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High Performance Light Weight Aggregate Fibrous Concrete Beam-Column Joints: An State of Art Overview

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***Abstract* – Beam-column and beam-column slab joints have been recognized as critical elements in seismic design of reinforced concrete frames. Under seismic excitations, these are subjected to high horizontal and vertical forces whose magnitudes are much higher than those within adjacent beams and columns. Conventional concrete loses its strength after formation of multiple cracks. However, fibrous concrete can sustain a portion of its resistance following cracking to resist more cycles of loading. The main objective of this paper is to present a comprehensive review of published literature pertaining to high performance light weight aggregate fibrous concrete structural systems with special reference to beam-column and beam column slab junctions. Some gap areas in the existing published work have been identified and presented in this paper so that further studies can be undertaken by incorporating these areas effectively, in order to get an inside and comprehensive findings on the issue.**

***Keywords* – Slurry Infiltrated Fibrous High Performance Concrete (SIFHPC), High Performance Light Weight Aggregate Fibrous Concrete (HPLWAFRC), Failure Mechanism, High Performance, Beam Column Joints.**

I. Introduction

Joint shear failure has been observed as one of the main reason, in many reinforced concrete structures, subjected to severe earthquake loadings primarily because of inadequate transverse reinforcement in the region, in a weak column/strong beam joint. The strength and ductility of structures mainly depend on proper detailing of reinforcement in beam-column joints. The flow of forces within a beam-column joint may be interrupted if the shear strength of the joint is not adequately provided. Under seismic excitations, the beam-column joint region is subjected to high horizontal and vertical forces whose magnitudes are much higher than those within the adjacent beams and columns. Recent earthquakes in different parts of the world have once again revealed the significance of design of structures with high ductility. Conventional concrete loses its tensile resistance after the formation of multiple cracks. However, fibrous concrete can sustain a portion of its resistance following cracking to resist more cycles of loading. Beam-column and beam-column-slab structural systems have a crucial role in the structural integrity of building and as such, they have to be provided with adequate strength and stiffness to sustain the load transmitted from either beam or column. Use of closely spaced hoops as transverse reinforcement was recommended in the ACI-ASCE committee 352 report (ACI 2002). However due to congestion of reinforcement, casting of beam-column joints becomes difficult and lead to honeycombing to concrete (Kumar et al. 1991).

Fiber reinforce composites have made striking advances in the recent years in this direction due to technological developments on one hand and, on the other hand, to a better understanding of the fundamental mechanism controlling their structural behavior. The attribute "High Performance" implies an optimized combination of structural properties such as strength, toughness, energy absorption, stiffness, and durability, multiple cracking and corrosion resistance, taking into account the final cost of the material and above all, of the produce manufactured. High performance is meant to distinguish structural materials from the conventional once, as well as to optimize a combination of properties in term of final application in terms of civil engineering.

The specific term "High Performance Fiber Reinforced Cement based Composites (HPFRCC)" refers to high performance cement based materials, particularly developed for specific application, for which toughness, ductility and energy absorption are fundamental properties. The use of light weight aggregates further helps designers, contractors and owners optimize the design, construction and long term performance of concrete structures. Structural light weight aggregates are produced in manufacturing plants from raw materials including suitable shale, clays, slates, fly ashes, or blast furnaces slag. Naturally occurring light weight aggregates are mined from volcanic deposits that include pumice and scoria. The benefits that have made using lightweight aggregates economical for nearly 100 years have same characteristics that make the material what is now being called "Sustainable". Such structural light weight concrete has strengths comparable to normal weight concrete, yet it is typically 25- 35 percent lighter and offers design flexibility and substantial cost saving by providing less dead load, improved seismic structural response, longer spans, better fire ratings, thinner sections, decreased story height, small size structural members, less reinforcing steel and lower foundation cost. Structural lightweight concrete pre-cast elements have reduced trucking & placement cost. High performance lightweight aggregate concrete also has less cracking, improved skid resistance and is readily placed by the concrete pumping method. Such aggregates optimize structural efficiency by improving strength to weight ratio and may conveniently be used in beam column joint region effectively.

