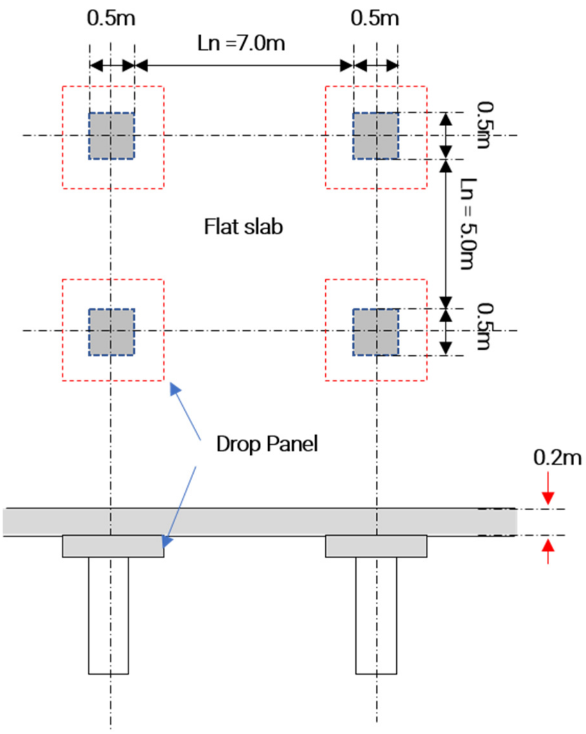


Figure 3.Flat Slab Model

[ACI 318M-14]

Table 8.3.1.1—Minimum thickness of nonprestressed two-way slabs without interior beams (mm)[1]

f_y, MPa[2]	Without drop panels[3]			With drop panels[3]		
	Exterior panels		Interior panels	Exterior panels		Interior panels
	Without edge beams	With edge beams[4]		Without edge beams	With edge beams[4]	
280	$\ell_n/33$	$\ell_n/36$	$\ell_n/36$	$\ell_n/36$	$\ell_n/40$	$\ell_n/40$
420	$\ell_n/30$	$\ell_n/33$	$\ell_n/33$	$\ell_n/33$	$\ell_n/36$	$\ell_n/36$
520	$\ell_n/28$	$\ell_n/31$	$\ell_n/31$	$\ell_n/31$	$\ell_n/34$	$\ell_n/34$

Reference 1. Table 8.3.1.1 of ACI 318M-14

When using f_y = 420Mpa,

In case of flat slab with drop Panel, Slab thickness = Ln/36 = 7.0m / 36 = 0.194m → Apply 0.20m.

* The drop panels have set in this example.

In case of flat slab without drop Panel, Slab thickness = Ln/33 = 7.0m / 33 = 0.212m → Apply 0.22m.

1.3.2 Create the flat slab in nGen

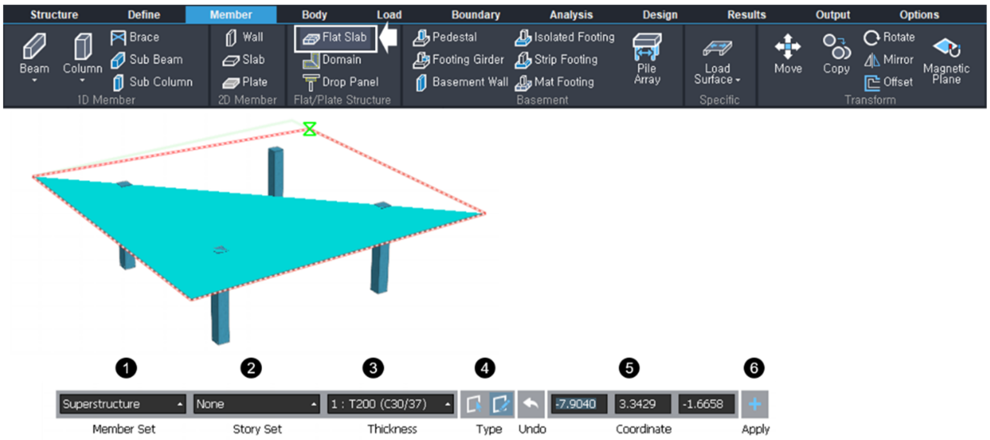


Figure 4. How to Create Flat Slab in nGen Example

Member > Flat/Plate Structure > Flat Slab

❶ Select Member Set.

❷ Select Story Set.

❸ Select Thickness of 0.2m.

❹ Select 'by Draw' as the creating type.

❺ Click the corner point of target area.

❻ Click 'Apply' or push Enter key.

1.3.3 Determine the size and thickness of the drop panel

1. How to determine a size of drop panel

> **[ACI 318M-14]**
>
> **8.2.4** A drop panel in a nonprestressed slab, where used to reduce the minimum required thickness in accordance with 8.3.1.1 or the quantity of deformed negative moment reinforcement at a support in accordance with 8.5.2.2, shall satisfy (a) and (b):
>
> (a) The drop panel shall project below the slab at least one-fourth of the adjacent slab thickness.
>
> (b) The drop panel shall extend in each direction from the centerline of support a distance not less than one-sixth the span length measured from center-to-center of supports in that direction.

Reference 2. Section 8.2.4 of ACI 318M-14

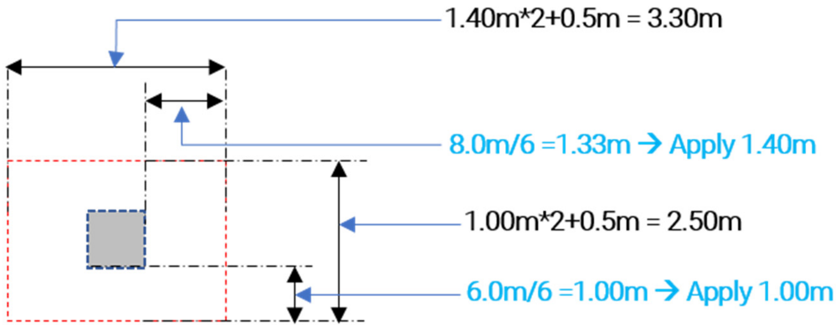


Figure 5. Drop Panel Model

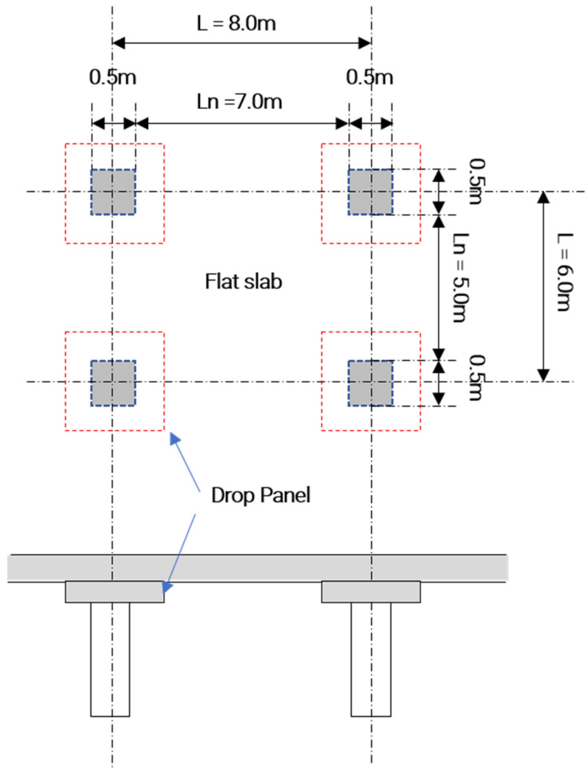


Figure 6a. Determining Size and Thickness of Drop Panel Model

2. The thickness of drop panel is determined by the shear design.

However, the two conditions below must be satisfied.

So, the thickness of the drop panel is assumed to be 0.40m (≤ d_s + Max. h_d = 0.2m+0.25m).

i) The thickness of drop panel below shall not be greater than one-fourth of the face of column.

$$h_d \leq \frac{d_{min}}{4} = 0.25m$$

[ACI 318M-14]

8.5.2.2 In calculating M_n for nonprestressed slabs with a drop panel, the thickness of the drop panel below the slab shall not be assumed to be greater than one-fourth the distance from the edge of drop panel to the face of column or column capital.

Reference 3. Section 8.5.2.2 of ACI 318M-14

ii) The thickness of drop panel shall project below the slab at least one-fourth of slab thickness.

$$h_d \geq \frac{d_s}{4} = 0.05m$$

[ACI 318M-14]

8.2.4 A drop panel in a nonprestressed slab, where used to reduce the minimum required thickness in accordance with 8.3.1.1 or the quantity of deformed negative moment reinforcement at a support in accordance with 8.5.2.2, shall satisfy (a) and (b):

(a) The drop panel shall project below the slab at least one-fourth of the adjacent slab thickness.

