

Tips For Designing Constructable Concrete Buildings

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Seminar goal

To review easy ways to improve the constructability cast-in-place concrete structures.



Keep in mind.....

These tips are only suggestions.

There are often several good solutions.

The best solution often depends on local construction practices and contractor preferences.



Constructability

Constructability defines the ease with which structures can be built.

Constructability = Economy



Principles of constructability for cast-in-place concrete construction

Simplicity of Formwork = Economy

Simplicity (ease) of rebar placement = Economy

Repetition = Economy



Make sure that the contract documents are complete and coordinated

Avoid notes like this...

“PROVIDE ADDITIONAL REINFORCING STEEL AS REQUIRED TO MEET THE REQUIREMENTS OF THE BUILDING CODE.”



Make sure the reinforcing steel fits

18"x18" column w/ 4-#9 vert. (1.2%)

12-#7T

9" thick roof slab

slab

column

SECT. A-A

Problems:

- Hooks on column vertical bars extend only 6" into slab - insufficient to transfer slab moment to column.
- Heavy congestion of reinforcing steel makes correct placement of bars difficult to achieve.

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Draw details (including bar bends) to scale

3-#6 T&B

#3 closed stirrups

6"

7 1/2"

interference between stirrups & top bars

insufficient clear distance between bars

WISHFUL THINKING BY ENGINEER

ACTUAL CONDITION

3

Consider development lengths when doweling reinforcing steel

#11@12" VERT.

#11@12" TOP

1'-2"

4"

1'-2"

AS DESIGNED & DRAWN

BAR CONFIGURATION DRAWN TO SCALE

#8@6" VERT.

#8@6" TOP

1'-2"

1'-0"

1'-8"

MORE CONSTRUCTIBLE DESIGN

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Consider conflicts where multiple typical details occur at one location

Examples:

- Clashes between facade embeds and reinforcing steel and tendon anchors at slab edges
- Clashes between column reinforcing steel and tendon anchors

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Look for congestion when there are more than two layers of top or bottom bars in thin slabs

What is the reinforcing steel placing priority?

Especially a problem with hooked top bars at slab edges in thin slabs

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Consider hook dimensions when choosing bar sizes

#5 bar w/ stirrup hook

#6 bar w/ standard hook

3/4"

7 1/2"

#5 bar w/ 90 degree stirrup hook

...and allow the use of 90 degree stirrup hooks for #5 and smaller bars

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Avoid using 180 degree hooks in slabs

perpendicular (interfering bar)

bar can't be dropped straight down on top of perpendicular bar

formwork

7 1/2"

bar w/ 180° hook

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Limit the percentage of column vertical steel to 2% for economy & 4% for constructability

24"x24" CONCRETE COLUMN DESIGN OPTIONS				
f'_c	A_s	ρ	OP_n	% increase
5 ksi	8-#11	2.2%	1635k	-
5 ksi	16-#11	4.3%	1977k	22%
6.5 ksi	8-#11	2.2%	2008k	23%

Most capacity comes from the concrete

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Limit the percentage of column vertical steel to 2% for economy & 4% for constructability

For 24"x24" column w/ $f'_c=5$ ksi & 8-#11:

Strength from concrete = 1245.4 k (76%)
 Strength from steel = 389.4 k (24%)
 Total = 1634.8 k

(from ACI 318, equation 10-2)

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Limit the percentage of column vertical steel to 2% for economy & 4% for constructability

8-#11 (2.2%) 16-#11 (4.3%)

2'-0"

24"x24" Column
(View at splice)

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Avoid bundled bars in columns

Problems with bundling bars:

- Congestion
- Staggered splices
- Non-typical bar bends in ties

If the bars have to be bundled, then either the column is too small or the compressive strength is too low

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Avoid requiring higher strength column concrete to be "puddled" in the slab

ACI 318, Section 10.15 permits differences in concrete strength in slabs and columns to be ignored when f'_c of columns is $< 1.4 \times f'_c$ of slabs

Otherwise,
 For columns with slab on all sides,
 f'_c effective = $0.75 \times f'_c$ column + $0.35 \times f'_c$ slab

For columns with one or more unsupported edges,
 f'_c effective = $1.4 \times f'_c$ slab or add dowels

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Coordinate placement of slab embedded electrical conduit



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Specify reinforcing steel placing priority in slabs

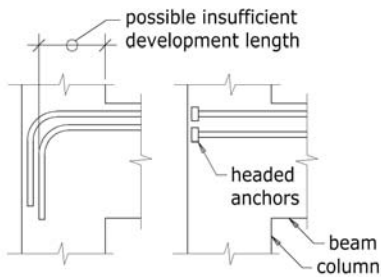
- B = Bottom
- BB = Bottom Bottom
- T = Top
- TT = Top Top

Typical recommendation:
For rectangular bays, place BB and TT bars in direction with longest spans



