BOND STRENGTH

- ***Bond strength*** is defined as the resistive stress, against the pulling out of a steel bar from concrete mass, developed per unit surface area of a reinforcing bar.
- The bond stress balances the force present in the bar.
- In case of no bond, the steel bar will be pulled out of the concrete and the tensile force, T, will drop to zero, causing the beam to fail.

- ***Development length*** is the embedded length of bar that is sufficient to develop maximum expected force in the bar after strain hardening (generally taken as $1.15 f_y A_b$).
- Greater bond strength would mean smaller required development length.
- Development length of a larger diameter bar increases more rapidly due to smaller surface area compared with the area of cross-section.
- ***Splice length*** is defined as the lap length required to safely transfer the force from one bar to the surrounding concrete and then back in the other overlapped bar.
- It is used to extend length of a bar; although bars of different diameters may also be spliced.

FORCE TRANSFER BY BOND

- Bond is developed in a smooth bar embedded in concrete by the chemical adhesion between the steel and the concrete and some friction between the two materials.
- However, when the bar is pulled it is reduced in diameter due to Poisson's effect.
- The chemical adhesion and friction disappear after certain reduction in diameter.
- Smooth bars must always be anchored at the ends by hooks or other mechanical anchorages.

- In case of a deformed bar, the deformation provide bearing on the interlocked concrete besides chemical adhesion and friction between the two materials.
- The latter two mean of bond are eliminated upon application of tensile load and bond is only developed by the bearing stresses produced in the concrete around the steel deformations.
- The bond stress varies along the length of the bar as a complex function and generally the average bond stress is used for design calculations.

- The bond was primarily measured in the past by the ***pullout test*** and ***beam test*** with heavy transverse reinforcement.
- The failure in such cases is by breaking of the concrete present within the deformations and the bar is pulled out without any splitting of the concrete around the bars.

PULLOUT TEST

- To investigate the bond strength, a steel bar is cast inside a concrete block of large size, which is projecting from the block on one side.

- After the concrete hardening, the block is placed on a platform as shown in Fig. 11.1 and tensile load is applied on the bar.
- The load (P) at which the bar is pulled out is noted.
- The bond strength (μ) may then be calculated as follows:

Bond strength × surface area of bar = failure load

$$\mu \times (\pi\, d_b) \times \ell_d = P$$

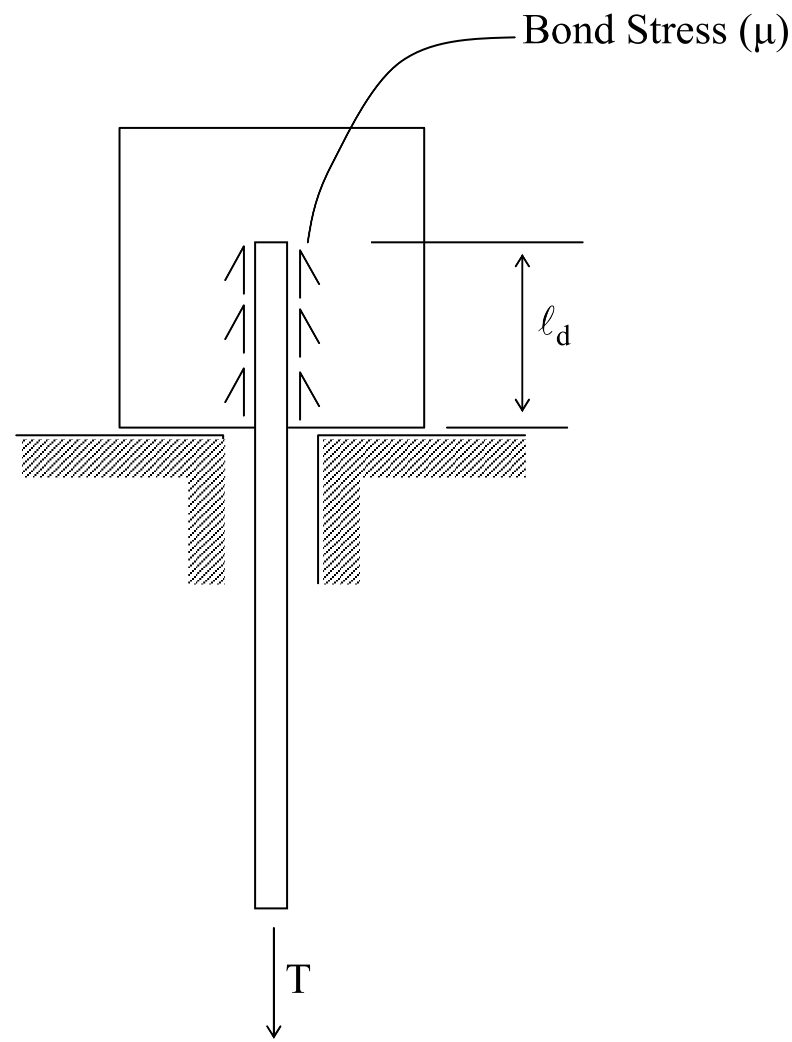

Fig. 11.1.Experimental Setup For Pullout Test.

$$\mu = \frac{P}{\pi d_b \ell_d}$$

where ℓ_d = length of the bar embedded in concrete.

The bond strength (μ) is found to be directly proportional to tensile strength of concrete or $\sqrt{f_c'}$. Early tests indicated that $\mu \approx 0.79\sqrt{f_c'}$ for bar numbers 10 through 29. However, the splitting strength alone is approximately $0.55\sqrt{f_c'}$ (MPa).

For an ideal design, the maximum force in steel bar must be equal to the available ultimate bond strength.

Bond failure is a brittle failure mechanism. To make development safe and ductile, we design for $1.15\, f_y$ stress in bar which includes capacity reduction factor and strain hardening in steel.

$$T = 1.15 A_b f_y = \mu (\pi d_b)\, \ell_d$$

$$\ell_d = \frac{1.15 A_b\, f_y}{\mu \pi d_b}$$

$$= \left(\frac{A_b\, f_y}{d_b}\right) \left(\frac{1.15}{\pi}\right) \times \frac{1}{0.79\sqrt{f_c'}}$$

$$= \frac{0.46\, A_b\, f_y}{d_b \sqrt{f_c'}} \cong \frac{0.36\, d_b\, f_y}{\sqrt{f_c'}}$$

- Later research showed that the pullout and other tests gave more bond strengths than the actual situation because of the following:
- The bearing of a big block on the surface prevents the splitting of the block due to its bigger size and the local bearing compression produced.
- The transverse reinforcement in beam tests can actually be less and reduce the bond strength.

FAILURE MODES

- Due to anchorage of deformations on the surface of steel bars, bearing stresses are produced in the concrete, which have a longitudinal and a radial component.
- When pull acts on the bar, the above radial component acts like an internal bursting pressure and concrete acts like a thick cylinder subjected to internal pressure.
- If sufficient cover is not available to steel bar, it cannot withstand the tensile stresses.