Reference 4. Section 8.2.4 of ACI 318M-14

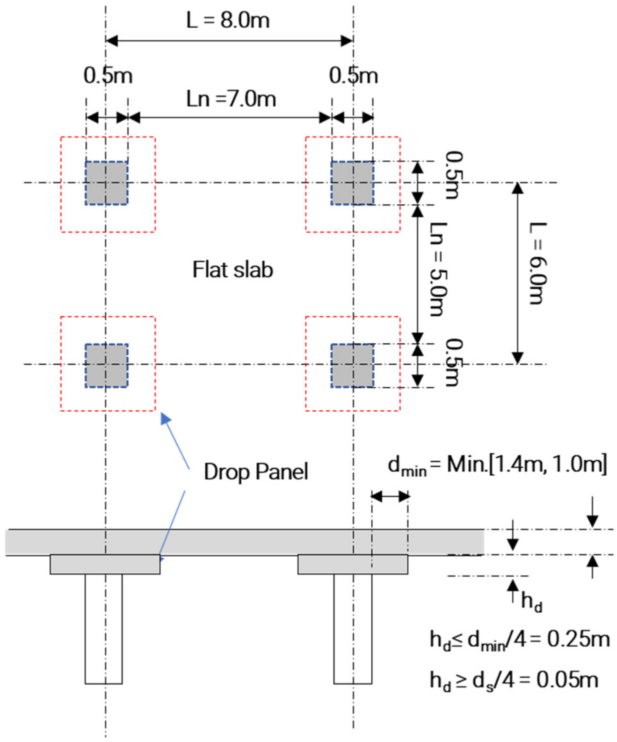


Figure 6b. Determining Size and Thickness of Drop Panel Model

1.3.4 Create the drop panel in nGen

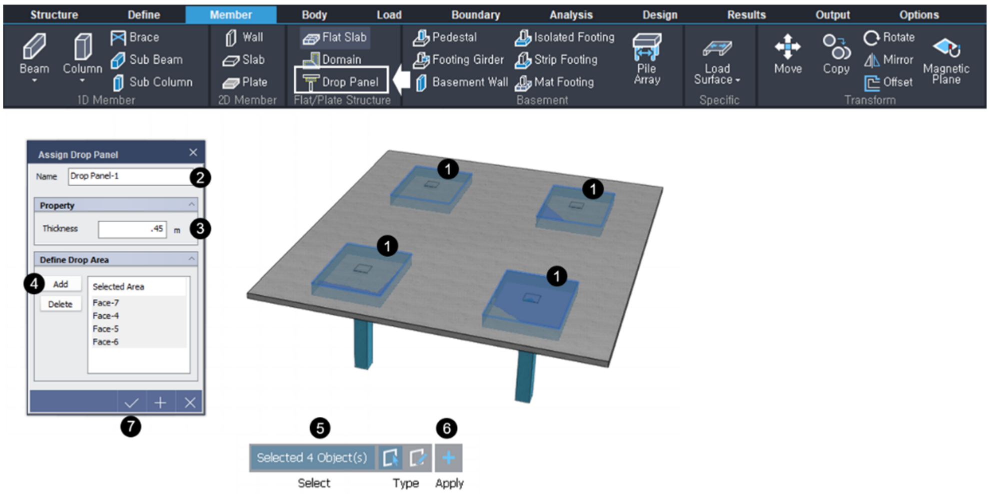


Figure 7. How to Create Drop Panel in nGen Example

Member > Flat/Plate Structure > Drop Panel

❶ Create the bodies (faces) on columns.

❷ Enter 'Name' after click 'Drop panel' of main menu.

❸ Enter 'Thickness' of 0.45m.

❹ Click "Add" button.

❺ Select the target bodies created in ❶.

❻ Click 'Apply' or push Enter key.

❼ Click "V" button.

1.3.5 Create the column capital in nGen

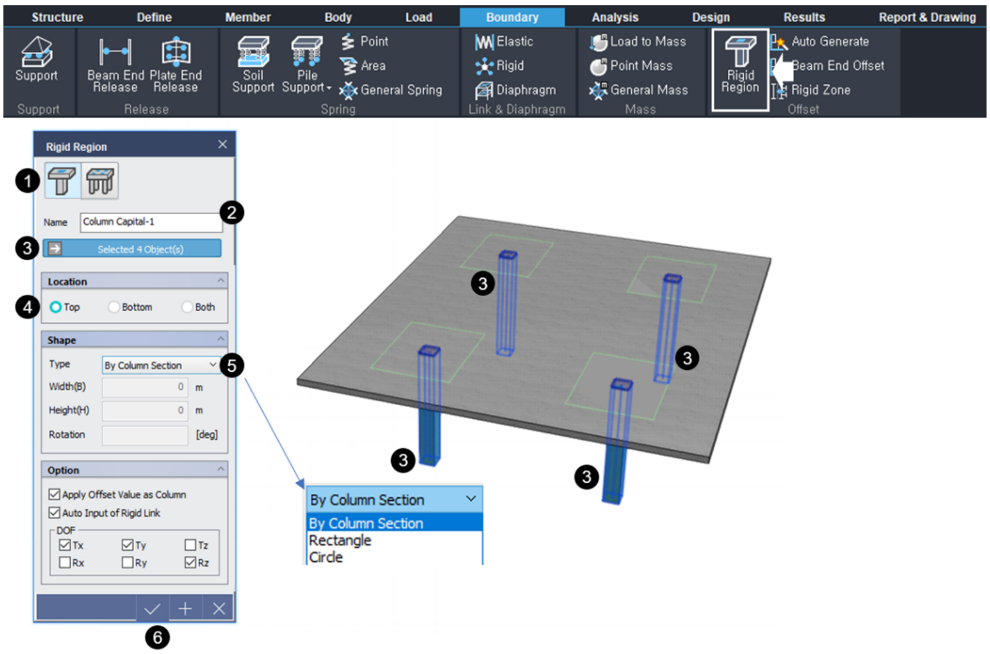


Figure 8. How to Create Column Capital in nGen Example

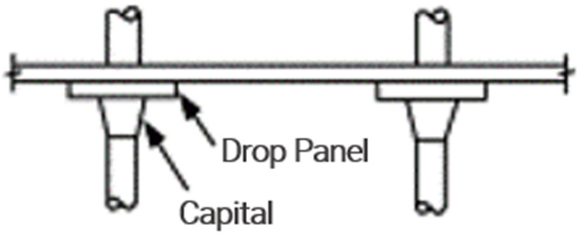


Figure 9. Capital and Drop Panel Model

This is a function to set the column capital; choose 'By column section' or enter the width and height. When the column capital is set, the interior region is considered rigid, and the member force of the slab is applied as zero. Also, when examining the punching shear, it applies the size of the shape.

Boundary > Offset > Rigid Zone

❶ Click ‘Column Capital’

❷ Enter ‘Name’.

❸ Select the target column in model.

❹ Select the location to apply a column capitals.

❺ Select the shape type.

If the columns don’t have a capital, select ‘by Column Section’.

If having a capital, select ‘Rectangle’ or ‘Circle’, and B and H should be entered by manual.

❻ Click “V” button.

Chapter 2

How to Arrange Rebar

Chapter 2

How to Arrange Rebar

In this chapter, the method of arranging flat slab rebar according to the method presented in ACI318M-14 and how to apply it in nGen will be introduced.

[ACI 318M-14]

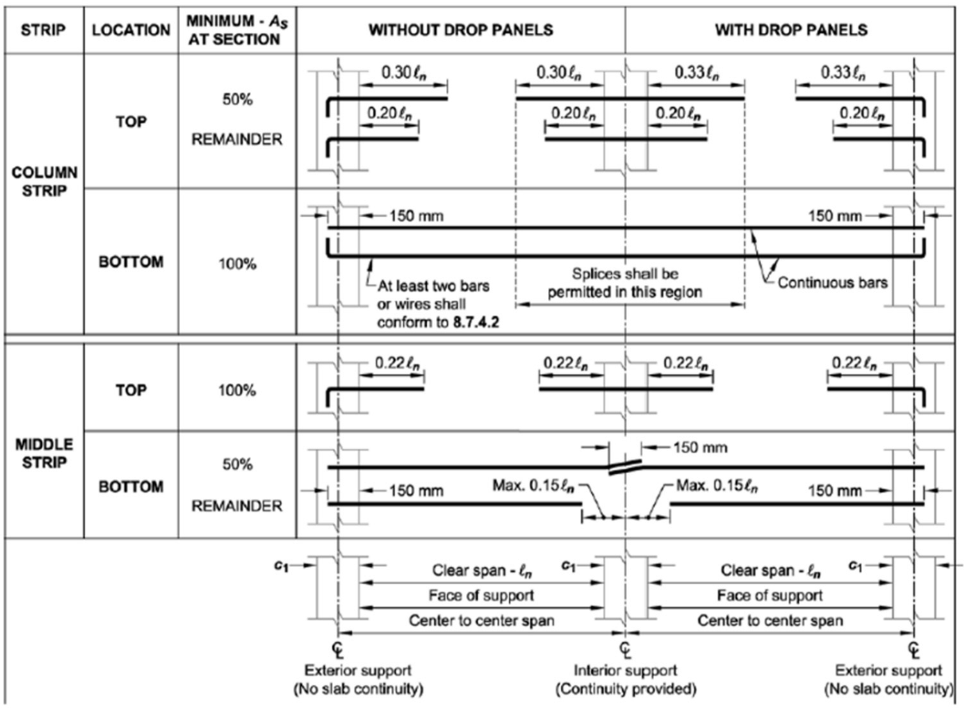


Fig. 8.7.4.1.3a—Minimum extensions for deformed reinforcement in two-way slabs without beams.

Reference 5a. Minimum Extensions for Deformed Reinforcement in Two-Way Slabs without Beams

2.1. Rebar Arrangement Procedure

2.1.1 Define a design strip

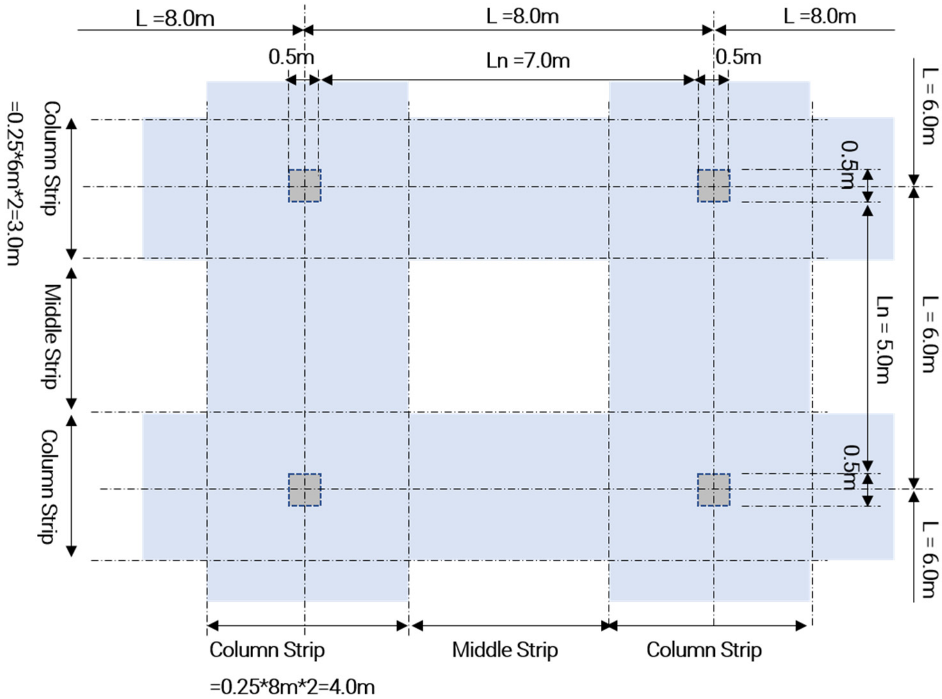
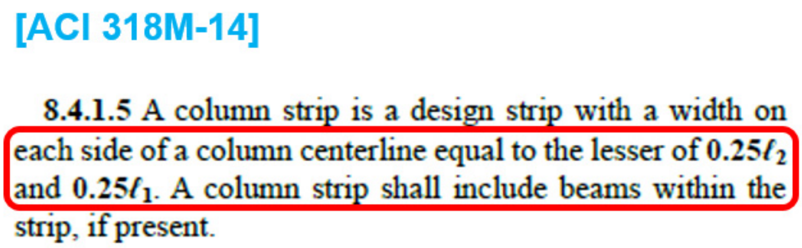


Figure 10a. Column Strip and Middle Strip Model

The design for strip is divided into column strip and middle strip. These strips are used as the width for rebar arrangement.



