CHAPTER TWO

LITERATURE REVIEW

1.1. REINFORCED CONCRETE

Reinforce concrete is a non-homogeneous material that contains concrete and steel reinforcement. Concrete is made of cement, fine aggregate (sand), coarse aggregate (gravel), water and other additive materials. Concrete (plain concrete) possesses high compressive strength but little tensile strength and therefore, it cracks easily. In order to provide strength in tension, a steel rod (bar) is embedded in the plain concrete to produce reinforced concrete structures.

Steel and concrete work readily for several reasons (Wang and Salmon, 1979)

- Bond (interaction between bars and surrounding hardened concrete) prevents slip of the bars relatives to the concrete.
- Proper concrete mixes provide adequate impermeability of the concrete against bar corrosion.
- Sufficiently similar rate of thermal expansion: 0.000010 – 0.000013 for concrete and 0.000012 for steel per degree Celsius.

2.2. SNI PROVISION FOR SEIMIC RESISTANT

The loadings are calculated in this final project are dead load, live load, and earthquake load with the combination that based on SK SNI T-15-1991-03 subchapter 3.2.2 about the factor load:

- Required strength (U) to support Dead load (D) and Live load (L):

  $U = 1.2\,D + 1.6\,L$ ....(2.1)

- Earthquake (E) loading is considered, so:

  $U = 1.05\,(D + L_R \pm E)$ or $U = 0.9\,(D \pm E)$..................................(2.2)

Design strength of the structure is calculated based on the Strength reduction factors:

- Flexure, without axial load = 0.8
- Axial tension and flexure with axial tension = 0.8
- Axial compression and flexure with axial compression
  - ✓ Members with spiral reinforcement = 0.7
  - ✓ Other reinforced members (column with ties)= 0.65
- Shear and torsion = 0.6
- Bearing on concrete = 0.7

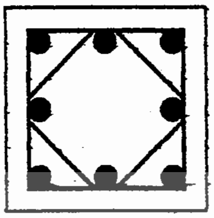
2.3. COLUMN

2.3.1. Introduction

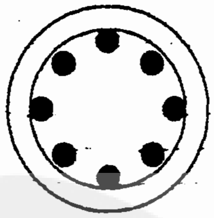
Columns are structural elements used primarily to support axial compressive loads. As compression members subjected to pure axial load rarely exist, columns normally support combined bending moment and axial load.

2.3.2. Type of column

Most reinforced concrete columns have circular or rectangular cross sections and are reinforced with longitudinal bars. To ensure that longitudinal reinforcement will be securely placed so that bars will not be pushed out of position when concrete is poured and compacted in column forms, the longitudinal steel is wired to lateral reinforcement to form a rigid cage. If individual hoops of steel, called ties, are used to position the longitudinal steel, the column is called a *tied column*. If the longitudinal steel is placed in a closely spaced continuous spiral and wired to it, the column is termed a spiral column. A composite column is one in which a structural steel shape, pipe, or tubing is used, with or without additional longitudinal bars. One common arrangement may contain a structural steel shape completely encased in concrete, which further reinforced with both longitudinal and lateral reinforcement (spiral or ties) as shown in figure 2.1 (c).



(a) Tied column



(b) Spiral Reinforced column

(c) Composite Column
(spiral bound encasement
around structural steel core)

Figure 2.1. Type of Columns

2.3.1. Strength of Short Columns for Axial Load and Moment

The basic problem in column design is to establish the proportion of a reinforced concrete cross section whose theoretical strength, multiplied by a reduction factor, is just adequate to support the axial load and maximum moment in the column produced by factored design loads. This criterion can be summarized as:

$$P_u \le \phi P_n \quad and \quad M_u \le \phi M_n \quad \text{.......} \quad (2.3)$$

where P_u and M_u are the axial load and moment produced by factored service loads, and P_n and M_n are the theoretical axial and bending strengths, also referred to as the nominal strengths.

Since the stress distribution produced by axial load and moment depends on the cross section's proportions, which are not initially known, column design cannot be carried out directly. Instead, the proportions of a cross section must be estimated and then investigated to determine whether its capacity is adequate for the design loads. Although various combinations of steel and concrete areas are possible to support a particular set of loads. Code restrictions on the percentage of steel and architectural limitations on dimensions usually result in similar cross sectional dimensions regardless of who designs the column.

The axial load capacity decreases when the moment is also present. A plot of the column load capacity against the moment it can carry is called a column interaction diagram. Schematically, figure 2.2 shows such a diagram, with key points and areas noted.

