Tips For Designing Constructable Concrete Buildings

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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.

Principles of constructability for cast-in-place concrete construction

Simplicity of Formwork = Economy
Simplicity (ease) of rebar placement = Economy
Repetition = Economy

Seminario goal

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

Constructability

Constructability defines the ease with which structures can be built.

Constructability = Economy

Strive to produce complete and coordinated contract documents

Avoid notes like this…

3. SLAB CONSTRUCTION 1/2 INCH THICK CONCRETE PRESSURE SLAB REINFORCED WITH A CONTINUOUS 1/8/12" ON CLINTON TOP AND BIDDOM END MEASURED AS MAX. 16, 123/1000, 100/1000, OR 128 1/48 ON 12/12/12, ADDITIONAL REINFORCEMENT LAYERS ARE INDICATED ON THE PLAN.
Strive to produce complete and coordinated contract documents

And this....

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

Translate the analysis model to a well-documented and constructable configuration

- Modeling vs. detailing
- Analysis models may not be buildable
- Reinforcing steel in analysis models may not meet building code requirements

Verify that the reinforcing steel fits

18"x18" column w/ 4-#9 vert. (1.2%) Problems:
- Hooks on column vertical bars extend only 6" into slab - insufficient to transfer shear moment to column.
- Heavy corrosion of reinforcing steel makes correct placement of bars difficult to achieve.

Verify that the reinforcing steel fits

3-#6 T&B

3-3/4" closed stirrups

Interference between stirrups & top bars

Inadequate clear distance between bars

WISHFUL THINKING BY ENGINEER

ACTUAL CONDITION

Consider development lengths when doweling reinforcing steel
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

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

Consider hook dimensions when choosing bar sizes

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

Avoid using 180 degree hooks in slabs

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

<table>
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<th>24&quot;x24&quot; CONCRETE COLUMN DESIGN OPTIONS</th>
<th>( f'_c )</th>
<th>( \lambda_s )</th>
<th>( \rho )</th>
<th>( OP_s )</th>
<th>% increase</th>
</tr>
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<tbody>
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<td>8-1/11</td>
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<td>1635k</td>
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</table>

Most capacity comes from the concrete

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

For 24"x24" column w/ \( f'_c=5ksi \) & 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)
Limit the percentage of column vertical steel to 2% for economy & 4% for constructability

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

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

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

Coordinate placement of slab embedded electrical conduit

Avoid multiple parallel layers of hooked bars
Consider development and installation of hooked column vertical bars into slabs at tops of columns.

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

Do not specify hooks larger than standard hooks.

Avoid “spaghetti” bars.

Properly detail bars at re-entrant corners.

Avoid one-piece closed stirrups in beams.
Simplify beam stirrups

Avoid long bars with hooks at both ends

Avoid long bars with hooks at both ends

Avoid complex column tie configurations

Detail bar configurations in beams and columns

Consider clear dimensions between bars at lap splice locations
Coordinate locations of slab openings during design

Do not put reinforcing steel through keyways

Avoid details where holes have to be drilled through formwork

Do not put waterstops through keyways

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
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.

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.

Coordinate tendon anchor locations at,
- Columns
- At slab edges near facade connections
- In thin slabs (balcony slab edges)

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

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%
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.

Summary

To enhance constructability,

1. Produce clear, complete, concise and coordinated contract documents
2. Be aware that the analysis model may not be a buildable design
3. Envision building what you modeled
4. Always be thinking, “Will the reinforcing steel fit with the proper clearances?”
5. Look for conflicts and interferences
6. Simplicity = economy
7. Simplify the formwork
8. Don’t “pass the buck” to others to figure out how to build your design

Thank you!

Questions?

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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 $F_y$.