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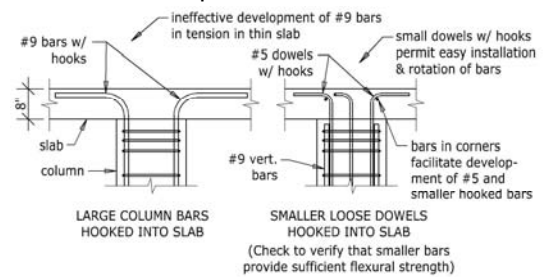
Avoid multiple parallel layers of hooked bars



14



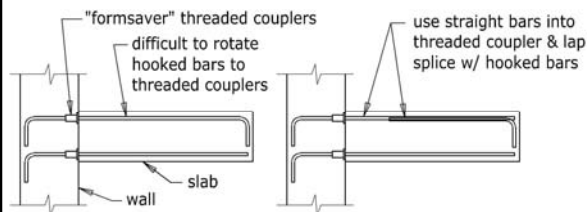
Consider development and installation of hooked column vertical bars into slabs at tops of columns



15



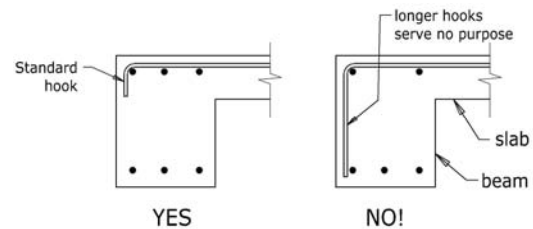
Do not hook ends of bars that are threaded to mechanical splice couplers



16



Do not specify hooks larger than standard hooks



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Avoid "spaghetti" bars

"spaghetti" bar

bar bends on inside of re-entrant corners may not develop required flexural strength

NO!

YES

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Properly detail bars at re-entrant corners

YES

NO

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Avoid one-piece closed stirrups in beams

difficult to install T&B bars inside one-piece stirrup

top leg of stirrup installed after installation of T&B bars

slab

beam

ONE-PIECE STIRRUP

TWO-PIECE STIRRUP

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Simplify beam stirrups

NO

YES

- Less congestion on bottom
- Fewer types of bars to fabricate
- Easier to install

NEVER!!

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Avoid long bars with hooks at both ends

Long bars with hooks at both ends

NO

Straight (long) bars with shorter hooked bars lapped at each end

YES

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Avoid long bars with hooks at both ends

PROVIDE TENSION LAP SPLICES BETWEEN ALL CORNER BARS AND HORIZ WALL REINFORCING.

CORNER BARS

CORNER BARS

HORIZ REINF.

VERT REINF.

HORIZ REINF.

VERT REINF.

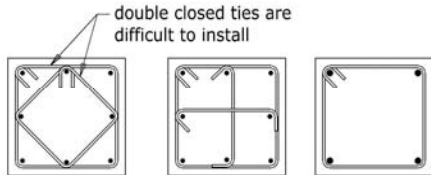
HORIZONTAL CORNER BARS SHALL MATCH SIZE AND SPACING OF HORIZONTAL REINFORCING.

CORNER REINFORCING IN CONCRETE WALLS

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Avoid complex column tie configurations



DIFFICULT-TO-INSTALL TIE ARRANGEMENT BETTER BEST

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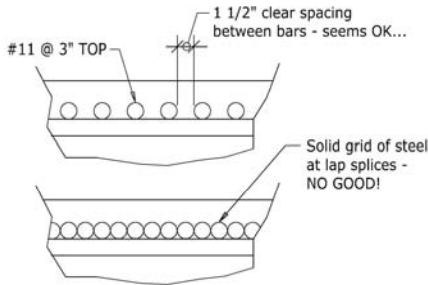
Detail bar configurations in beams and columns

- Configuration of vertical bars and ties in columns
- Configuration of flexural reinforcing steel and stirrups in beams
- Coordination between beam and column reinforcing steel at joints in heavily reinforced members

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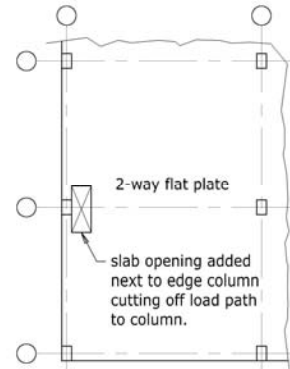
Consider clear dimensions between bars at lap splice locations



25



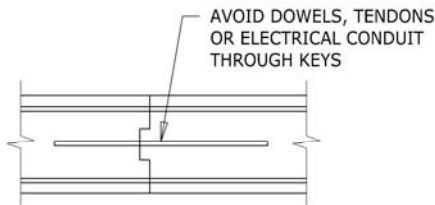
Coordinate locations of slab openings



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Do not put reinforcing steel through keyways