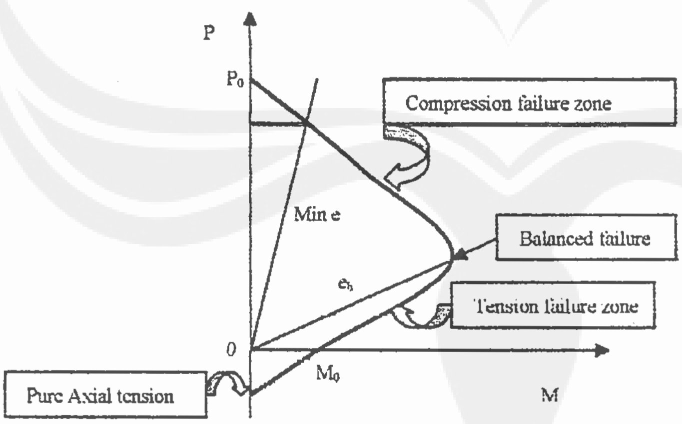


Figure 2.2. Column Interaction Diagram

2.3.1.1. Axial Load Capacity

Although in design, axial load without moment is not a practical case, P_0 is a convenient theoretical limit and one well document experimentally.

The ultimate strength of either a tied or a spiral column as shown in figure 2.3, axially loaded, as:

$$\begin{aligned} P_0 &= 0.85 f_c' A_n + f_y A_{st} \\ &= 0.85 f_c' \left(A_g - A_{st}\right) + f_y A_{st} \end{aligned} \qquad \text{...(2.4)}$$

where:

P_0 = ultimate load capacity (yield point strength) of tied or spiral column when eccentricity is zero (for ideal materials and dimensions)

A_n = net area of concrete = $A_g - A_{st}$

A_g = gross area of concrete

A_{st}= area of longitudinal column reinforcement

f_c'= standard cylinder strength of concrete

f_y= yield point stress for steel

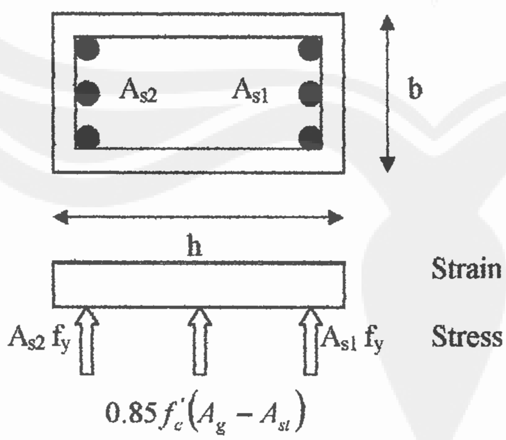


Figure 2.3 Axial Load Capacity

However, to account for the effect of accidental moments, the maximum load on a column may not exceed 0.8 P_0 for tied columns and 0.85 P_0 for spirally reinforced column.

2.3.1.2 Balanced Loading

Any column, regardless of its reinforcement, will reach its balanced strain at ultimate load when the load is so placed as to maintain the eccentricity $e_b = M_b / P_b$. Balanced in a column is a matter of loading, and it is more descriptive to speak of balanced loading rather than of a balanced column. Furthermore, although it is possible to avoid balanced beams in order to avoid compression failures and thus obtain ductility, it is not possible to avoid either compression failures or balanced failures in column; these are primarily compression members.

Balanced condition can be explain as the loading condition that produces at ultimate strength, simultaneously, a strain of 0.003 in the extreme fiber of concrete and the strain $\varepsilon_y = f_y / E_s$ on the tension steel.

For a balanced failure, from similar triangles of strain diagram of Figure 2.4, we have

$$c_b = \frac{0.003}{E_s + 0.003} \cdot d = \frac{0.003E_s}{f_y + 0.003E_s} \cdot d$$
$$c_b = \frac{600}{600 + f_y} \cdot d \qquad \text{...(2.5)}$$

and

$$a_b = \beta_1 c_b \qquad \text{...(2.6)}$$

where

c_b = distance of neutral axis from compression surface as flexural failure impends when cross section reinforced with balanced steel

d = distance from extreme compression fiber to centroid of flexural reinforcement

E_s = modulus elasticity of steel

a_b = depth of equivalent stress block

β_1 = ratio of depth of stress block a to the distance between neutral axis and extreme compression fiber

