GOVERNMENT POLYTECHNIC
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DEPARTMENT OF CIVIL ENGINEERING
LECTURE NOTES

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CHAPTER-1

INTRODUCTION TO DESIGN AND DETAILING

2.1 Objectives Of Design and Detailing

Every structure must be **designed** to satisfy three basic requirements;

1) **Stability** to prevent overturning, sliding or buckling of the structure, or parts of it, under the action of loads;
2) **Strengths** to resist safely the stresses induced by the loads in the various structural members;
3) **Serviceability** to ensure satisfactory performance under service load conditions – which implies providing adequate stiffness to contain deflections , crack widths and vibrations within acceptable limits , and also providing impermeability , durability etc.

There are two other considerations that a sensible designer ought to bear in mind, viz. **economy** and **aesthetics.**

A good structural design often involving elaborate computations is a worthwhile exercise if only it is followed by good detailing and construction practices. In normal design practices it is often seen that analysis of structures for stress resultants and design of individual members (critical sections of beams, slabs and columns) for maximum load effects(bending moments, shear, torsion and axial forces) are done regularly with insufficient attention given to supposedly lesser important aspects e.g. termination, extending and bending of bars, anchorage and development, stirrup anchorage, splices, construction details at joints or connections (slab-beam, beam-column etc.), provision of continuity and discontinuity at connection of members , construction sequencing and reinforcement placement, deflection calculations and control, crack control, cover to reinforcement ,creep and shrinkage etc.

The factors as enumerated above are very critical from the point of view of a successful structure and needs to be fairly assessed with sufficient accuracy and spelt out in detail through various drawings and specifications by the designer so that the construction of the structure can be handled by the site engineer.

2.2 Advantages Of Reinforced Concrete

The following are major advantages of reinforced cement concrete (RCC)

- Reinforced Cement Concrete has good compressive stress (because of concrete).
- RCC also has high tensile stress (because of steel).
- It has good resistance to damage by fire and weathering (because of concrete).
- RCC protects steel bars from buckling and twisting at the high temperature.
- RCC prevents steel from rusting.
- Reinforced Concrete is durable.
- The monolithic character of reinforced concrete gives it more rigidity.
- Maintenance cost of RCC is practically nil.

It is possible to produce steel whose yield strength is 3 to 4 time more that of ordinary reinforced steel and to produce concrete 4 to 5 time stronger in compression than the ordinary concrete. This may high strength material offer many advantages including smaller member cross-sections, reduce dead load and longer spans.

2.3 Different Methods of Design

Over the years, various design philosophies have evolved in different parts of the world, with regard to reinforced concrete design. A design philosophy is built upon a few fundamental assumptions and is reflective of a way of thinking.

Working Stress Method:

The earliest codified design philosophy is that of **working stress method** of design (WSM). Close to a hundred years old, this traditional method of design, based on linear elastic theory is still surviving in a number of countries. In WSM it is assumed that structural material e.g. concrete and steel behave in linearly elastic manner and adequate safety can be ensured by restricting the stresses in the material induced by working loads (service loads) on the structure. As the specified permissible (allowable) stresses are kept well below the material strength, the assumption of linear elastic behavior considered justifiable. The ratio of the strength of the material to the permissible stress is often referred to as the factor of safety. While applying WSM the stresses under applied loads are analyzed by 'simple bending theory' where strain compatibility is assumed (due to bond between concrete and steel).

Ultimate Load Method:

With the growing realization of the shortcomings of WSM in reinforced concrete design, and with increased understanding of the behavior of reinforced concrete at *ultimate loads*, the ultimate load method of design (ULM) evolved in the 1950s and became an alternative to WSM. This method is sometimes also referred to as the *load factor method* or the *ultimate strength method.*

In this method, the stress condition at the state of impending collapse of the structure is analyzed, and the nonlinear stress-strain curve of concrete and steel are made use of the concept of 'modular ratio' and its associated problems are avoided. The safety measure in the design is introduced by an appropriate choice of the load factor, defined as the ratio of the ultimate load(design load) to the working load. This method generally results in more slender sections, and often more economical design of beams and columns (compared to WSM), particularly when high strength reinforcing steel and concrete are used.