II. Failure Mechanism of HPFRCC

HPFRCC being special class of Slurry Infiltrated Fibrous Concrete (SIFCON) type of concrete in which the formwork or moulds are filled to capacity with high volume of fibres and resulting fiber network is then infiltrated by cement based slurry. SIFCON composites differs from conventional FRC mainly in two aspects, they contain a much larger volume fraction of fibers ranging 4 to 20 percentage and they use matrix consisting of very fine particles from the behavioral view point.

The fibers are subjected to frictional and mechanical interlock in addition to the bond with the matrix. The matrix plays the role not only of transferring of forces between fibers by shear but also acts as bearing to keep the fibers interlocked, Figs. 1-2. In general, when fibers are added to concrete, tensile strain in the neighborhood of fibers improves significantly. In the case of high performance fiber-reinforced concrete, since the concrete is dense even at the micro-structure level, tensile strain would be much higher than that of conventional Fibre Reinforced Composites (FRC). This, in turn, improves cracking behavior, ductility and energy absorption capacity of the composites. In order to tap the potential of Slurry Infiltrated Fibrous High Performance Concrete (SIFHPC), the existing body of knowledge has been expanded to investigate the performance characteristics of SIFHPC beam-column and beam-column-slab joints under positive cyclic loading.

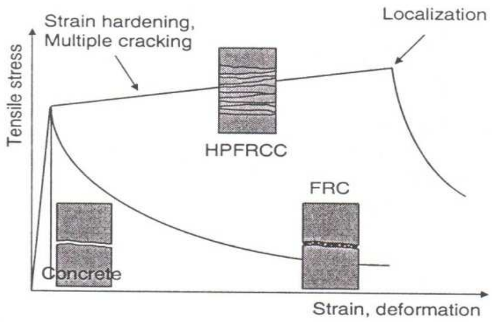

Fig. 1. Schematic Stress-Strain Behavior of Cementitious Matrices in Tension [Fischer, 2004]

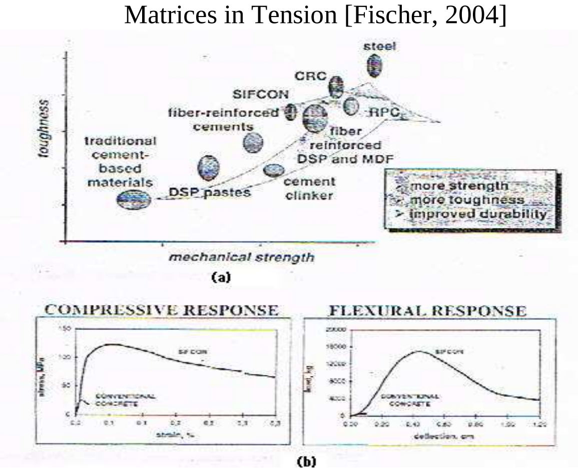

Fig. 2. (a) Trends of cement based materials and (b) typical mechanical behavior of SIFCON [Guerrini, 2000]

III. History of Published Literature

Beam-column joints have been recognized as critical elements in the seismic design of reinforced concrete frames (ACI 1998, AIJ 1990, Euro Code 1994, SNZ 1995). Numerous studies were conducted in the past to study the behaviour of beam-column joints with normal concrete (Shamim and Kumar 1999, Gefken and Ramey 1989, Filiatrault et al. 1994). The study conducted by Gefkon and Ramey (1989) illustrated that the joint hoop spacing specified by ACI-ASCE committee can be increased by a factor of 1.7 by the addition of fibers in the concrete mix. A study conducted on fiber reinforced normal strength concrete by Filiatrault et al. (1994) indicated that this material can be an alternative to the confining reinforcement in the joint region.

Tjiptobroto and Hansen (1991) conducted studies to investigate multiple cracking behavior of fiber reinforced small particle densified concrete containing high volume fraction (more than 3 percent) of fine and short steel fibers. It was observed that by increasing fiber volume fraction, crack localization did not occur during multiple cracking. Further, at 12 percent fiber volume fraction, a total strain capacity of about 0.2 percent was measured from flexure tests, which were an increase of about 15 to 20 times over that of plain matrix.