[ACI 318M-14]

8.4.1.5 A column strip is a design strip with a width on each side of a column centerline equal to the lesser of $0.25\ell_2$ and $0.25\ell_1$. A column strip shall include beams within the strip, if present.

Reference 6. Section 8.4.1.5 of ACI 318M-14

2.1.2 Define a length of top rebar in design strip

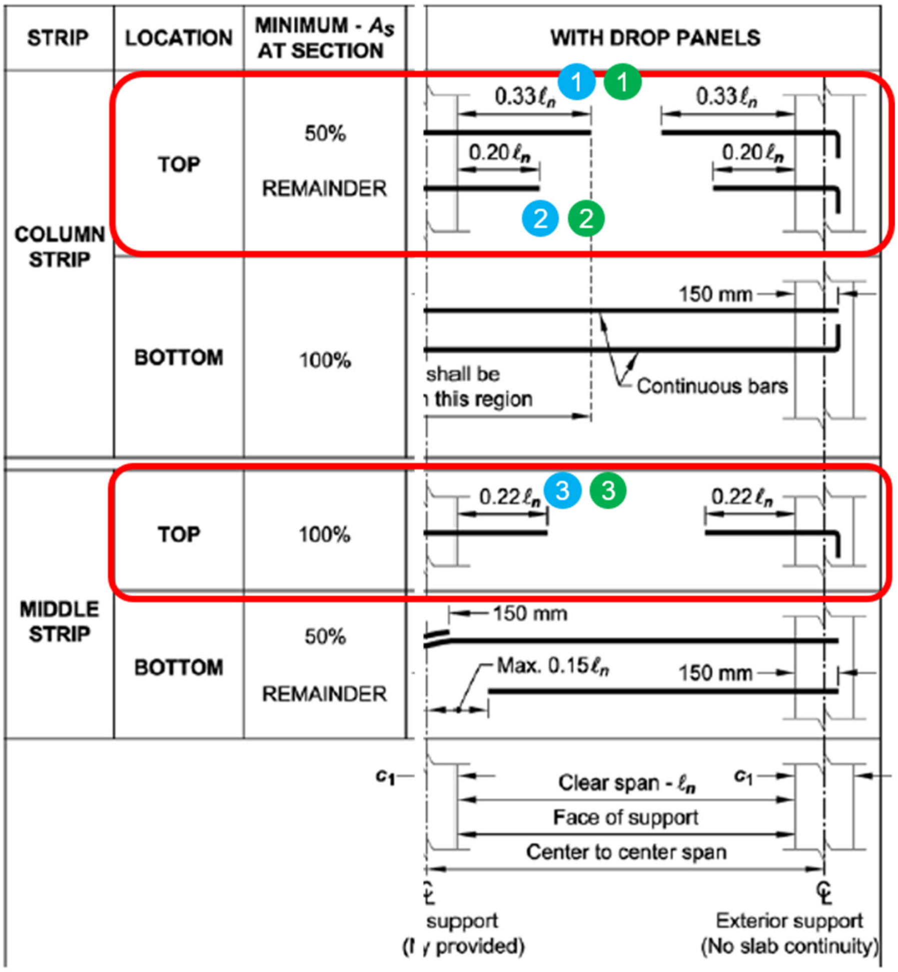


Fig. 8.7.4.1.3a—Minimum extensions f bs without beams.

Reference 5b. Minimum Extensions for Deformed Reinforcement in Two-Way Slabs without Beams

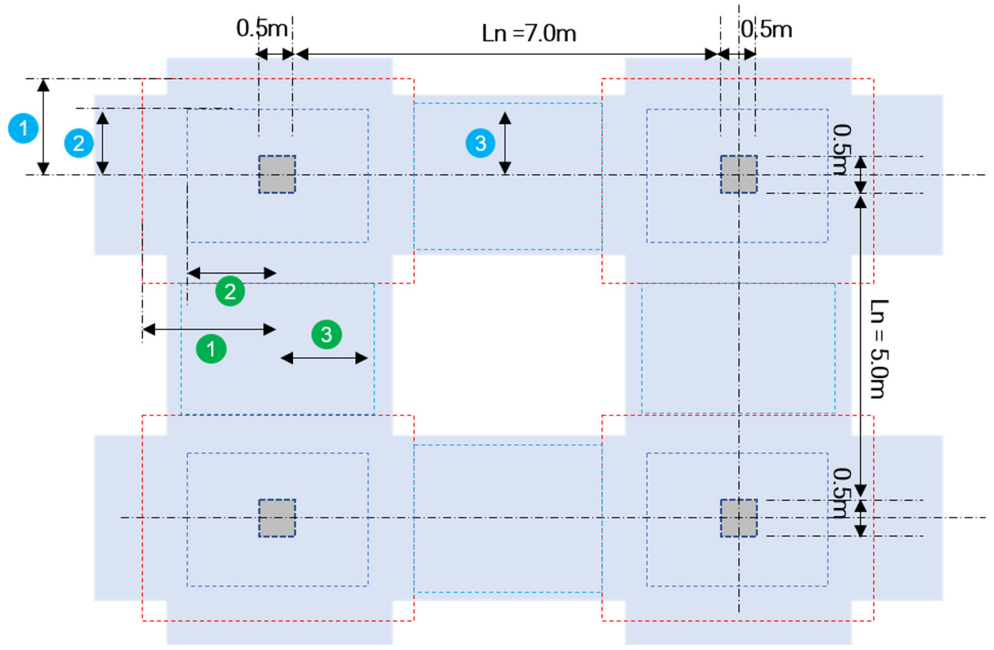


Figure 10b. Column Strip and Middle Strip Model

(1) = 0.33Ln + Column width/2 = 0.33*5.0m + 0.5m/2 = 1.90m

(2) = 0.20Ln + Column width/2 = 0.20*5.0m + 0.5m/2 = 1.25m

(3) = 0.22Ln + Column width/2 = 0.22*5.0m + 0.5m/2 = 1.35m

(1) = 0.33Ln + Column width/2 = 0.33*7.0m + 0.5m/2 = 2.56m → apply 2.60m

(2) = 0.20Ln + Column width/2 = 0.20*7.0m + 0.5m/2 = 1.65m

(3) = 0.22Ln + Column width/2 = 0.22*7.0m + 0.5m/2 = 1.79m → apply 1.80m

2.1.3 Arrange top rebar of x-dir. and y-dir.

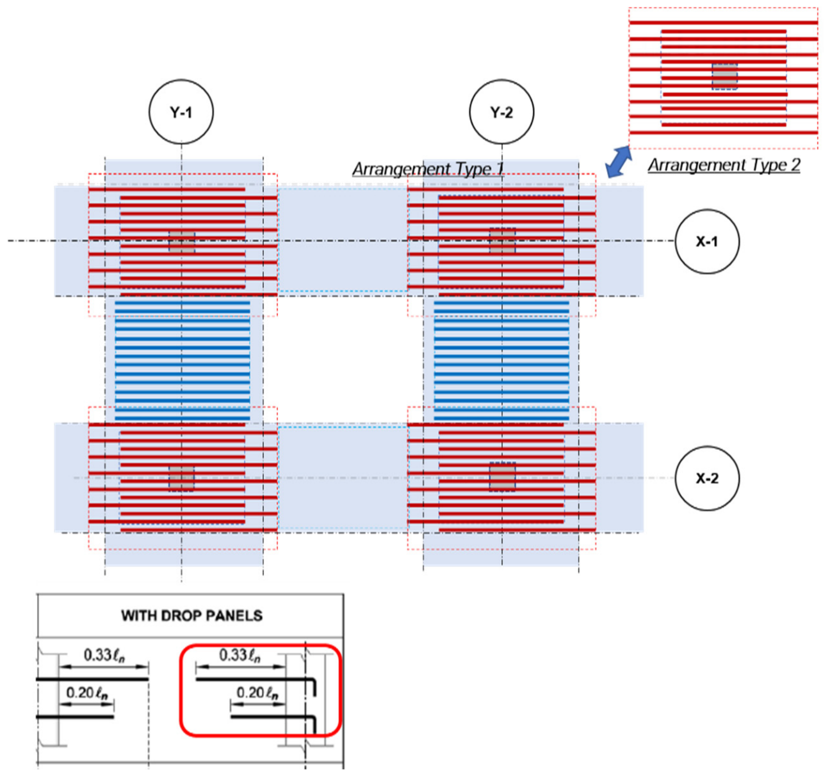


Figure 11. Top of Column Strip and Middle Strip Arrangement Type Model

	X-Direction	Y-Direction
Column Strip Top	HD 16@200 (CT)	HD 13@200 (CT)
Middle Strip Top	HD 13@200 (MT)	HD 10@200 (MT)
Column Strip Bottom	HD 10@200 (CB)	HD 10@200 (CB)
Middle Strip Bottom	HD 13@200 (MB)	HD 10@200 (MB)

It can be applied with the length of 0.33ln, but for economical design, the length is alternately applied as in the above arrangement so that it becomes 0.33ln+0.20ln.

