CHAPTER 2

REVIEW OF LITERATURE

2.1 GENERAL

This chapter presents the literature reviewed on the self compacting concrete with fly ash content on various material properties of self compacting concrete and structural action on concrete structures. A brief review on the experimental studies of self compacting concrete structures is presented. They are then followed by the experimental investigation on the behaviour of beam, column and exterior beam column joints under earthquake type loading reported in the literature.

2.2 LITERATURE REVIEW ON SELF COMPACTING CONCRETE

Nan et al. (2001) proposed a new mix design method for self-compacting concrete in which the amount of aggregates required was determined and the paste of binders is then filled into the voids of aggregates to ensure that the concrete thus obtained has flowability, self-compacting ability and other desired SCC properties. The amount of aggregates, binders and mixing water as well as type and dosage of superplasticizer to be used are the major factors influencing the properties of SCC. Slump flow, V-funnel, L-flow, U-box and compressive strength tests were carried out to examine the performance of SCC and the results indicate that the proposed method could produce successfully SCC of high quality.
Bouzoubaa and Lachemi (2001) stated that SCC has gained wide use for placement in congested reinforced concrete structures with difficult casting conditions. For such applications, the fresh concrete must possess high fluidity and good cohesiveness. The use of fine materials such as fly ash can ensure the required concrete properties. The initial results of an experimental program aimed at producing and evaluating SCC made with high volumes of fly ash are presented and discussed. The mechanical properties of hardened concrete such as compressive strength and drying shrinkage were also determined. The SCCs developed 28-day compressive strengths ranging from 26 to 48 MPa. The results show that an economical SCC could be successfully developed by incorporating high volumes of class F fly ash. They concluded that it is possible to design SCC incorporating high volumes of class F fly ash. The HVFA SCCs have a slump flow in the range of 500-700 mm, a flow time ranging from 3 to 7 seconds, a segregation index ranging from 0.025 to 0.129 ml/cm².

Steffen and Walraven (2001) concluded self-compacting concrete offers several economic and technical benefits by the inclusion of steel fibres in SCC. Steel fibres bridge the cracks and retard their propagation, and improve several characteristics and properties of the concrete. Fibres are known to significantly affect the workability of concrete. Therefore, an investigation was performed to compare the properties of plain SCC and SCC reinforced with steel fibres. Two mixtures of SCC with different aggregate contents were used as reference. Each of the concretes was tested with four types of steel fibres at different contents in order to answer the question to what extent the workability of SCC is influenced. The slump flow, a fibre funnel and the J-ring test were used to evaluate the material characteristics of the fresh concrete. This paper discussed the suitability of the applied test methods and the effect of the coarse aggregate content, the content and type of steel fibres on the workability of SCC.
Subramanian and Chattopadhyay (2002) conducted research on an approximate mix proportion of self-compacting concrete, which would give the procedure for the selection of a viscosity modifying agent, a compatible superplasticizer and the determination of their dosages. The Portland cement was partially replaced with fly ash and blast furnace slag, in the same percentages as Ozawa has done before. The two researchers have tried to determine different coarse and fine aggregate contents from those developed by Okamura. The coarse aggregate content was varied, along with water-powder (cement, fly ash and slag) ratio, being 50%, 48% and 46% of the solid volume.

Youjun et al. (2002) in their paper presented the preparation technology of high strength SCC containing ultrapulverized fly ash (UPFA) and superplasticizer. After selecting the parameters of mix proportions, a SCC with good workability, high mechanical properties and high durability was developed. The experimental results indicate that the fresh mixture has low slump loss. The compressive strength of concrete reached 80 MPa and the concrete presents low permeability, good freeze-thaw resistance and low drying shrinkage. They concluded that

(i) The workability of high-strength SCC with UPFA can be evaluated by the method combining slump flow and L-box test.

(ii) The effect of UPFA on fresh concrete is to improve the viscosity of fresh concrete and its effect is the same as that of a viscosity agent. It does not decrease the flowability of fresh concrete.
(iii) This SCC with UPFA has higher mechanical properties, excellent impermeability and freezing resistance and lower drying shrinkage.

Geiker et al. (2002) conducted test on Torque versus time during testing of the rheological properties of fresh concrete. The testing was performed in a BML viscometer and on a self-compacting concrete \((w/c = 0.45, 70\%\) rapid hardening Portland cement, 3\% silica fume, 27\% fly ash, third generation super plasticizer). He concluded that the relaxation period needed to obtain steady-state flow may affect the rheological properties estimated and should be taken into account in the selection of measuring procedures. Non steady state is likely to cause an overestimation of the plastic viscosity and an underestimation of the yield value. Furthermore, lack of steady state may explain the apparent shear-thickening behaviour of self-compacting concrete reported elsewhere.

Bui et al. (2002) developed a simple apparatus and a rapid method for testing the segregation resistance of self-compacting concrete (SCC). Extensive test programs on SCC with differences in water–binder ratios, paste volumes, combinations between fine and coarse aggregates and different types as well as different contents of cements and mineral admixtures were carried out. The test results showed that the developed apparatus and method are useful in rapidly assessing the segregation resistance of SCC in both vertical and horizontal directions.