Kumar et al. (1991) studied use of SIFCON as a substantial material in RC beams. It was reported that SIFCON can be used in place where structures need to be designed to resist impact loads. It was also concluded that with proper design the cross-section can be optimized by replacing certain portion by SIFCON.

Jiuru et al. (1992) studied effect of fibers on the beam-column joints and developed equation for predicting shear strength of joints for normal strength concrete.

Oh (1992) indicated that the ductility and ultimate resistance of flexural members are increased remarkably due to the addition of steel fibers. ACI committee 544 (1998) also reported considerable improvement in strength, ductility and energy absorption capacity with addition of steel fibres. All these studies are, however, confined to normal strength concrete and the research in the area of High Performance Lightweight Fibrous Concrete joints is limited.

Singh and Kaushik (2001) studied behavior of fiber reinforced concrete corners under opening bending moments. It was indicated that there is a noticeable gain in efficiency with increase in fiber volume fraction up to a certain limit beyond which there is a drop in mix workability and joint efficiencies.

Thirugnanan et al. (2001) investigated experimentally effect of using SIFCON in the hinging zones of multistoried frames subjected to cyclic loading. The aspects related to strength, stiffness and ductility, energy absorption and failure mechanism of RC frames with SIFCON beam-column joints were studied. It was concluded that the use of SIFCON in the hinging zones increases first crack loads and ductility by 40 and 100 percent, respectively. The energy absorption capacity was also increased by 50 percent by adopting SIFCON in the selected fuse locations of RC structures. ACI- ASCE Committee 352 (2002) makes recommendation on the design aspects of different types of beam-column joints, calculation of shear strength, and on reinforcement details to be provided (ACI 2002). These recommendations are however not intended for high performance light weight fiber reinforced concrete joints.

Bayasi and Gebman (2002), also experimentally proved the confinement effects of fibers in the joint region, and a reduction in the lateral reinforcement by the use of fiber concrete. Besides these, several investigations also exist on the effect of addition of fiber on the strength and durability of flexural members.

Bakir (2003), conducted extensive research on parameters that influence behavior of cyclically loaded joints and has derived equations for calculating shear strength of the joints.

Killar et al. (2003) explored possibilities to use high performance concrete for the design of seismic resistant cost effective and durable buildings. Buildings frames made up of SIFCON and high strength light weight aggregate fiber reinforced concrete were tested and analyzed under dynamic loads and the response of building in terms of force displacement relationship and rotation ductility factors were investigated.

Kayali et al. (2003) studied the effect of polypropylene and steel fibers on high strength light weight aggregate concrete. Sintered fly ash aggregates were used in the light weight concrete; the fines were partially replaced by fly ash. The effects on compressive strength, indirect tensile strength, modulus of rupture and modulus of elasticity, stress–strain relationship and compression toughness were reported. Compared to plain sintered fly ash lightweight aggregate concrete, polypropylene fiber addition at 0.56 percent by volume of the concrete caused 90 percent increase in indirect tensile strength and a 20 percent increase in the modulus of rupture. Polypropylene fiber addition did not significantly affect the other mechanical properties that were investigated. Steel fibers at 1.7 percent by volume of the concrete caused an increase in the indirect tensile strength by about 118 percent and an increase in the modulus of rupture by about 80 percent. Steel fiber reinforcement also caused a small decrease in the modulus of elasticity and changed the shape of the stress–strain relationship to become more curvilinear. Significant increase in the compression toughness was also recorded.

Naaman et al. (2006) presented that behavior of strain-hardening FRC composites can be essentially characterized by providing a minimum three key properties, which are, their tensile strength after cracking, tensile strain capacity, and elastic modulus. The tensile response of fiber reinforced concrete (FRC) composites can be generally classified in two distinct categories on their behavior after first cracking.