2.1.4 Arrange top rebar of x-dir. + y-dir.

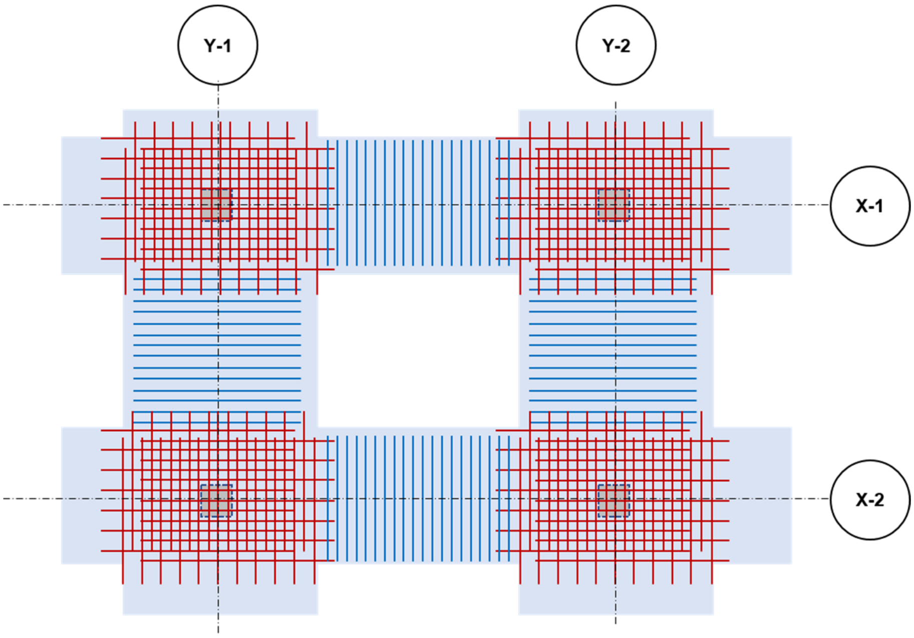


Figure 12. X-Dir. and Y-Dir. Combined Model

2.1.5 Arrange bottom rebar

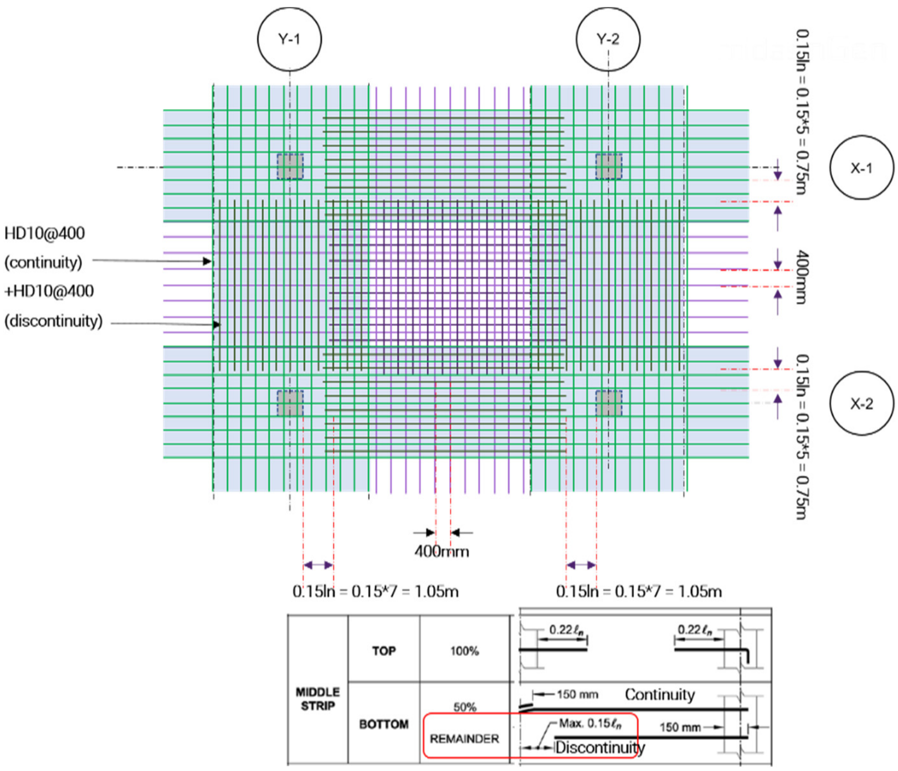


Figure 13. Bottom of Column Strip and Middle Strip Arrangement Type Model

	X-Direction	Y-Direction
Column Strip Top	HD 16@200 (CT)	HD 13@200 (CT)
Middle Strip Top	HD 13@200 (MT)	HD 10@200 (MT)
Column Strip Bottom	HD 10@200 (CB)	HD 10@200 (CB)
Middle Strip Bottom	HD 10@200 (MB)	HD 10@200 (MB)

HD 10@400 (continuity) + HD 10@400 (discontinuity)

In the case of the bottom rebar of the middle strip, 50% of the rebar is placed continuously, and the remainder is placed discontinuously only in the middle part for economical design.

Chapter 3

Application of Flat-Slab in nGen

Chapter 3 • • •

Application of Flat-Slab in nGen

3.1. Checking the Design Result

Path: Result > Category tap > Design Result > Design Result Tree > RC > Flat Slab

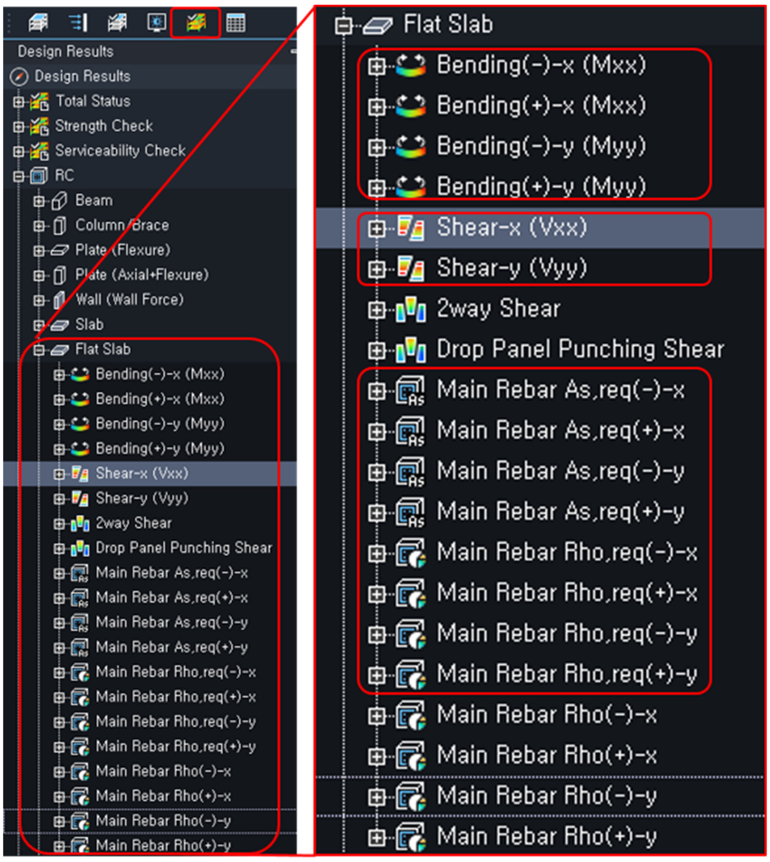


Figure 14. Path Instruction of How to Check the Design Result

* In the case of flat slab, a separate design result table is not provided, so it is necessary to check each result of the element

Main rebar result: Refer to the direction and sign of the moment.

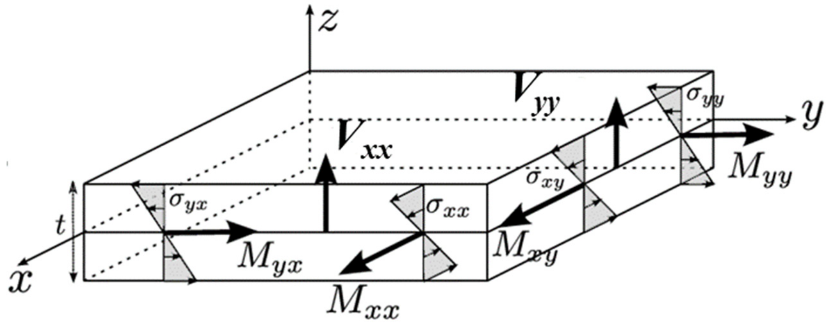


Figure 15. Main Rebar Result

Main rebar A_s, Req.: The amount of rebar against the moment. (Minimum reinforcement cost is considered.)

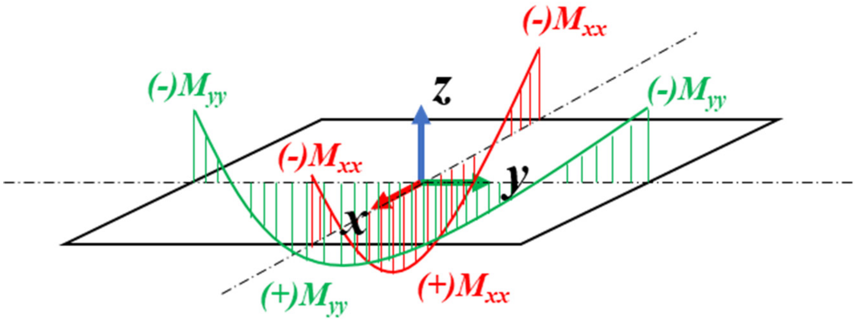


Figure 16. Main Rebar As, Req.