Limit State Method:

The philosophy of the limit state method of design (LSM) represents a definite advancement over the traditional WSM (based on service load conditions alone) and ULM (based on ultimate load conditions alone). LSM aims for a comprehensive and rational solution to the design problem, by considering safety at ultimate loads and serviceability at working loads. The LSM uses a multiple safety factor format which attempts to provide adequate safety at ultimate loads as well as adequate serviceability at service loads by considering all possible 'limit states'

CHAPTER-2

WORKING STRESS METHOD OF DESIGN

2.1 General Concept

Working stress method is based on the behavior of a section under the load expected to be encountered by it during its service period. The strength of concrete in the tension zone of the member is neglected although the concrete does have some strength for direct tension and flexural tension (tension due to bending). The material both concrete and steel, are assumed to behave perfectly elastically, i.e., stress is proportional to strain. The distribution of strain across a section is assumed to be linear. The sections that are plane before bending remain plane after bending. Thus, the strain, hence stress at any point is proportional to the distance of the point from the neutral axis. With this a triangular stress distribution in concrete is obtained, ranging from zero at neutral axis to a maximum at the compressive face of the section. It is further assumed in this method that there is perfect bond between the steel and the surrounding concrete, the strains in both materials at that point are same and hence the ratio of stresses in steel and concrete will be the same as the ratio of elastic moduli of steel and concrete. This ratio being known as 'modular ratio', the method is also called 'Modular Ratio Method'.

In this method, external forces and moments are assumed to be resisted by the internal compressive forces developed in concrete and tensile resistive forces in steel and the internal resistive couple due to the above two forces, in concrete acting through the centroid of triangular distribution of the compressive stresses and in steel acting at the centroid of tensile reinforcement. The distance between the lines of action of resultant resistive forces is known as 'Lever arm'.

Moments and forces acting on the structure are computed from the service loads. The section of the component member is proportioned to resist these moments and forces such that the maximum stresses developed in materials are restricted to a fraction of their true strengths. The factors of safety used in getting maximum permissible stresses are as follows:

Material	*Factor of Safety*
For concrete	3.0
For Steel	1.78

Assumptions of WSM

The analysis and design of a RCC member are based on the following assumptions.

(i) Concrete is assumed to be homogeneous.

(ii) At any cross section, plane sections before bending remain plane after bending.

(iii) The stress-strain relationship for concrete is a straight line, under working loads.

(iv) The stress-strain relationship for steel is a straight line, under working loads.

(v) Concrete area on tension side is assumed to be ineffective.

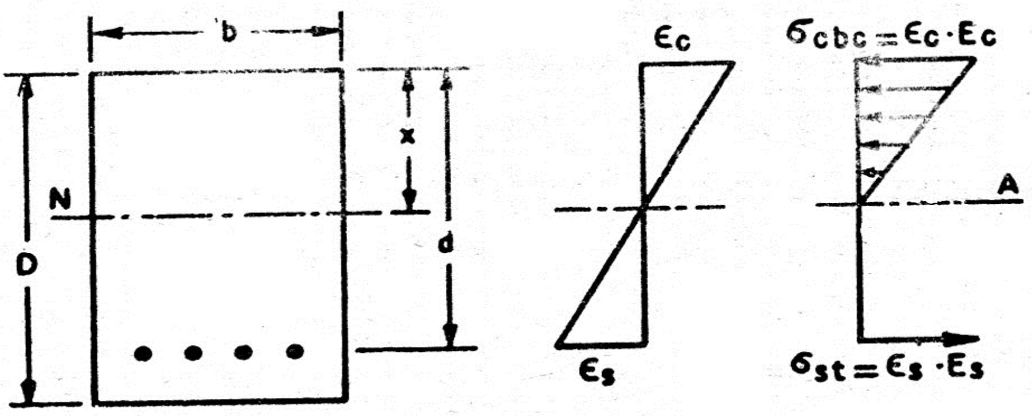
(vi) All tensile stresses are taken up by reinforcements and none by concrete except when specially permitted.

