# CHAPTER II
# THEORETICAL BACKGROUND

In this chapter, the properties of structures for earthquake resistance design and the specifications of the American Association of State Highway and Transport Officials (AASHTO) regarding the determination of longitudinal and lateral reinforcements of concrete columns for non-seismic and seismic areas are discussed. Finally, the concrete models for both cover and core concrete are presented.

## 2.1 Structural Properties for Earthquake Resistance Design

Paulay and Priestly (2002) described the fundamental properties of structures for lateral force design as follow:

### 2.1.1 Strength

The strength of a structural member is the maximum lateral force that it can resist. In the capacity design concept, member strength must be designed to control failure of a structure to the flexural mode. So, brittle failure could be avoided and ductility is ensured through the provision of sufficient energy dissipation to the structure.

### 2.1.2 Stiffness

Stiffness is the property of structure that quantifies its resistance against impending displacement or deformation. In the design of structures under gravity or earthquakes, possible lateral displacements that may affect the serviceability or failure of the structural or non-structural components should be approximated from stiffness.

### 2.1.3 Ductility

Ductility is a property describing the ability of structures to deform in-elastically under several cycles of displacements larger than the yield displacement wherein there is no significant strength degradation. The displacement ductility is defined as:

$$\mu = \frac{\delta_m}{\delta_y} \tag{2.1}$$

where

$\delta_m$ = ultimate displacement when the resistance reduced by 20% from maximum load

$\delta_y$ = yielding displacement

## 2.2 Column Reinforcement According to the AASHTO Standard Specifications (2002)

### 2.2.1 Requirements for Non-seismic Design

1) Longitudinal Reinforcement

The minimum and maximum area of longitudinal steel reinforcement shall be greater than 1% and less than 8% times the gross area, $A_g$, of the column section, respectively. The minimum number of longitudinal reinforcing bars should be six for bars in a circular arrangement and four for bar in a rectangular arrangement. The minimum size of bars shall be No. 5 (16 mm).

2) Lateral Reinforcement

Spiral reinforcement for compression members shall consist evenly spaced continuous bar or wire with a minimum diameter of 3/8 inch. The volumetric ratio, $\rho_s$, of spiral reinforcement for a circular column shall be computed using Equation 2.2.

$$\rho_s = 0.45 \left( \frac{A_g}{A_c} - 1 \right) \frac{f_c'}{f_y} \tag{2.2}$$

where

$A_g$ = gross area of section;

$A_c$ = area of core of spirally reinforced compression member measured to the outside diameter of the spiral;

$f_c'$ = specified compressive strength of concrete; and

$f_y$ = specified yield strength of spiral reinforcement ($\leq$ 60,000 psi).

The clear spacing shall be the greater of 1 inch or 1 1/3 times the maximum size of coarse aggregate. Anchorage of spiral reinforcement shall be provided by 1 ½ extra turns of spiral bar or wire at each end.

For tie reinforcement, all bars shall be enclosed by lateral ties which shall be at least No.3 in (10 mm) size for longitudinal bars that are No. 10 (32 mm) or smaller, and at least No. 4 (13 mm) in size for No. 11 (36 mm), No. 14 (43 mm), No. 18 (57 mm) and bundled longitudinal bars. The spacing of ties shall not exceed the least dimension of the compression member or 12 inches (30 mm). When two or more bars larger than No. 10 (32 mm) are bundled together, tie spacing shall be 1/2 as specified above. Ties shall be placed not more than half of tie spacing from the face of a footing or from the nearest longitudinal reinforcement of a cross-framing member.

2.2.2 Requirements for seismic Design

1) Longitudinal Reinforcement

The specifications for longitudinal reinforcements are consistent with the provisions of non-seismic design standard.

2) Lateral Reinforcement

The transverse reinforcement for confinement shall have yield strength not more than that of the longitudinal reinforcement. The volumetric ratio of spiral reinforcement, $\rho_s$, shall be equal to or greater than that obtained from either Equation (2.3a) or (2.3b) whichever is larger.

$$\rho_s = 0.45\left[\frac{A_g}{A_c} - 1\right]\frac{f_c'}{f_{yh}} \qquad (2.3a)$$

$$\rho_s = 0.12\frac{f_c'}{f_{yh}} \qquad (2.3b)$$

where

$A_g$ = gross area of section

$A_c$ = area of core of spirally reinforced compression member measured to the outside diameter of the spiral

$f_c^{'}$ = specified compressive strength of concrete

$f_{yh}$ = yield strength of transverse reinforcement.

The total gross sectional area, $A_{sh}$, of rectangular hoop or stirrup reinforcement for a rectangular column shall be the greater of Equation (2.4a) or (2.4b).

$$A_{sh}=0.30ah_c\frac{f_c^{'}}{f_{yh}}\left[\frac{A_g}{A_c}-1\right] \qquad (2.4a)$$

$$A_{sh}=0.12ah_c\frac{f_c^{'}}{f_{yh}} \qquad (2.4b)$$

where

$A_{sh}$ = total cross-sectional area of hoop (stirrup) reinforcement including supplementary cross ties having a vertical spacing of a (mm) and crossing a section having a core dimension of $h_c$ (mm). This should be calculated for both principal axes of a rectangular column

a = vertical spacing of hoops (stirrups) with a maximum value 150 mm

$f_c^{'}$ = specified compressive strength of concrete

$f_{yh}$ = yield strength of hoop or spiral reinforcement

$h_c$ = core dimension of tied in the direction under consideration.

For the spacing of transverse reinforcement for confinement, it shall be provided at the top and bottom of the column over a length equals to the maximum cross sectional column dimension or 1/6 of the clear height of the column whichever is the larger, but not less than 450 mm.

Transverse reinforcement shall be extended into the top and bottom connections for a distance equal to a half of the maximum column dimension or greater than 375 mm from the face of the column connection into the adjoining member. In addition, the maximum spacing for reinforcement shall not exceed the smaller of 1/4 of minimum member dimension or 150 mm.