Main Rebar Rho, Req.: Rebar cost against the moment. (Rebar area/Concrete area)

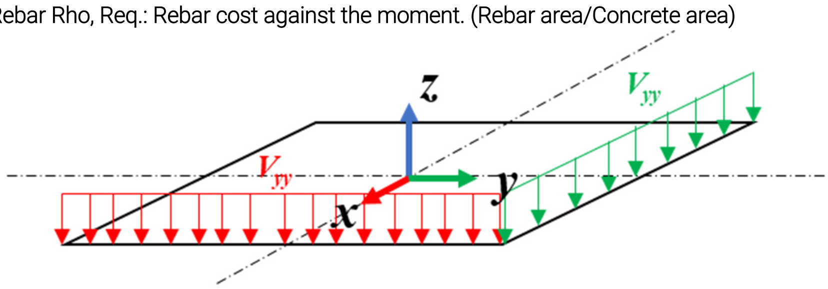


Figure 17. Main Rebar Rho, Req.

3.2. Example Model

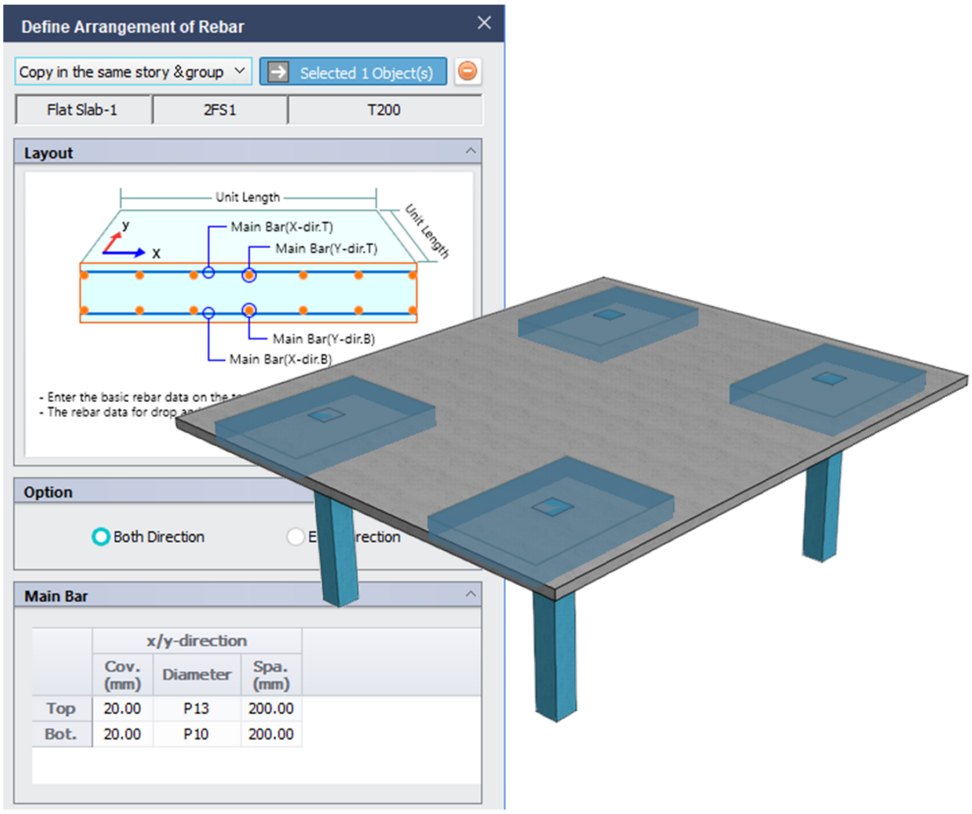


Figure 18. Define Arrangement of Rebar Example Model

Model Information

Column Span	10.0m x 8.0m
Slab Thickness	200mm
Drop Thickness	400mm
Concrete Material	30MPa (300kg/cm^2)
Slab Load	Dead Load = 3.0kN/m^2 Live Load = 5.0kN/m^2

Load Information

Self-Weight	4.8kN/m^2
Dead Load	3.0kN/m^2
Live Load	5.0kN/m^2
Used Load Combination	1.2DL + 1.6LL

Rebar Information

Material	400MPa (4,000kg/cm^2)
All x-Dir. Top Bar	D13@200
All x-Dir. Bottom Bar	D13@200
All y-Dir. Top Bar	D10@200
All y-Dir. Bottom Bar	D10@200

* All: Column Strip + Middle Strip

3.3. Design Result for Example Model

3.3.1 (-)Mxx ratio (Design ratio)

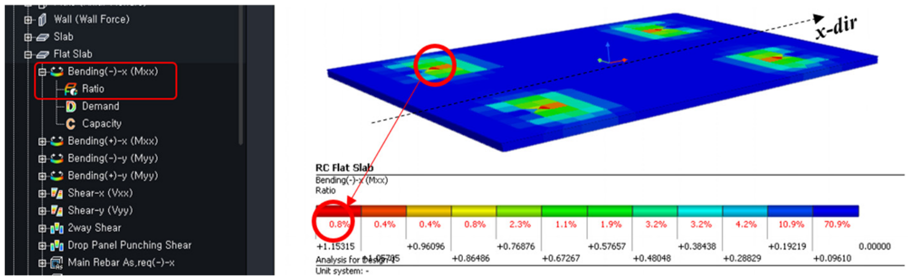


Figure 19. (-)Mxx Ratio (Design Ratio)

Check the ratio of member force (Demand)/design strength (Capacity).

3.3.2 (-)Mxx main rebar A_s, Req.(-) ratio

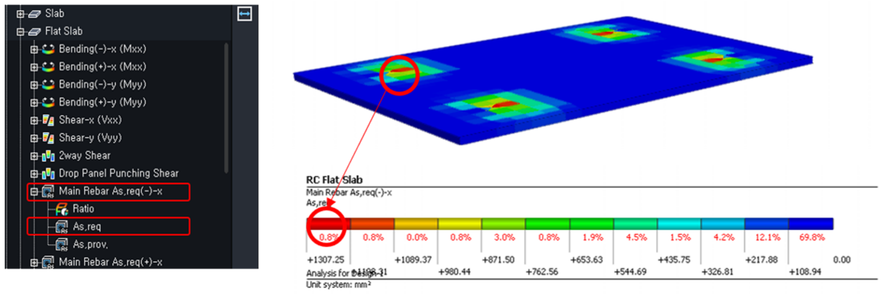


Figure 20. (-)Mxx Main Rebar A_s, Req.(-) Ratio

Calculation of rebar amount should be added when Design Ratio is greater than 1.0.

Design ratio value is 1.153 that means N.G. Thus the rebar should be added to the column strip.

Calculation of Additional Rebar

Provided A_s (D13@200) = 663.66 mm^2

Needed additional A_s = 1307.25 – 663.66 = 643.59 mm^2

→ Apply D13@200 (Additional rebar).

3.3.3 Apply a rebar arrangement

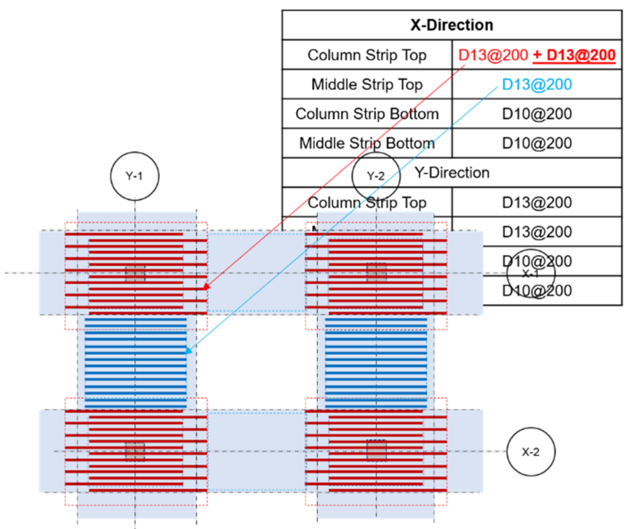


Figure 21. Added Column Strip Top and Middle Strip Top in X-Direction

3.3.4 (-)Myy ratio (Design ratio)

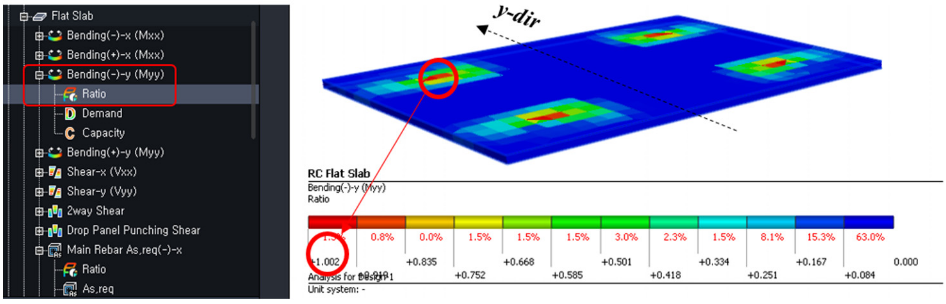


Figure 22. (-)Myy Ratio (Design ratio)

Check the ratio of member force (Demand)/design strength (Capacity).

3.3.5 (-)Myy main rebar A_s, Req.(-) ratio

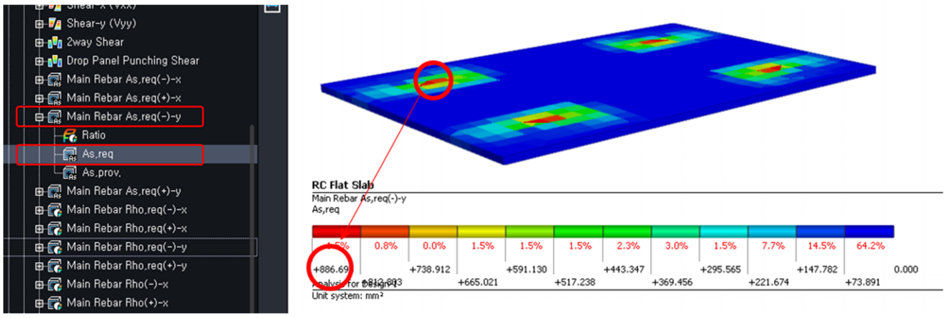


Figure 23. (-)Myy Main Rebar A_s, Req.(-) Ratio

Calculation of rebar amount to be added when Design Ratio is greater than 1.0.