Soylev and Francois (2003) investigated the influence of steel–concrete interface defects on reinforcing steel corrosion. The defects that were analyzed in this paper relate to the gaps caused by bleeding, settlement and segregation of fresh concrete under horizontal reinforcing bars. These defects are increasing with the concrete depth below the horizontal reinforcement and depend on the bleeding capacity of concrete mixture. Various concrete
mixtures including self-compacting concrete were tested. The defects at the interface were characterized by the ultimate bond strength recorded in a pullout test and by the defect length under the reinforcement measured with a video microscope. The results indicate a good correlation between these two characterization methods. The corrosion was measured by the resistance of polarization and corroded surface area. The results allow us to conclude that the quality of conventional concrete and steel–concrete interface, decreases with height of concrete section and hence affects directly the corrosion rate.

Bertil (2003) analysed the salt frost scaling and internal frost resistance of self-compacting concrete that contained increased amount of filler, different air content and dissimilar methods of casting. The results were compared with the corresponding properties of normal concrete with the same water-to-cement ratio (0.39) and air content (6%). The start of the testing was applied at ages of 28 and 90 days. The strength development of the concrete was followed in parallel. Six SCC mixes and two NC mixes were studied. The effects of normal and reversed order of mixing (filler last), increased amount of filler, fineness of filler, limestone powder, increased air content, and large hydrostatic concrete pressure were investigated. The results indicated a substantial improvement of the internal frost resistance of SCC as compared to NC. The salt frost scaling performed more or less in the same way in SCC and in NC. No relationship of frost resistance was found to the air-void structure of the concrete.

Hajime and Masahiro (2003) discussed about mechanism for achieving self-compactibility, factors of self-compactability in terms of test results, rational mix design method, new type of superplasticizer suitable for SCC and segregation-inhibiting agent. They concluded that rational mix design method and an appropriate acceptance testing method at job site have both largely been established for SCC.
Bertil (2003) studied on sulphate resistance of self-compacting concrete. For this more than 40 cylinders of concrete were subjected to a solution with sodium sulphate, sea or distilled water during 900 days. Age at start of testing was either 28 or 90 days. Weight and internal fundamental frequency were measured. Comparison was done with the corresponding properties of vibrated concrete. When cured in a solution with sodium sulphate, the results show larger loss of mass of SCC than that of vibrated concrete probably due to the limestone filler content in SCC. After curing in water, sea or distilled, no such weight difference between the curing types was observed. Internal fundamental frequency did not decrease or differ between the two types of concrete, i.e. no internal deterioration took place due to thaumasite sulphate attack during the 900 days of exposure.

Violeta (2003) stated that non pozzolanic fillers are frequently used to optimise the particle packing and flow behaviour of cementitious paste in self-compacting concrete (SCC) mixes. He had dealt with the influence of finely ground limestone and crushed limestone dust on the properties of SCC mixes in the fresh and hardened state. Mixes were prepared using poorly graded crushed limestone aggregate. To compensate the lack of fine material in the crushed sand, a viscosity agent was added to the mixtures. The results obtained indicate that finer and better-graded limestone dust significantly increases the deformability of the paste. When a high volume of this filler was added to the SCC mix, the required self-compacting properties were achieved at a lower water/ (cement + filler) ratio, and it also appeared that the addition of filler improves the 28-day compressive strength of concrete mixes due to the filler effect and improved fine-particle packing.

Hyun et al. (2003) focussed on the rheological design and modification of the material ingredients for self-consolidation behavior in the
fresh state. The rheological design adopts complementary electrosteric dispersion and stabilization technique to obtain cement pastes with desirable flow properties at constant particle concentrations dictated by the micromechanics based design. Such stabilization is realized by optimizing the dosages of strong polyelectrolyte and non-ionic polymer and by controlling the mixing procedure of the polymers. The fresh cement paste designed thereby leads to fresh mortar mix with desirable deformability, cohesiveness, and high consistency, and thus satisfies the self-consolidating performance of fresh ECC (Engineered Cementitious Composite) mix. In addition, ductile strain-hardening performance of the self consolidating ECC is confirmed through uniaxial tensile test. This ductile composite with excellent fluidity can be broadly utilized for a variety of applications, e.g. in repair of deteriorated infrastructures requiring horizontal formworks, or in seismic-resistant structures with dense reinforcements and requiring high ductility.

Wenzhong and Bartos (2003) have done an experimental study on permeation properties of a range of different self-compacting concrete mixes in comparison with those of selected traditional vibrated reference concretes of the same strength grade. The SCC mixes with characteristic cube strength of 40 and 60 MPa were designed containing either additional powder as filler or containing no filler but using a viscosity agent. The results indicated that the SCC mixes had significantly lower oxygen permeability and sorptivity than the vibrated normal reference concretes of the same strength grades. The chloride diffusivity, however, appeared to be much dependent on the type of filler used; the SCC mixes containing no additional powder but using a viscosity agent were found to have considerably higher diffusivity than the reference mixes and the other SCCs.