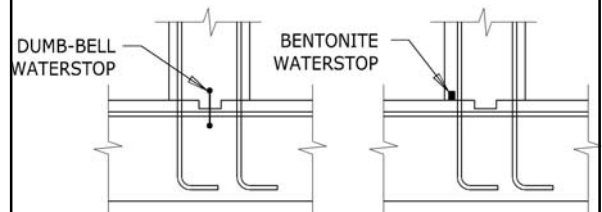


- ELIMINATE KEYS IF POSSIBLE
- INTERRUPT KEYS AT MID-DEPTH TENDONS

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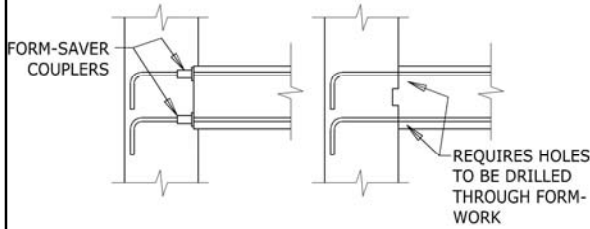
Do not put waterstops through keyways



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Avoid details where holes have to be drilled through formwork



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Dimension column strips

Don't "pass the buck" to the reinforcing steel detailer to figure out the column strip dimensions

Round column strip dimensions down and configure symmetrically. (There's nothing wrong with specifying column strip dimensions nominally smaller than $0.25 \times L_n$ on either side of a column line.)

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Simplify formwork

Formwork cost is 50% of total cost

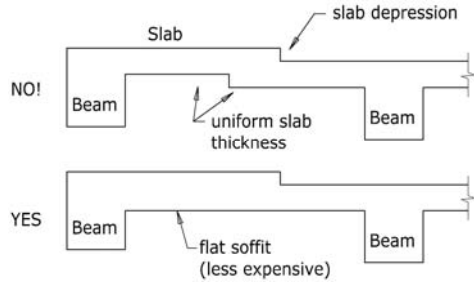
Tips for lowering formwork cost:

- Keep columns same size for full height
- Use as few different column sizes as possible
- Use square columns
- Standardize slab thicknesses
- Eliminate column capitals and drop panels
- Minimize irregularities at slab edges
- Make beams wider than columns

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Simplify formwork



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Where possible, use 0.5% reinforcing steel in columns

ACI 318-08

10.8.4 – Limits of section

For a compression member with a cross section larger than required by considerations of loading, it shall be permitted to base the minimum reinforcement and strength on a reduced effective area A_g not less than one-half the total area. This provision shall not apply to special moment frames or special structural walls designed in accordance with Chapter 21.

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Avoid full tendon drapes in heavily reinforced post-tensioned beams

May have a "floor of steel" at high points and low points of tendon drapes.

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Coordinate tendon anchor locations at,

- Columns
- At slab edges near facade connections
- In thin slabs (balcony slab edges)

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For flat plates,

Make slabs as thin as possible and increase column sizes to avoid the need for column capitals or shear reinforcing for punching shear

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Consider using Grade 75 steel for #9 and larger bars

Grade 75 versus Grade 60:

- Grade 75 mill cost premium ~ 5% (as of 4/11)
- Grade 75 installed cost premium ~ 2%
- Material cost savings with Grade 75 = 20%
- Net cost savings = 18%

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Consider using Grade 75 steel for #9 and larger bars

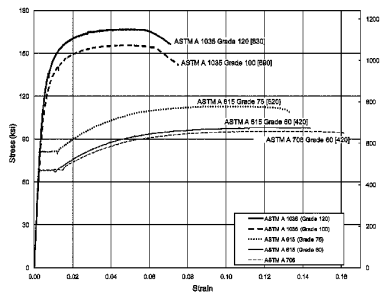
Rules-of-thumb for specifying Grade 75 bars:

1. Specify Grade 75 when there are at least 100 tons required for each bar size for which Grade 75 will be used
2. Use Grade 75 in columns, shear walls, foundations and flexural members for #9 and larger bars
3. When Grade 75 bars are used for particular bar sizes, all bars of those sizes on the project should be Grade 75.

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Consider using Grade 75 steel for #9 and larger bars



Note: Grade 75 may not have a well-defined plastic zone as indicated in this stress-strain curve. Thus, the ACI 318, Section 3.5.3.2 requirement for additional testing to determine F_y

(From ACI ITG-6R-10 Design Guide for the Use of ASTM A1035/A1035M Grade 100 (690) Steel Bars for Structural Concrete)

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Summary

To enhance constructability,

1. Always be thinking, "Will the reinforcing steel fit – with the proper clearances?"
2. Envision that you are trying to build the structure
3. Look for conflicts and interferences
4. Simplicity = economy
5. Simplify the formwork
6. Strive for clarity and completeness of the contract documents
7. Don't "pass the buck" to others to figure out how to build your design



Thank you!

Questions?

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