Design ratio value is 1.002 that means N.G. Thus, rebar should be added to the column strip.

Calculation of Additional Rebar

Provided A_s (D13@200) = 663.66 mm^2

Needed additional A_s = 886.70 – 663.66 = 223.04 mm^2

→ Apply D10@200 (Additional rebar) (A_s = 392.70mm^2)

3.3.6 Apply a rebar arrangement

X-Direction	
Column Strip Top	D13@200 **+ D13@200**
Middle Strip Top	D13@200
Column Strip Bottom	D10@200
Middle Strip Bottom	D10@200
Y-Direction	
Column Strip Top	D13@200 **+ D10@200**
Middle Strip Top	D13@200
Column Strip Bottom	D10@200
Middle Strip Bottom	D10@200

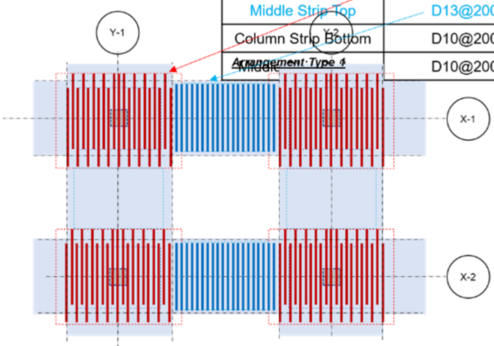


Figure 24 Added Column Strip Top and Middle Strip Top in Y-Direction

3.3.7 (+)Mxx ratio (Design ratio)

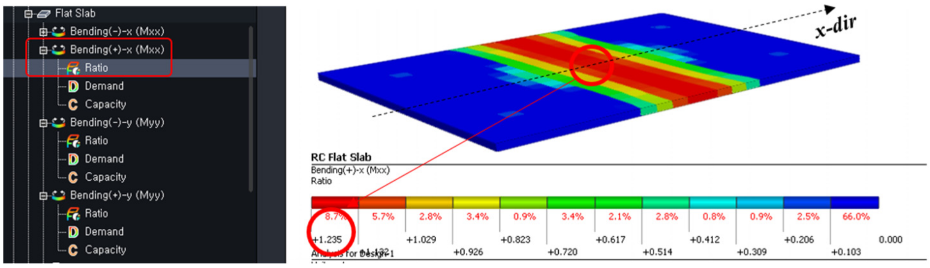


Figure 25. (+)Mxx Ratio (Design Ratio)

Check the ratio of member force (Demand)/design strength (Capacity).

3.3.8 (+)Mxx main rebar A_s, Req.(-) ratio

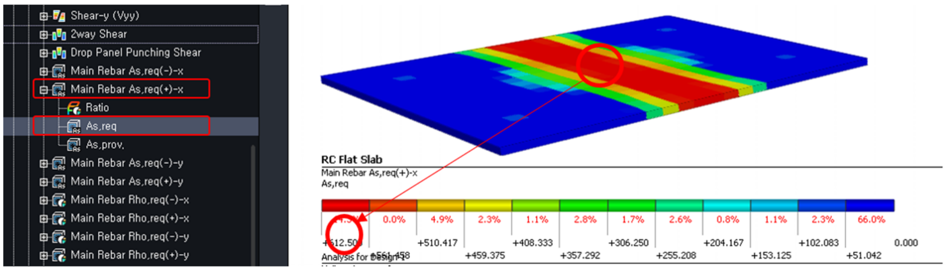


Figure 26. (+)Mxx Main Rebar A_s, Req.(-) Ratio

Calculation of rebar amount should be added when Design Ratio is greater than 1.0.

Design ratio value is 1.235 that means N.G. Thus, rebar should be added to column and middle strip.

<u>Calculation of Additional Rebar</u>

Provided A_s (D10@200) = 392.70mm^2

Needed additional A_s = 612.5 – 392.7 = 219.8mm^2

→ Apply D10@200 (Additional rebar)

3.3.9 Apply a rebar arrangement

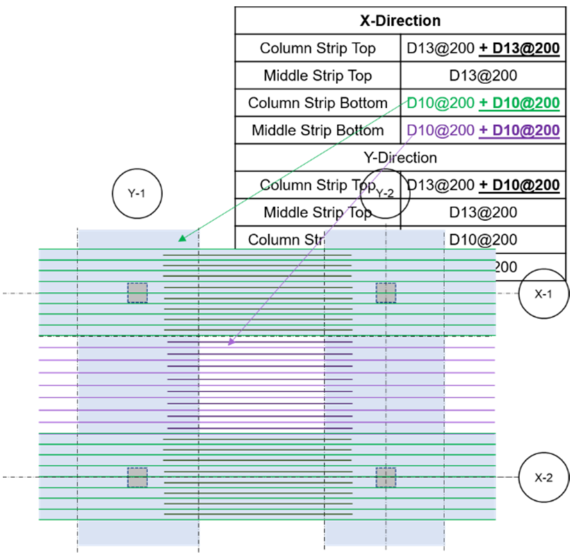


Figure 27. Added Column Strip Bottom and Middle Strip Bottom in X-Direction

3.3.10 (+)Myy ratio (Design ratio)

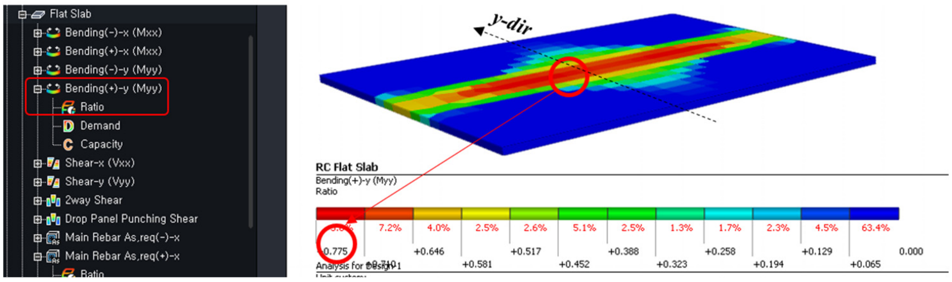
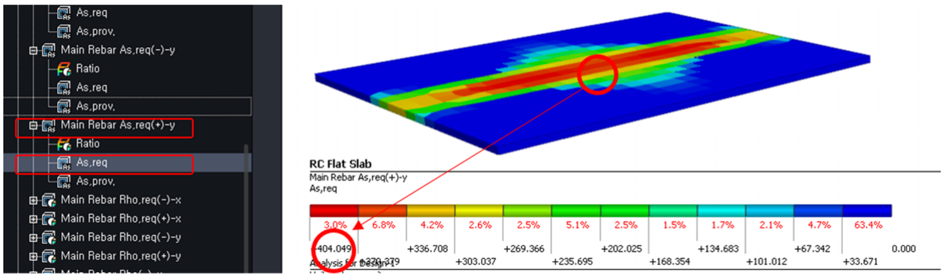


Figure 28. (+)Myy Ratio (Design Ratio)

Check the ratio of member force (Demand)/design strength (Capacity).

3.3.11 (+)Myy main rebar A_s, Req.(-) ratio



$\rho = 0.00238 < \rho_{min} = 0.00245$

Figure 29. (+)Myy Main Rebar A_s, Req.(-) Ratio

$\rho = 0.00238 < \rho_{min} = 0.00245$ → It does not satisfy the minimum reinforcement ratio of code.

Calculation of rebar amount should be added when Design Ratio is greater than 1.0.

Design ratio value is 0.775 that means O.K.

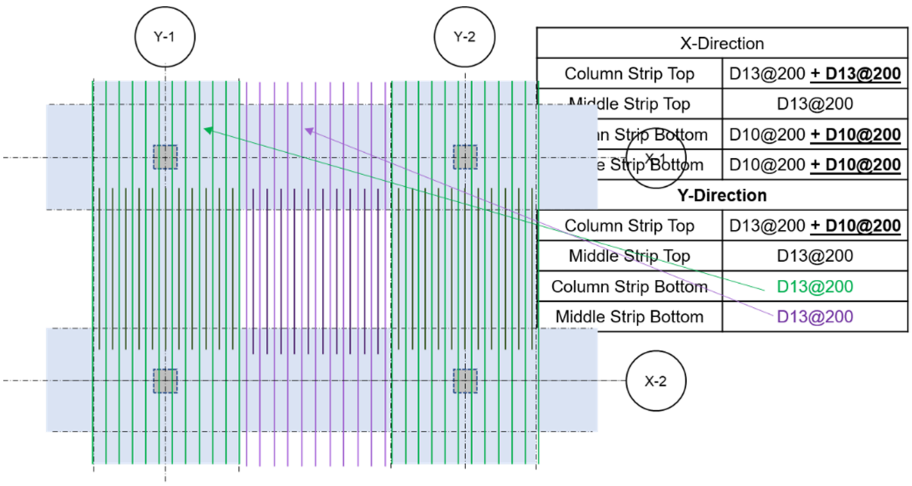
<u>Calculation of Additional Rebar</u>

Provide A_s (D10@200) = 392.70mm^2

Needed additional A_s = 404.05 – 392.7 = 11.8mm^2

→ Change D10@200 to D13@200 (663.66 mm^2)

3.3.12 Apply a rebar arrangement (Final)



X-Direction	
Column Strip Top	D13@200 **+ D13@200**
Middle Strip Top	D13@200
Column Strip Bottom	D10@200 **+ D10@200**
Middle Strip Bottom	D10@200 **+ D10@200**
Y-Direction	
Column Strip Top	D13@200 **+ D10@200**
Middle Strip Top	D13@200
Column Strip Bottom	D13@200
Middle Strip Bottom	D13@200

Figure 30. Added Column Strip Bottom and Middle Strip Bottom in Y-Direction

3.3.13 One-way shear: Shear-x (Vxx) and Shear-y (Vyy) ratio (Design ratio)

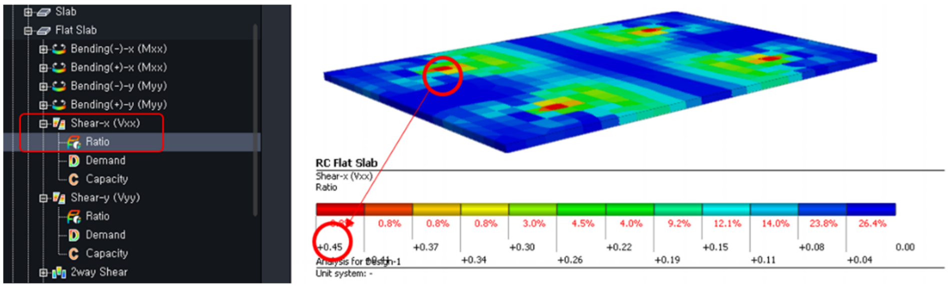


Figure 31. Shear-x (Vxx) Ratio

Check the ratio of member force (Demand)/design strength (Capacity).