Corinaldesi and Moriconi (2004) had produced self-compacting concrete thin precast elements with homogeneously dispersed steel fibres
instead of ordinary steel-reinforcing mesh to the concrete mixture at a dosage of 10% by mass of cement. An adequate concrete strength class was achieved with a water to cement ratio of 0.40. Compression and flexure tests were carried out to assess the safety of these thin concrete elements. Moreover, serviceability aspects were taken into consideration. Firstly, drying shrinkage tests were carried out in order to evaluate the contribution of steel fibres in counteracting the high concrete strains due to a low aggregate–cement ratio. Secondly, the resistance to freezing and thawing cycles was investigated on concrete specimens in some cases superficially treated with a hydrophobic agent. Both carbonation and chloride penetration tests were carried out to assess durability behavior of this concrete mixture.

Manu and Subramanian (2004) discussed the potential for use of SCC in construction projects that has been effectively demonstrated in several countries. However, a number of issues need to be addressed further to make this a widely-acceptable technology. These issues, along with the existing level of research about various aspects of SCC, including materials and mixture design, test methods, construction-related issues and properties. Also they concluded that, use of viscosity modifying agents with high range water reducing agent for dynamic control of flow and segregation is increasing.

Amit et al. (2004) had described the methodology adopted for the design of SCC mix, test methods to qualify SCC and method adopted for concreting of walls and other structures of a condenser of cooling water pump house at Tarapur Atomic Power Project 3 and 4 and also concluded that SCC was used for concreting these walls and a few appurtenant structures of a pump house in Tarapur Atomic Power Project. The placing conditions were difficult and the reinforcement was congested. The SCC produced with the water content of 175 l/m³ and a low powder content of 500 kg/m³ was suitable for placing in difficult conditions without using external vibration.
Bapat et al. (2004) Nuclear Power Corporation of India Ltd. (NPCIL) intended to develop SCC mixtures, full scale mock ups and actual use of SCC at the NPP at Kaiga in Karnataka. The authors concluded that an economical SCC mixture can be developed incorporating low powder and water contents with fly ash content being as high as 50 percent of the total powder content and manufactured sand being 70 percent of the total fine aggregate content, They concluded that it is possible to produce SCC with a lower water content of 165 kg/m$^3$, a powder content of 450 kg/m$^3$, cement content of 225 kg/m$^3$ and manufactured sand percentage could be as high as 70 percent of the total fine aggregate content. An economical mix can be developed with SCC by using as high as 50 percent of fly ash out of the total powder content.

Pai (2004) discussed the comparison of SCC with control concrete in proportioning, fresh properties and hardened properties and he made the cost analysis of SCC and control concrete of approximately 40 MPa strength. He gave a very promising picture emerging as SCC is comparable in fact superior to conventional concrete in respect of all properties, preferred when concreting conditions are difficult. Cost of only the materials of SCC may appear to be slightly more, say about 15 percent or so. However, on a more rational basis of the total costs, including the labour charges for formwork and making good finished surfaces, SCC will be more advantageous. From holistic considerations, SCC will be more cost-effective.

Lachemi et al. (2004) expressed that self-consolidating concrete (SCC) is known for its excellent deformability, high resistance to segregation and use without applying vibration in congested reinforced concrete structures characterized by difficult casting conditions. The use of viscosity modifying admixtures (VMA) has proved very effective in stabilizing the rheology of SCC. Commercial VMAs currently available on the market are costly, which
increases the cost of such a concrete. They presented the suitability of four different types of new polysaccharide-based VMA in the development of SCC. A preliminary investigation was carried out on the rheological properties and setting times of mortar mixes with various types and dosages of VMA to study the influence and suitability of new VMAs. A more detailed study was then carried out on the SCC fresh and hardened properties such as slump flow, segregation, bleeding, flow time, setting time and compressive strength of different mixes with various dosages of an identified new VMA. The performance of various SCC mixtures with the new VMA was compared with a SCC using a commercial VMA designated as ‘COM’ and a SCC mixture with welan gum. The study on new VMA was encouraging and confirmed the production of satisfactory SCC with acceptable fresh and hardened properties comparable with or even better than that made with commercial VMA and welan gum. The suggested mix with 0.05% of the new Type VMA satisfied the requirement of fresh and hardened properties of SCC and required 7% less VMA dosage than that required in the commercial VMA mixture. The SCC with new VMA was also conducted as cost-effective.

Praveen and Kaushik (2004) carried out the studies on the microstructure of the interfacial transition zone (ITZ) in concrete that governs its mechanical properties and durability. The two basic differences in SCC and the conventional concrete are the relatively high water content in SCC and the presence of extra powdery material like fly ash. They investigated the ITZ in SCC vis-a-vis conventional concrete on the Scanning Electron Microscope based study.

(i) Observations using scanning electron microscopy on the transition zone in samples of SCC reveal a microstructure distinctly different from that observed in normal concrete.
(ii) The presence of microsilica and fly ash particles in the transition zone densifies and reduces the porosity of this zone and the transition zone in SCC was free of micro cracks, in contrast to the normal concrete.

