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Layout Of Post-Tensioning And Passive Reinforcement In Floor Slabs

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SYNOPSIS

This Technical Note presents the layout and profile of post-tensioning tendons, and the layout of supplemental non-prestressed (passive) reinforcement for post-tensioned floor systems. The presentation is based on governing codes, where applicable, or the preferred practice of structural design professionals and post-tensioning suppliers in USA. The placement of passive reinforcement (rebar) covers both the minimum requirements of the codes, and the requirements to meet strength demand. The thrust of the presentation is on the application of unbonded mono-strand tendons, although most of the discussion applies equally to grouted and multi-strand systems in building construction. Finally, an example of a flat slab floor system is presented to illustrate the practice.

1 - INTRODUCTION

In post-tensioned floor slab construction, the placement of post-tensioning tendons and associated nonprestressed reinforcement does not strictly follow the practice of nonprestressed slabs. Five underlying features of post-tensioned construction allow greater flexibility in reinforcement layout. These are:

(i) In post-tensioned structures, crack formation and the consequent increase in deflection, are not influenced by the position of reinforcement, to the same degree as in nonprestressed structures. Under the service condition, the precompression from the tendons in a post-tensioned floor tends to restrain crack formation. Since precompression disperses rapidly within the slab from its point of application, the actual position of the tendon becomes less critical. Fig. 1-1 illustrates this phenomenon. Since the resultant force of the tendons is the same for the two layout options in Fig. 1-1, the precompression will also be the same at regions away from the anchorage. This flexibility in reinforcement layout does not apply to nonprestressed construction, where the reinforcement must be placed across the anticipated crack path to be effective.

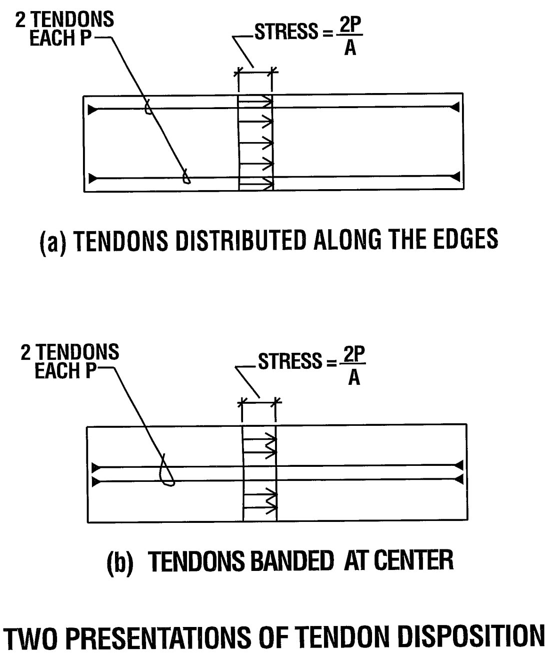

FIGURE 1-1

(ii) The uplift imparted by the tendons in a post-tensioned floor system typically counteracts between 50 and 100 percent of the self-weight of the structure. As a result, the net bending stresses are smaller, and the floor system deflects less. Cracks are also smaller in number, and do not play a significant role in most floor systems if the hypothetical[4] tensile stresses are kept low [within $1.0\sqrt{(f'c)}$ MPa, or $12\sqrt{(f'c)}$ psi]. Therefore, apart from locations over the top of columns where high tensile stresses develop, it is seldom necessary to place rebar in other regions of a floor system for crack control due to service load bending stresses.

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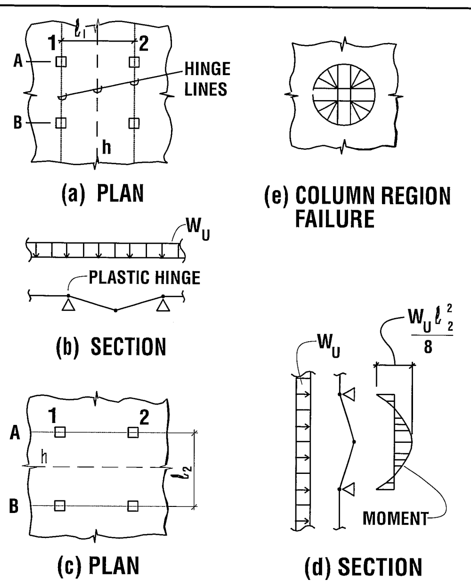
The computed stresses are termed hypothetical, since they are obtained by applying the resultant of all bending and axial loads acting at a section as a uniform loading on the entire cross-sectional area of the design strip. Hence, the resulting stresses represent average values that can exceed the cracking stress of concrete.

Cracks that are developed due to the restraint to the free shortening of the slab caused by supporting walls and columns require special attention and treatment in rebar detailing. These types of cracks are not discussed in this work. Interested readers are directed to a comprehensive treatment of the topic in the reference [Aalami and Barth, 1988].

(iii) Due to the biaxial precompression in post-tensioned floor systems, concrete can sustain longer spans between adjacent, parallel tendons without diminishing the service or safety of the structure. For this reason, the maximum spacing for tendons is several times larger than for reinforcement in nonprestressed floors.



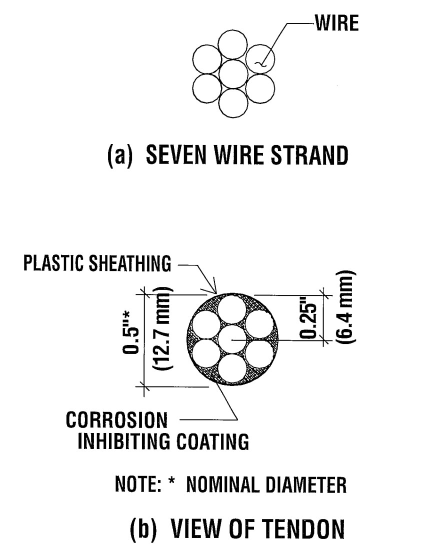
SIMPLIFIED FAILURE MECHANISMS OF FLAT PLATES

FIGURE 1-2

(iv) At the strength limit state, the failure of a slab is preceded by the mobilization of all reinforcement running across the hinge lines that develop over the entire width of the span, or around the columns. Fig. 1-2, illustrates possible alternatives of two-way floor system failure due to formation of plastic hinge lines. Apart from the column region, where a concentration of reinforcement becomes necessary to avoid column hinge failure (Fig. 1-2(e)), for a hinge line across a span the total amount of reinforcement is critical. The disposition of reinforcement across the span hinge line does not change the ultimate strength limit of the slab at the hinge line to any significant extent (Figs. 1-2 (a) and (c)).

v) The restriction imposed on the placement of reinforcement through the "column strip, middle strip" designation, when using the Direct Design Method [ACI 318, 1995] in the design of nonprestressed floor systems, does not apply to post-tensioned floors. Neither the tendon layout, nor the nonprestressed reinforcement are governed by the "column strip, middle strip" concept.

The following describes the layout of tendons and the associated nonprestressed reinforcement for the gravity design of common structural conditions. The discussion covers the overall layout of reinforcing. Detailing at discontinuities and where restraint by supports to the free movement of the slab become critical, requires special attention that is not covered herein. For seismic and wind design, the placement of reinforcement is governed by the demand due to seismic and wind actions respectively. ACI-318 [1995] and ACI-423 [1996] are used where applicable. Otherwise, the standard of practice exercised by the profession is reported.



