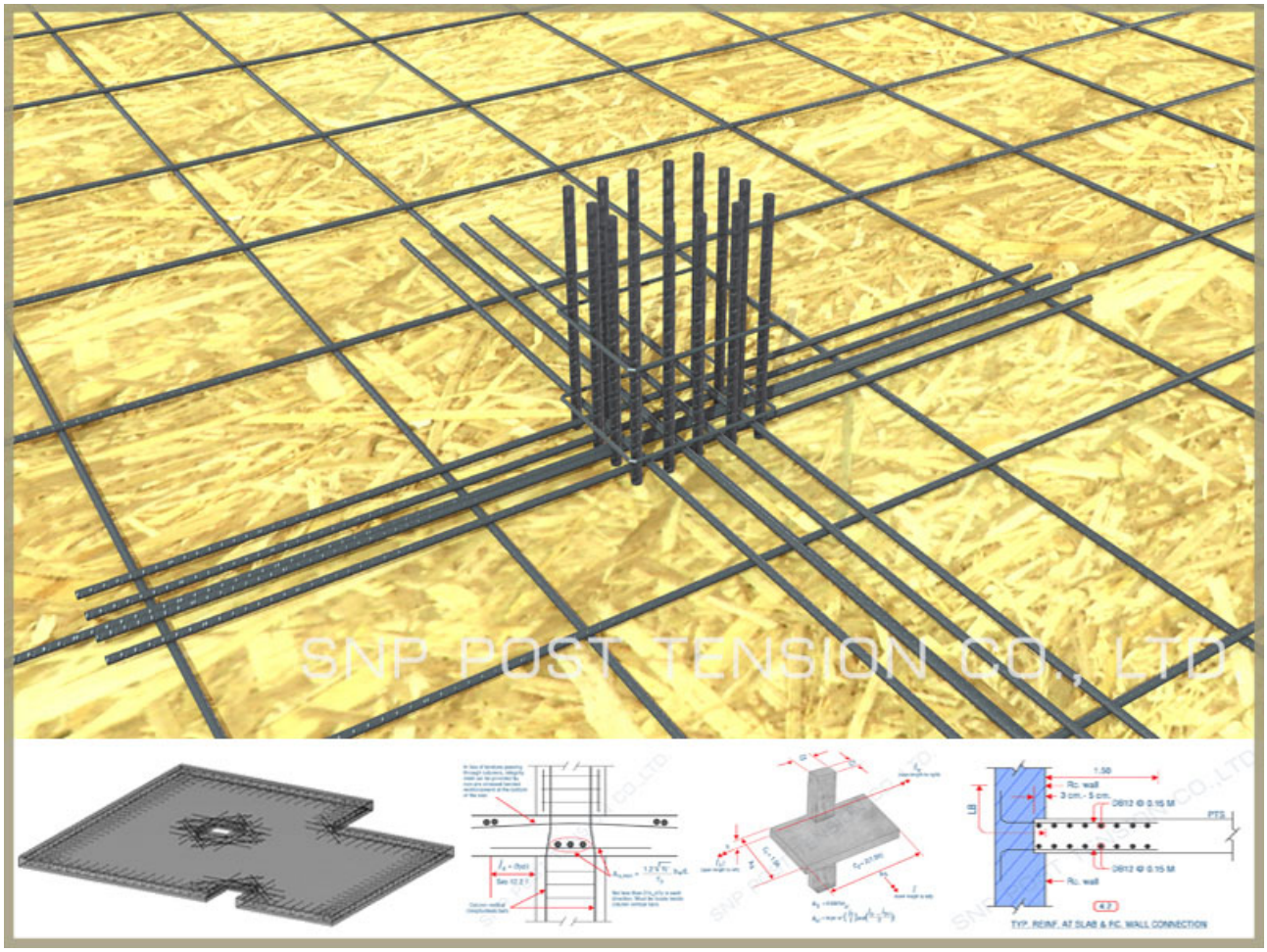
Reinforcing Steel in Post-Tensioned Floor



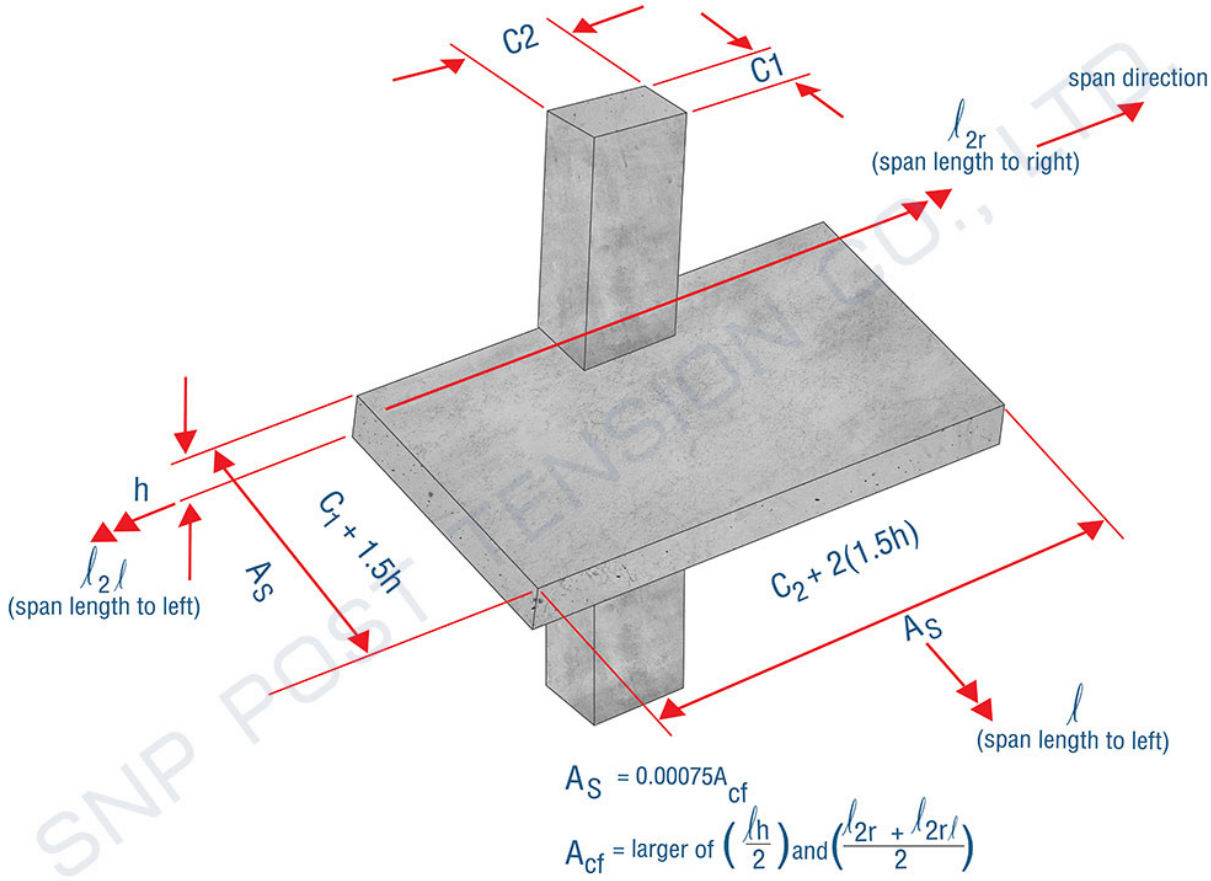
In general design for post-tensioned floor, the design tends to be fully prestressed. This is to supply sufficient amount of strands to accommodate the occurred moment so that the post-tensioned floor is completely efficient with sufficient ductility as designed. It is crucial to have reinforcing steel bars according to the specified code especially for safety purposes in particular area where the earthquake-resistant design is employed. Post tension requires addition amount of reinforcing steel bars as required by law. The type and requirements of reinforcing steel bar are exhibited in the table.