(iii) Distinctive features of the transition zone in SCC lead to the durability incorporating fly ash and microsilica and hence will be better than normal concrete.

Poon and Ho (2004) concluded that SCC requires high powder content or a viscosity agent to increase its segregation resistance. This paper presented the results of a preliminary study on the utilization of rejected fly ash (r-FA) as part of powder content. Unsuitable r-FA is used in the production of blended cements simply due to its coarseness. Preliminary results suggested that r-FA could be used to replace in the production of SCC and possibly, with additional benefits. It is technically feasible to utilize r-FA as part of the powder content in the production of SCC. Besides environmental benefits, there could be some technical and financial advantages as well. Further research should cover the influence of r-FA in improving the segregation resistance of SCC and to evaluate its compatibility with selected SP.

Mohammed (2004) investigated to develop medium strength SCC. The cost of materials will be decreased by reducing the cement content and by using pulverised fuel ash with a minimum amount of superplasticizer. A factorial design was carried out to mathematically model the influence of five key parameters on filling and passing abilities, segregation and compressive strength which are important for the successful development of medium strength self-compacting concrete incorporating PFA. The parameters considered in the study were the contents of cement and PFA, water-to-powder (cement + PFA) ratio (W/P) and dosage of SP. The responses of the
derived statistical models are slump flow, fluidity loss, Orimet time, V-funnel time, L-box, J Ring combined to the Orimet, J Ring combined to cone, rheological parameters, segregation and compressive strength at 7, 28 and 90 days. Twenty-one mixes were prepared to derive the statistical models, and five were used for the verification and the accuracy of the developed models. The models are valid for mixes made with 0.38 to 0.72 W/P, 60 to 216 kg/m$^3$ of cement content, 183 to 317 kg/m$^3$ of PFA and 0% to 1% of SP by mass of powder. The influences of W/P, cement and PFA contents, and the dosage of SP were characterised and analysed using polynomial regression, which can identify the primary factors and their interactions on the measured properties. The results show that MS-SCC can be achieved with a 28-day compressive strength of 30 to 35 MPa by using up to 210 kg/m$^3$ of PFA.

Mahesh and Manu (2004) concluded that the slump flow and U-box test are good qualitative measures of the acceptability of a particular SCC mixture, while the T 50 slump flow and V-funnel test used to develop quantitative measures of the flow properties.

Brouwers and Radix (2005) conducted experiments on self compacting concrete. First, the features of “Japanese and Chinese Methods” are discussed, in which the packing of sand and gravel were found to play a major role. Here, the grading and packing of all solids in the concrete mix serves as a basis for the development of new concrete mixes. Mixes, consisting of slag blended cement, gravel (4–16 mm), three types of sand (0–1, 0–2 and 0–4 mm) and a polycarboxylic ether type superplasticizer were developed. These mixes were extensively tested, both in fresh and hardened states, and found to meet all practical and technical requirements such as medium strength and low cost.
Soo et al. (2006) concluded that proper selection of test methods and workability specifications are key concerns in the optimization and control testing of self-consolidating concrete (SCC). Various workability characteristics were determined for approximately 70 SCC mixtures made with water-cementitious material ratios (w/cm) of 0.35 and 0.42. Workability responses included the slump flow, J-Ring, V-funnel flow time, L-box, filling capacity, and surface settlement tests. Comparisons of various test methods indicate that the L-box blocking ratio (h2/ h1) and the J-Ring flow diameter can be related to filling capacity values determined using the caisson test. It is recommended that SCC used in structural applications should have slump flow values of 620 to 720 mm. To ensure proper filling capacity greater than 80%, such concrete should have high passing ability that corresponds to L-box blocking ratio (h2/ h1) ≥ 0.7, J-Ring flow of 600 to 700 mm, slump flow minus J-Ring flow diameter ≤ 50 mm, or V-funnel flow time ≤ 8 seconds. Such SCC should have a settlement rate of 0.16%/h at 30 minutes, corresponding to 0.5% maximum settlement.

Arnaud et al. (2006) investigated on two self-consolidating concretes (SCCs) and two vibrated concretes (VCs) (25 and 40 MPa [3625 and 5800 psi]). Different casting conditions were used to study the effect of the reinforcement orientation (vertical or horizontal) in relation with the casting direction and the effect of the horizontal bars location along the height of small and tall concrete elements. In this study, the concrete casting direction was always vertical. For small-size concrete elements, SCC25 showed a better resistance against bleeding than VC25. The difference, however, is not significant for SCC40 and VC40. For samples reinforced with ribbed bars, the orientation of the bars (horizontal or vertical) had a significant and equivalent influence on both 25 MPa (3625 psi) concretes. The VC40 and SCC40 bond strength values were almost equivalent and not affected by the orientation of the bars. For tall concrete elements, voids
formation under the horizontal bars was clearly observed for every type of concrete. The size of the voids was almost equivalent for SCC25, SCC40, and VC40, but significantly larger in the case of VC25, especially near the top casting surface. Finally, the maximum ultimate bond strengths obtained were approximately 20% higher for SCC than for VC, regardless of the concrete strength.