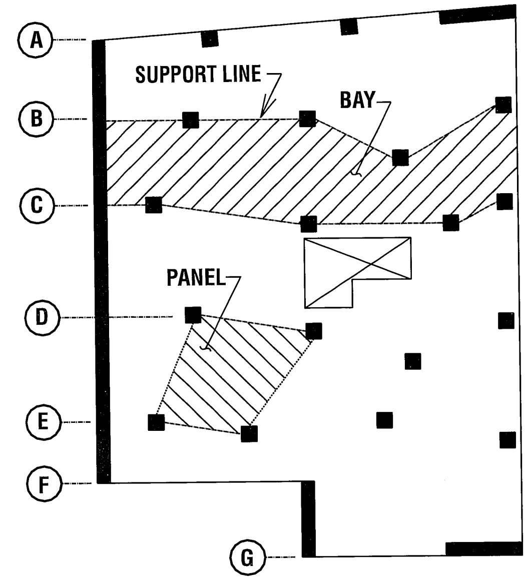
12.7mm (1/2") SEVEN WIRE UNBONDED EXTRUDED TENDON

FIGURE 1-3

The following sections describe the disposition of the tendons and reinforcement in a typical floor system. No distinction is made or deemed necessary between flat plates, flat slabs, floor slabs, two-way slabs, and floor systems. The terms are used interchangeably. Refer to Fig. 1-3 for further clarification of other terms. A tendon is defined as the sheathing (duct), the strand(s) within it and the corrosion inhibiting grease or grout filling its voids. A tendon may contain one or more seven-wire strands.

Other definitions used herein are illustrated in Figs. 1-4 and 1-5. Figure 1-5 is a partial view of a floor slab presented in the previous figure, and shows a region of the slab referred to as a design strip. A design strip is a region assigned to a hypothetical support line that joins a line of columns and/or walls in one direction. Design strips are used to divide up the floor system in two essentially orthogonal directions in modeling the floor for design. Selection of design strips

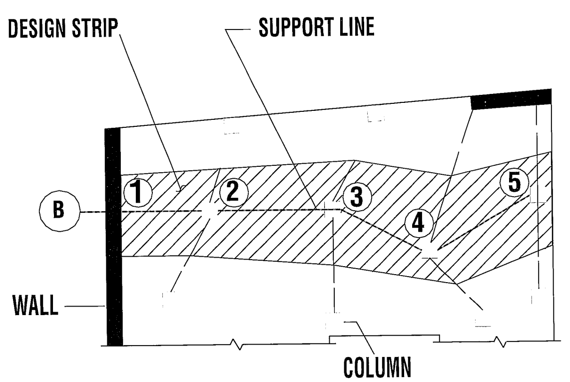
4 The computed stresses are termed hypothetical, since they are obtained by applying the resultant of the bending and axial loads, which act at a section across the design strip, to the entire cross-sectional area of the design strip at the same location. The stresses represent average values that can exceed the cracking stress of concrete.



DEFINITION OF SUPPORT LINE, BAY AND PANEL

FIGURE 1-4

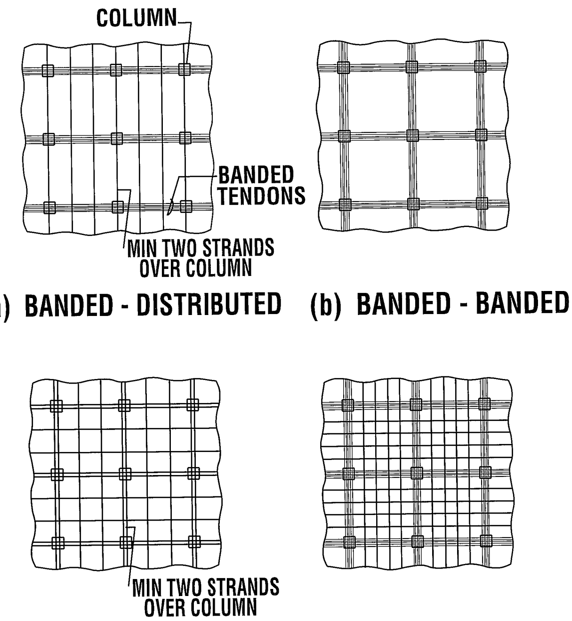
and the design procedure are not the subject of discussion herein. The computation of total prestressing and the associated reinforcement for a design strip are considered independent from the disposition of tendons and rebar within a design strip. For this review, it suffices to recognize that the structural design of a post-tensioned floor system generally concludes with the total amount of prestressing and nonprestresses reinforcement required for each design strip in each direction. The design also concludes with the profile of tendons, the force in each tendon, the total number of tendons and the location of all rebar for any given design strip.



PARTIAL PLAN

DEFINITION OF SUPPORT LINE AND DESIGN STRIP

FIGURE 1-5



PRINCIPAL OPTIONS OF TENDON LAYOUT

FIGURE 2.1-1

2 – TENDON LAYOUT

2.1 - OVERALL LAYOUT OF TENDONS

There are several possible arrangements for the layout of the tendons in each design strip. Fig. 2.1-1 illustrates the alternatives. Note that the tendons in each direction may be arranged in banded, distributed, or a mixed layout. In the banded direction all of the tendons of a design strip are grouped in a number of flat bundles and placed parallel to one another with a relatively small gap separating the constituent bundles. The tendons form a narrow band, typically up to or slightly larger than 1.20 m (4 ft) in width, following the support line. Tendons in the distributed direction are placed in bundles of one to 4 strands, spread over the entire width of the design strip with essentially equal spacing between the bundles. The four options illustrated in Fig. 2.1-1 are [Aalami, 1999]:

- Banded tendons in one direction, and distributed in the other direction
- Banded in both directions
- Distributed in both directions
- Mixed banded and distributed in both directions.

All of the stated four options are deemed to provide equal strength capacity. The choice of layout is generally governed by constructability.

The option of banded in both directions (Fig. 2.1-1(b)) is not permitted by the ACI Code [ACI-318, 1995]. The preferred layout is banded in one direction and distributed in the other (Fig. 2.1-1(a)). The constructability advantage of this scheme is that it does not require

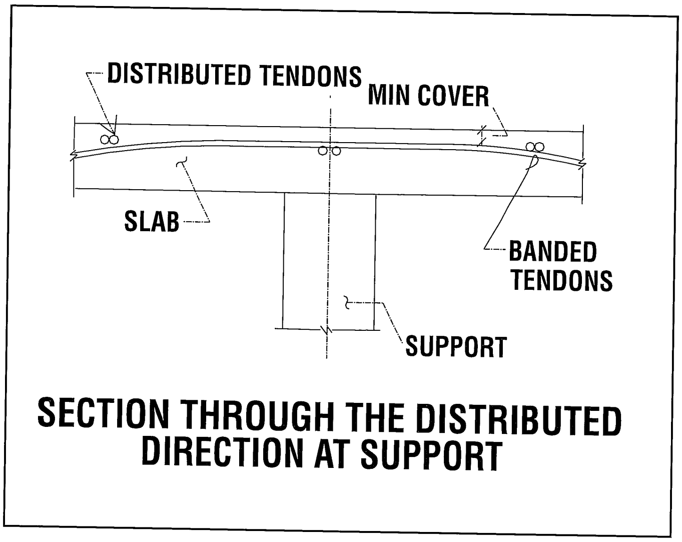


FIGURE 2.1-2

interweaving of tendons in different directions. The distributed tendons directly over the support (see Fig 2.1-2) are placed and secured in position first, followed by placement of all banded tendons. Then the rest of the distributed tendons are placed over the bands. Most other tendon layout schemes require some interweaving.

One other advantage of the banded-distributed option, from a design standpoint, is that both directions can be designed with the maximum permissible tendon drape. Banded and distributed tendons generally do not cross at their high or low points, with the exception of two distributed tendons over the supports (see Fig. 2.1-2). Therefore, the bulk of the strands can be placed with the maximum allowable drape without interference from tendons in the perpendicular direction.