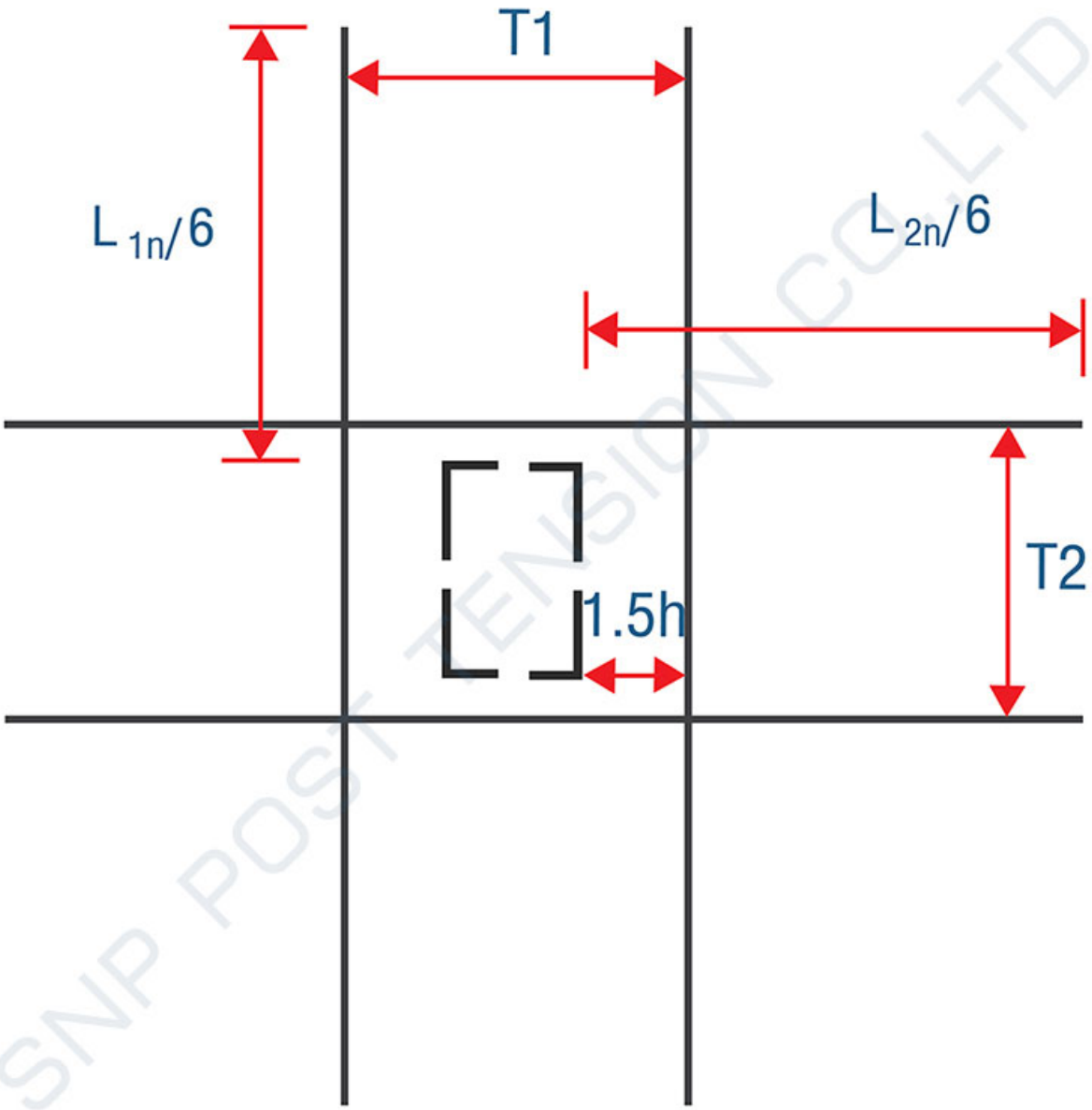
ลำดับ	ชนิดของเหล็กเสริม	ข้อกำหนดในการออกแบบ
1	เหล็กเสริมยึดเหนี่ยวปริมาณน้อยที่สุดบริเวณที่เกิดโมเมนต์ลบ (Minimum bonded reinforcement in negative moment Areas at column supports)	วสท 1009-34 ข้อที่ 3.4.2.1 (ข) ACI318 ปีก่อนหน้าจนมาถึง ACI318-2011 ข้อที่ 18.9.3.3 ACI318-2014 ข้อที่ 8.6.2.3
2	เหล็กเสริมล่างบริเวณหัวเสา (Bottom deformed reinforcement and progressive collapse protection)	มผย. 1301-54 ข้อที่ 4.8 ACI318-2008 เป็นต้นมา ข้อที่ 18.12.7 ACI318-2014 ข้อที่ 8.7.5.6.3
3	เหล็กเสริมรับแรงเฉือนทะลุ (Shear reinforcement in slab)	วสท 1008-38 ข้อที่ 4412(ด) ACI318 ปีก่อนหน้าจนมาถึง ACI318-2005 ข้อที่ 11.12.3 ACI318-2008 ถึง ACI318-2011 ข้อที่ 11.11.3 ,21.13.6 ACI318-2014 ข้อที่ 8.7.6 ,18.14.5
4	เหล็กเสริมยึดเหนี่ยวปริมาณน้อยที่สุดบริเวณที่เกิดโมเมนต์บวก (Minimum bonded reinforcement in positive moment areas	วสท1009-34 ข้อที่ 3.4.2.1(ก) ACI318 ปีก่อนหน้าจนมาถึง ACI318-2011 ข้อที่ 18.9.3.2 ACI318-2014 ข้อที่ 8.6.2.3
5	เหล็กเสริมขั้นต่ำสำหรับหมวกหัวเสา,แป้นหัวเสา และคานกว้าง (Minimum reinforcement for column capital, drop panel and band beam)	วสท1008-38 ข้อที่ 3412 ACI318 ปีก่อนหน้าจนมาถึง ACI318-2011 ข้อที่7.12 ACI318-2014 ข้อที่ 7.6
6	เหล็กเสริมใน (Pour strip)	Manual calculation
7	เหล็กเสริมรอบผนังลิฟท์	Manual calculation
8	เหล็กเสริมพิเศษบริเวณรอบช่องเปิด หรือมุมของพื้น	Typical detail
9	เหล็กกันระเบิด (Anti-bursting reinforcement)	Typical detail
10	เหล็กเสริมพิเศษอื่น ๆ	Typical detail