Forces equilibrium requires:

$$P_{nb} = C_{cb} + C_{sb} - T_{sb} \quad \text{.......(2.7)}$$

where

$$C_{cb} = 0.85 f_c' a_b b \quad \text{.......(2.8)}$$

$$C_{sb} = A_s\left(f_y - 0.85 f_c'\right) \quad \text{.......(2.9)}$$

$$T_{sb} = A_s f_y \quad \text{.......(2.10)}$$

Therefore

$$P_{nb} = 0.85 f_c' a_b b + A_s (f_y - 0.85 f_c') - A_s f_y \quad \text{.......(2.11)}$$

Moment about the centroid of column can be formulated as:

$$M_{nb} = P_{nb} \times e_b = C_{cb}\left(\frac{h}{2} - \frac{a_b}{2}\right) + C_{sb}\left(\frac{h}{2} - d'\right) + T_{sb}\left(d - \frac{h}{2}\right) \quad \text{.......(2.12)}$$

In which:

C_{cb} = force in compression concrete

C_{sb} = force in compression steel

T_{sb} = tension force in steel

P_{nb} = value of axial load producing balanced failure in column

A_s = area of flexural steel

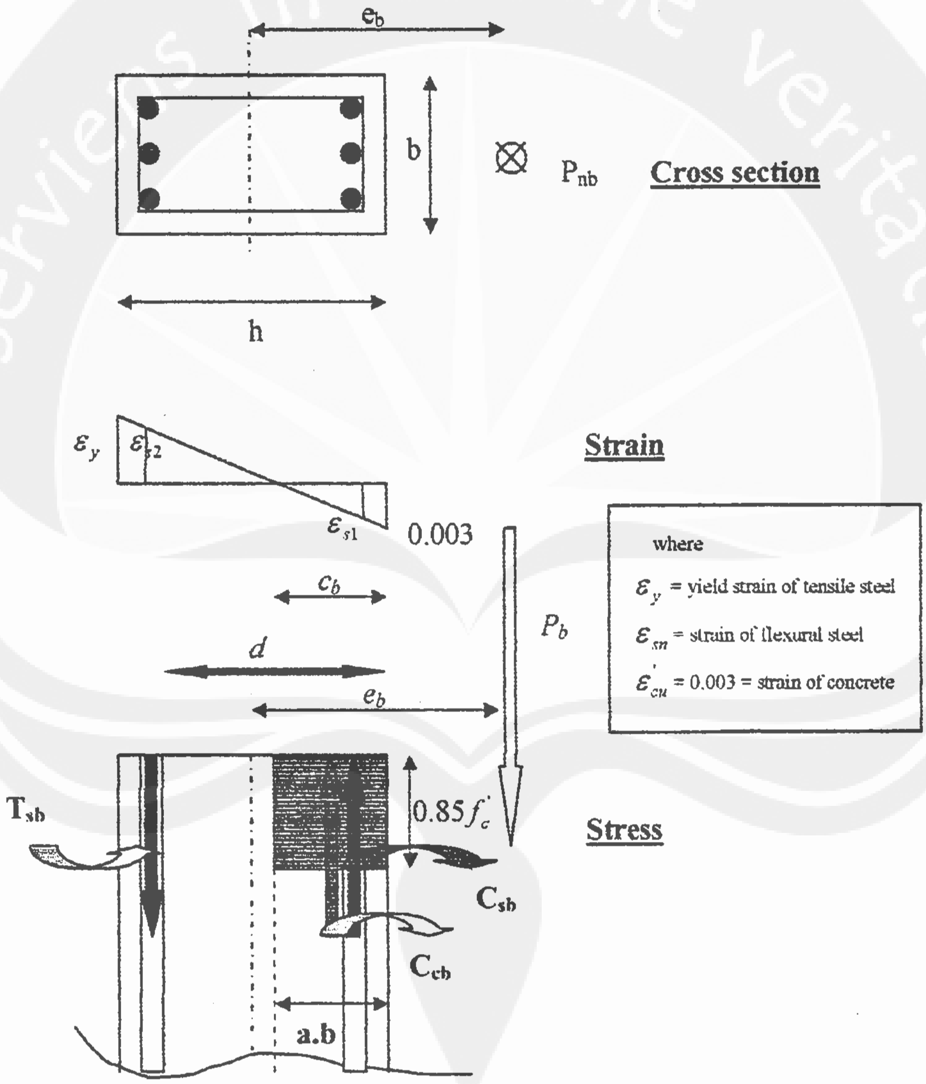


Figure 2.4. Balanced Failure

2.3.1.3 Compression and Tension Failure

Based on the magnitude of the strain in the steel reinforcement as shown in figure 2.5, at tension side, the section is subjected to one of these conditions:

a. Tension failure by initial yielding of steel at the tension side. Tension in a large portion of the section such that the strain in the tension steel is greater than the yield point strain when the compressive strain in the concrete reaches 0.003.

b. Compression failure by initial crushing of the concrete at the section such that the compressive strain in the concrete reaches 0.003 before the tension steel yields.