Reinhardt and Michael (2006) carried out the study on fire behavior of this specialized SCC of different types with compressive strengths between 25 and 65 MPa designed, and specimens with an edge length of 300 mm were subjected to fire according to ISO 834 at an age of 180 days. The compressive strength at 28 days, the weight loss due to drying, the spalling of the specimens and the residual compressive strength of the concretes after fire testing were measured and related to the performance of a reference vibrated concrete.

Aloia et al. (2006) concluded that the use of a Viscosity Enhancing Admixture (VEA) along with an adequate superplasticizer content enables to ensure high deformability and stability. However, little is known about the interactions between superplasticizer and viscosity agent. Hence, we propose to study several cement pastes formulated from the original paste of a typical SCC mix. Finally, test results enable to underline the interactions between superplasticizer and viscosity enhancing admixture used in designing self compacting concrete.

Burak et al. (2007) studied the adjustment of the water/cement ratio and superplasticizer dosage as one of the main key properties in proportioning of SCC mixtures. In their study, five mixtures with different combinations of water/cement ratio and superplasticizer dosage levels were
investigated. Several tests such as slump flow, V-funnel, L-box were carried out to determine optimum parameters for the self-compactibility of mixtures. Compressive strength development, modulus of elasticity and splitting tensile strength of mixtures were also studied. They concluded that optimum water/cement ratio for producing SCC is in the range of 0.84–1.07 by volume. The ratios above and below this range may cause blocking or segregation of the mixture, respectively.

Domone (2007) concluded that the Bond strength of SCC to reinforcing and prestressing steel is similar to or higher than that of normally vibrated concrete. Variation of in situ properties in structural elements cast with SCC is similar to that with NVC and the performance of the structural elements is largely as predicted by the measured material properties.

Binu et al. (2008) investigated, with large amount of powder replaced with high volume fly ash based on a rational mix design method developed by the authors. Because of high fly ash content, essential to study the development of strength at early ages of curing which may prove to be a significant factor for the removal of formwork. Rate of gain in strength at different periods of curing such as 12 h, 18 h, 1 day, 3 days, 7 days, 21 days and 28 days were studied for various grades of different SCC mixes and suitable relations have been established for the gain in strength at the early ages in comparison to the conventional concrete of same grades. Relations have also been formulated for compressive strength and split tensile strength for different grades of SCC mixes.

Khatib (2008) has investigated in the influence of fly ash (FA) on the properties of self-compacting concrete (SCC). Portland cement (PC) was partially replaced with 0–80% FA. The water to binder ratio was maintained
at 0.36 for all mixes. Replacing 40% of PC with FA resulted in a strength of more than 65 N/mm\(^2\) at 56 days. High absorption values are obtained with increasing amount of FA, however, all FA concrete exhibits absorption of less than 2%. Increasing the admixture content beyond a certain level leads to a reduction in strength and increase in absorption. The correlation between strength and absorption indicates that there is sharp decrease in strength as absorption increases from 1 to 2%.

Dinakar et al. (2008) had done experimental study on the durability properties of self compacting concretes (SCCs) with high volume replacements of fly ash. Eight fly ash self compacting concretes of various strength grades were designed at desired fly ash percentages of 0, 10, 30, 50, 70 and 85%, in comparison with five different mixtures of normal vibrated concretes (NCs) at equivalent strength grades. The durability properties were studied through the measurement of permeable voids, water absorption, acid attack and chloride permeation. The results indicated that the SCCs showed higher permeable voids and water absorption than the vibrated normal concretes of the same strength grades. However, in acid attack and chloride diffusion studies the high volume fly ash SCCs had significantly lower weight losses and chloride ion diffusion.

Tayyeb et al. (2009) had conducted that to produce low cost SCC, it is prudent to look at the alternates to help reducing the SSC cost. They evaluated the usage of bagasse ash as viscosity modifying agent in SCC, and to study the relative costs of the materials used in SCC. In their research, the main variables were the proportion of bagasse ash, dosage of superplasticizer for flowability and water/binder ratio. The parameters kept constant are the amount of cement and water content. Test results substantiated the feasibility to develop low cost self compacting concrete using bagasse ash. In the fresh state of concrete, the different mixes of concrete had slump flow in the range
of 333 mm to 815 mm, L-box ratio ranging from 0 to 1 and flow time ranging from 1.8 s to no flow. Out of twenty five different mixes, five mixes were found to satisfy the requirements suggested by European federation of national trade associations representing producers and applicators of specialist building products (EFNARC) guide for making self compacting concrete. The compressive strengths developed by the self compacting concrete mixes with bagasse ash at 28 days were comparable to the control concrete. Cost analysis showed that the cost of ingredients of specific self compacting concrete mix is 35.63% less than that of control concrete, both having compressive strength above 34 MPa.