* As enforced by the Ministerial Regulations on load bearing, resistance, durability of buildings and structural ground support for earthquake resistance B.E.2550

1. Minimum Bonded Reinforcement in Negative Moment Areas at Column Supports

Since earlier ACI standards up until ACI 318-2011, it was specified to add minimum reinforcement in negative moment areas in unbonded post-tension floor system at AS, MIN = 0.00075ACF, where ACF is the maximum value of both ways of cross sectional area of the design strip. The calculable reinforced steel bars are the upper bars distributed at columns away from the edge of another column for not exceeding 1.5 times of floor thickness whereas the length of the steel bar that spans out equals to 1/6 of clear span.





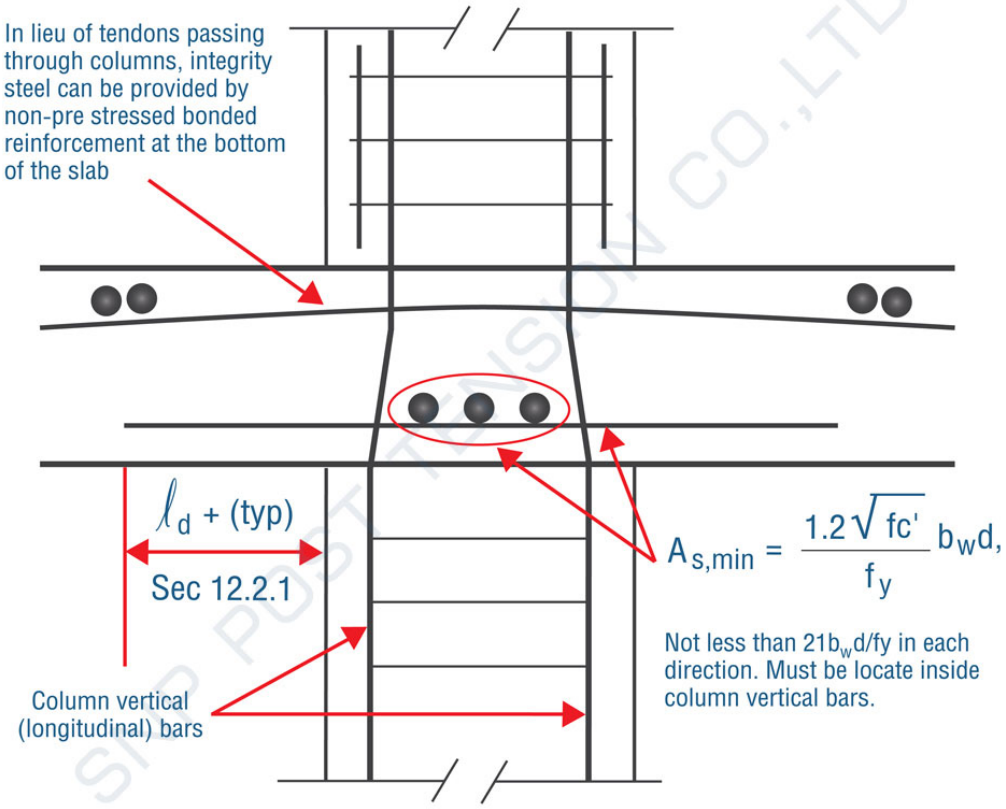
As of ACI318-2014, it is required to add the minimum reinforcement in negative moment areas for both bonded and unbonded post-tension floor systems as exhibited in table 8.6.2.3 and if there is any lateral force applied that causes more negative moment to occur to the column head, more steel reinforcement is required both in volume and length enough to accommodate the increased bending moment diagram due to the summation of the moment of lateral force.

2. Bottom Deformed Reinforcement in Column Area or Progressive Collapse Protection

According to ACI318-2005, section 18.12.4, unbonded post-tensioned floor system required minimum two tensioned strands through a column head. As of ACI318-2008, as specified in section 18.12.6, and additionally in the case where it is impossible to insert tensioned strands to the column, which is in consistent with the case of bonded post tension floor system, bottom deformed reinforcement in column area must be in an equal amount of:

$$As,min = \frac{1.20\sqrt{fc'}}{fy} bw.d \geq \frac{21}{fy} bw.d$$

The span range which spans to the area must be the same as the embed range as exhibited in the image.



"Therefore, according to the implication set forth by ACI318, post tensioned floor without stranded column must be reinforced with bottom deformed reinforcement in every column head."

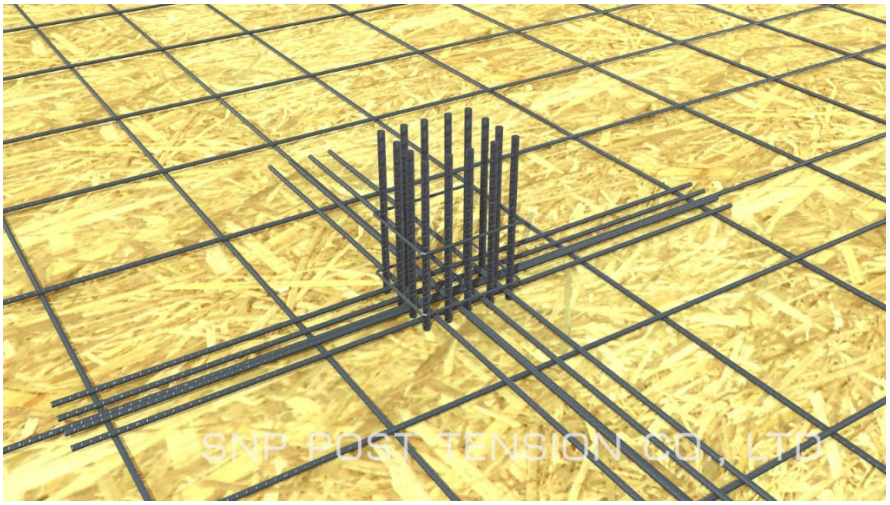
Ministerial Regulations on load bearing, resistance, durability of buildings and structural ground support for earthquake resistance B.E.2550 requires buildings sustain the entire structural system to have at least the limited ductile in accordance with 1301-54 standards. Ministerial Regulations classifies building types by referencing to their locations and requires that each building must possess the specified details which can be summarized as follows:

<table>
<tr><th>บริเวณเฝ้าระวัง และบริเวณที่ 1</th><th>บริเวณที่ 2</th></tr>
<tr><td colspan="2">(ก) อาคารที่จำเป็นต่อความเป็นอยู่ของสาธารณะชน เช่น สถานพยาบาลที่รับผู้ป่วยไว้ค้างคืน สถานีดับเพลิง อาคารศูนย์บรรเทาสาธารณภัย อาคารศูนย์สื่อสาร ทำอากาศยานโรงไฟฟ้า โรงผลิต และเก็บน้ำประปา</td></tr>
<tr><td colspan="2">(ข) อาคารเก็บวัตถุอันตราย เช่น วัตถุระเบิด วัตถุไวไฟ วัตถุมีพิษ วัตถุกัมมันตรังสี หรือวัตถุที่ระเบิดได้</td></tr>
<tr><td colspan="2">(ค) อาคารสาธารณะ ได้แก่ โรงมหรสพ หอประชุม หอศิลป์ พิพิธภัณฑสถาน หอสมุด ศาสนสถาน สนามกีฬา อัฒจันทร์ ตลาด ห้างสรรพสินค้า ศูนย์การค้า สถานีรถ โรงแรม (สำหรับบริเวณเฝ้าระวัง และบริเวณที่ 1 อาคารเหล่านี้ต้องมีผู้ใช้อาคารตั้งแต่ 300 คนขึ้นไป)
(สำหรับบริเวณที่ 2 บังคับอาคารเหล่านี้และเพิ่มสถานบริการและอาคารจอดรถ)</td></tr>
<tr><td>(ง) สถานศึกษาที่รับนักเรียนหรือนักศึกษา ตั้งแต่ 250 คนขึ้นไป
(จ) สถานรับเลี้ยงเด็กอ่อนที่รับเด็กอ่อนได้ตั้งแต่ 50 คนขึ้นไป</td><td>(ง) สถานศึกษา
(จ) สถานรับเลี้ยงเด็กอ่อน</td></tr>
<tr><td colspan="2">(ฉ) อาคารที่มีผู้ใช้อาคารตั้งแต่ 5000 คนขึ้นไป
(ช) อาคารที่มีความสูงตั้งแต่ 15 เมตรขึ้นไป
(ซ) สะพานหรือทางยกระดับที่มีช่วงระหว่างศูนย์กลางตอม่อยาวตั้งแต่ 10 เมตรขึ้นไป
(ฌ) เขื่อนเก็บกักน้ำ เขื่อนทดน้ำหรือฝายทดน้ำ ที่ตัวเขื่อนหรือตัวฝายมีความสูงตั้งแต่ 10 เมตรขึ้นไป</td></tr>
</table>

* Watch Area: Territories or areas likely to be affected by earthquakes, such as Krabi, Chumphon, Phang Nga, Phuket, Ranong, Songkhla, and Surat Thani.

Area 1 = Territories or areas that contain soft soil which may be affected by remote earthquakes including Bangkok, Nonthaburi, Pathum Thani, Samut Prakan, and Samut Sakhon.

Area 2 = Territories or areas near fault lines which may be affected by an earthquake include Kanchanaburi, Chiang Rai, Tak, Nan, Phayao, Phrae, Mae Hong Son, Lampang, and Lamphun.



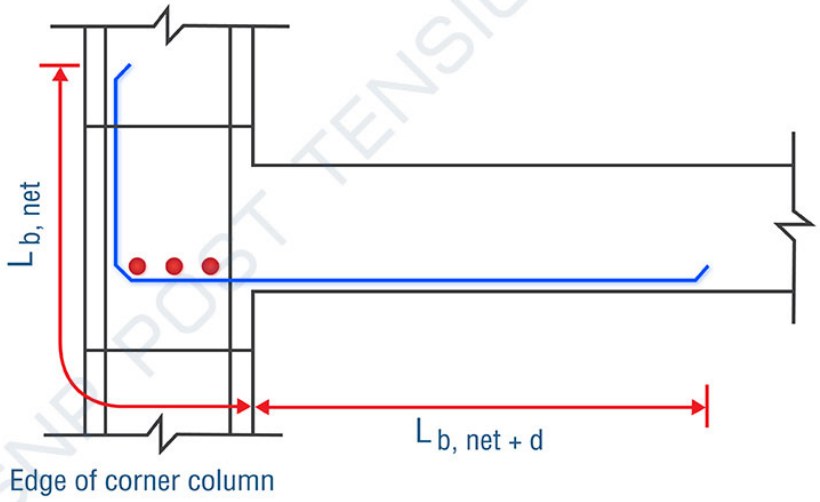
To ensure that post-tensioned flooring meets the requirements on limited ductile, it is necessary to add bottom deformed reinforcement in column area not less than that of specified in 1301-54 standards, section 4.8 detailed as follows:

$$A_{sm} = \frac{0.5w \quad L_1 L_2}{0.9 f_y}$$

โดยที่ W_u คือค่าที่มากกว่าระหว่าง 1.4WD+1.7WL กับ 2.0WD

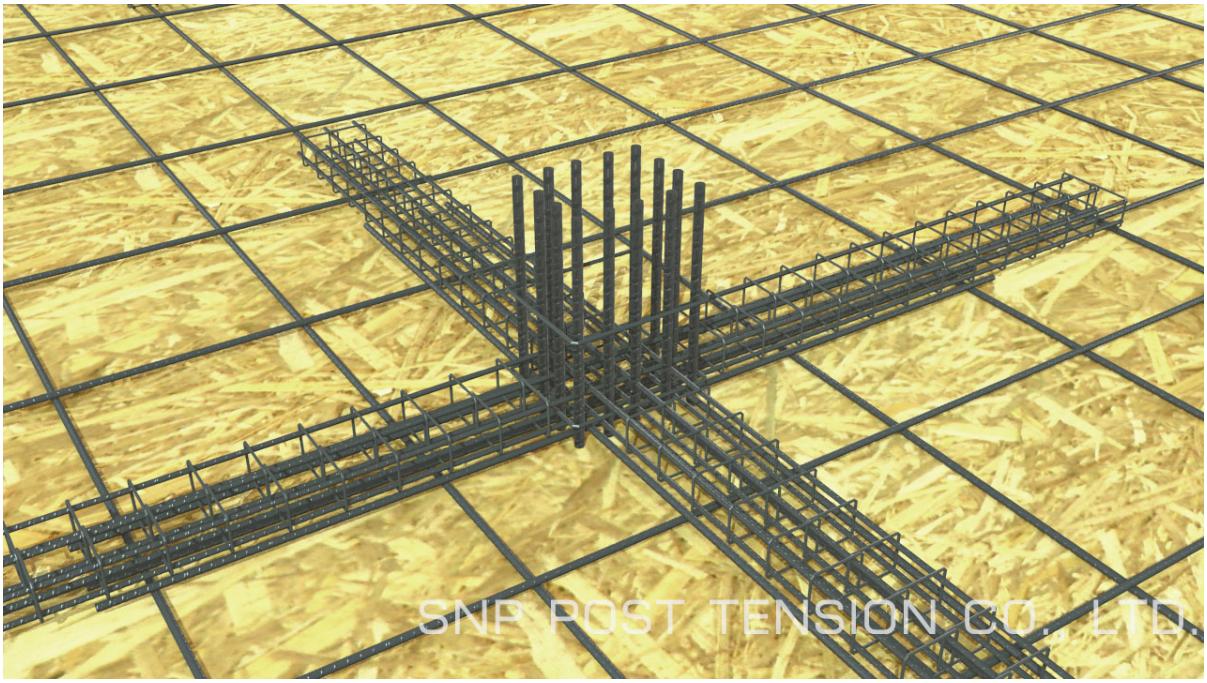
A_{sm} ที่เสาขอบ มีค่าไม่น้อยกว่า $\frac{2}{3}$ A_{sm}

