References

Text: Sections 4.1 – 4.6, 5.1, 5.2, 5.5

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Temperature and shrinkage reinforcement for slabs

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Useful Tables and Figures:

Areas of reinforcement for slab design | Table A-9, text |

Standard bar details (cut-off locations) for slabs & beams | Figure A-5, text |

Background

Many types of reinforced concrete slabs exist including: slabs on grade, one-way slabs, two-way slabs, and composite floors (see figure on next page)

slab-on-grade: slab cast against the ground. Reinforcement usually consists of wire mesh.

one-way slabs: slab designed for one-way bending; usually supported by beams or joists; the ratio of the long side to the short side of a slab panel usually exceeds 1.5

two-way slabs: slabs designed for two-way bending and shear; can be supported by beams, or directly by columns (flat plate); the ratio of the long side to the short side of a slab panel is less than 2.0.

composite floors: concrete slab is supported on steel beams; shear studs welded to the top of the beam flange ensure composite action.

This handout describes the design process for one-way slabs.
Typical Concrete Floor Systems (copied from Ceco Concrete Construction pamphlet)

Design Procedure

A one-way slab is designed by considering a one-foot-wide strip of slab. This strip is designed basically as if it were a 12-inch-wide beam, “t” inches thick. The procedure for designing a one-way slab section is explained below, followed by an example.

1. **Determine slab thickness.** Slab thickness is usually controlled by deflection considerations or fire ratings. ACI sets minimum thicknesses for beams and one-way slabs *not supporting partitions likely to be damaged by deflections* unless deflections are calculated in ACI Table 9.5a. Calculating deflections (a lengthy process and covered later in this course) will often result in a thinner section. Another consideration when selecting a slab thickness is fire
rating. For example, the minimum slab thickness for a two-hour fire rating is 4.75 in.) Finally, since shear reinforcement is not used in one-way slabs, the concrete must be able to resist the maximum shear force.

2. **Design flexural reinforcement at each section (at supports and midspan).** The flexural reinforcement must a) supply sufficient flexural strength \( (\phi M_n) \) to resist the factored moment \( (M_u) \), b) provide for a ductile failure, and c) extend a sufficient distance to develop the yield strength of the bars.

Calculate factored moment, \( M_u \). The bending moments in slabs continuous over multiple supports must be calculated using a structural analysis program for multiple load patterns. A conservative but much simpler procedure is to use the ACI moment coefficients specified in Section 8.3. The factored moment at a particular location (e.g. exterior face interior support), \( M_u \), is calculated from:

\[
M_u = w_{u} \frac{l_n^2}{C},
\]

where \( C \) represents the moment coefficient from ACI Section 8.3 and \( l_n \) is the clear span. Clear span is the span from face-of-support to face-of-support.

Select \( A_s \) to that \( \phi M_n > M_u \). The reduced nominal moment capacity \( (\phi M_n) \) is a function of the area of steel \( (A_s) \) and the moment arm \( (d – a/2) \). The effective depth \( (d) \) is a function of slab thickness, concrete cover (specified for slabs in ACI 7.7) and bar diameter (depends on which bars were selected to provide \( A_s \)). This is essentially a trial-and-error process. The text provides a useful table containing area of reinforcement for various rebar sizes and spacing. We will learn how to construct a similar table in class using Excel, and an estimate of the \( A_s \) required (based on an estimate of \( d \)).

Check for Ductile Failure. A ductile failure is one in which significant deformation precedes collapse. Deformation before collapse allows people to observe distress in the structure and abandon it before collapse. Deformation before collapse also (in indeterminate structures) allows loads to be redistributed to other members. Three failure scenarios are presented below. The first scenario is the desired failure mode. The other two represent non-ductile failure and therefore must be designed against.

Failure Scenario #1 (just right steel). The preferred order of flexure response events is: beam cracks, steel yields, concrete crushes.
Failure Scenario #2 (too little steel).
\( M_u < M_{cr} \). In this case, the beam has so little steel, that when the beam does crack, it collapses. ACI 10.5.4 specifies a minimum area of steel, \( A_{s\text{min}} \). For slabs, this is set equal to the reinforcement required to prevent excessive temperature and shrinkage cracking (ACI 7.12.2)

Failure Scenarios #3 (too much steel).
\( e_s \gg e_y \). In this case, the beam has so much steel that even at ultimate conditions \( (e_c = 0.003) \) the steel has not yielded. ACI 10.3.5 specifies that the strain in the extreme tension steel must be well beyond yield \( (e_t > 0.004) \) to prevent crushing the concrete before observable deformation. A practical upper limit on reinforcement is
\[
\rho = \frac{A_s}{b d} = 0.01
\]

3. Distribute reinforcement. Stress transfer from the rebar to the surrounding concrete is more effective if smaller-diameter closely-spaced rebar is used, rather than larger-diameter, widely-spaced rebar. Also, smaller, closely-spaced rebar is more effective keeping cracks small. ACI limits the rebar spacing for one-way slabs to 3 t or 18” (ACI 7.6.5, ACI 10.5.4). ACI also limits the rebar spacing of beams and one-way slabs as a function of the steel stress under service loads (fs) in Section 10.6.4.

4. Design bar cutoffs.

5. Design temperature & shrinkage reinforcement. As water evaporates from wet concrete, the total volume of the concrete decreases. The loss of volume causes the concrete to shrink, which can cause tensile stresses in the concrete leading to cracking. Thermal contraction can also cause tensile stresses in the concrete. Reinforcement (specified in ACI Section 7.12.2.1 and 7.12.2.3) limits crack widths. Concrete elements that are completely restrained from moving (e.g. a slab attached to a stiff shear wall) require approximately three times this reinforcement (Text, Section 10-4).

Slabs have a lot of surface area (leading to rapid evaporation) and are relatively flexible compared to the beams, columns and walls to which they may be attached. The flexural reinforcement parallel to the span of a one-way slab serves to limit crack widths (in fact, ACI 10.5.4 specifies that the minimum flexural reinforcement is the temperature and shrinkage steel specified in Sections 7.12.2.1 and 7.12.2.2). Temperature and shrinkage reinforcement must also be provided transverse to the flexural reinforcement. The text recommends using #4 bars (as #3 bars are bent by workers walking on the reinforcement) and placing the bars on top of the bottom layer of reinforcement.