Design ratio value is 0.450 that means O.K. Thus, there is no need to adjust the thickness of slab and drop panel.

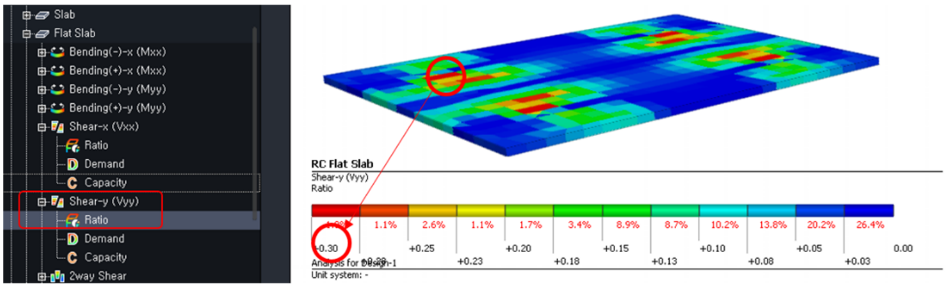


Figure 32. Shear-y (Vyy) Ratio

Design ratio value is 0.300 that means O.K. Thus, there is no need to adjust the thickness of slab and drop panel.

3.3.14 Two-way shear (Punching shear) ratio (Design ratio)

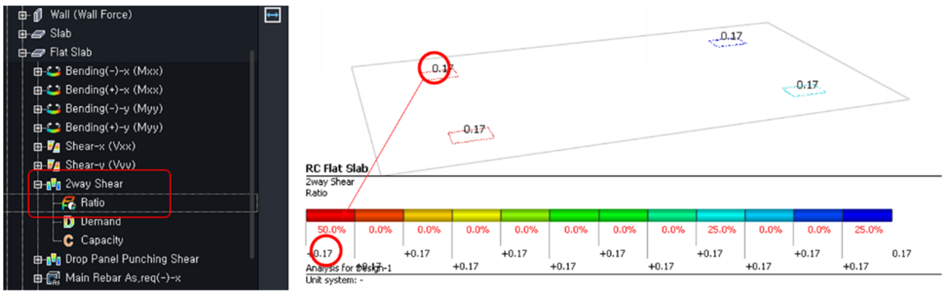


Figure 33. Two-Way Shear (Punching Shear) Ratio (Design Ratio)

Check the ratio of Member force (Demand) / Design strength (Capacity).

Design ratio value is 0.17 that means O.K. Thus, there is no need to adjust the thickness of drop panel.

Chapter 4

Tip for Flat Slab Design

Chapter 4

Tip for Flat Slab Design

Model shape

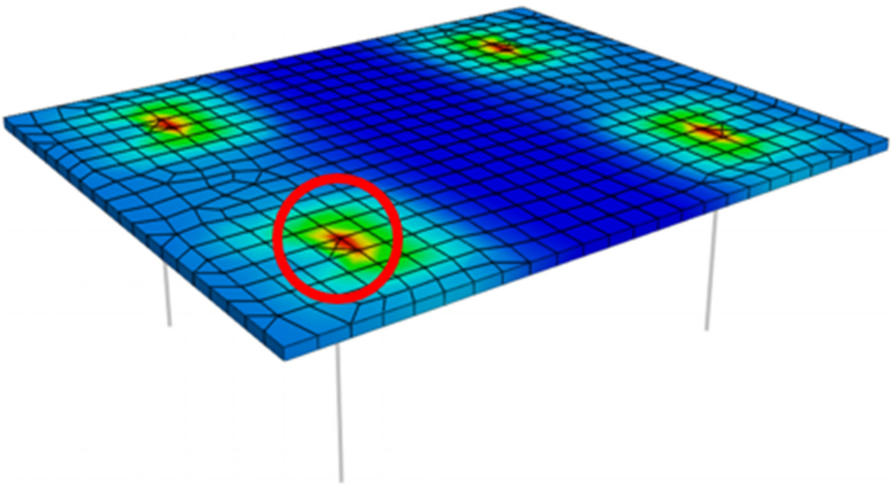
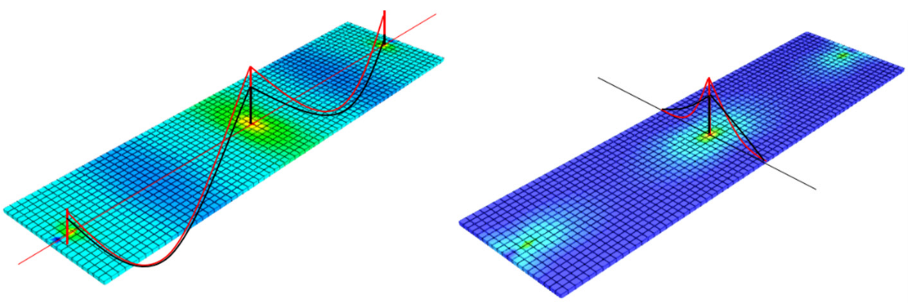


Figure 34. FEM Analysis of 2D Elements



: Moment Diagram of Plate by Analysis   : Moment Diagram of Plate Considered a Crack

Figure 35. Moment Diagrams of Plates

FEM analysis of 2D elements shows very large results at specific locations. In general, you can see this result in an element where it is connected to another element with high rigidity.

However, in an actual RC member, when large bending occurs, the stiffness of the element decreases due to the occurrence of minute cracks, and redistribution of the member force occurs, so the member force of the element decreases.

Therefore, it is very important to obtain a design member force considering cracks, since an excessive amount of reinforcement may be required during design according to the analysis results.

In nGen, plate forces can be processed and reflected in the design, and this article introduces how to convert values.

4.1. Design Result of Plate Element

4.1.1 How to select a design force in a plate

Design > Design Setting > Checking Control Tap

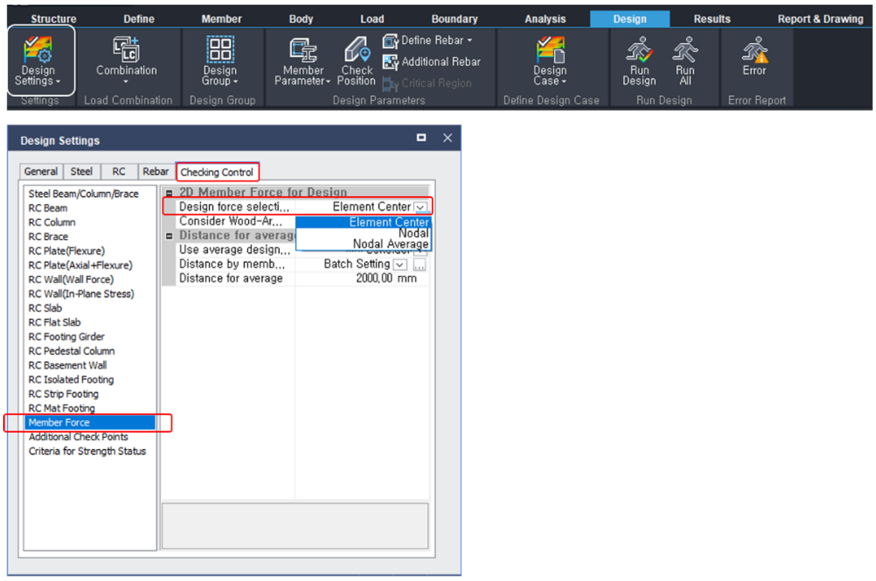


Figure 36. How to Design Setting in nGen

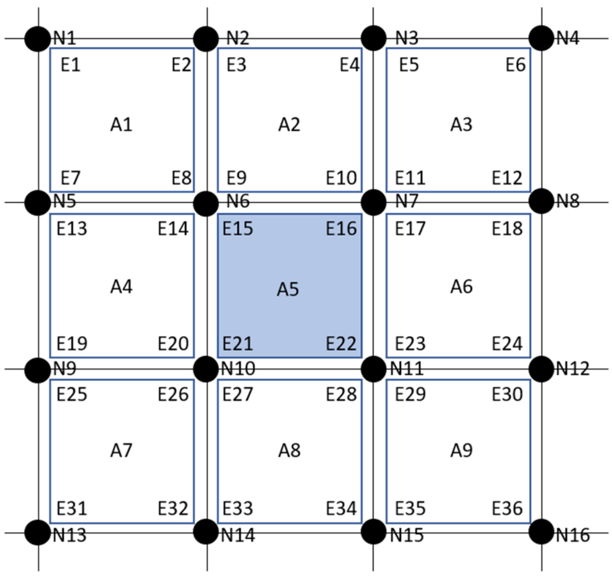


Figure 37. Target Element Plate

- Target Element (A5) for design
- Element Center

  → Design force

  = Average (E15, E16, E21, E22)
- Nodal

  → Design force = Max (E15, E16, E21, E22)
- Nodal Average

  → Design force = Max (E15, E16, E21, E22)

When

E15 → Average (E8, E9, E14, E15)