A_{sm} ที่เสามุม มีค่าไม่น้อยกว่า $\frac{1}{2}$ A_{sm}



According to 1301-54 standards, it specifies that steel reinforcement must have sufficient embed range to develop its strength up to the yield point. In this regard, it can be referred to FIP recommendations, “recommendations for the design of post-tensioned slabs and foundation rafts" which requires the calculable reinforcing steel must be embedded within the steel core of the column. Extend the steel into post-tensioned floor of no less than the effective embedding range." For the discontinuous edge, the bottom deformed reinforcement at the support point must be able to develop a yield point at the edge of the support.

3. Shear Reinforcement in Slab



SHEAR STIRRUP

It is necessary to add steel reinforcement in case where the shear stress is greater than shear load capacity of concrete. More details on this can be found in the previous article.

1. แรงเฉือนเจาะทะลุ ตอนที่ 1

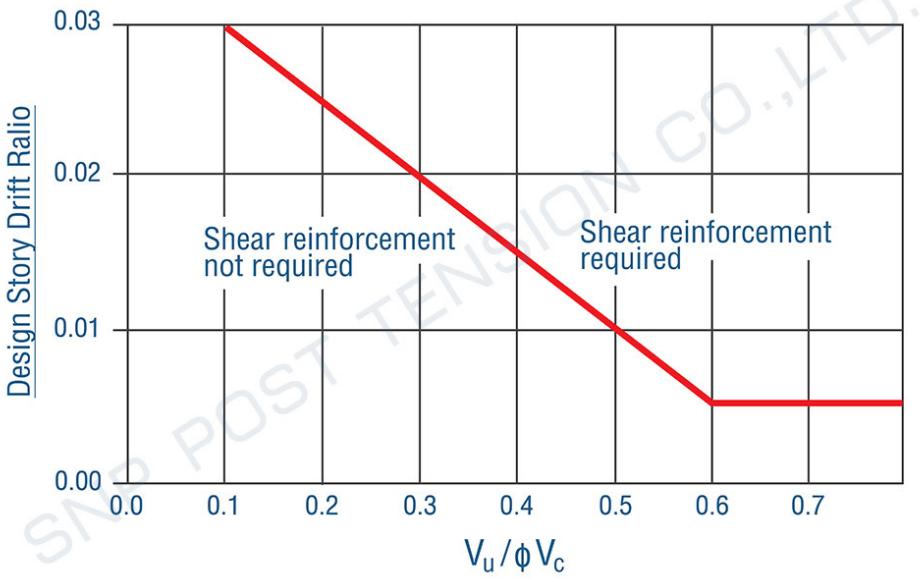
2. แรงเฉือนเจาะทะลุ ตอนที่ 2

More importantly, in designing of shear penetration in the two-way beamless floor for moment resisting frame with limited ductile in 1301-54 and ACI 21.13.6 standards, to allow connecting points of floor and column to have limited ductile, the VU/ΦVC value must not be greater than 0.40 where VU is the shear force adjusted on the critical section around the column caused by vertical load. The multiplier or load factor must be 1.2D + 1.0L where the multiplier for live load can be reduced from 1.0 to 0.5 when the live load is less than 500 kg/m2, unless the building is a parking lot or areas used for populated congregation, the Φ can be 0.75. In terms of VC, it can be calculated as described in the previous section.

For joints of floors and columns in a two-way beamless floor system that is not part of any lateral force system, shear reinforcement must be provided in the floor. The counter she strength of reinforcing steel must be at least 0.93√fc'bo.d and the reinforcing steel must be placed off the support edge not less than 4 times of the floor thickness. However, the above specifications may be excepted if the design is in accordance with either section (1) or section (2).

(1) Shear force on the critical section around the column caused by shear force adjusted from VU value associated with shear forces caused by unbalance moment that transfer among column and floor under design displacement must not exceed the counter shear strength specified in the standards on steel reinforced concrete buildings using the method of force set forth the Engineering Institute of Thailand.

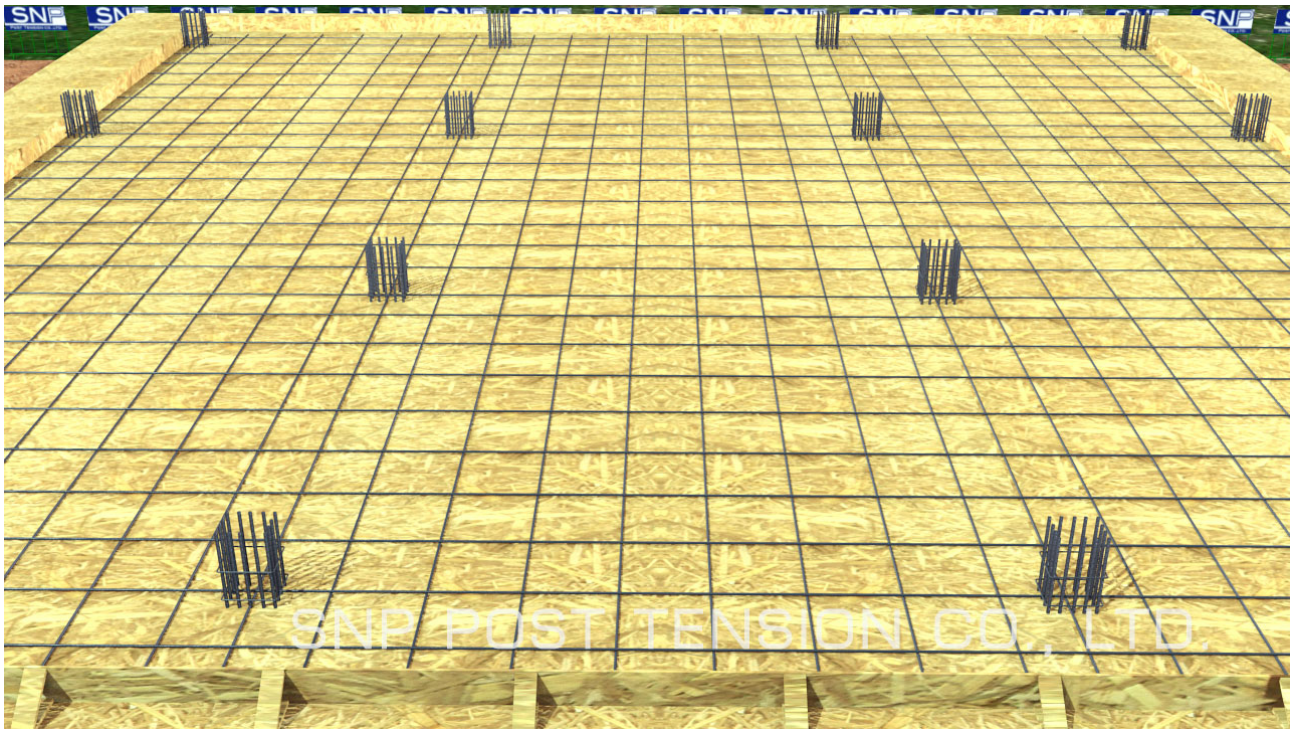
(2) Lateral relative velocity between design story drift should not be greater than a higher value between 0.005 and [0.035 - 0.05 (VU/ΦVC)].



