CHAPTER 3

REVIEW OF LITERATURE

3.1 Introduction

A critical review of the published literature in the field of present study reveals that work available on thin-walled compression members is only related to steel and research on reinforced concrete thin-walled compression members is scant. However, review of published literature directly related to the scope of the investigation either in reinforced concrete or otherwise is presented under the following heads.

i. Torsional - Flexural Buckling

ii. Rigid Plastic Theory

iii. Local Buckling

iv. Experimental Programmes.

3.2 Torsional - Flexural Buckling

Chajes and Winter [9] have presented a simple method to account for the torsional - flexural buckling of thin-walled linear elastic compression member with singly symmetric sections subjected to axial loading. The solution of equilibrium equations to determine torsional - flexural buckling load is presented in interaction form. The
interaction equation as given or in the form of curves provide a simple method for checking singly symmetric sections against torsional-flexural buckling. They provide relatively uncomplicated and straightforward procedure for determining the torsional-flexural buckling using the interaction equation along with charts to determine certain geometric constants involved in the calculation for sections investigated. A criterion is presented to determine the critical buckling mode for any given section based on its geometric parameters. The theory applicable only for linear elastic materials is further restricted to pin-ended and to completely fixed end columns. The appropriateness of the theory to predict the load carrying capacity of actual columns were evaluated based on available experimental evidence including tests made by them. Extension of the theory to point-symmetric sections and for columns with other end conditions are briefly cited.

Pekoz and Winter [35] have studied the general behaviour of linear elastic thin-walled singly symmetric open sections under eccentric loading in the plane of symmetry. Galerkin's method of solution are presented for equation of equilibrium of a thin-walled column loaded by longitudinal load with biaxial eccentricities for various combinations of end conditions assuming the functions for the deflection components. The solution is extended to
monosymmetric sections and the behaviour is analysed for complete range of possible eccentricities with example. Galerkin's method of solution is compared with exact solutions and observed to give satisfactorily accurate results. The solution presented is valid for indefinitely elastic material. The effect of precritical deflections is introduced to the basic theory and the behaviour is explored. Simplified interaction equations for various eccentricity ranges are presented to calculate torsional - flexural load for use in design. Charts are provided to facilitate the computational procedure. Experimental confirmation of the theory is cited.

3.3 Rigid Plastic Theory

Murray [29, 30, 31, 32, 50] used the rigid plastic theory to study the post - collapse behaviour by plotting the rigid plastic curve (draw down curve or collapse curve) for steel thin-walled structures. This behaviour is studied to determine the nature of failure, whether ductile or brittle. A method of measuring the ductility of the structure during failure is presented. He has shown that the plastic mechanism of a member can be analysed by combining certain basic plastic mechanisms so as to satisfy the requirements of compatibility and equilibrium. He has classified the mechanisms into true mechanism and quasi-mechanisms and presented the definition for them. Eight
basic mechanisms have been identified and their characteristic equations are presented. Typical examples are cited to show how the basic mechanisms and full plastic zones could be combined to form the plastic mechanism and analysed. The theoretical results are compared with experimental results and the theory is found to underestimate the load carrying capacity during collapse. The reason quoted for such discrepancy is that the mechanism do not always form at the centre of the uniform strut and in quasi-mechanism strain hardening in the plastic zone is neglected.

3.4 Local Buckling

Bleich [6] has discussed the fundamental laws which control the behaviour of compressed plates under the various conditions of restraint to which the plate elements of a column are subjected to and has provided the basis for reliable rules for the required thickness of steel plates for practical purposes. He has dealt with rectangular plates subjected to uniformly distributed compressive loading on two opposite edges with loaded edges hinged and the following end conditions at unloaded edges,

i. both edges elastically restrained

ii. one edge elastically restrained and the other free
which are the governing problems in local buckling of plate elements of thin-walled columns.

