BIRZEIT UNIVERSITY

Reinforced Concrete Design I
ENCE 335

Serviceability

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Why serviceability ?

- Provide adequate performance of structural members
- It is important to study the behavior of structural members at service load conditions (load factors = 1)
- Immediate or Long-term deflections due to sustained load may cause damage
- Tension cracks may be visually disturbing or cause durability problems

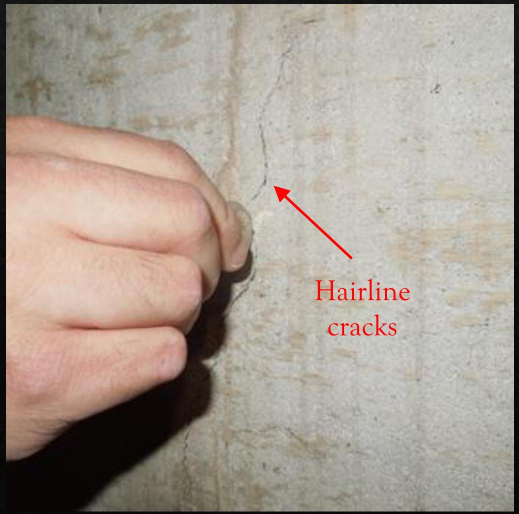
Cracking in flexural members

- Cracks in flexural RC members form at very small loads

  Recall the example in CH1 at stage I (linear uncracked section), bending moment was only 60 kN.m (below cracking moment) compared to 120 kN.m and 338 kN.m at service load conditions and ultimate conditions, respectively.

- Cracks are necessary for the steel to be used efficiently

  Recall the example in CH1, stress in steel was only ~19 MPa before cracking and ~160 MPa after cracking (service load) with only doubling the moment. Compared to the yield strength of steel 420 MPa.



- Cracks are random in RC members and we only study the probable crack width (90% of cracks are less than calculated)

  Many variables affect the crack width such as; Bond strength, strength in steel at service load conditions, concrete cover, spacing between bars

ACI requirements for crack control

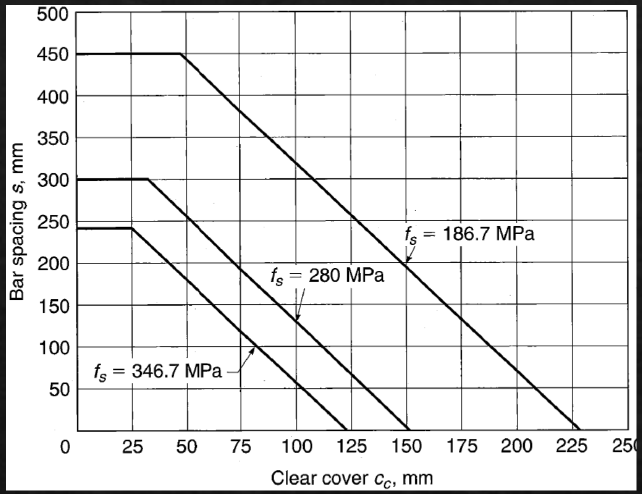
- Crack widths in structures are highly variable.
- The Code provisions for spacing are intended to limit surface cracks to a width that is generally acceptable in practice but may vary widely in a given structure.
- Spacing of bonded reinforcement closest to the tension face shall not exceed