Lateral relative velocity between design story drift can be calculated from the high value of the lateral relative velocity of the connecting point of bottom column and VC using the mentioned method where VU is the shear force on the critical section around the column using 1.2D + 1.0L multiplier.

4. Minimum Bonded Reinforcement in Positive Moment Areas

Steel reinforcement according to this section is the reinforcement in post-tensioned floor. According to the requirements on post-tensioned floor in both bonded and unbonded systems, should tensile stress occurs in positive moment areas which is stronger than 0.53√(FC '), minimum steel reinforcement must be added equals to AS = NC/(0.5FY), where NC is the total tensile stress that occurs at the cross section of the concrete in the stressed area. However, the calculation must be done in a cross section that is not cracked. (using IGROSS)



รูปภาพ การวางเหล็กเสริมล่าง

If tensile stress does not exceed 0.53√ (FC '), ACI318 does not require to add bottom deformed reinforcement however, in past practices, the requirements of the beamless unbonded floor system according to EIT 1009-34 section 3.4.2.1(a) require bonded steel reinforcement to be added for no less than 0.001 of the concrete cross section in close proximity to the surface taking tensile stress. AS = 0.001 BT.

AS = 0.001 BT

For example post-tensioned floor with 0.23M thickness, AS = 0.001(100)(23) = 2.3 CM2, use SD40 lower steel mesh reinforcement of approximately DB12MM@0.50M

Some construction site employs wire mesh with FY 5,500 KSC instead. From the same example, it can be calculated to use wire mesh as following.

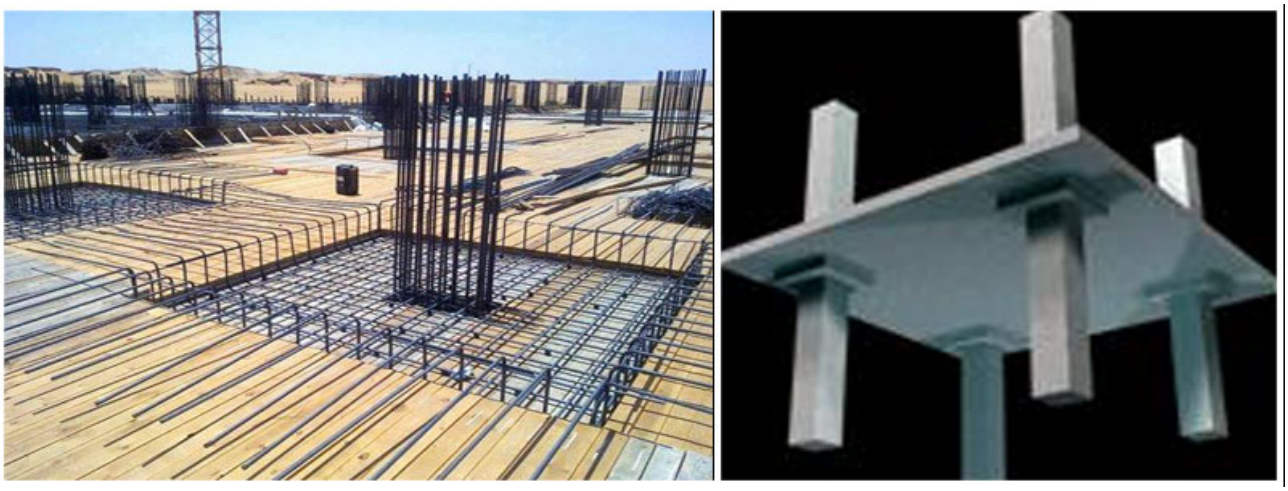
$$As = 0.001\left(\frac{4000}{5500}\right)(100)(23) = 1.6727\ cm^2$$

Wire mesh can be used as lower mesh at approximately Φ8MM@0.30M

WIRE MESH

5. Minimum Reinforcement for Column Capital, Drop Panel And Band Beam

Since general design of the post tension floor employs fully prestressed system which uses strands to accommodate tensile stress from bending moment, column capital, drop panel and band beam are the minimum reinforcement to only prevent flexing due to temperature and shrinkage. The amount used must be according to the EIT or ACI318 in steel reinforcement against shrinkage for SD40 AS = 0.0018BT steel.



COLUMN CAPITAL, DROP PANEL

6. Pour Strip

Pour strip is designed in consistent with determined work sequence, for example, a pour strip can be designed for one-way slab or designed for post-tensioned floor where both ends extend to take the point load from pour strips.

Design of pour strip and post-tensioned floor can also be a continuous process. This type of design must take into account the strandless pour strip area which has no initial support and compression compared to areas like post-tensioned floor.