(vii) The steel area is assumed to be concentrated at the centroid of the steel.

(viii) The modular ratio has the value $280/3\sigma_{cbc}$ where σ_{cbc} is permissible stress in compression due to bending in concrete in N/mm^2 as specified in code(IS:456-2000)

Moment of Resistance

(a) *For Balanced section*: When the maximum stresses in steel and concrete simultaneously reach their allowable values, the section is said to be a 'Balanced Section'. The moment of resistance shall be provided by the couple developed by compressive force acting at the centroid of stress diagram on the area of concrete in compression and tensile force acting at the centroid of reinforcement multiplied by the distance between these forces. This distance is known as 'lever arm'.



(a) Rectangular Section with Reinforcement (b) Strain Distribution (c) Stress Distribution

Let in Fig.2.1(a-c): b = width of section

D = overall depth of section

d = effective depth of section (distance from extreme compression fiber to the centroid of steel area,

A_s = area of tensile steel

ϵ_c = Maximum strain in concrete,

ϵ_s = maximum strain at the centroid of the steel,

σ_{cbc} = maximum compressive stress in concrete in bending

σ_{st} = Stress in steel

E_s/E_c = ratio of Yong's modulus of elasticity of steel to concrete

= modular ratio 'm'

Since the strains in concrete and steel are proportional to their distances from the neutral axis,

$$\frac{\varepsilon_c}{\varepsilon_s} = \frac{x}{d-x} \text{ or } \frac{d-x}{x} = \frac{\varepsilon_s}{\varepsilon_c}$$

$$\frac{d}{x} - 1 = \frac{\sigma_{st.} E_c}{E_s \sigma_{cbc}} = \frac{\sigma_{st}}{m.\sigma_{cbc}}$$

Or

$$\frac{d}{x} = 1 + \frac{\sigma_{st}}{m.\sigma_{cbc}} \text{ or } x = \frac{1}{1 + \frac{\sigma_{st}}{m.\sigma_{cbc}}}.d = k.d$$

Where k= neutral axis constant= $\dfrac{1}{1 + \sigma_{st}/m\sigma_{cbc}}$

Total compressive force = $\dfrac{b.x.\sigma_{cbc}}{2}$

Total tensile forces = $\sigma_{st}.A_s$

Z= Lever Arm= $d - \dfrac{x}{2} = d - \dfrac{kd}{3} = d\left[1 - \dfrac{k}{3}\right] = j.d$

Where j is called the lever arm constant.

Moment of resistance = $MR = \dfrac{b.x}{2}.\sigma_{cbc}.jd = \dfrac{kd.j}{2}.\sigma_{cbc}.b.d = \dfrac{1}{2}k.j.\sigma_{cbc}.b.d^2 = Q.b.d^2$

Where Q is called moment of resistance constant and is equal to $\frac{1}{2}$. k. j. σ_{cbc}

(b) Under reinforced section

When the percentage of steel in a section is less than that required for a balanced section, the section is called 'Under-reinforced section.' In this case (Fig.2.2) concrete stress does not reach its maximum allowable value while the stress in steel reaches its maximum permissible value. The position of the neutral axis will shift upwards, i.e., the neutral axis depth will be smaller than that in the balanced section as shown in Figure2.2. The moment of resistance of such a section will be governed by allowable tensile stress in steel.