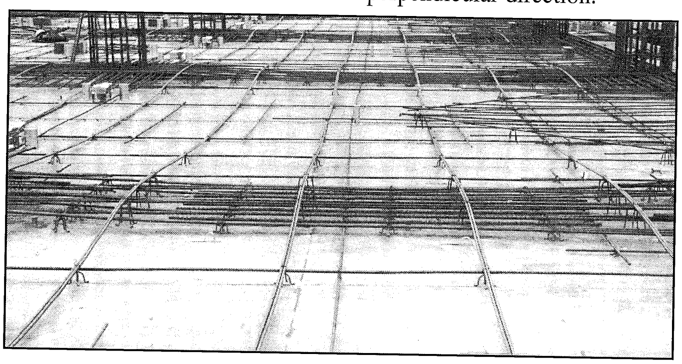


FIGURE 2.1-3

Views of distributed and banded tendons are shown in Figs. 2.1-3 and 2.1-4 respectively.

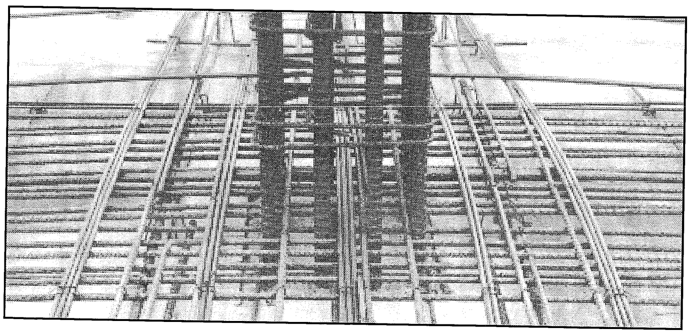


FIGURE 2.1-4

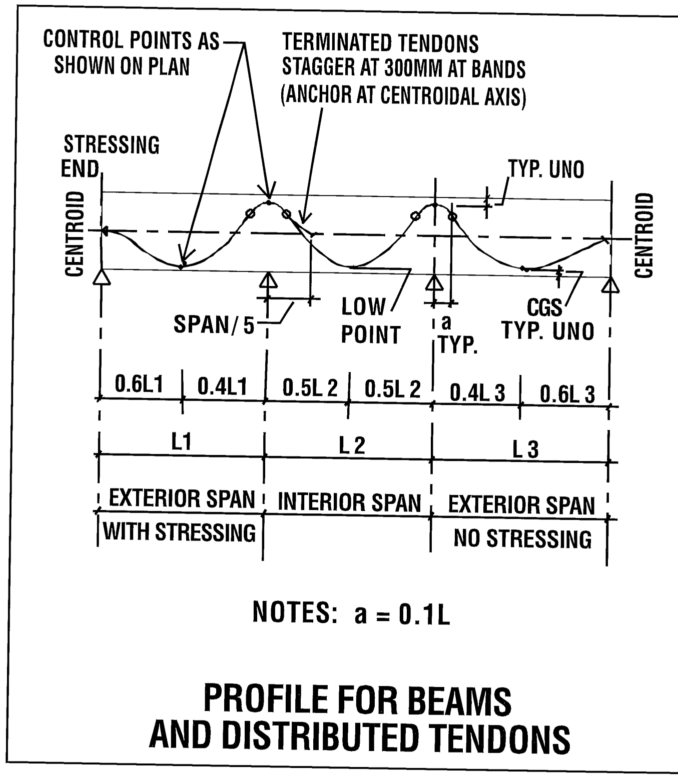


FIGURE 2.2-1

2.2 - TENDON PROFILES

Tendon profiles are generally made up of parabolic segments and straight lines. In the distributed direction and in beams the reversed parabola shown in Fig. 2.2-1, is adopted. For banded tendons, a partial parabola as illustrated in Fig. 2.2-2 is commonly used. In practice, the sharp break shown for the banded tendon profile over the support is not achieved. The actual tendon profile follows a more gradual transition over this region.

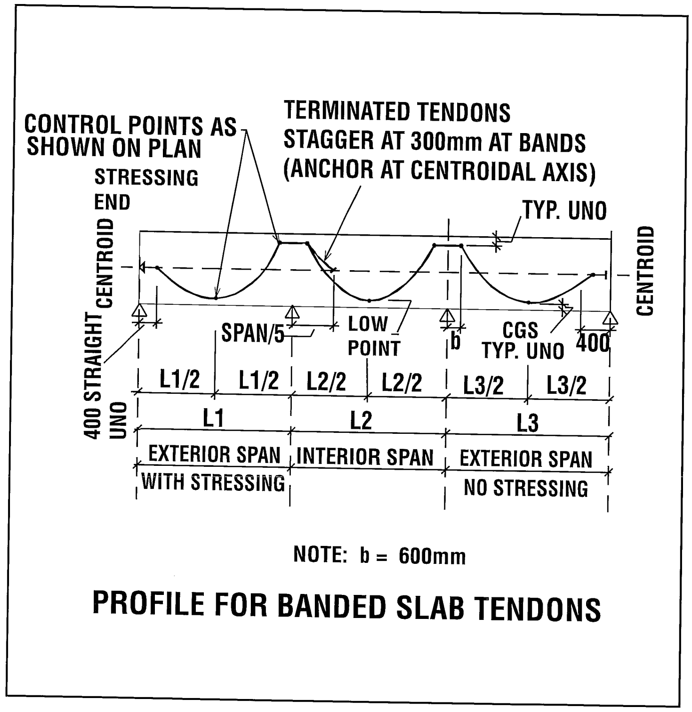


FIGURE 2.2-2

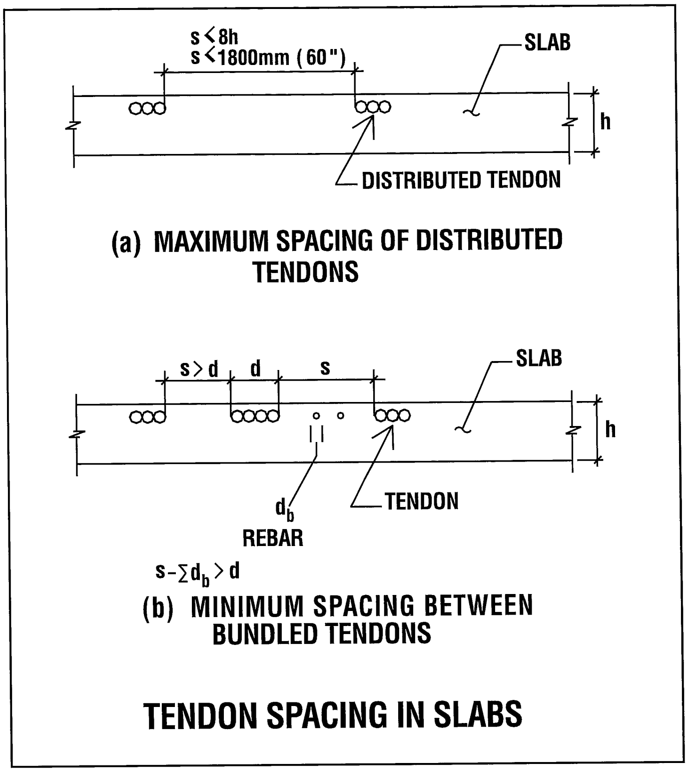


FIGURE 2.3-1

2.3 - DETAILING OF TENDON LAYOUT

A. Minimum Tendons Over Supports

According to the ACI-318 Code, a minimum of two tendons in each direction must pass directly over each support, regardless of how many strands each tendon contains. For unbonded mono-strand tendons, where a tendon contains one seven-wire strand only, a total of two seven-wire strands must pass over the support in each direction. However, when a tendon contains more than one strand, the total num ber of strands passing over the support will be more.

The Canadian Code is more rational. In its recommendation for non-prestressed designs the amount of reinforcement required to pass over each support is related to the weight of the slab tributary at that support.

B. Maximum Spacing Between Tendons

The maximum spacing between any two tendons is the lesser of eight times the slab thickness (refer to Fig. 2.3-1(a)) or 1.50 m (5 ft), except for the banded-distributed layout, where this restriction does not apply to the banded tendons.