Ganesan et al. (2007) carried out study to investigate the effect of hybrid fibres on the strength and behaviour of high performance concrete beam column joints subjected to reverse cyclic loads. A total of 12 reinforced concrete beams column joints were cast and tested. High performance concrete of M60 grade was designed using the modified ACI method suggested by Aitcin. Crimped steel fibres and polypropylene fibres were used in hybrid form. The main variables considered were the volume fraction of crimped steel fibers viz. 0.5 percent (39.25 kg/m^3) and 1.0 percent (78.5 kg/m^3) and Polypropylene fibers viz. 0.1 percent (0.9 kg/m^3), 0.15 percent (1.35 kg/m^3), and 0.2 percent (1.8 kg/m^3). It was observed that the addition of fibres in hybrid form improved many of the engineering properties such as the first crack load, ultimate load and ductility factor of the composite. The combination of 1 percent (78.5 kg/m^3) volume fraction of steel fibres and 0.15 percent (1.35 kg/m^3) volume fraction of polypropylene fibres gave better performance with respect to energy dissipation capacity and stiffness degradation than the other combinations.

Yung Chih Wang (2007) studied reinforced concrete beam column junctions strengthened with ultra high steel fiber reinforced concrete (UFC). It was concluded that UFC displayed excellent performance in terms of mechanical and durability behavior. The test results show that UFC replaced joint frame behaves very well in seismic resistance. The performance was found to be much better than the frame strengthened with RC jacketing, as normally seen in the traditional retrofit schemes.

Choi et al. (2007) conducted analytical studies to investigate punching shear strength of interior slab-column made of steel fiber reinforced concrete by using the shear capacity. A new strength model for the punching shear strength of SFRC slab-column connections was developed. Kiyoung-Kyuchoi et al. (2007) conducted analytical studies to investigate punching shear strength of interior slab-column connections made of steel fiber reinforced concrete. A new strength model for the punching shear strength of SFRC slab-column connections was developed.

Elnono et al. (2009) used Slurry Infiltrated Fiber Concrete (SIFCON) in reinforced concrete corner connections subjected to opening bending moments. An experimental program was carried out in which fifteen specimens were tested; six reinforced concrete joints, one fiber reinforced concrete joint, and eight SIFCON joints. Different reinforcing bar details and different volumes of fraction of fibers have been investigated. It was found that in all the RC specimens, the joints failed before reaching the capacity of the connecting members. There was also a significant difference in the different joint's efficiency due to the variety of reinforcement details. The use of SIFCON in the joints increased both the joint capacity and ductility. The enhancement of joint capacity and ductility could reach as high as 66 percent and 173 percent, respectively. The increase in the amount of fiber in SIFCON was proven to proportionally enhance the behavior of the SIFCON joints. In joints with volume of fraction of fibers 6 to 8 percent, the joint capacity exceeded the connecting member capacity, leading to failure in the member before the joint. The crack width decreased with increase in the fiber volume. No visible cracks were observed in the joints with fiber volume of 8 percent. It was also observed that no cover spalling occurs in the SIFCON concrete joints.

Sorankom et al. (2009) conducted analytical studies to provide computational efficiency over the commonly used strain compatibility analysis of a layered beam in determining moment capacity of FRC members. The closed form equations and guidelines are compatible with ACI 318-05 design method procedures, while allowing deflection and serviceability criteria to be calculated based on fundamentals of structural mechanics. These computations allow engineers to reliably design and compare overall performance of a conventional reinforced concrete system and FRC.

Wille et al. (2011) developed experimentally concrete mixtures with compressive strengths exceeding 150 MPa and without heat or pressure treatment. These include not only the properties and particle size of materials component used but also mix proportions, mixing procedure, specimen preparation and test method. The spread value is good that measured from the slump cone test on a flow table and quick indicator of the optimized mix packing density and its desired compressive strength.

Montesinos et al. (2011), presented the recent advances in the field of high performance fiber reinforced cement composites focusing mainly on the mechanical behavior under compressive, tensile and shear loading, impact and fire resistance, fresh and hardening properties and durability. Also, the properties of textile reinforced concrete and ultra high performance fiber reinforced concrete with their structural applications and modeling were discussed.