Nicolas et al. (2010) have studied the effect of chemical and mineral admixtures, including superplasticizer, viscosity modifying agent (VMA), limestone powder and fly ash in different w/c on fluidity, viscosity, and stability of self-consolidating mortar. They obtained results which indicate that w/c is the most significant parameter influencing the rheological properties of cementitious mixtures, specially their stability. The maximum allowable w/c for preventing in homogeneity could not be a fixed value for all the mixtures and should be adjusted for the target fluidity. Using VMAs is an effective method for stabilizing self-consolidating mortars and preventing any kinds of instability while limestone powder and fly ash mainly affect bleeding and aggregate blockage.

Miao (2010) analyzed the self-compacting concrete (SCC) with levels of up to 80% cement replacement by fly ash in mixes adjusted to give constant fresh concrete properties. The hardened concrete and the relationships between hardened properties were then studied. The results show that SCC with up 80% cement replaced by fly ash is possible. To keep the filling ability constant, replacement of cement with fly ash would require an increase in water/powder (W/P) ratio and a reduction in superplasticiser
dosage. They also show fly ash have negative effects on passing ability, consistency retention and hardened concrete properties such as strength. The comparison between SCC and normally vibrated concrete (NVC) shows that their material properties of are similar.

2.3 REPORTS OF FLEXURAL BEHAVIOUR ON BEAMS

Mohammed et al. (2003) had studied the structural performance of full-scale beams (200 × 300 × 3800 mm) cast using ordinary concrete and SCC with two configurations of reinforcement bars. A fibre beam cast with SCC containing steel fibres was also tested. SCC and ordinary concretes having standard compressive cube strengths of 35 MPa (Class C35) and 60 MPa (Class C60) for housing and civil engineering applications respectively, were used to cast a total of eight beams. One beam of each pair of beams was tested in flexure to determine the load deflection capacity; the second one provided core samples to determine the uniformity of the distribution of compressive strength along the length of beams. The core test results were expressed as estimated in-place cube strength in accordance with British standard practice and were compared with strengths obtained from standard cubes cured.

Muthu et al. (2003) presented the results of strength and deformation behaviour of high strength concrete beams. The beam has been provided with/without minimum flexural reinforcement specified in Canadian, Newzealand and Indian standards. A total of eighteen beams were cast and tested under two point loading. They found the first crack load, ultimate load, ultimate strain and reserve strength of beams. They concluded that flexural strength of beam was about one tenth of compressive strength of concrete, the deflection at ultimate load for high strength concrete beam occurred at an average value of span/220 and reserve strength beyond
cracking load showed a decreasing trend with increase in percentage of silicafume.

Annie et al. (2004) had done the experimental work to understand the structural behavior of conventionally vibrated concrete (CVC) and SCC in hardened stage, reinforced concrete beam of size 150 mm × 400 mm × 3000 mm with similar concrete strength and identical reinforcement were cast and tested in flexure. Load at first crack, Load Carrying Capacity and mode of failure were explained. Also they discussed the Load-deformation characteristics, Moment-Curvature relationship and crack spacing, crack widths, number of cracks and crack pattern. They concluded that the load-deformation behavior of both SCC and CVC beams were similar up to the peak load stage. Beyond the peak load stage, CVC beams showed no drop in load with increased deformation. While the peak and failure loads were nearly the same for CVC beams, the failure load was nearly 25 percent lower compared to the peak load in SCC beams.

Seshasayi and Reddy (2004) carried out an experimental work to study the deflection characteristics and ultimate strength capacities in flexure of high performance concrete beams with and without cement replacement. Twelve beams were cast and tested. Six beams were of ordinary reinforced concrete without cement replacement. Other Six beams had cement replacement of 29 percent (20 percent Fly ash and 9 percent by silicafume). Replacement of fly ash and silicafume were by equal quantities of weight of cement. Load-deflection characteristics and the moment carrying capacities of the two sets of beams were compared. They concluded that behavior in flexure of concrete with ordinary Portland cement and cement with mineral admixture will be similar.
Hassan et al. (2008) had done an experimental investigation on shear strength and cracking behavior of full scale beams made with self-consolidating concrete (SCC) as well as normal concrete (NC). A total of 20 flexural reinforced concrete beams, with no shear reinforcement, were tested under mid-span concentrated load until shear failure occurred. The experimental test parameters included concrete type/coarse aggregate content, beam depth and the longitudinal reinforcing steel ratio. The beam depth ranged from 150 to 750 mm while the shear span-to-depth ratio (a/d) was kept constant in all beams. The two longitudinal reinforcing steel ratios used were 1% and 2%. The performance of SCC/NC beams was evaluated based on the results of crack pattern, crack widths, loads at the first flexure/diagonal cracking, ultimate shear resistance, and failure modes. The ultimate shear strength of SCC beams was found to be slightly lower than that of NC beams and the difference was more pronounced with the reduction of longitudinal steel reinforcement and with the increase of beam depth. The performance of code based equations in predicting the shear resistance of SCC/NC beams is also presented. They concluded that SCC showed similar shear resistance characteristics in pre-cracking stage as compared with NC. No significant difference was noted between SCC and NC beam in terms of crack widths, crack height and crack angles or overall failure mode.