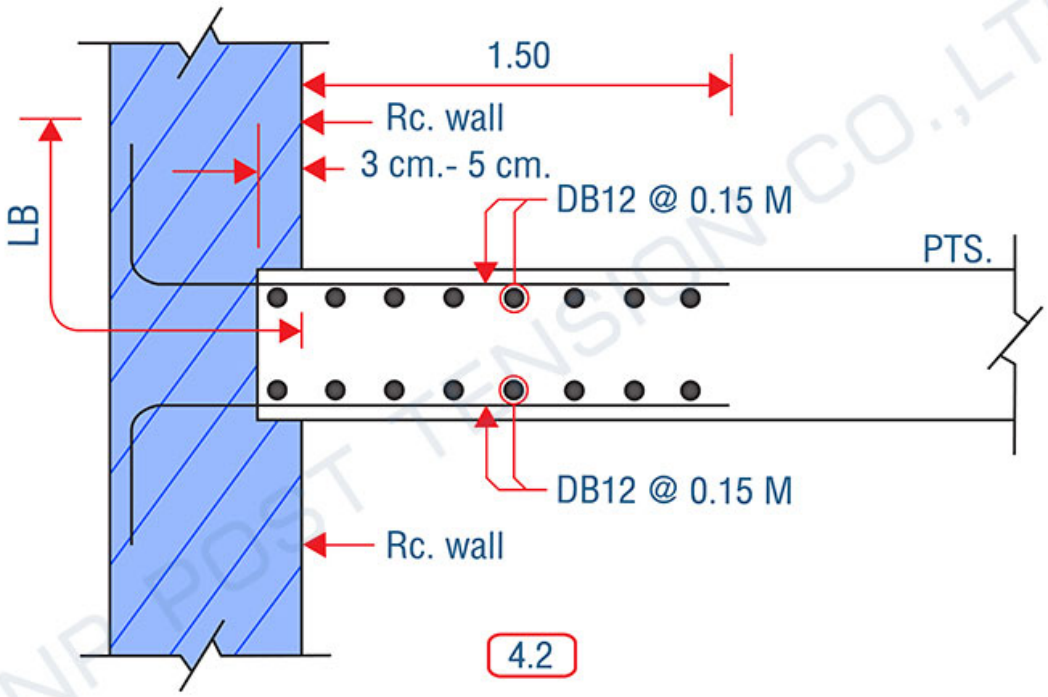
However, both mentioned methods require a consideration on the effect of shrinkage of the edge of pour strip on both ends due to the existing compressive stress. This topic is to be discussed in details in the next article.

รูปภาพ POUR STRIP

7. Shear Wall

รูปภาพ Shear Wall

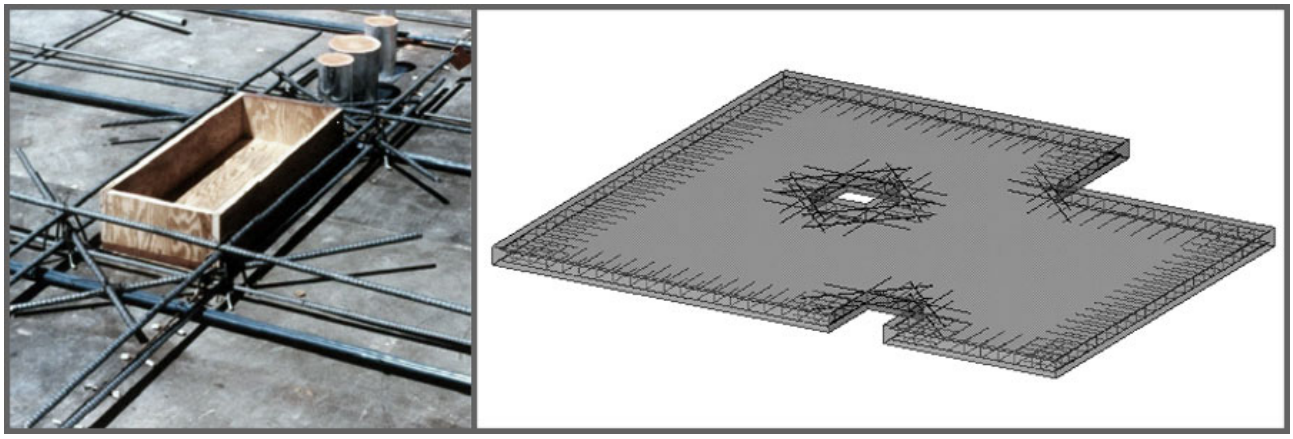
In general, shear wall is the area that has low compressive stress in post-tensioned floor compared to other areas of the floor. This is noticeable when finite element method (FEM) is employed to analyze the structure. Since the compressive stress is low on the floor, it is necessary to add steel reinforcement to prevent flexing due to temperature and shrinkage. In addition, if post-tensioned floor is desired to pin joint (M=0) with shear wall, it is necessary to transfer shear weight through the reinforcing steel sufficiently to extend to the support point. If post-tension floor and shear wall are designed to be connected in rigid joint, where the moment is transferrable, a test model must be simulated for structural analysis in accordance with the actual structure and then add steel reinforcement sufficiently to counter to the occurred moment.



TYP. REINF. AT SLAB & RC. WALL CONNECTION

8. Other Reinforcing Steel Bar in Opening Area or Floor Corner

Opening areas or floor corners are reinforced with steel bars to prevent cracking caused by stress concentration occurred to a certain area. In general, a typical detail is elaborated as in the image.

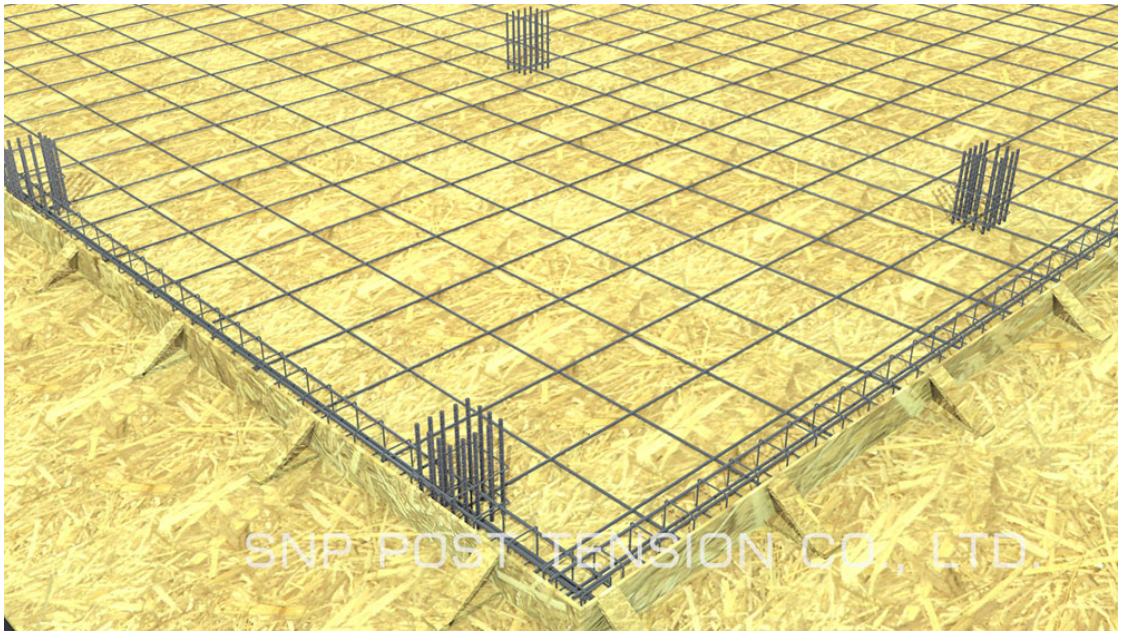


รูปภาพ เหล็กเสริมพิเศษบริเวณรอบช่องเปิดหรือมุมของพื้น

9. Anti-Bursting Reinforcement

Calculation for anti-bursting reinforcement is similar to a beam design. In general, a typical detail can be used where the design begins with the anchorage with highest number of strands and the lowest floor thickness. The derived reinforcement amount is then created as a typical detail for the work.