C. Minimum Spacing Between Tendons

The minimum spacing for tendons is shown graphically in Fig. 2.3-1(b). Typically tendons must be spaced at a distance (s) that is larger than the horizontal width (d) of the bundles, plus the sum of the widths (db) of all rebar placed between each bundle. This value varies from less than 25mm (1") for a single monostrand tendon to more than 50mm (2") for a flat bundle of four strands. However, in no case should tendons be placed closer than the minimum spacing allowed between two adjacent rebars at the same location.

D. Bundling of Unbonded Tendons

For ease of construction, it is common practice to bundle several unbonded mono-strand tendons together. Four1 strands per flat bundle is the maximum recommended number used in practice for floor slab construction. Apart from the possibility of poor consolidation of concrete around bundles, this limitation is followed for two reasons. First, there is an increased potential for delamination at high and low profile points as more strands are bundled together. Second there is an increased likelihood for blowouts at locations of horizontal curvature due to riding of the outer strands over the inner ones.

For beams, the strands are placed in a round bundle (Fig. 2.3-2). There is no limitation on the number of unbonded strands that can be bundled in a beam, provided concrete below the bundle can be satisfactorily placed and consolidated. In practice, bundle size is limited to six strands per bundle.

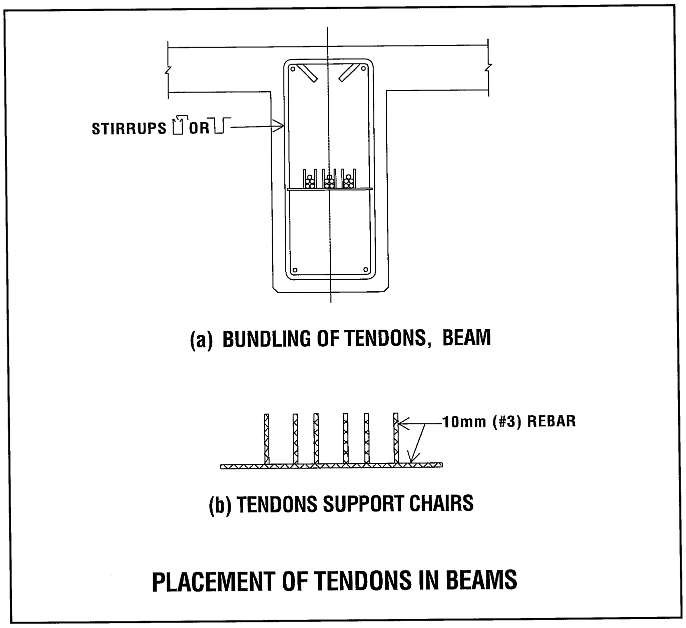


FIGURE 2.3-2

E. Curvature in Tendons

Maximum curvature in tendon is controlled for two reasons.

First, tendons that are curved horizontally to follow the nonaligned column layout, or to avoid openings tend to increase the risk of blow out. This risk can be minimized if tendon curvature is smaller than shown in Fig. 2.3-3. For larger curvatures (tighter swerves) properly placed hairpins as shown must be used. The details shown in the figure are for common slab construction with 12mm (0.50 in.) nominal diameter unbonded tendons, and the conservative stipulation that the lateral (horizontal) pressure imparted to concrete due to tendon curvature is not to exceed 3 MPa (450 psi)[1]. Thus the radius of curvature must be at least 3m (10ft).

Second, forcing a strand into a sharp curvature induces flexural stresses in the strand wires that may become significant if the curvature is tight. For unbonded tendons, CEB [1992] recommends that 20 times the strand's

1 The stress resisting a tendon curved along a circular arc is given by f=P/dR, where P is the force in tendon, R is the radius of arc, and d is the diameter of tendon.

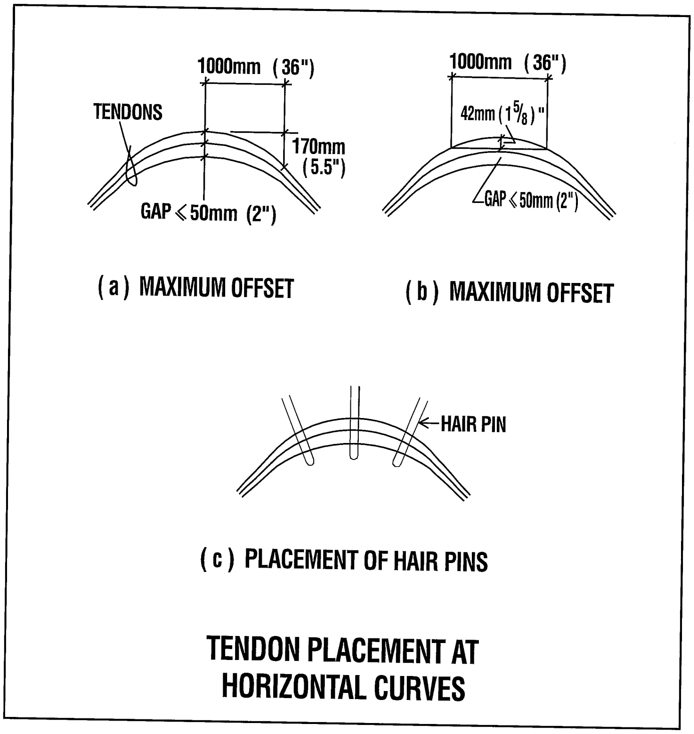


FIGURE 2.3-3

nominal diameter be the smallest radius for which a bent strand be considered to develop its full-specified tensile strength. Note that this second stipulation is for the integrity of the strand wire as opposed to the first restriction, which is for control of stresses in the concrete.

F. Spacing Between Tendon Supports.

Tendon support bars are used to position and secure tendons in their designated profile. The support bars are generally 12 mm (#4) reinforcing bars. For tendon heights (center of gravity) greater than 30 mm (1.25"), the support bars are secured on chairs at typically 1200 mm (4'-0") on center[2]. For tendon heights of 30 mm (1.25") or less, slab bolsters are used. The spacing of support bars depends upon the designated profile and the type of tendon, but usually does not exceed 1500 mm (48"). The number, location and other particulars of support bars are discussed further in the following section.

G. Tolerance in Deviation from Profiles Shown on Structural Drawings.

Tolerances for deviations from the tendon profiles and layouts shown on the placing diagrams are as follows:

- In the vertical (normal to the plane of the slab) direction, 6 mm (_") from the specified vertical profile for members up to 200 mm (8 ") thick; 10 mm (3/8") for members between 200 mm (8") and 600 mm (24"); and 12 mm (1/2") for members over 600 mm (24") thick;

2 A better practice, but not universally used, is to place a chair height below the intersection of each tendon bundle and support bar. This practice better ensures that tendons are maintained in the proper vertical location during concreting

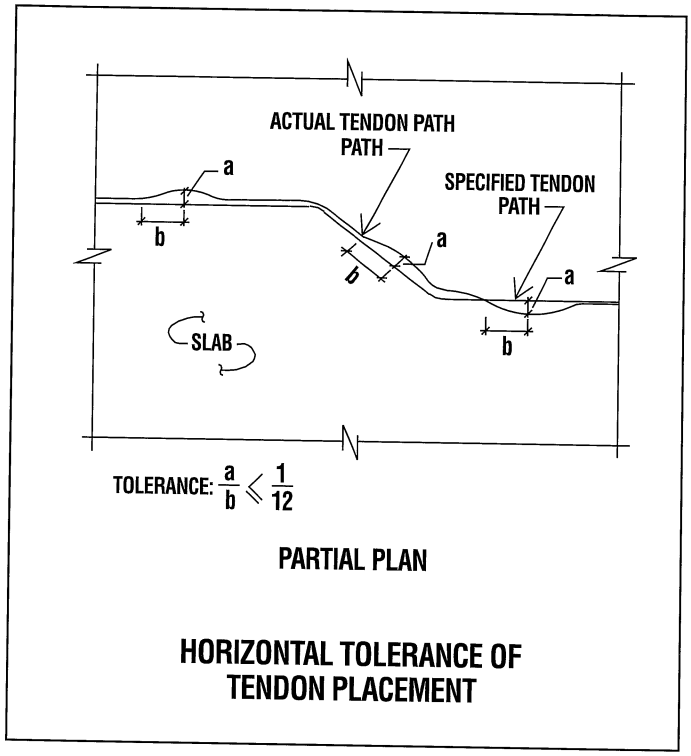


FIGURE 2.3-4

- In the horizontal direction (plane of the slab), undulation from the specified tendon path is limited to less than 1 in 12, as shown in Fig. 2.3-4.