Moment of Resistance = $\sigma_{st}.Ast\left(d-\frac{x}{3}\right) = \sigma_{st}.A_s.j.d$ where, $j = 1-\frac{k}{3}$

Since $p = \frac{A_s.\times 100}{b.d}$

Moment of resistance

$$= \sigma_{st}\, p.\frac{bd}{100}.jd = \frac{\sigma_{st}\, p.j}{100}\, bd^2 = Qbd^2$$ Where, $Q = \frac{\sigma_{st}\, p.j}{100}$

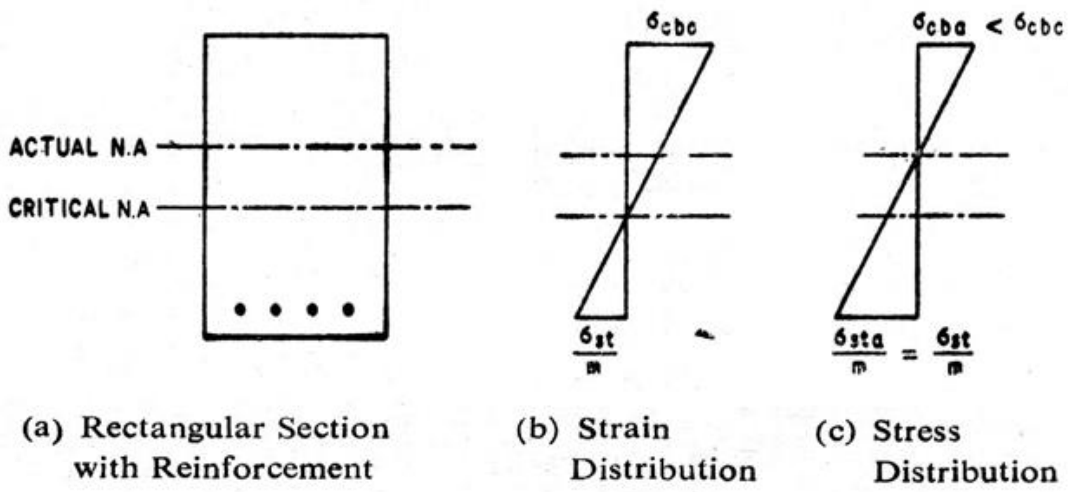


Fig.2.2 (a-c)

(c) **Over reinforced section**:

When the percentage of steel in a section is more than that required for a balanced section, the section is called 'Over-reinforced section'. In this case (Fig.2.3) the stress in concrete reaches its maximum allowable value earlier than that in steel. As the percentage steel is more, the position of the neutral axis will shift towards steel from the critical or balanced neutral axis position. Thus the neutral axis depth will be greater than that in case of balanced section.

Moment of resistance of such a section will be governed by compressive stress in concrete,

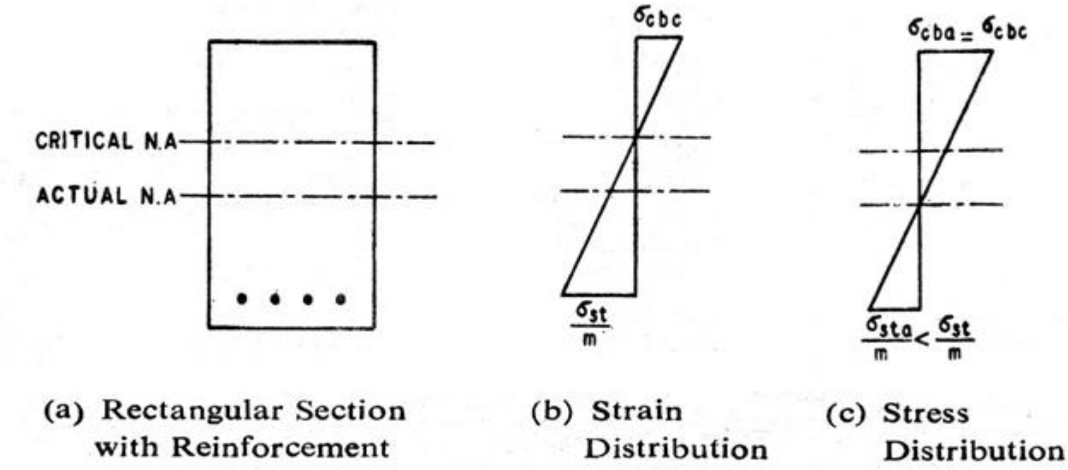


Fig.2.3 (a-c)