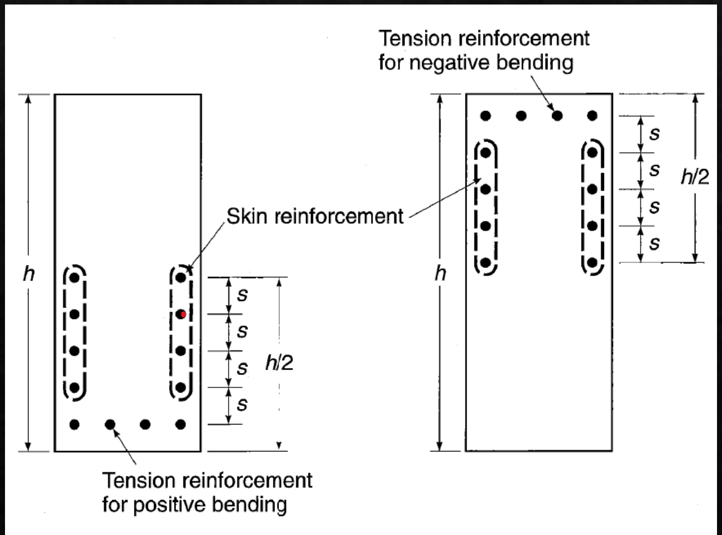
$$S_{max} = Min \begin{cases} 380\left(\frac{280}{f_s}\right) - 2.5\,C_c \\ 300\left(\frac{280}{f_s}\right) \end{cases}$$

Where: C_c: Clear cover for tension reinforcement

f_S: Calculated stress in steel at service load conditions (can be taken as $2/3\ f_y$)

- Design Aids minimum number of bars (Table A8)
- Skin reinforcement is required for deep beams with h ≥ 900mm





Deflection Control

- Large deflections may cause cracking of supported walls, ill-fitting doors, misalignment of sensitive machinery.
- Large deflections doesn't give a sense of safety and aesthetically pleasing.
- In previous chapters, we studied these requirements for deflection control

Table 9.3.1.1—Minimum depth of nonprestressed beams

Support condition	Minimum h[1]
Simply supported	$\ell/16$
One end continuous	$\ell/18.5$
Both ends continuous	$\ell/21$
Cantilever	$\ell/8$

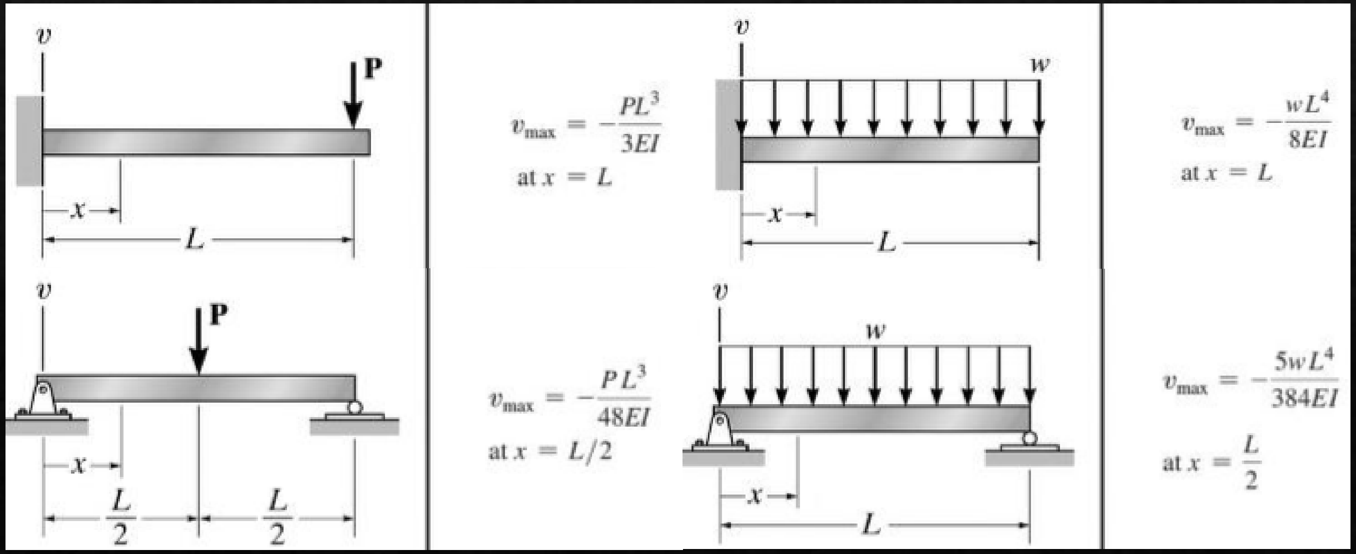
Table 7.3.1.1—Minimum thickness of solid nonprestressed one-way slabs