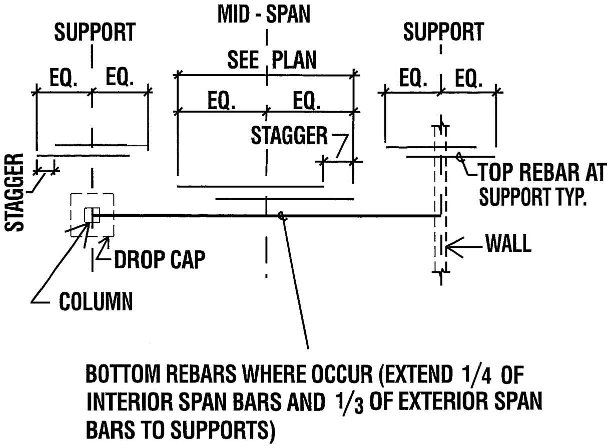
3 - LAYOUT OF NONPRESTRESSED (PASSIVE) REINFORCEMENT

Nonprestressed (also referred to as passive) reinforcement placed in conjunction with the prestressing tendons falls within one of the following categories:

- Reinforcement necessary to supplement prestressing in order to meet the code stipulated strength capacity;
- Reinforcement to meet the code stipulated minimum values for control of flexural cracking; and
- Reinforcement for crack control due to temperature and shrinkage effects.

The following discussion is limited to the placement of reinforcement only. The computation of required amounts follows the respective code provisions.

The disposition of reinforcement required for strength capacity, and the disposition of the minimum amount required by code follow essentially the same practice. The layout of reinforcement used for temperature and shrinkage is different, as outlined below.



NOTE: STAGGER ALL BARS 300mm (12"). FIELD ADJUST TO LESS STAGGER WHEN SPACE INSUFFICIENT

PARTIAL PLAN

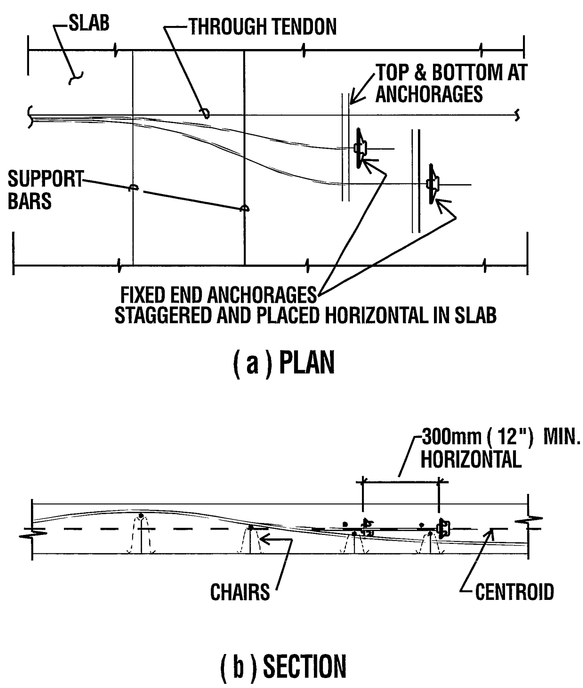
ARRANGEMENT OF BARS IN SLAB

FIGURE 3.1-1

3.1 - REINFORCEMENT FOR STRENGTH AND MINIMUM CODE REQUIREMENTS

A. General Features

Nonprestressed reinforcement may be needed for strength demand or temperature and shrinkage effects. In the case of unbonded tendons, a minimum amount of nonprestressed steel is required over the supports for crack control and ductility.



PLACEMENT OF TERMINATED TENDONS

FIGURE 3.1-2

For all conditions, adjacent reinforcing bars are recommended to be staggered 300 mm (12 inch) as shown in Fig. 3.1-1. The same holds true for added tendons (discontinuous), which terminate as a group at one location (Fig. 3.1-2).
Other stipulations for top and bottom bars are listed below.

B. Top Bars

(i) Minimum Number of Bars:
For unbonded tendon construction, a minimum of four top bars must be placed over each support in a flat slab, regardless of the size of the bars used in the design. In most cases this requirement is fulfilled automatically since small diameter bars are selected for design efficiency (see V below). The smaller the bar size, the larger the number of bars required to fulfill the rebar requirement.

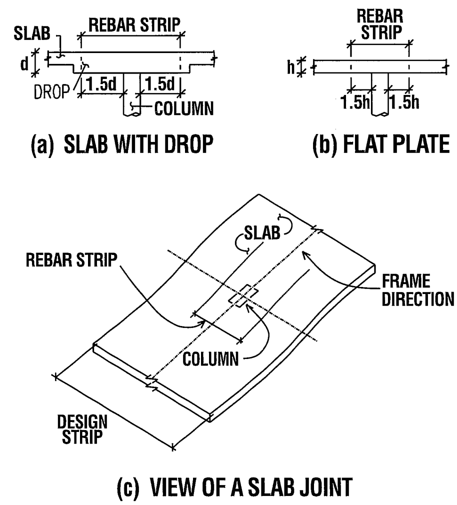


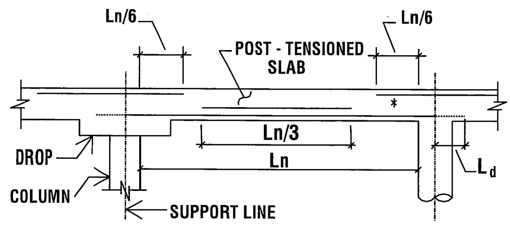
ILLUSTRATION OF STRIP FOR TOP REINFORCEMENT

FIGURE 3.1-3

(ii) Position:
All top bars required for strength or to fulfill the minimum code requirement must be placed over the column supports within a defined band in each direction. The band is defined to have a width extending 1.5 times the slab thickness (including drop cap or drop panel) on each side of the support as shown in Fig. 3.1-3.

(iii) Congestion of Reinforcement Over Support:
Reinforcement congestion over supports is an important construction consideration in post-tensioned slabs, especially where long spans occur. The condition can be aggravated by the selection of small diameter bars (12 to 16 mm, #4 or #5 bars) that are favored by most engineers. Small diameter bars maximize the moment arm of thin slabs, and avoid reducing the effective depth of tendons that cross in the perpendicular direction below the top reinforcement.

Observations made on previous construction projects suggest that the total area of reinforcement over a typical column (500 mm, 20 in.^{2}) in each direction should not exceed 4200 mm^2 (6.75 in.^{2}), in order to achieve effective consolidation of concrete and avoid the necessity of special procedures in placement. This amount translates into 21 – 16 mm diameter (#5) bars maximum.



* IF REQUIRED, EXTEND TO SUPPORTS EVERY THIRD BAR AT EXTERIOR SPAN AND EVERY FOURTH BAR AT INTERIOR SPANS

L_d = DEVELOPMENT LENGTH

NOTE: STAGGER ALL BARS 300mm (12"). FIELD ADJUST TO LESS STAGGER WHEN SPACE INSUFFICIENT

LENGTH OF NONPRESTRESSED REINFORCEMENT

FIGURE 3.1-4

(iv) Length of Bars over Supports:
Top bars must extend from the support one-sixth of the clear span in each direction, unless a larger length is required to fulfill the strength requirement (Fig. 3.1-4). For normal dimensions and typical loading, top bars rarely need to extend beyond the 1/6th of span requirement. The drop in negative moment within the vicinity of a support is sharp and the available prestressing provides adequate strength should there be residual moments at this location.