Stress anisotropy is introduced when critical stress exceeds proportional limit. The differential equation of equilibrium and boundary conditions are suitably modified to account for stress anisotropy and continuity of plates introducing a non-dimensional factor called coefficient of restraint. This factor depends on the dimensions of the restraining plate and buckling plate. The solution of differential equations lead to stability conditions in transcendental form. Charts and expressions are presented using these conditions, to facilitate the calculation of buckling coefficients and minimum buckling coefficients for various values of coefficient of restraint. Thin-walled columns being formed of long plates, critical stresses are calculated using minimum buckling coefficients. Approximate but simple method of determining the coefficient of restraint taking into account the effect of compressive stresses is provided. Expressions to calculate coefficient of restraint offered on web plates of I, channel and Z sections, outstand of flanges of I, channel and Z sections, webs of T section and outstanding legs of angles are presented. A design criteria for the required thickness to prevent premature failure of compression members by local buckling has been formulated.
Buison [7,8] has presented the determinantal equations for various edge conditions at unloaded edges of a buckled plate under uniform compressive stresses which are derived from the solution of fundamental differential equation of the buckled plate. An intermediate end condition of elastic restraint, where bending moments along an edge, as the plate deflects, are proportional to the angle of rotation is cited. The garland curves for buckling coefficient and aspect ratio for the various conditions are presented. The importance of minimum buckling coefficient which is normally taken as the buckling coefficient for long plates is examined using the energy method. Values of minimum buckling coefficient for plates with equal restraints along both unloaded edges and for plates restrained along one longitudinal edge and free along the other are presented in graphical form. Generalised methods are presented to derive the overall stability equation and hence the elastic buckling stress. Application of the method to some of the structural forms are presented.

Swartz and his associates [42, 43, 44, 45] made a pioneering study on the strength of slender reinforced concrete wall panels with simply supported edges. Using Hognestad's parabolic stress-strain curve and regarding concrete to be uncracked at the onset of buckling, the buckling loads were worked out. They made use of elastic
plate stability equation and their plate constants were based on both isotropic and orthotropic material behaviour. The theoretical results of the investigation were compared with results of tests conducted on concrete plates. The testing arrangement adopted by them and the details of the experimental results of twenty-four panels have been reported. They have prepared design charts for the design of panels with continuous support conditions.

Jayagopal [21] has made a detailed study on buckling of thin reinforced concrete wall panels subjected to in-plane axial loads with the following edge conditions.

i. all edges hinged

ii. three edges hinged and the fourth edge (unloaded edge) free

Buckling loads were calculated using stress-strain relationship reported by Desayi [12] using tangent modulus approach. Both stress isotropy and anisotropy are compared. Solutions are derived using energy approach. Based on the curves presented, approximate formulae are derived for practical use in predicting buckling loads. Results of sixteen panels with all edges hinged and eleven panels with one unloaded edge free and other three edges hinged are reported and compared with the theoretical findings.
3.5 Thin-Walled Reinforced Concrete Panels

No organised theoretical and experimental studies have been conducted on the behaviour and load carrying capacity of thin-walled open reinforced concrete columns. Even where studies have been conducted, [11, 13, 14, 15, 28, 47, 51] simplified conclusions have been drawn and only empirical design equations are proposed. The equations suggested for flat wall panels [1, 16, 25, 33, 36] have been used in most of the cases. The investigation on ferrocement wall panels conducted by Desayi and his associates helps as first information for understanding the structural behaviour and computation of ultimate strength of ferrocement panels.

Desayi and Joshi [13] have conducted a series of tests on undulated ferrocement wall panels (lipped trough sections and angle sections) which help as first information for the understanding of structural behaviour of the panels. A series of eight axially loaded specimens were tested by them to determine the influence of slenderness ratio and amount of reinforcement. Deflections were measured at salient locations. Specimens have failed with a cracking noise and exposed meshes were observed to have buckled. Deflections noticed were not large. They have observed that local buckling of the plates of the wall element or overall instability of the elements were not noticed at the failure of the specimen. They have suggested expressions taking
into account slenderness ratio and contribution from mesh and bar reinforcement. They have concluded from this series of tests that theoretical Euler buckling load and plate buckling load were found to be very large and ruled out the possibilities of buckling failure.

Desayi and Prasanna Kumar [14] have reported the results of nine light weight ferrocement panels of folded plate cross sections with varying slenderness ratio and reinforcement. They have indicated that prediction equations used for normal weight ferrocement wall elements did not work in the case of light weight wall panels.

Desayi and Gopal [15] have tested twelve specimens under varying small eccentricities to study the effect of eccentricity. They have transformed the section into equivalent section and equation for stress resultants are derived using equilibrium. They have felt the need for including the buckling effects in the prediction equations to arrive at improved solutions.

The lateral deformation of the cross sections of the specimens tested by Desayi et al., indicate that the phenomenon of torsional - flexural buckling had initiated which have not been accounted in the theoretical investigations made by them.
3.6 Concluding Remarks

Available literature has been reviewed which indicate that the work relating to theoretical and experimental investigations on thin-walled reinforced concrete columns have been very limited in quantity, scope and rigour. Even where studies have been conducted, simplified conclusions have been drawn and only empirical equations have been presented.