Support condition	Minimum h[1]
Simply supported	$\ell/20$
One end continuous	$\ell/24$
Both ends continuous	$\ell/28$
Cantilever	$\ell/10$

- If these requirements are not satisfied, immediate and long-term deflections must be calculated
- Calculating highly accurate deflections is complicated
- It is more practical to estimate these deflections (10 mm not 50 for example)

Types of deflection

- Immediate deflection (Deflections due application of load)
  - These deflections are calculated based on elastic theory
  - We learned in Structural Analysis I & II how to calculate these deflections for determinate and indeterminate beams



Types of deflection

- Immediate deflection (Deflections due application of load)
  - These deflections are a function of
    - Elastic modulus

      $E_c = 4700\sqrt{f_c'}$
    - Effective moment of inertia (I_e)
      - Depends on loading stage
        - Stage I: uncracked section → I_g (usually only the concrete is taken into consideration)
        - Somewhere in the middle
        - Stage II: Fully cracked → I_{cr} (All concrete in tension is ignored)
      - For continuous one-way slabs and beams, I_e is taken as the average of values obtained from Table 24.2.3.5 for the critical positive and negative moment sections.
      - I_e is taken as the value obtained from Table 24.2.3.5 at midspan for simple and continuous spans, and at the support for cantilevers
      - For the use of FEM software's, a relative value of I_e can be assigned

Service moment	Effective moment of inertia, I_e, mm[4]
$M_a \le (2/3)M_{cr}$	I_g
$M_a > (2/3)M_{cr}$	$\dfrac{I_{cr}}{1-\left(\dfrac{(2/3)M_{cr}}{M_a}\right)^2\left(1-\dfrac{I_{cr}}{I_g}\right)}$

Table 6.6.3.1.1(a)—Moments of inertia and cross-sectional areas permitted for elastic analysis at factored load level

Member and condition		Moment of inertia	Cross-sectional area for axial deformations	Cross-sectional area for shear deformations
Columns		$0.70I_g$	$1.0A_g$	b_wh
Walls	Uncracked	$0.70I_g$		
	Cracked	$0.35I_g$		
Beams		$0.35I_g$		
Flat plates and flat slabs		$0.25I_g$		

Types of deflection

- Long-term deflections (Shrinkage & creep)
  - Deflections increase significantly when loads are sustained for a long time.
  - Creep deformations are more significant in concrete than steel
  - Due to the complexity of calculation empirical relation to elastic deformation is used

Table 24.2.4.1.3—Time-dependent factor for sustained loads

Sustained load duration, months	Time-dependent factor ξ
3	1.0
6	1.2
12	1.4
60 or more	2.0

$$\Delta_{long} = \lambda \Delta_e$$

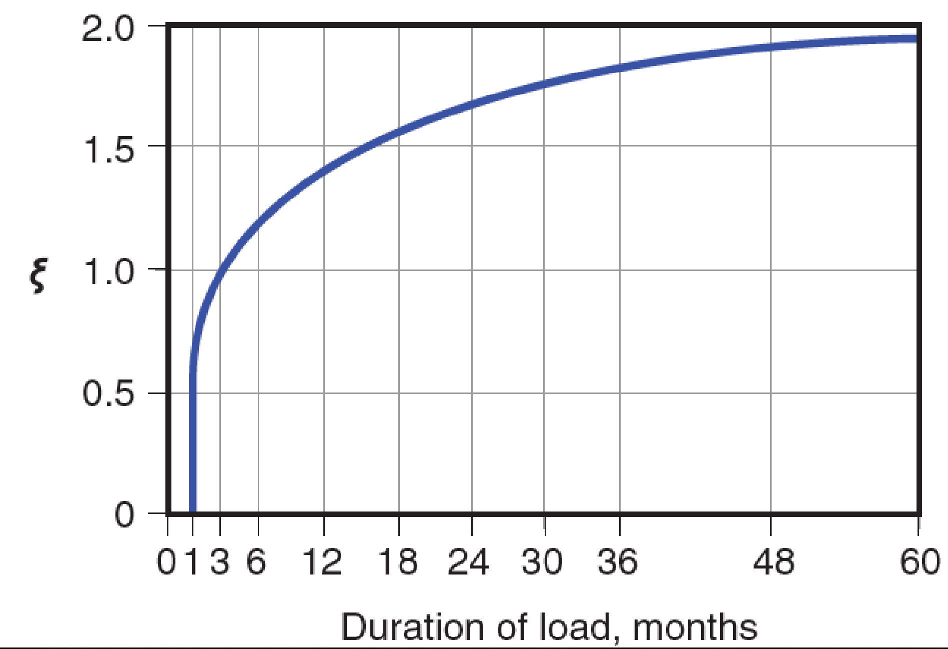
Where: Δ_l: additional long-term deflection