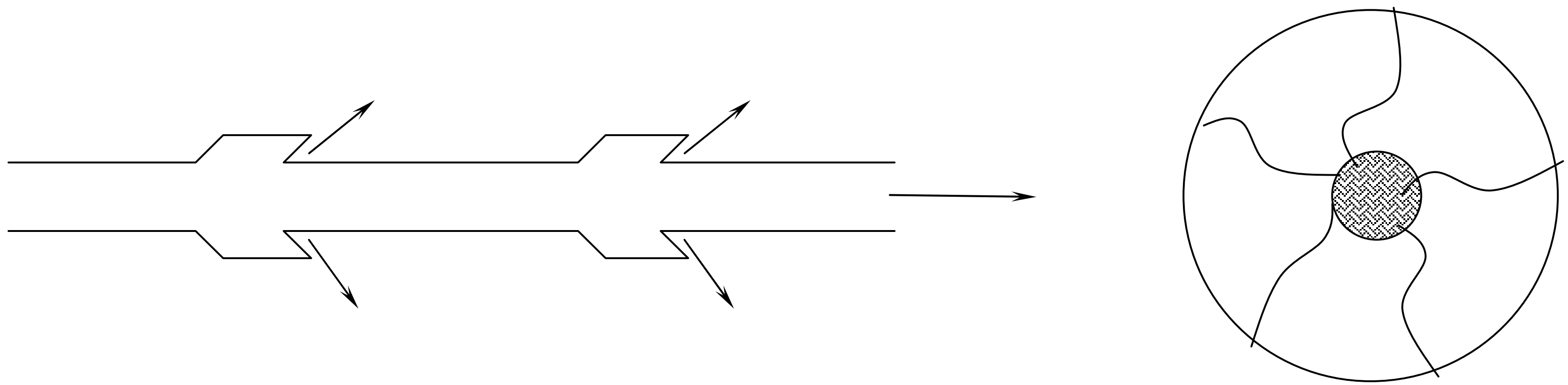

Fig. 11.2. Cracking in Concrete Due to Pull in Steel Bar.

- Eventually, the concrete splits parallel to the bar and the resulting crack extends up to the concrete surface.
- As shown in Fig. 11.2, a circle can be drawn around a bar in which burst pressure is critical.

- As the force in bar is increased, this circle touches with the outside and crack propagates towards that end.
- Similarly when this circle touches another circle from some other bar, crack occurs between the bars.
- The mechanisms of bond failure are explained below.

Side Split Mechanism

- This type of mechanism occurs when the spacing between the bars is much lesser and the splitting extends along the line of steel bars.
- At last, it breaks the outside cover and a part of concrete separates exposing the steel.
- The bottom cover is larger and hence the initial cracking does not propagate in this direction.

Edge cover, $c_{\mathrm{e}} > c_s / 2$

Governing cover parameter, $c_{\mathrm{b}} = c_s / 2$

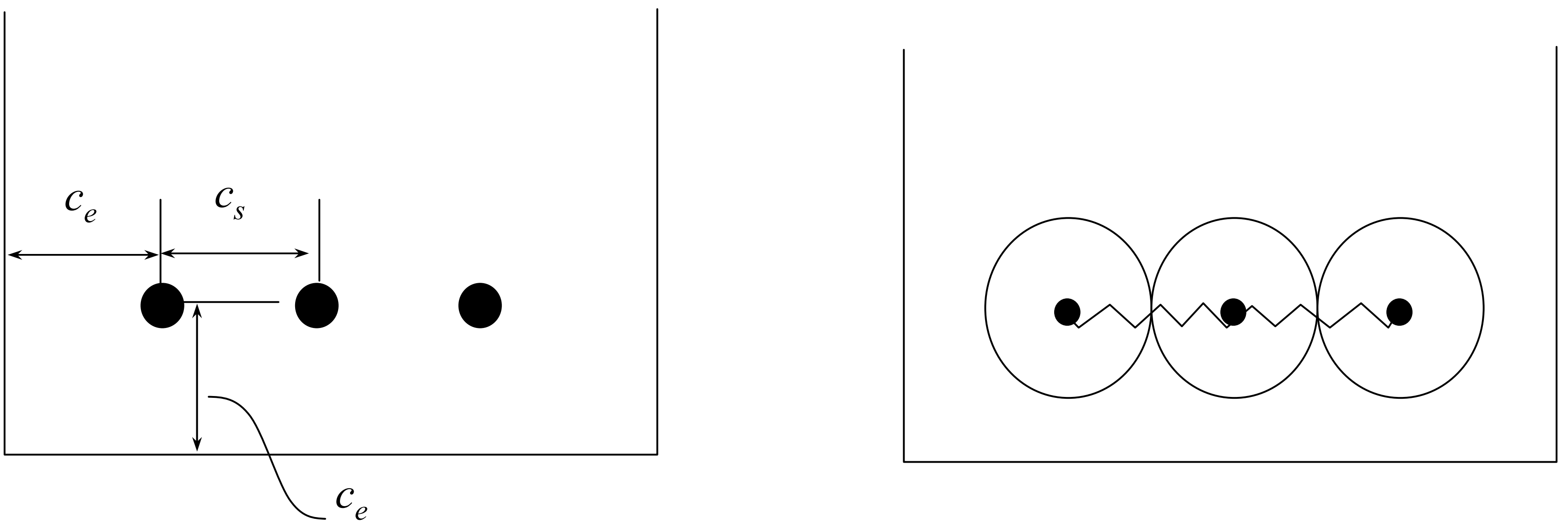

Fig. 11.3. Side Split Bond Failure Mechanism.