CHAPTER 3
LITERATURE REVIEW

Literature pertaining to the present work may be divided into three major categories. The first category relates to the studies on blast loading and its effects on structures. The second one is concerned with the behaviour of ferrocement subjected to impulsive loads. The last category deals with the nonlinear analysis of frames. The literature relating to these categories has been reviewed and the observations on the available literature are presented below.

3.1 BLAST AND BLAST LOADING

The major research on blast loading and its effects have been carried out in large scale by governments and the information from these tests were kept as secret for security reasons. Hence, only a few laboratory tests attempted by individual researchers found place in technical journals. One of the pioneering works on blast and blast loading was due to Newmark and Hansen [3]. This work illustrated the effect of nuclear blast on structures and recommended design procedures to withstand air blast. Simplified design charts were presented in this treatise, for the design of elasto-plastic structural elements subjected to a triangular pulse load. The nature and magnitude of load applied to various types of structures as a result of exposure to air blasts were discussed. Loading on the above ground and below ground structures were also dealt with separately.

Dowding [4],[8],[9] published extensive work on blast loading especially subsurface blast such as quarry and mining blast. Propagation of blast waves in rock or soil was investigated and the parameters affecting the blast transmission were analysed. The blast vibrations in a number of residential structures in the vicinity of mining sites were
monitored and reported. Based on the vibration records, the dynamic response properties namely the natural frequency and damping were determined. Using these properties, a single degree of freedom system had been modelled to find the combined response for air blast and ground motions due to blast. Dowding concluded from these studies that the natural frequency of the model had the greatest influence on model response and the damping coefficient was less significant. The works published concentrated mainly on subsurface blasting and consequent ground motions and suggested suitable instrumentation for blast monitoring.

Liebmann [10] conducted experiments to assess the pressure-time histories from bursting gas vessels in closed rooms. Two sets of tests were conducted in a closed room, first one with TNT explosives and then with gas storage vessels. The results were compared to evolve a TNT equivalent. A linear wave model was developed for finding the burst pressure at any point in the room assuming the explosion always occurred at the centre of the room producing a spherical wave front from the gas vessel burst. The magnitudes of blast in these cases were very heavy and the tests were carried out in a specially designed and well protected chamber. However, this work is useful in assessing the pressure-time histories that are likely to be produced during a gas vessel burst.

Wiss and Nicholls [11] investigated the damages and cracking to a residential structure due to an experimental blast under the soil and with the help of the compiled data, they found the peak particle velocity to be the best index of blast induced cracking in residential structures. This work focussed its attention on subsurface blast and the consequent cracking of residential buildings.

Woodson and Kiger [12] tested a number of reinforced concrete slabs to ascertain the stirrup requirements for blast resistance. The slabs were loaded to a very large uniform pressure in a gas chamber and the response in terms of support rotations were measured. The results of these tests indicated that the requirements for shear reinforcements in
the blast resistant manuals are highly conservative and suggested an effective way of improving the ductility at a lesser cost. The experiments, though could produce pressures equivalent to a blast, the pressure-time history could not be simulated for a realistic situation.

Watson, Hobbs and Wright [13] measured the damages caused to reinforced concrete T beams and slabs by contact and close proximity explosive charges using different areas of contact and angles of inclination for the explosives. Experiments of blast on the prototype and model specimens were conducted to find the agreement between the prototype and model behaviour. A good qualitative agreement between the damage caused to model and prototype elements was reported for a scale ratio of 1:2.5. This work though did not involve any quantitative conclusions on the reactions, displacements and strains of the tested elements, showed that laboratory tests on models can be attempted to study the effects of blast loading.

Ellis and Crowhurst [14] reported an experimental study for the elastic response of panels to gas explosions. A large scale explosion test facility was developed to conduct the tests with sophisticated instrumentation. A single degree of freedom system elastic model was adopted to predict the response of the panel analytically. The results compared well indicating that if the dynamic characteristics of any panel can be measured accurately, then the response of the panel to a given explosion can be determined accurately. This study has proved the applicability of simple analytical methods for the blast response of structural elements.

Though wide ranging studies have been conducted on large scale blast loading on actual structures and methods developed for blast resistant design, the creation of a realistic air blast environment within the laboratory for model testing is not found to have been reported by anyone.
3.2 FERROCEMENT UNDER DYNAMIC ENVIRONMENT

Reinhorn and Prawell [6] had presented an useful observation in employing ferrocement for improving dynamic characteristics of a shake table facility. This work emphasized the usefulness of ferrocement as a material in a dynamic system. This opened a new series of investigation on the dynamic characteristics of ferrocement, and its adaptability as a supporting material in a dynamic environment like impact and blast. The authors found the use of ferrocement to be advantageous because of ease of construction, improved tensile properties, crack control, reduced dimensions and light weight as compared with similar structures made of reinforced or prestressed concrete. In the opinion of the authors, the performance of ferrocement made it suitable for construction of vibration sensitive structures or seismic resistant components.

In order to examine the energy absorption capacity of ferrocement, impact tests were conducted by a few authors. The reported literature based on these tests are reviewed below.

Shah and Key [15] conducted tensile and impact tests on ferrocement specimens and showed that the superior cracking performance of ferrocement is primarily due to the large surface area of reinforcement and to the consequently improved bond. Impact testing was carried out with Izod's type pendulam hammer on small square panels of ferrocement. Impact strengths were found for varying specific surface and ductility of reinforcement.

