# ARCH 631. Topic 10 Reading Notes

- Reinforced concrete is used for horizontal systems with one-way slabs for short spans and lighter loads; ribbed slabs for larger loads; beams integral with slabs can span relatively long distances with heavy load (more with posttensioning) and spacing dependent on slab span
- One-way pan joist system is a ribbed slab made with pan forms that frame into beams; not economical for short spans; can have beams or walls for support; good for frame action
- Flat plate is two way slab system; more flexible for odd placement of columns; can use more reinforcement because of the two way bending; shear at column supports often dictates plate thickness or extra reinforcement (no drop panels); not great in rigid frame action because of plate thinness; simple construction
- Flat slab is two-way but has drop panels or column capitals for higher shear at the columns; good for heavy loading and longer spans than flat plates; resists lateral load better than flat plates
- Two-way beam and slab has beams around all sides of the plate; good for medium spans and high loads; good for concentrated loads if on the beams; rigid frame action
- Waffle slabs have ribs in both directions constructed with domed pans; voids make it deeper with less material; useful for longer spans and can be posttensioned; "drop panels" formed by filling in voids around column; can also have periphery beams
- Shells, domes, vaults can be made with reinforcing in the shell; posttensioning common for tensioning or stiffening
- Precast means made off site; usually one-way elements commonly prestressed; good for occupancy and roof loads and repetitively; planks are usually hollow core and prestressed with added topping and must be simply supported; channels and double tees are prestressed and longer with added topping; single tees are big and useful for heavier occupancy and roof loads like in parking garages
- Thickness to height ratios commonly are 1:15 to 1:6 for beams, 1:22-1:10 for walls
- Concrete good in compressive stress but cracks under low tensile stresses; reinforcement required to resist tensile forces; longitudinal steel, stirrups resist bending and shear stress in beams
- Too little reinforcement results in yield at maximum moment; too much results in sudden compression failure at maximum moment with no warning
- Reinforced concrete does not behave linear-elastically. Cracking is assumed in tension and the steel resists the stress while there is a compression region in the concrete resisting the moment
- Old design method was called "working stress design" based on service loads
- Current design method is call "ultimate strength design" based on ultimate loads (*NOTE: really called STRENGTH DESIGN)* ; load factors are applied by load type
- For ACI 318 design method of singly reinforced beams, $h$ is the overall depth (minimum depths are listed in the code and text for deflection limits), $b$ is the width of the beam, $d$ is the effective depth to the centroid of the reinforcing steel, $M_n$ is the nominal moment and is equal to $T(d-a/2)$ or $C(d-a/2)$, $a$ is the depth of the compression field stress block; $T=A \times F_y$; $M_U$ *(big U)* is the "ultimate" moment capacity defined as $\phi M_n$ *(NOTE: ACI does not have a* $M_U$ *symbol.* $M_u$ (*little u) is defined as the* ***factored moment****. I do NOT advocate using* $M_U$ *at all.)*