λ: Long-term multiplier, $\lambda = \frac{\xi}{1+50\,\rho'}$

ξ: time dependent factor for sustained load

ρ': Compression reinforcement ratio

Δ_e: immediate deflection caused by sustained load



Permissible (allowable) deflections

Table 24.2.2—Maximum permissible calculated deflections

Member	Condition		Deflection to be considered	Deflection limitation
Flat roofs	Not supporting or attached to nonstructural elements likely to be damaged by large deflections		Immediate deflection due to maximum of L_r, S, and R	$\ell/180$[1]
Floors	Immediate deflection due to L		$\ell/360$	
Roof or floors	Supporting or attached to nonstructural elements	Likely to be damaged by large deflections	That part of the total deflection occurring after attachment of nonstructural elements, which is the sum of the time-dependent deflection due to all sustained loads and the immediate deflection due to any additional live load[2]	$\ell/480$[3]
		Not likely to be damaged by large deflections		$\ell/240$[4]

[1]Limit not intended to safeguard against ponding. Ponding shall be checked by calculations of deflection, including added deflections due to ponded water, and considering time-dependent effects of sustained loads, camber, construction tolerances, and reliability of provisions for drainage.

[2]Time-dependent deflection shall be calculated in accordance with 24.2.4, but shall be permitted to be reduced by amount of deflection calculated to occur before attachment of nonstructural elements. This amount shall be calculated on basis of accepted engineering data relating to time-deflection characteristics of members similar to those being considered.

[3]Limit shall be permitted to be exceeded if measures are taken to prevent damage to supported or attached elements.

[4]Limit shall not exceed tolerance provided for nonstructural elements.

How to calculate deflections

- Based on these requirements
  - Within the floor (i.e. Not supporting non-structural elements)
    - We need to calculate the deflections due to addition of live load
      1. Calculate immediate deflection due to dead load $\Delta_D \rightarrow use\ M_D\ and\ I_e\ (for\ M_D)$
      2. Calculate immediate deflection due to dead & live loads $\Delta_{D+L} \rightarrow use\ M_{D+L}\ and\ I_e\ (for\ M_{D+L})$
      3. Calculate immediate deflection due to addition of live load $\Delta_L = \Delta_{D+L} - \Delta_D$
      4. Compare with allowable deflection
  - Supporting non-structural elements
    - We nee to calculate deflection due to sustained load (dead + sustained live load)
      1. Calculate immediate deflection due to dead load + sustained live load $\Delta_{D+SL} \rightarrow use\ M_{D+SL}\ and\ I_e\ (for\ M_{D+SL})$
      2. Calculate immediate deflection due to sustained live load $\Delta_{SL} = \Delta_{D+SL} - \Delta_D$
      3. Calculate the long-term deflection multiplier
      4. Calculate the total long-term deflection $\Delta_{long} = \Delta_L + \lambda_\infty \Delta_D + \lambda_t \Delta_{SL}$
      5. Compare with allowable deflection

Deflections

- Example:

  Simply supported beam with 6m span. The beam is supporting a uniform live load of 16 kN/m and uniform dead load of 12 kN/m. The beam cross section is 300mm x 550mm and reinforced with 4ϕ22 bars.

  $f_c' = 28\ MPa\ \ldots\ldots f_y = 420\ MPa$

Deflections