2.4 REPORTS ON BEHAVIOUR OF COLUMNS UNDER AXIAL LOADS

Fumio et al. (1995) have done a new reinforcing method to improve the inelastic behavior of reinforced concrete columns. The method combines the use of high-strength and ordinary strength longitudinal bars. When the column is subjected to bending moment, the ordinary strength longitudinal bars yield first and then the high-strength bars yield later in large post-yield range. Up to the stage of yielding of the high-strength bars, the column does
not show significant degradation of load carrying capacity. To confirm the advantages of the new reinforcing method, flexural analyses on reinforced concrete columns with different grades of longitudinal bars were conducted. The results of the analyses indicate that the combined use of different grades of longitudinal bar improves the inelastic behavior of reinforced concrete columns.

Shanthi and Sundararajan (2003) have done experimental work on 11 small scale concrete encased build up steel columns under concentric and eccentric loads. They studied the effects of external compressive load on the columns, their ultimate strength, failure modes, load-deflection, moment – curvature and stress-strain. They concluded that failure occurred by crushing of the concrete at the compression face of the cross section, where the moment was maximum throughout the test. Hence, concrete encased composite steel built up columns can be recommended where the loading is heavy and space saving is of top priority.

Sonebi and Bartos (2003) carried out experimental study on the structural performance of full scale \((300 \times 300 \times 3000 \text{ mm})\) columns cast using ordinary concrete and self compacting (SCC) concretes with stirrup configurations representing different degrees of confinement. SCC and ordinary concrete having compressive strengths of 35 MPa (housing) and 60 MPa (Civil Engineering) were used to cast a total of eight columns. Two pairs of columns were cast using ordinary concrete and SCC. From each pair of the reinforced column, one column was tested in uniaxial compression to determine its load carrying capacity, while the other one was used to take core samples to determine the distribution of in-situ compressive strength and its height. The core results were compared to strengths. The in-situ compressive strengths of SCC were closer to standard cube than those of ordinary concrete. The distribution of in-situ properties was found to be more uniform
in the case of SCC than that of the ordinary concrete. The compressive strength and the ductility of SCC and the ordinary concrete obtained from the 3m column tests are also compared.

Chien et al. (2004) investigated the behaviour of high-workability concrete (HWC) columns under concentric compression. Fifteen of the columns were made with HWC and the rest were made with normal concrete. The test variables included the concrete strength, amount of longitudinal reinforcement, volumetric ratio of transverse reinforcement, strength of transverse reinforcement and the arrangement of transverse reinforcement. Comparisons were made between HWC columns and normal concrete columns. The results show that HWC columns have higher stiffness than normal concrete columns. The ductility and crack control ability of HWC columns are better than those of normal concrete columns. A decrease of concrete strength, increase of longitudinal reinforcement, increase of transverse reinforcement strength and decrease of transverse reinforcement spacing were found to improve the ductility of confined concrete columns effectively.

Mohamed et al. (2006) compared the performance of axially loaded concrete filled steel tube (CFST) columns cast using a conventionally vibrated normal concrete (NC) and a self-consolidating concrete (SCC) made with a new viscosity-modifying admixture (VMA). A total of 16 columns with a standard compressive strength of approximately 50 MPa for both SCC and NC were tested by applying concentric axial load through the concrete core. The effect of various parameters such as slenderness ratios, types of concrete and the addition of longitudinal and hoop reinforcements at different degrees of confinement was studied. In the service stage, the performance was judged based on strength, ductility, stress-strain characteristics, degrees of confinement, load sharing between steel tube and confined concrete and
failure modes. Test results showed that the ease of placement and time of casting were considerably improved for columns with SCC compared to those with NC. The strength of SCC columns was found comparable to that of their NC counterparts as the maximum strength enhancement in NC columns ranged between 1.1 and 7.5% only. The ductility of comparatively shorter columns with both SCC and NC was similar.

2.5 REPORTS OF EXTERIOR BEAM COLUMN JOINT

Hanson and Connor (1967) had tested seven full size exterior beam column joints. The principal variables of their study were column size, column load and degree of confinement in joint. They observed that the presence of axial load on column improved the behaviour and stressed the importance of proper detailing of the joint. They emphasized a design procedure for hoops on supplying adequate confinement and shear resistance for isolated beam-column joints. It was presented that hoops are not required for exterior joints confined on at least three sides by beams.

Uzumeri (1977) carried out an experimental study of behaviour of eight cast in place reinforced concrete beam-column joints subjected to slow load reversals simulating seismic loading. Variables were the amount and size of joint reinforcement and stress vs. strain characteristics of joint steel. His results indicated that the assumption of rigid beam-column joints could give invalid results. He suggested that the use of joint reinforcement with flat yield plateau might be undesirable for confinement. He recommended that joint stirrups should be extended above and below the beam steel at same spacing as in the joint for a distance of at least half the core dimension to prevent premature failure in the column just above or below the beam.