Anti-Bursting Reinforcement

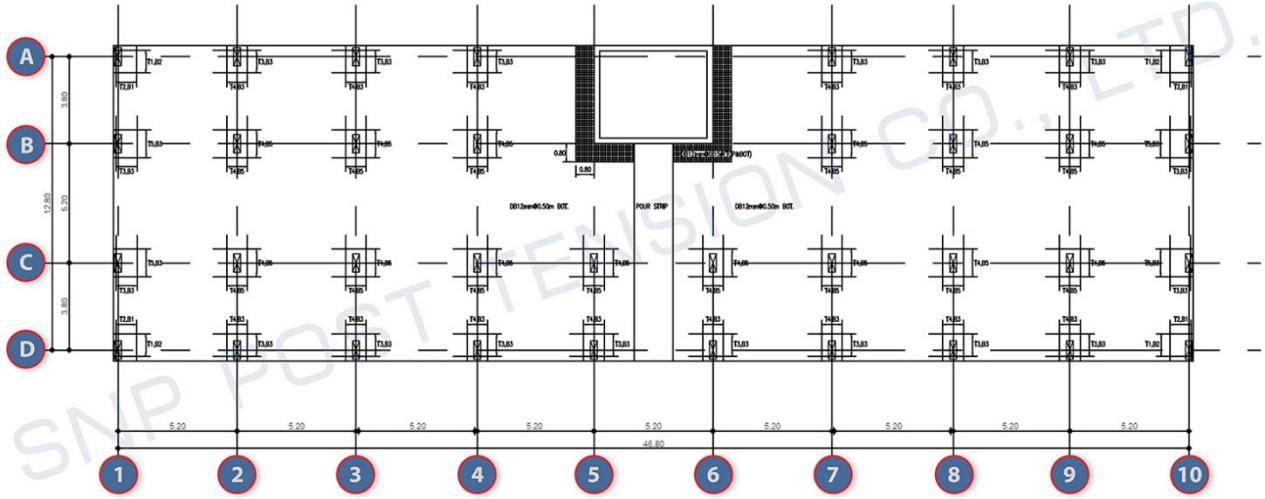


10. Other Reinforcing Steel Bar

Such reinforcing steel bars are prepared for abnormal post-tensioned floor, such as beam-jointed post-tensioned floor or steel reinforced wall with level reduction or floor bed.

Example data on amount of reinforcing steel bar in post-tensioned floor

Floor at 0.20m thickness, column at 0.30X0.80M SDL 250 KG/M2 , LL 200 KG/M2 without shear reinforcement around the column area and the column range does not exceed 5.20m.

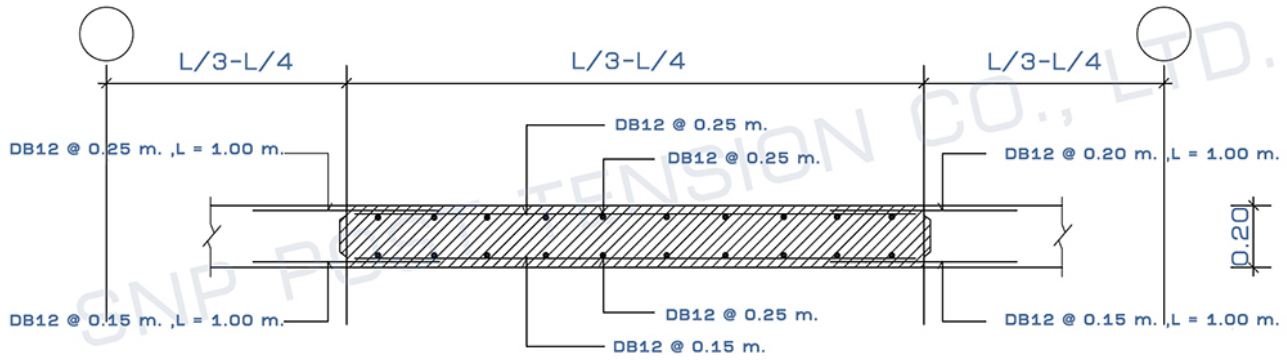


PROGRESSIVE STELL (เหล็กเสริมล่าง เสริมผ่านเสาเท่านั้น)

NAME	DETAIL	LENGTH (m.)		SHAPE	
B1	2-DB12	-	1.75	-	1.58 COL. 0.17
B2	2-DB12	-	1.00	-	0.83 COL. 0.17
B3	3-DB12	1.50	1.75	0.75 0.75	1.58 COL. 0.17
B4	3-DB16	2.00	-	1.00 1.00	-
B5	3-DB16	1.50	-	0.75 0.75	-

TOP REINFORCEMENT INSERT DB12 @ 0.50 # M. ALL AREA FOR DECK OR ROOF

NAME	DETAIL	LENGTH (m.)		SHAPE	
T1	3-DB12 @ 0.10	-	1.00	-	0.85 0.15
T2	3-DB12 @ 0.10	-	0.75	-	0.60 0.15
T3	4-DB16 @ 0.10	2.00	-	1.00 1.00	-
T4	7-DB12 @ 0.10	2.00	1.00	1.00 1.00	0.85 0.15
T5	6-DB12 @ 0.10	-	0.75	-	-



POUR STRIP DETAIL

ลำดับ	ชนิดของเหล็กเสริม	กรณีมี Pour Strip	กรณีไม่มี Pour Strip
1	เหล็กเสริมยึดเหนี่ยวปริมาณน้อยที่สุดบริเวณที่เกิดโมเมนต์ลบ (Minimum bonded reinforcement in negative moment Areas at column supports)	14%	16%
2	เหล็กเสริมล่างบริเวณหัวเสา (Bottom deformed reinforcement and progressive collapse protection)	9%	10%
3	เหล็กเสริมรับแรงเฉือนทะลุ (Shear reinforcement in slab)	0%	0%
4	เหล็กเสริมยึดเหนี่ยวปริมาณน้อยที่สุดบริเวณที่เกิดโมเมนต์บวก (Minimum bonded reinforcement in positive moment areas	48%	54%
5	เหล็กเสริมขั้นต่ำสำหรับหมวกหัวเสา,แป้นหัวเสา และคานกว้าง (Minimum reinforcement for column capital, drop panel and band beam)	0%	0%
6	เหล็กเสริมใน (Pour strip)	11%	0%
7	เหล็กเสริมรอบผนังลิฟท์	6%	7%
8	เหล็กเสริมพิเศษบริเวณรอบช่องเปิด หรือมุมของพื้น	0%	0%
9	เหล็กกันระเบิด (Anti-bursting reinforcement)	12%	13%
10	เหล็กเสริมพิเศษอื่น ๆ	0%	0%
คำนวณเป็นปริมาณเหล็กเสริมต่อพื้นที่ได้เท่ากับ		7.43 kg/m2	6.61 kg/m2

* In the next article, we will discuss samples of reinforcing steel bars for different column ranges with comparison

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