Nimityongsul, Chen Bor-shiun and Karasudhi [16] presented a method for predicting single strike impact resistance of ferrocement boat hulls. 49 panels with varying steel content and specific surface of the reinforcing mesh were tested by drop weight impact testing procedure. Impact resistance was worked out based on the cracking and the subsequent leakage in storing water for a specified period. In this work no measurement on forces or deformations was attempted. Hence this investigation presented a limited application for water retaining structures.
Grabowski [17] reported the results of numerous tests conducted on ferrocement slabs subjected to impact loads both by drop impact and Charpy impact. In drop impact test, two types of projectiles with different weights were used. The influence of thickness of the element and the specific surface of mesh reinforcement on the impact resistance were studied. The crater depth was taken to be an index of the cumulative damage and the formation of perforation going through the entire thickness of the slab was considered as failure. No dynamic measurements were made to quantify the response. However, this work attempted to quantify the impact damage and presented a procedure for impact testing.

It is seen from the reported literature on impact testing of ferrocement that all the works were more of qualitative in nature and that there is a large scope for the investigation of ferrocement under other dynamic environments such as blast. Quantitative assessment of the resistance of ferrocement to these loadings also are yet to be explored.

3.3 FRAME ANALYSIS

3.3.1 Effect of cladding on frame response

Goodno and Palsson [18] considered the effect of architectural precast cladding on the dynamic response of high rise buildings. They presented four different analytical models to account for this effect in the finite element analysis of framed structures. An inter-storey shear stiffness model, an incremental failure model, a hysteresis model and a slotted connection model were used for the lateral stiffening effect of the building facade. It was found that the added stiffness provided by the architectural elements might alter the overall structural response substantially and invalidate response predictions based on a model of the frame alone for selected ground motion cases.

Henry and Roll [19] analysed the interaction between a precast wall cladding panel and a reinforced concrete frame under linear static and dynamic forces. They developed a modified cladding element to be used
along with the frame elements. It was shown that the natural period of vibration changed significantly by the inclusion of cladding elements. The forces on the connectors also were found to increase enormously when compared to those produced by the normally considered gravity loads of the elements. Significant changes in the lateral displacement, natural frequency, member force distribution and connector forces were indicated by the results when compared with a frame neglecting the structural characteristics of the cladding.

The above two works prove the importance of cladding on the response of frames subjected to dynamic loads and indicate the methods to account for them.

3.3.2 Nonlinear analysis of frames

The behaviour of rigid frames in the inelastic region both under static and dynamic loads has been the subject of many earlier investigators. Some of these works, based on which the inelastic blast analysis of frames is carried out by the author, are presented below.

Bozzo and Gambarotto [20] developed a method to analyse multi-storey frames beyond the elastic limit taking the geometrical nonlinearities into account. The plastic zones were assumed to be concentrated at the ends of the members and a single stiffness matrix was developed to describe the behaviour of the member in the presence of plastic hinges at one or both ends of the member. An incremental iterative procedure was adopted for the analysis of the frame. The work presented an effective way of incorporating inelastic action in the behaviour of the frame.

Gunnin, Rad, and Furlong [21] formulated a computational technique for the general nonlinear analysis of large planar frames under static loading. The moment - thrust - curvature relationships were reduced to polynomials to represent the material behaviour. Axial shortening, P-Δ effects and beam-column effects were also included in the analysis. This paper presented a comprehensive procedure of inelastic
static analysis of plane frames.

Anderson and Gupta [22] found that, for a given ductility ratio and strain hardening rate, frames could be designed so that most of the inelastic action is evenly distributed in the girder elements while the columns remain elastic. They listed the inelastic stiffness coefficients in beam elements for various end conditions.

Beam-column experiments were carried out by Galambos and Van Kuren [23] to verify the interaction formulae suggested by American Institute of Steel Construction (AISC). They reported good correlation between the estimated values and the experimental results.

Nigam [24] stressed the importance of interaction between forces existing at sections where yielding occurs during the inelastic response of frames. He derived force–displacement relations to incorporate such interaction and established that interaction causes yielding, leading to dissipation by hysteresis and permanent set, at load levels lower than those corresponding to elasto-plastic behaviour without interaction.

Neuss and Maison [25] employed a linear solution approach in the matrix formulation to account for P–A effects in the static analysis of frames.

Czeslaw Cichon [26] used a total Lagrangian approach in formulating the fundamental incremental equations of a large displacement problem. The plasticity effects were taken into account by combining the incremental solution procedure with tangent modulus method of iterations. However, this method was expected to involve heavy computations in dynamic situations.

Claes Dyrbye [27] developed a method for analysing plane frames subjected to ground motions or dynamic forces using numerical integration with an approximation of constant acceleration at each time step. This method, employing the Newmark's method of numerical integration, had the
advantages of lesser computer space and easier understanding. The accuracy was improved by smaller time steps. However, too small a time step would enormously increase the computer time.

The various methods of P-Δ analysis of building structures were reviewed by Regina Galotti and Smith [28]. A new method based on the actual gravity loading applied to successive deflected shapes was developed. The methods were differentiated by the factors such as accuracy, ease of use, mode of use and whether they were applicable to all types of structures or to specific ones.

On going through the available literature on dynamic analysis of frames including elasto-plastic behaviour and second order effects etc., the need is felt for a single programme which incorporates all those aspects so as to analyse structures subjected to blast.