E16 → Average (E10, E11, E16, E17)

E21 → Average (E20, E21, E26, E27)

E22 → Average (E22, E23, E28, E29)

4.1.2 Smoothing of plate force (Calculation of plate force considering a crack)

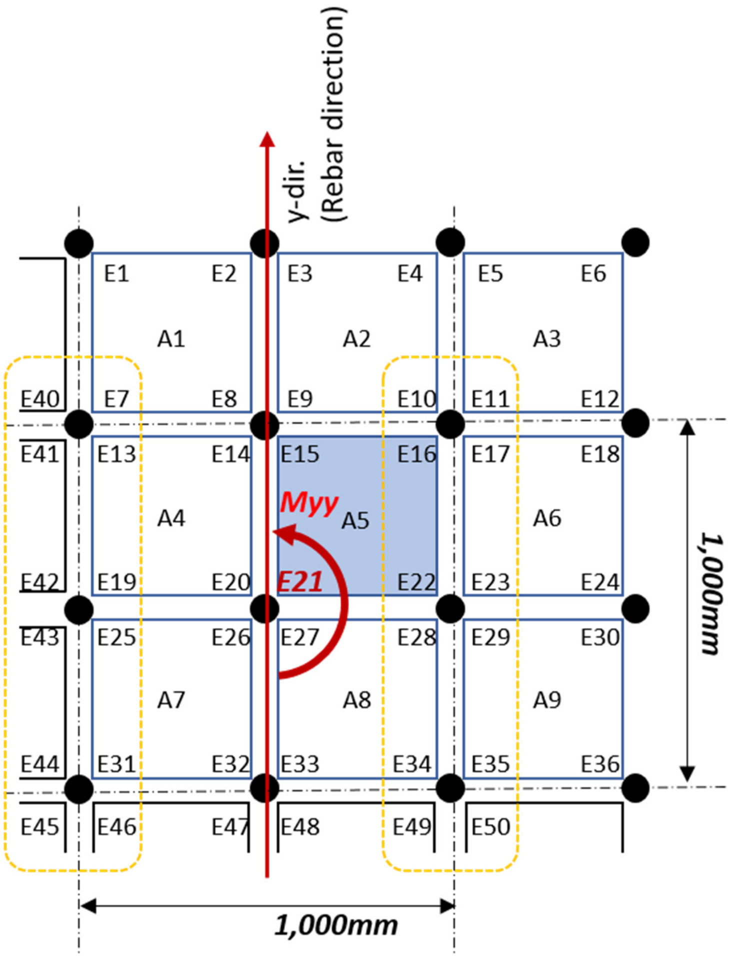


Figure 38. Smoothing of Plate Force

Example: Smoothing of design force of EN21

In one plate element, 4 internal forces exist. For the element A5, member forces exist at the node EN15, EN16, EN21 and EN22. Following equations show how the smoothing option works for the node EN21. (Assume to calculate the smoothing design force for the rebar of y-direction (Myy))

** Smoothing is performed in the perpendicular direction of the reinforcing bar.

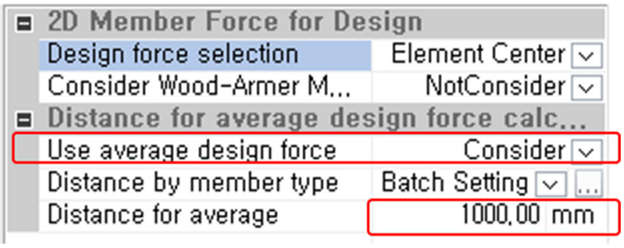


Figure 39. 2D Member Force for Design

Recalculated design force of E21 =

{(EN21+EN40)*0.5m/2+(EN21+EN7)*0.5m/2+(EN21+EN41)*0.5m/2+(EN21+EN13)*0.5m/2

+(EN21+EN42)*0.5m/2+(EN21+EN19)*0.5m/2+(EN21+EN43)*0.5m/2+(EN21+EN25)*0.5m/2

+(EN21+EN44)*0.5m/2+(EN21+EN31)*0.5m/2+(EN21+EN45)*0.5/2+(EN21+EN46)*0.5m/2

+(EN21+EN10)*0.5m/2+(EN21+EN11)*0.5m/2+(EN21+EN16)*0.5/2+(EN21+EN17)*0.5m/2

+(EN21+EN22)*0.5m/2+(EN21+EN23)*0.5m/2+(EN21+EN28)*0.5m/2+(EN21+EN29)*0.5m/2

+(EN21+EN34)*0.5m/2+(EN21+EN35)*0.5m/2+(EN21+EN49)*0.5m/2+(EN21+EN50)*0.5m/2}
/(0.5m*24)

4.2. Example for Design Force

Not Smoothing

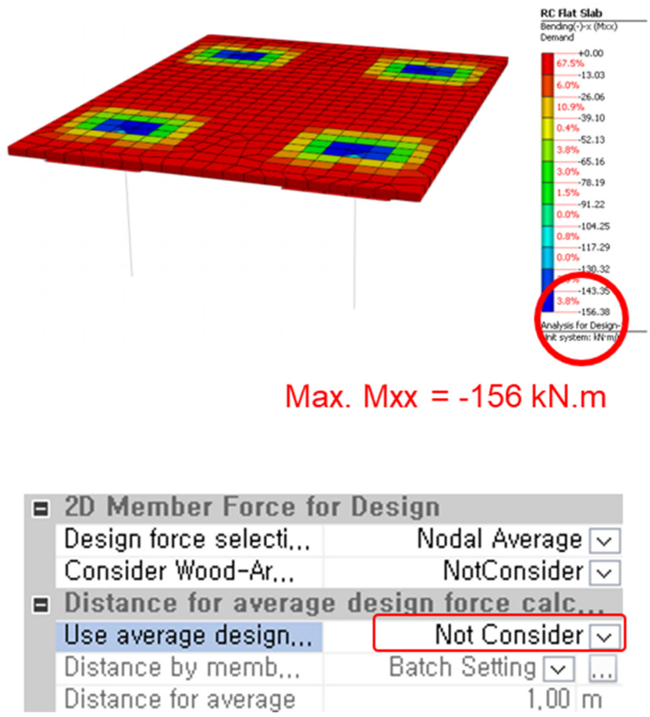


Figure 40. Not Smoothing Example

Smoothing with width 1.0m

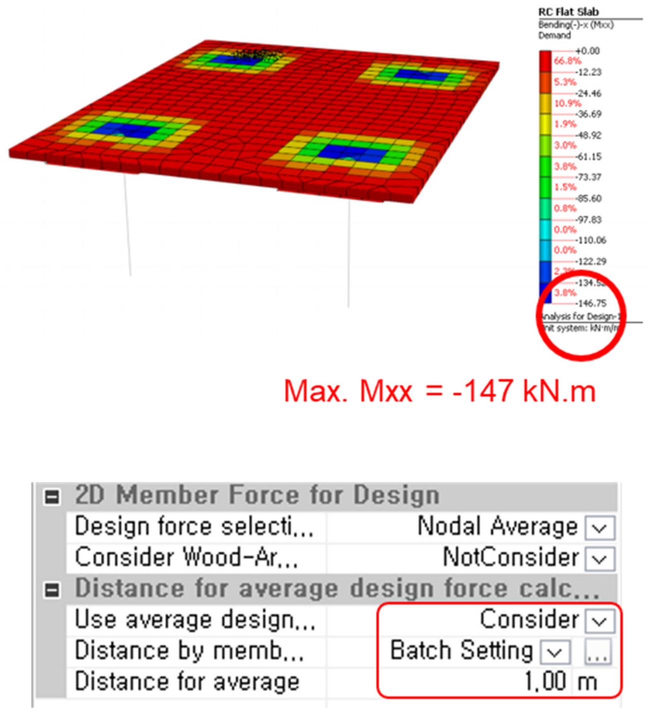


Figure 41. Smoothing with Width 1.0m Example

Smoothing with width 2.0m

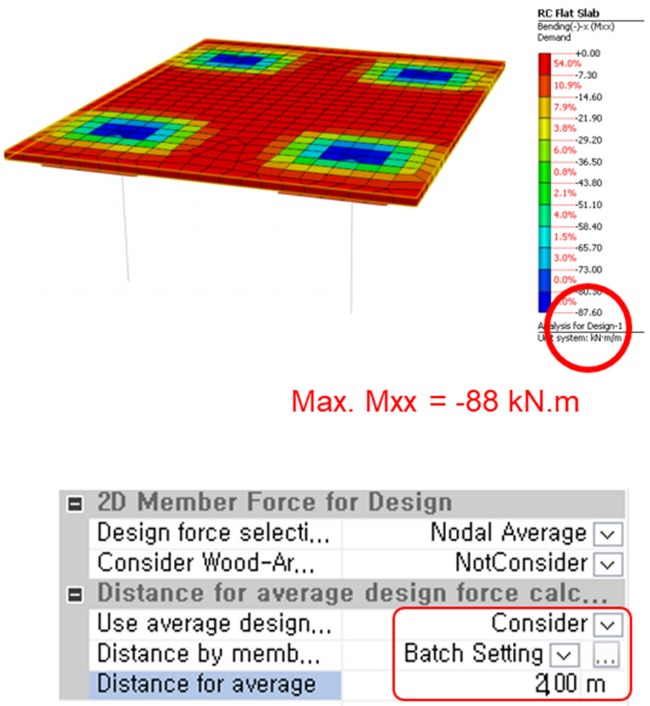


Figure 42. Smoothing with Width 2.0m Example

What is the proper width?

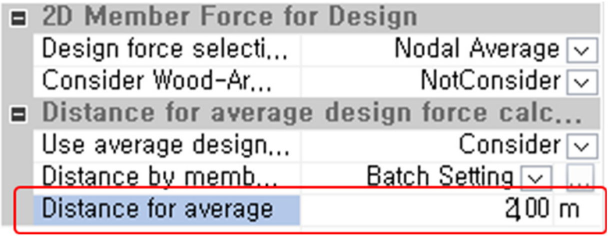


Figure 43. Distance for Average Value

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