Moment of resistance = $b.x.\sigma_{cbc}.\frac{1}{2}\left(d - \frac{x}{3}\right) = \frac{\sigma_{cbc}}{2}.b.d.x.\left(1 - \frac{k}{3}\right)$

$= \frac{\sigma_{cbc}}{2}.b.d.x.j = \frac{1}{2}.\sigma_{cbc}.k.j.b.d^2 = Q.b.d^2$ where, $Q = \frac{1}{2}.\sigma_{cbc}.k.j$ = Constant

Basic concept of design of single reinforced members

The following types of problems can be encountered in the design of reinforced concrete members.

(A) Determination of Area of Tensile Reinforcement

The section, bending moment to be resisted and the maximum stresses in steel and concrete are given.

Steps to be followed:

(i) Determine k, j, Q (or Q') for the given stress.

(ii) Find the critical moment of resistance, $M=Q.b.d^2$ from the dimensions of the beam.

(iii) Compare the bending moment to be resisted with M, the critical moment of resistance.

(a) If B.M. is less than M, design the section as under reinforced.

$$M = \sigma_{st}.Ast\left(d - \frac{x}{3}\right)$$

To find A_{st} in terms of x, take moments of areas about *N.A.*

$$b.x.\frac{x}{2} = m.Ast.(d-x)$$

$$A_{st} = \frac{b.x^2}{2(m)(d-x)} \quad \therefore \quad M = \frac{\sigma_{st}.b.x^2}{2.m.(d-x)}\left(d - \frac{x}{3}\right) = \text{B.M . to be resisted}$$

Solve for 'x', and then A_s can be calculated.

(b) If *B.M.* is more than *M*, design the section as over-reinforced.

$M = \frac{\sigma_{cbc}}{2}.b.x.\left(d - \frac{x}{3}\right) = B.M.$ to be resisted. Determine 'x'. Then A_s can be obtained by taking moments of areas (compressive and tensile) about using the following expression.

$$A_s = \frac{b.x^2}{2.m.(d - x)}$$

(B) Design of Section for a Given loading

Design the section as balanced section for the given loading.

Steps to be followed:

(i) Find the maximum bending moment (*B.M.*) due to given loading.

(ii) Compute the constants k, j, Q for the balanced section for known stresses.

(iii) Fix the depth to breadth ratio of the beam section as 2 to 4.

(iv) From $M=Q.b.d^2$, find'd' and then 'b' from depth to breadth ratio.

(v) Obtain overall depth 'D' by adding concrete cover to'd' the effective depth.

(vi) Calculate A_s from the relation

$$A_{st} = \frac{B.M.}{\sigma_{st}.j.d}$$

(C) To Determine the Load carrying Capacity of a given Beam

The dimensions of the beam section, the material stresses and area of reinforcing steel are given.

Steps to be followed:

(i) Find the position of the neutral axis from section and reinforcement given.

(ii) Find the position of the critical *N.A.* from known permissible stresses of concrete and steel.

$$x = \frac{1}{1 + \frac{\sigma_{st}}{m.\sigma_{cbc}}}.d$$

(iii) Check if (i) > (ii)- the section is over-reinforced

(i) < (ii)- the section is under-reinforced

(iv) Calculate M from relation

$$M = \frac{1}{2}.b.x.\sigma_{cbc}\left(d - \frac{x}{3}\right)$$ for over-reinforced section

and $M = \sigma_{st}.\left(A_{st}.\ d - \frac{x}{3}\right)$ for under -reinforced section

(v) If the effective span and the support conditions of the beam are known, the load carrying capacity can be computed.