Lee et al. (1977) investigated the behaviour of six beam-column joints designed according to ACI-ASCE committee 352. The design and test
variables were the amount of transverse reinforcement, magnitude of axial load on the column and the severity of loading. They stated that the effect of column axial load on cracking was that each specimen had cracks in joint and beam but the cracks were more numerous and severe in specimen without column axial load. Their results also indicated that there was slightly higher initial stiffness in specimen with column axial load and lower shear level in beam due to its larger shear span. They observed that the shear resisted by the transverse reinforcement increased as the amount of transverse reinforcement increased.

Ehsani and Wight (1985) investigated the effect of key variables on the behaviour of external reinforced beam to column connection subjected to earthquake type loading. The primary variables were the ratio of the column to beam flexural capacity, the joint shear stresses and the transverse reinforcement in the joint. They suggested that flexural strength ratio should be more than 1.4 in order to avoid formation of plastic hinges in the joint. A significant improvement in the behaviour of a connection was observed if the joint shear stress was limited to the value recommended by ACI 352R-76. Their tests indicated that additional transverse reinforcement enhanced the behaviour of sub assemblage but the construction of such connection was found to be extremely difficult. They concluded that in case where either the flexural strength ratio, the joint shear stress or the anchorage requirement were significantly more conservative than the limit of ACI 352R-76 the amount of joint transverse reinforcement could be safely reduced.

Abrams (1987) conducted tests on eight small-scale joints, four medium-scale joints and six large-scale joints. Specimens were subjected to reversals of lateral force to study scale correlations for nonlinear hysteretic properties. It was observed that stiffness deterioration was the highest for small-scale specimens as a result of weaker bond between model
reinforcement and mortar. One-quarter scale specimens showed force-deflection response similar to those of large-scale specimens. He recommended that minimum usable scale for testing of isolated reinforced concrete components be one-quarter.

Alameddine and Ehsani (1991) investigated exterior beam to column connections with high strength concrete with compressive strength of over 69MPa. The key variables were concrete compressive strength, joint shear stress and joint transverse reinforcement. They observed that joint performance was more influenced by the joint shear stress and joint confinement level than the level of concrete compressive strength. The increase in joint transverse reinforcement ratio provided additional confinement for the joint concrete and delayed the deterioration of concrete in the joint. The improved behaviour of joints with high transverse steel ratio was less pronounced in specimens with high joint shear stresses. They emphasized that confinement cannot compensate for the deteriorating effect of high joint shear stresses.

Tsonos et al. (1992) investigated the improvement in the seismic behaviour of exterior reinforced concrete beam-column joints resulting from the presence of inclined reinforcing bars in the joint region. The principal variables of the testing program were the percentage of inclined reinforcing bars, the ratio of column moment strength versus beam moment strength and the horizontal joint shear stress. The exterior beam-column joints with crossed inclined bars showed high strength and large energy dissipation capacity. The presence of inclined bars introduced additional new mechanism of shear transfer. Exterior beam-column joints with inclined bars resisted horizontal shear stresses higher than the recommendations of the Committee ACI 352R-85.
Kumar et al. (2002) carried out an experimental study to clarify the effect of joint detailing on the seismic performance of lightly reinforced concrete frames. The parameters studied were the effect of joint rotation, column axial load, cross-reinforcement in the joint and percentage of longitudinal reinforcement in the beam. About eight T-shaped beam to column joint subassemblies designed and detailed as per IS 13920-1993 were tested under cyclic loading. They found that use of cross reinforcement in the joint reduced damage in the joint but also reduced the ductility and energy dissipation capacity. The test results indicated that presence of axial load in column and allowing free joint rotation not only increased the strength and ductility but also reduced the damage in the joint region, they concluded that ductility and energy dissipation capacity increased with a decrease in the percentage of longitudinal reinforcement.

Murty et al. (2003) reported the experimental evaluation of effectiveness of different details of longitudinal beam bar anchorage and transverse joint reinforcement in exterior beam-column joints of moment resistant frames. Twelve specimens were tested with four different arrangements for anchorage of beam longitudinal bars namely Type P, Type Q, Type R and Type S and three different arrangements of reinforcement in joint regions namely Type 1, Type 2 and Type 3. Their tests indicated that among all, the specimens with joint reinforcement Type 2 were the most effective and that they provided additional strength to the specimens beyond cracking and reduce the strength deterioration. The Type R specimens (with full anchorage of longitudinal beam bars) provide the best performance consisting the strength and ductility of specimens. They concluded that of all the joint reinforcement detailing schemes investigated, the ACI standard hook with hairclip-type transverse reinforcement was a preferred combination because of its ease of construction and overall effectiveness.
2.6 SUMMARY OF LITERATURE REVIEW

Most of the research literature reviewed, concentrated on experimental study on the fresh properties of SCC. It is indicated in the literature that SCC should possess high flowability, high passing ability, high filling ability and high segregation stability. It is difficult to achieve both high flowability and high segregation stability at the same time. Another difficulty is interlocking between the aggregate particles. To improve the cohesiveness and reduce particle interlocking actions it is good practice to increase powder content to SCC mixes. Fly ash has been found to improve the mechanical properties and durability of concrete when used as a cement replacement material. The literature on beam column joint region indicated the importance of anchorage through bond strength in the joint region and hence they are proposed to be investigated in the present study.