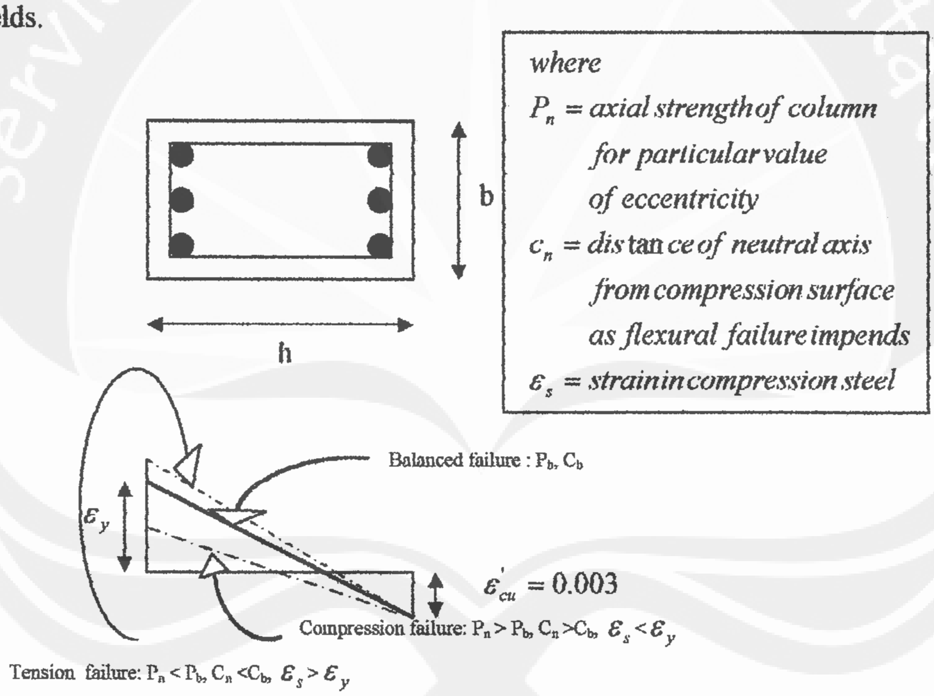


Figure 2.5. Strain Diagram of Column

2.3.1.4. Rectangular Sections with Bars at Four Faces

When a section bars distributed at all faces, the derivation of equations for analysis and design becomes difficult because the bars may be at various stress levels throughout the section. The analysis of such a section can be carried out using the requirements of strain compatibility and equilibrium.

Consider the symmetrically reinforced column section shown in figure 2.6 at the ultimate load. For the general bar i in the section, the strain diagram indicates that

$$\varepsilon_{si} = \left(\frac{c - d_i}{c}\right)0.003 \quad \text{......(2.13)}$$

where compressive strains are positive, and tensile strains are negative. Then the stress f_{si} in bar i is given by the following relationships. If

$$\varepsilon_{si} \geq \frac{f_y}{E_s}, \quad f_{si} = f_y$$

or if

$$\frac{f_s}{E_s} > \varepsilon_{si} > -\frac{f_y}{E_s}, \quad f_{si} = \varepsilon_{si} E_s \quad \text{......(2.14)}$$

or if

$$\varepsilon_{si} \leq -\frac{f_y}{E_s}, \quad f_{si} = f_y$$

The stress in concrete:

$$C_c = 0.85 f_c' ab \quad \text{......(2.15)}$$

where,

$$a = \beta_1 c \quad \text{......(2.16)}$$

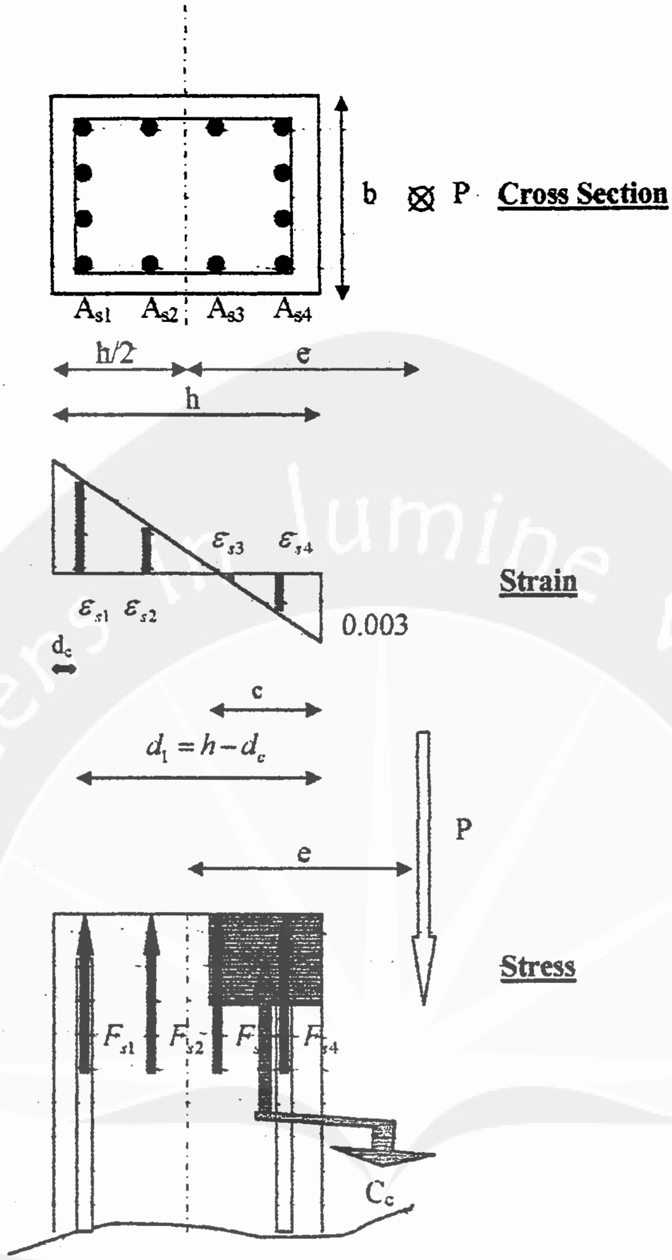


Figure2.6 Eccentrically Loaded Column Section with Bars at Four Faces at the Ultimate Load

The stresses in the steel layer:

If c < d_i:

$$F_{si} = A_{si} f_{si} \quad (\textit{negative in tension}) \quad \text{(2.17)}$$

If $c > d_i$:

$$F_{si} = A_{si}\left(f_{si} - 0.85 f_c^{'}\right) \rightarrow displaced\ concrete \quad \ldots\ldots(2.18)$$

The force in the bar *i* is then given by $A_{si} f_{si}$ where A_{si} is the area of bar *i*.

The equilibrium equations for a section with n bars may be written as

$$P_u = C_c + \sum_{i=1}^{n} F_{si}$$
$$P_u = 0.85 f_c^{'} ab + \sum_{i=1}^{n} f_{si} A_{si} \quad \ldots\ldots(2.19)$$

$$M_n = P_u e = 0.85 f_c^{'} ab\left(\frac{h}{2} - \frac{a}{2}\right) + \sum_{i=1}^{n} f_{si} A_{si}\left(\frac{h}{2} - d_i\right) \quad \ldots\ldots(2.20)$$

2.4. EARTHQUAKE LOAD

Earthquake horizontal base shear force can be calculated using static equivalent analysis:

$$V = c \cdot I \cdot K \cdot W_t \quad \ldots\ldots(2.21)$$

Where:

V = horizontal base shear force

c = base shear coefficient

I = building type factor

K = structural type factor (ductility level)

W_t = total weight of the building

Note: For determine the c value, we need to calculate the T (natural period):

$T = 0.06 H^{3/4}$ for reinforced concrete structure……………(2.22)

The Earthquake horizontal load can be working in each floor which formulated as:

$$F_i = \frac{W_i \cdot H_i}{\sum W_i \cdot H_i} \cdot V \qquad (2.23)$$

where:

F_i = earthquake horizontal load in each floor

W_i = i floor weight

H_i = i floor height from based of the building

V = horizontal base shear force