(v) Bar Size:
Small diameter top bars are generally selected for most applications since the bars must be placed in two layers over the supports (one layer in each direction). In such a layout the selection of a larger diameter bar adversely affects the effective depth of the lower layer of rebar and tendons. Also, small diameter bars are more effective at resisting potential cracks. 16 mm diameter (#5) bars are the typical choice for top bars, as these match the diameter of an unbonded tendon.

C. Bottom Bars

(i) Minimum Number of Bars:
There is no minimum number of bars required at the bottom of the slab, provided stresses are low under service conditions [ACI-318, 1995] and the tendons are adequate for strength. As a result, it is feasible that a two-way post-tensioned floor will be constructed without any bottom bars. At high tensile stresses, the ACI Code stipulates a minimum amount of nonprestressed steel, but sets no restrictions as to the minimum number of bars that can be used to cover the requirement.

In several countries outside the USA, the practice is to place a bottom mat of welded wire fabric (120x120mmx3mm), regardless of stress conditions.

(ii) Position:
Bottom bars required for a particular design strip must be placed within the tributary of that strip. From a structural standpoint, the position of the bottom bars within the design strip is not critical. However, for ease of construction, the bottom bars in the banded direction are typically placed next to one another within the width of the tendon band along the line of supports with due consideration for minimum bar spacing. The bottom bars for a particular design strip in the distributed tendon direction are placed uniformly within the tributary of the design strip. Bottom bars in the banded direction are placed first, followed by the bars in the distributed direction.

(iii) Congestion:
Congestion of the bottom bars is typically not a problem since the bars can be placed anywhere within the tributary of the design strip.

(iv) Length:
(a) Bars for minimum requirements:
Bottom steel is required for crack control where the service stress exceeds the minimum code stipulated value. ACI 318 specifies that these bars must be at least one third of the clear span (Fig. 3.1-4). They need not extend to the supports.

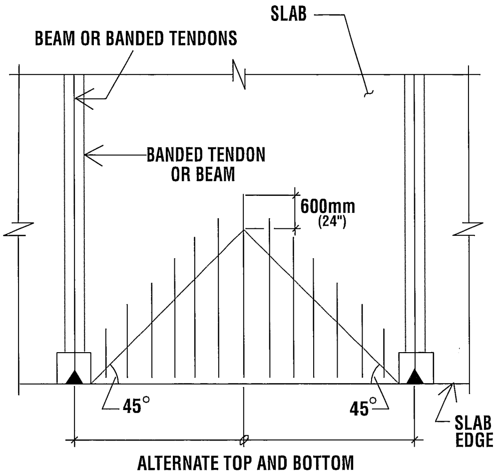
(b) Bars for strength requirements:
The length of the bars needed for strength is obtained by calculation. Although the calculated length is often less than one-third of span length, a minimum of one-third the span length is typically used. In addition, the following requirements must be met when placing bottom bars for strength:

- In end spans, extend one-third of the bars to the supports, and

- In interior spans, extend one-quarter of the bars to the supports.

3.2 - TEMPERATURE AND SHRINKAGE REINFORCEMENT

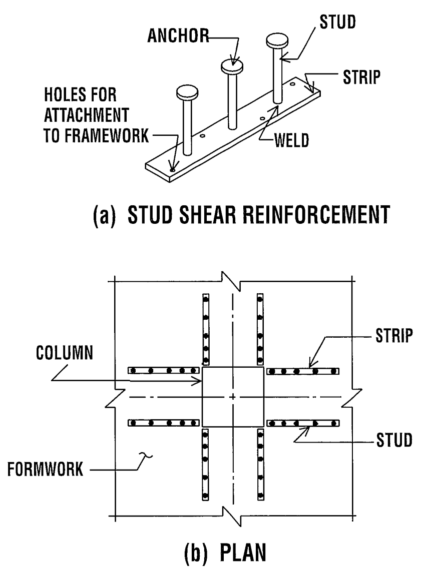
Temperature and shrinkage reinforcement is required where the average precompression is below 0.70MPa (100 psi). Since in common construction, the average precompression in the direction of prestressing is generally selected to be more than 0.85 MPa (125 psi), temperature and shrinkage reinforcement or added tendons are rarely required in the direction of prestressing. The exception to this statement is the wedge-shaped regions between the banded tendons (Fig. 3.2-1). In this case, nonprestressed steel is placed in the direction of the banded tendons as shown in Fig. 3.2-1. Bars are alternated so that half are placed at the top and half at the bottom of the slab.



ARRANGEMENT OF TEMPERATURE AND SHRINKAGE REINFORCEMENT

FIGURE 3.2-1

An alternative, but less economical practice, to the temperature reinforcement shown in Fig. 3.2-1 is to place two or three tendons at equal spacings parallel and between the beams/banded tendons. The added tendons are positioned at mid-depth of slab.



ARRANGEMENT OF STUD SHEAR REINFORCEMENT AROUND COLUMN

FIGURE 3.3-1

3.3 - SHEAR REINFORCEMENT

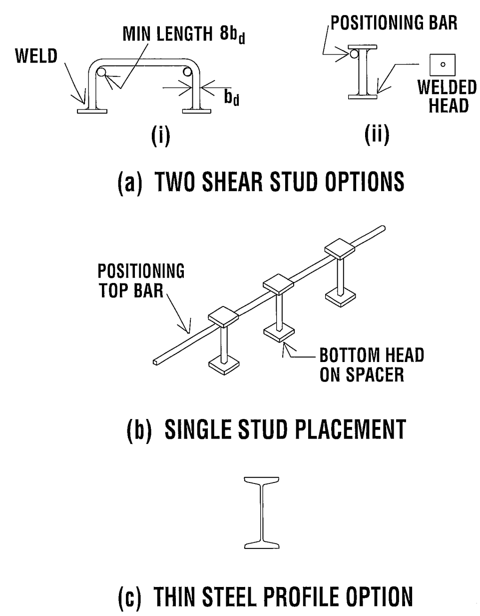
Shear reinforcement in flat slabs is generally limited to punching around the columns. In most cases where punching shear is of concern, the thickness of the slab does not allow satisfactory placement of stirrups in the same manner used for beams. Therefore, shear stud reinforcement (Fig. 3.3-1), or variations of it, are the most suitable alternative. Shear studs can be placed around the column in a variety of configurations. One recommended arrangement for shear stud placement is shown in Fig. 3.3-1. However, other arrangements with different stud shapes are equally viable. The number of studs along a given perimeter around a column is determined by the demand of the shear (and in ACI with a contribution from demand moment), the diameter and material of the vertical leg and the efficiency of the anchorage device. Full efficiency is where the anchorage provided by the stud head, or the combination of the stud head and placement (positioning) bars (Fig. 3.3-2) would lead to full development of the stud bar strength. The disposition of the required number of studs along the perimeter is essentially uniform. The studs may be shifted along the perimeter of the support to avoid interference with other reinforcement.

The contribution of the slab shear reinforcement to resist demand shear is given by the area of the vertical shear reinforcement device times its yield strength, duly multiplied by the material1 and strength reduction factors. Using the ACI Code, the shear contribution of each device is:

$$V_s = \phi A_b * F_y$$

where,

V_s = capacity of each vertical shear device;
A_b = cross sectional area of each vertical shear device;
F_y = yield stress of each vertical shear device; and
ϕ = strength reduction factor (0.85)



SELECTED SHEAR STUD OPTIONS

FIGURE 3.3-2

In the design of a shear device, the mechanical connection at the end shall be designed to develop the full strength of the vertical member. If a welded plate is used, its area is typically selected to be equal to or larger than 10 times the area of the vertical member. Two other options of vertical shear studs are shown in Fig. 3.3-2. Option (c) in the figure shows a thin cut from a steel profile.