Mahoutian et al. (2011) in the study used several devices to provide support in an underground space. Wooden prop was generally employed for the purpose of passive secondary or short-term support of the mine roadway roof and sides. The wooden prop has various known usage limitation, including low strength, deterioration of wood in humid environment, poor ductility, and generally low service life. Substitution of the wooden prop with a prop made with a more suitable material could thus yield important advantages. In this study, light weight aggregate concrete (LWAC) was used as a prop material. Since light weight aggregate has a relatively low ductility, steel fibers are used in this investigation to achieve enhanced ductility levels. Five mixtures of fiber reinforced lightweight aggregate concrete were considered with different steel fiber percentages and pumice light weight aggregates produced in Iran. The density, compressive, tensile and flexural strength as well as the toughness index of different fiber reinforced light weight aggregate concrete materials were measured in order to assess their potential as replacement for wood in prop production. The experimental results indicated that the density of light weight aggregate concrete is higher than wood. Since the strength and toughness of LWAC is significantly more than those of wood, the weight of a LWAC element with the same strength turns out to be 22 percent less than the wood element. Hence, wooden prop may be replaced with light weight aggregate concrete prop to achieve improved service life and ductility while reducing the weight of the prop.

Kim et al. (2012) investigated experimentally the workability, and mechanical, acoustic, and thermal properties of light weight aggregates with a high volume of entrained air. The effects of light weight aggregates and entrained air on the flow characteristics, density, porosity, compressive strength and dynamic elastic modulus of concrete were investigated. The author concluded that the light weight aggregate cellular concrete containing 0.5-1 percent of air entraining agent illustrated the excellent characteristics including very high workability, low density and proper strength, and can be applied in architectural members with high acoustic shielding and thermal insulating properties.

Zhutovsky et al. (2012) studied influence of internal curing (IC) on durability related properties of high performance concrete and concluded that no degradation in durability related properties was found, air permeability of HPC was reduced by internal curing except at early ages. For internally cured concrete, reduction of w/c ratio did not result in perceptible improvement of durability. Further research on the effect of IC on concrete durability with a micro-filler is required. Reduction of w/c ratio for internally cured HPC had a beneficial effect on drying shrinkage. Use of pumice, which has a very high open porosity in combination with vacuum absorption, is very effective strategy for elimination of autogenous shrinkage.

Xu et al. (2012) conducted experimental study to determine dynamic compressive properties of fibre reinforced concrete material with different fibres. A volume fraction of 1 percent fibre was used for seven types of fibres including synthetic and steel fibres. The impact forces on top and bottom of specimens were measured to investigate the axial inertia effect and the stress wave propagation effect. The test results demonstrated that concrete specimens reinforced with a new spiral II steel fibre reinforced concrete specimens in resisting the impact loading. Better anchorage bond and mechanical deformation capability of steel fibres lead to more significant rate sensitivity for both strength and toughness.

Yi et al. (2012) evaluated experimentally the blast resistant capacities of ultra-high performance concrete (UHPC) and reactive powder concrete (RPC) to determine the possibilities of using UHPC and RPC in concrete structures susceptible to terrorist attacks or accidental impacts. Slumps flow, split tensile strength, compressive strength, elastic modulus and flexural strength tests were carried out. The compressive strength, split tensile strength, elastic modulus and Poisson's ratio values of UHPC and RPC are 3.0-7.9 fold higher than the corresponding normal strength concrete (NSC) values. The Poisson's ratio of UHPC is 1.2-fold greater than that of RPC and has a higher split tensile strength than UHPC because of the crack-controlling effect of the short steel fibers.

Ganesan et al. (2014) described the experimental results of ten steel fiber reinforced high performance concrete (SFRHPC) exterior beam-column joints under cyclic loading. The M60 grade concrete used was designed by using modified ACI method .Volume fraction of the fibers used in this study varied from 0 to 1 percent with an increment of 0.25 percent Joints were tested under positive cycle loading and the results were evaluated with respect to strength, ductility and stiffness degradation. Test results indicated that the provision of SFRHPC in beam column joints enhances strength, ductility and stiffness, and is one of the possible alternative solutions for reducing the congestion of transverse reinforcement in beam-column joints. The SFRHPC joints undergo large displacements without developing wider cracks when compared to the HPC joints. This indicates that steel fibers impart high ductility to the SFRHPC joints, which is one of the essential requirements of the beam-column joints.