(D) To Check The Stresses Developed In Concrete And Steel

The section, reinforcement and bending moment are given.

Steps to be followed:

(i) Find the position of *N.A.* using the following relation.

(E) Determine lever arm, $z = d - \frac{x}{3}$

(F) $B.M. = \sigma_{st}.A_s.z$ is used to find out the actual stress in steel σ_{sa}.

(G) To compute the actual stress in concrete σ_{cba}, use the following relation.

B

Doubly Reinforced Beam Sections by Working Stress Method

Very frequently it becomes essential for a section to carry bending moment more than it can resist as a balanced section. Such a situation is encountered when the dimensions of the cross section are limited because of structural, head room or architectural reasons. Although a balanced section is the most economical section but because of limitations of size, section has to be sometimes over-reinforced by providing extra reinforcement on tension face than that required for a balanced section and also some reinforcement on compression face. Such sections reinforced both in tension and compression are also known as "Doubly Reinforced Sections". In some loading cases reversal of stresses in the section take place (this happens when wind blows in opposite directions at different timings), the reinforcement is required on both faces.

MOMENT OF RESISTANCE OF DOUBLY REINFORCED SECTIONS

Consider a rectangular section reinforced on tension as well as compression faces as shown in Fig.2.4 (a-c)

Let b = width of section,

d = effective depth of section,

D = overall depth of section,

d'= cover to centre of compressive steel,

M = Bending moment or total moment of resistance,

M_{bal} = Moment of resistance of a balanced section with tension reinforcement,

A_{st} = Total area of tensile steel,

A_{st1} = Area of tensile steel required to develop M_{bal}

A_{st2} = Area of tensile steel required to develop M_2

A_{sc}= Area of compression steel,

σ_{st} = Stress in steel, and

σ_{sc} = Stress in compressive steel

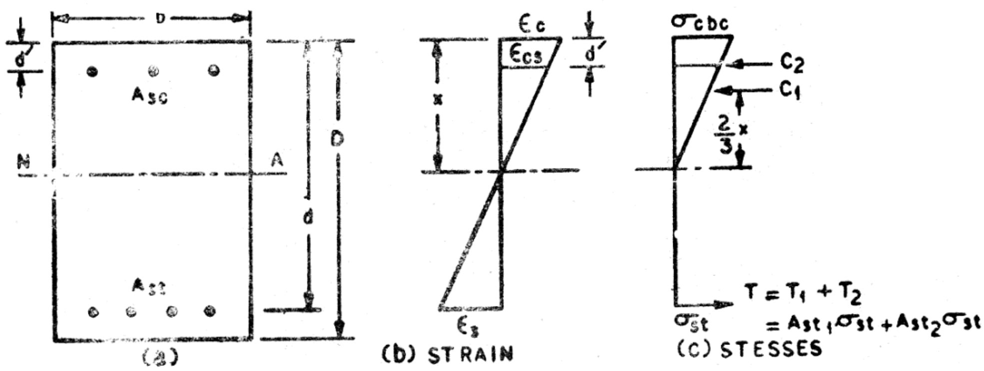


Fig.2.4 (a-c)

Since strains are proportional to the distance from *N.A.*,

$$\frac{Strain\ in\ top\ \ fibre\ \ of\ \ concrete}{Steel} = \frac{x}{x - d'}$$

Strain in Compression

$$\frac{\sigma_{cbc} / E_C}{\sigma_{sc} / E_s} = \frac{x}{x - d'}$$

$$\frac{\sigma_{cbc}}{\sigma_{sc}} \cdot \frac{E_s}{E_c} = \frac{x}{x - d'}$$

$$\sigma \quad = \sigma \quad . \frac{x}{\quad} .m$$