The design of shear studs for post-tensioned slabs is covered by ACI-421 [ACI-421, 1992]

4 - SUPPORT BARS

4.1 - SUPPORT BARS FOR DISTRIBUTED TENDONS

Tendons in the distributed direction are generally supported by continuous bars placed perpendicular to the tendons. Though not required by computation, their presence also improves crack control and the distribution of loading between the uniformly spaced tendons. Typically, 12 mm (#4) bars are selected. These are placed not more than 1.20m (4'-0") apart and are lapped 400mm (15"). The support bars prevent horizontal displacement of tendon during concreting. They rest on "chairs" of a specific height necessary to maintain the correct vertical position of the tendons (see Fig. 3.1-2). Apart from the bars used to secure the tendons over the column support lines, a minimum of five support bars are typically provided for each span.

4.2 - SUPPORT BARS FOR BANDED TENDONS

Banded tendons are supported by short bars 80mm (3") longer than the width of the band (Fig. 4.2-1). At the sides of each column typically a heavier bar is used (22mm, #7). Away from the columns 12 mm (#4) bars are used. The support bars are spaced at approximately 1.10 m (3'-6") intervals.

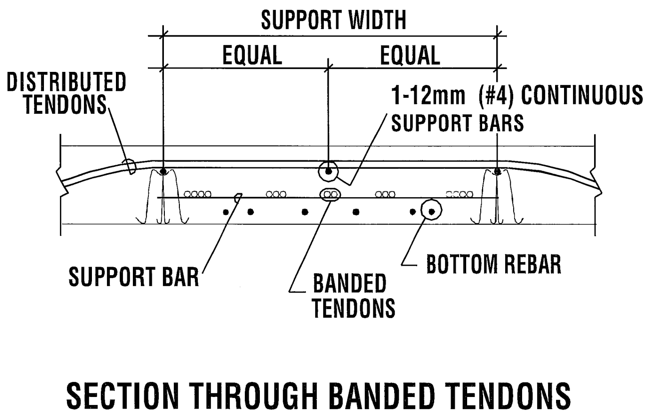


FIGURE 4.2-1

5 - DETAILING

The structural modeling and the ensuing computations yield the overall amount of post-tensioning and nonprestressed reinforcement necessary to meet the serviceability and strength requirements of the governing codes. In most cases, the structural model used in design includes simplifications of the actual floor slab. Discontinuities, such as openings and constraints of the walls and columns often are not represented faithfully in the structural model. For this reason, after the post-tensioning and the nonprestressed reinforcement are determined and recorded on the structural drawings, the designer must review the drawings and add or modify the reinforcement, to ensure that:

- The load path envisaged in the structural design is continuous from the point of the application of the loading to the foundation.
- The applied loading can be satisfactorily distributed and can reach the designated load path without distressing the unreinforced or lightly reinforced regions of the floor system.
- In addition, at locations of stress concentration such as reentrant corners, nonprestressed rebar must be added to reduce crack width (Fig. 5-1 illustrates one example).

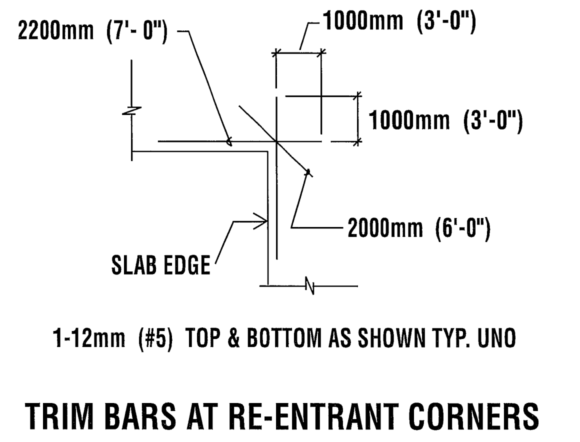


FIGURE 5-1

Reinforcement required behind the post-tensioning anchorage devices is generally shown on the shop drawings. The amount and configuration of the reinforcement depends on the post-tensioning system selected.

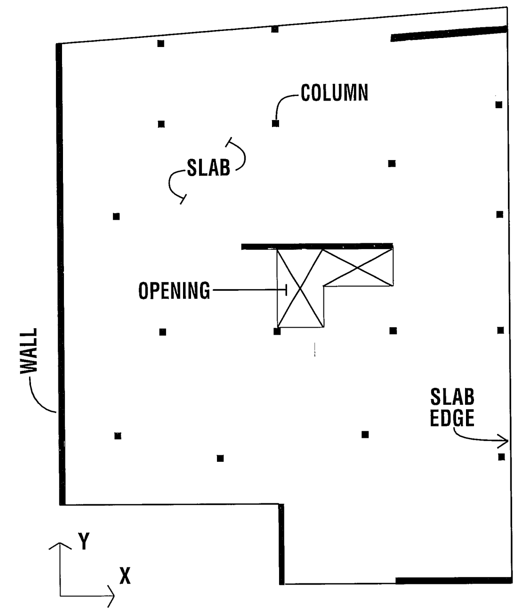
6 – EXAMPLE

In this section, through schematic illustrations prepared for a floor system, the placement of post-tensioning and nonprestressed reinforcement is described.

Fig. 6-1 shows the plan of the floor slab, including the general locations of all support, openings and other features. For design, this slab would be divided into design strips in both directions. For each design strip, all post-tensioning and mild reinforcement requirements would then be calculated. The disposition of reinforcing would then follow the general scheme outlined below.

Fig. 6-2 shows the general tendon layout and reinforcement arrangement. Note the following:

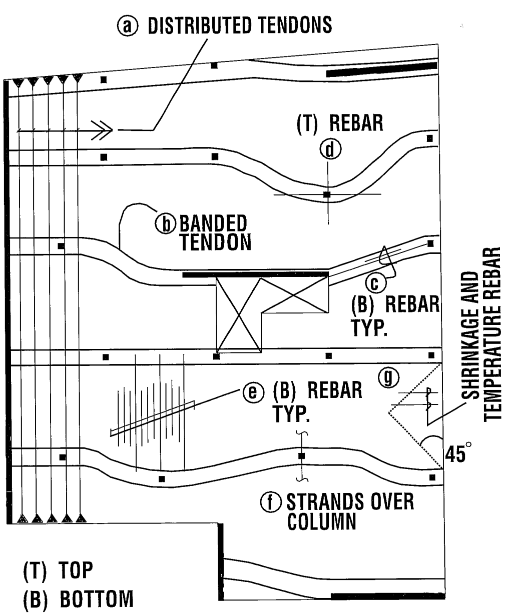
- Banded tendons (marked "b" in the figure) are placed close together, in a narrow strip, and swerved over the support lines used in the design. No tendons are placed between the bands. Banded tendons are placed before distributed tendons.



PLAN OF FLOOR SLAB

FIGURE 6-1

- Distributed tendons (a) are laid out along uniformly spaced straight lines. The tendons do not follow corresponding support lines. Distributed tendons are placed after banded tendons.



TYPICAL DISPOSITION OF TENDON AND REINFORCEMENT

FIGURE 6-2

- Top rebar in both directions (d) is placed directly over the supports, within a pre-defined width.