- Ductility is ensured by providing an amount of steel that is small enough (under-reinforced) to meet the moment required and will fail by yielding rather than too much steel that won't yield so that the concrete fails brittle-y and explosively (over-reinforced)
- Balanced steel condition is the exact amount of steel that yields at the same time the concrete fails in crushing at peak strain.
- Beam design must consider an initial size by a guess or span to depth chart so that self weight is included in the loads on the beam; $d$ can be estimated to be *h-2in.* or *h=d-1.5 in. (concrete cover)* – ½ of the assumed bar diameter;
- If steel area is known, $a$ can be determined from $0.85f'_cA_sb/F_y$ and $\phi M_n = 0.9A_sF_y(d-a/2)$
- Compression reinforcement can increase the moment capacity without violating the ductility characteristics; compression steel won't reach the yield stress
- T and I section provide more concrete to be compressed and reduce the width of the concrete at the tension reinforcement; might not be suitable with negative moments because the compression zone is in the stem
- Slabs are designed as one-way beams with unit width and also require minimum reinforcement in the non-bending direction for temperature and shrinkage requirements; concrete cover requirement is smaller than beams
- Principal stresses are the largest stresses that occur in any direction so principal tensile stresses are the smallest and result from the interaction of shearing and bending stress and are diagonal; vertical cracks at the maximum bending moment with zero shear are all from bending; reinforcement is required to bridge the diagonal tension cracks; stirrups are most common
- The largest shear design value is allowed to be taken at a distance $d$ away from the face of the support; shear strength by ACI 318 is $2\sqrt{f'_c}\ b_wd$; stirrups needed if the design shear is more than half the concrete shear capacity; stirrup strength is $A_vf_yd/s$ where $s$ is the stirrup spacing and not allowed to be more than 4 times the concrete capacity
- Prestressing and posttensioning can reduce the size of the cross section (making it more efficient) by adding initial axial stress and possibly an initial negative bending moment; putting the beam in precompression also takes advantage of the material properties (more efficient) to avoid tension stresses
- Prestressing is typically done in a factory, uses high strength steel wires or tendons (strands) with yield strengths over 200 ksi; concrete is cast and when it has sufficiently hardened the strands are cut; prestressing force must be carefully controlled; too much camber (bending up) can cause cracking on the top
- Posttensioning is done on site by having strands in channels or conduit that do not get filled with concrete when the concrete is cast; after hardening the tendons are clamped and jacked against the concrete, anchored on the jacking end and grout can be put in the tubes
- Creep is a major concern in prestressed members because it is deformation that occurs over time when there is stress (not elastic or plastic deformation), and can lead to loss of prestressing force

- Prestressing strand can be draped, but it is more difficult with prestressing (when the concrete isn't hard)

- The behavior of a prestressed concrete beam isn't very difference from a regularly reinforced concrete beam at "ultimate" loads (strength design state), but the performance is improved under working or service loads to resist deflections

- Concrete column typically see compression and bending stresses; they can be spirally reinforced when round, and tied when rectangular; the spirals and ties contain the longitudinal reinforcement an prevent separation and buckling of the reinforcement;

- For ductility requirements the amount of reinforcement must be 1% to 8% of the gross area of the concrete cross section; 4% is a practical upper limit

- The nominal capacity listed in the text is **incorrect by ACI 318**. $\underline{P_o} = 0.85f'_cA_c + F_yA_s$; $\phi = 0.65$ for tied columns and $\phi = 0.7$ for spirally reinforced

- When there is bending and axial load, an interaction diagram can be developed which shows the reduction in axial load capacity with added bending moment (P vs. M); some P-M tables exist for specific materials and arrangement of reinforcement

- When a column is long and slender, it must be designed for buckling; bracing can be from shear walls, elevator shafts, etc.; unbraced columns are more prone to buckling; when there are bending moments, the amplification of moment from P-Δ(delta) must be considered by code

- Continuous concrete beams are common and reinforcement must be provided for any region in tension or that may experience tension; can also be prestressed or posttensioned, although it can be difficult to construct or move to site

- ACI 318 strength design: tension force, T is in steel, compression force C is in the concrete at failure; resistance factor for bending $\phi = 0.9$; moment capacity is $\phi M_n$; concrete crushing occurs at a strain of 0.003; $\phi M_n = 0.9A_sF_y(d-a/2)$

- ACI prescribes the maximum level of reinforcement as that which generates at least a steel strain of 0.004; 0.005 is recommended for practicality; text shows a calculation for $a$ (depth of stress block) from a value $c = 0.375d$, and $a = \beta_1 c$ where $\beta_1 = 0.85$ for $f'_c \leq 4000$ psi concrete and is reduced by 0.05 for every 1000 psi over 4000 psi up to a limit value of 0.65

- Reinforcing bars are listed by No. and how many 1/8ths of an inch in diameter; spacing limits are commonly the bar diameter, not smaller than 1" and may depend on the aggregate size; concrete cover is required to protect the reinforcement from corrosion with minimum of 1.5 in. for interior beams, 2. in for exterior beams, 3 in. in contact with soil; reinforcement requires development length, possibly from anchoring hooks; better to have more smaller bars than few larger bars

- Deflection calculations are complicated because of the cracking; following code minimum thicknesses ensure deflections within limits; a simplified approach allows use of 60% of the transformed moment of inertia to calculate deflections

- Minimum area of tension steel is a function of the concrete strength and steel yield stress but must be at least $(200/F_y)\cdot A_{gross}$