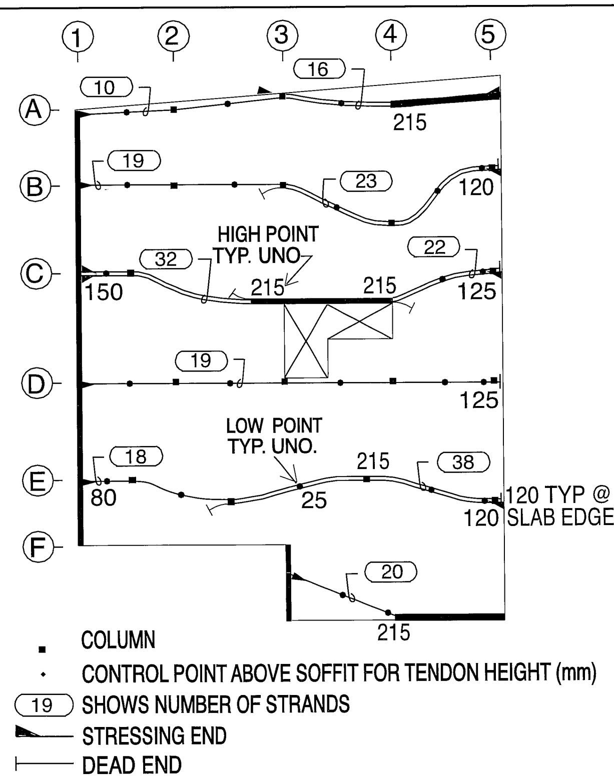
- Bottom rebar in the banded direction (c) is placed within the width of the band. One-third of bars in the end spans and one-fourth of bars in the interior spans are extended to the supports as shown. Bottom rebar in the distributed direction (e) is distributed over the entire tributary width of each design strip. The distributed rebar is placed after the banded tendons and rebar.

- At least two tendons in each direction (f) must pass directly over the support.

- Added rebar for temperature and shrinkage is included in areas at the slab edge between banded tendons.

Fig. 6-3 shows the details of the disposition of the banded tendons, including the number of tendons in each band, locations of added tendons and all profile points. Note that all tendon low points are located 25 m (1") above the slab soffit and all high points at 215 mm (8 _") above the soffit, unless noted otherwise (UNO). For instance the span between gridlines 1 and 2, along gridline E has a low point at 80 mm (3") above the soffit.

Fig. 6-4 shows the details of the disposition of the banded tendons, including the number of tendons, their disposition and profiles.



DISPOSITION OF BANDED TENDONS

FIGURE 6-3

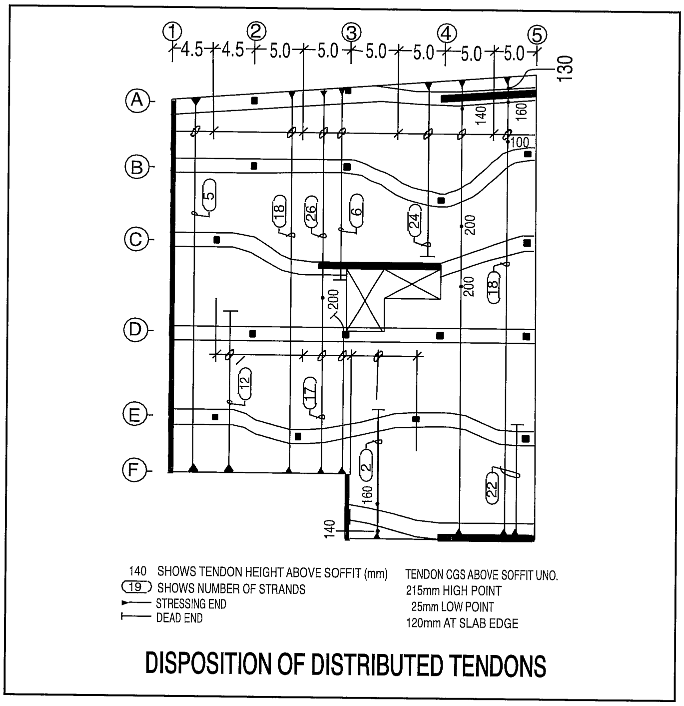


FIGURE 6-4

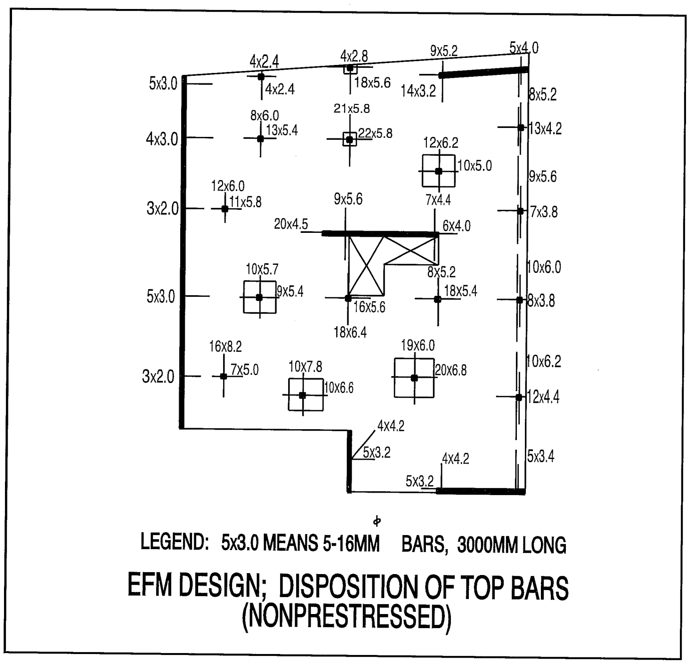


FIGURE 6-5

Fig. 6-5 shows the details of top reinforcing at the supports. Note that the bars for each direction are typically placed perpendicular to each other regardless of the orientation of the associated support lines. Also specified are the lengths and size of each set of bars. For this example all rebar are 16 mm diameter (#5) bars.

Fig. 6-6 details the required bottom rebar in the slab. Note that at least 1/3 of bars in end spans and _ of bars in interior spans are extended to the supports. Also observe that rebar in the banded direction is oriented along the support line while rebar in the distributed direction is oriented in one perpendicular direction.

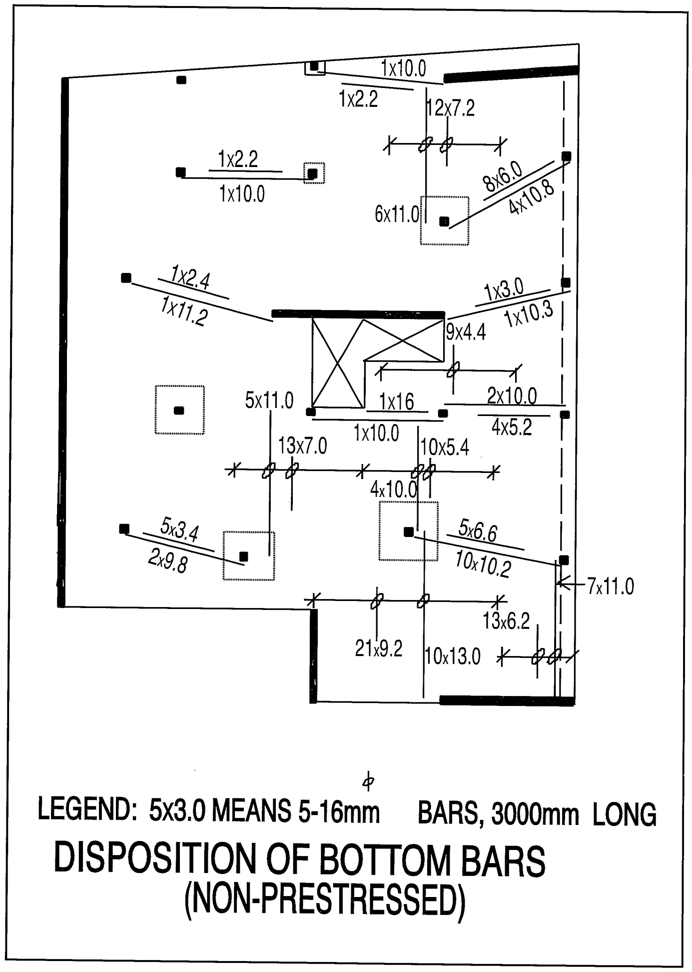


FIGURE 6-6

POST-TENSIONING INSTITUTE

Technical Notes

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