Metelli et al. (2015) found that beam-to-column joints are commonly considered critical regions for RC frames subjected to earthquake actions. When designed for gravity loads only, beam-to-column corner joints strongly affect the global structural behaviour of a frame, and they can be cause of its collapse, as shown by recent earthquakes in Europe. In the paper, a component-based finite element model for external beam-to-column joints has been presented to simulate seismic behaviour of RC existing structures designed without any capacity design criteria (smooth bars with hooked-end anchorages and with no transverse reinforcements in the joint). The joint deformation is modeled by means of two separate contributions, the shear deformation of the panel zone, and the rotation at the interface section between the joint and the structural members, due to the reinforcing bars slip within the joint core. The work focused on the evaluation of the joint strength and stiffness, and it pointed out importance of modeling the bar bond slip within the panel zone to describe the actual frame response. The component based finite element model was validated by experimental results of tests on beam-to-column corner joints realized according to the construction practice of the 1960s–1970s in Italy, thus confirming the effectiveness of the presented model for the assessment of existing structures.

Salim Barbhuiya et al. (2015) found beam–column connection as one of the vital sub-assemblages of a structural system. This is mainly because of theircritical behaviour during earthquakes .In the study, an experimental programme was undertaken by considering three types of beam–column connections with some specific deficiencies. For each type, three different sizes of specimens were considered to evaluate the existence of size effect in beam–column connections. Cyclic load was applied using servo hydraulic dynamic actuators with displacement-controlled load of frequency of 0.025 Hz. Amplitudes of the displacement histories were scaled down for two-third and one-third models. It was observed that the size effect became more pronounced with the increase in the brittleness of the specimens. To compare the energy dissipation of specimens having different sizes of beam–column joints, a parameter called 'energy dissipation per unit volume of joint (e_N) was introduced. This parameter was correlated with different drift angle for different sizes of the specimen and accordingly variation of e_N with drift angle for different sizes of size of the specimens was studied. It was observed that energy dissipation of specimens per unit volume as well as the variation of stress with relative deflection indicated the existence of size effect.

Hyeon-Jong Hwang et al. (2015) found that the seismic performance of beam–column connections and joints can be enhanced by using improved details in the joint and ensuring a strong connection behavior. However, specific provision to evaluate quantitatively the increased bar–concrete bond and shear strengths in the beam–column joint is not given in current design codes. In the present study, cyclic loading tests were performed for beam–column connections of which joint detailing were improved by placing additional 45 degrees bent bars and 90 degree hooked bars. The test results showed that despite small height of column to depth of beam ratio (h**c**/db.)Values, by using the improved details, bond–slip of beam flexural bars and diagonal cracking were substantially decreased in the joint. To address the enhanced performance in the design of beam-column joints, the bond resistance and joint shear strength were quantitatively redefined considering the details of the additional bars. In addition, the relationship between the bond parameter and energy dissipation capacity was proposed. On the basis of the results, considerations for the seismic design and detailing of beam–column joints with additional bars were recommended.

The literature review of previous published works conducted by various researchers on high performance fibrous concrete structural systems illustrate that most of the researchers have used Steel Fiber Reinforced Concrete (SFRC) in the beam–column junctions. The fiber contents were restricted to 2 percent by volume. It was observed that the enhancement in terms of strength, ductility, energy absorption capacity, toughness and other structural properties was not significant, primarily because of low fiber volume contents. The effect of fiber types, fiber volume content and aspect ratio was also not studied. The influence of type of aggregate for improving structural characteristics and failure mechanism has also yet not been fully understood. Likewise, mechanism of improved tensile strain capacity of discontinuous fibre composites is also not known. Most of the research work was restricted to the study of behavior of structural members independently using normal weight concrete only. Very few researchers have studied behavior of beam-columns and beam-column-slab junctions collectively. Since beam-column & beam-column-slab junctions are the vulnerable locations which are subjected to high horizontal and vertical forces whose magnitudes are much higher than those within the adjacent beams & columns, the use of SFRC was found to be inadequate. In order to reduce dead load of structural members, HPLWAFRC would prove to be next generation development in the study of beam column joints under different loading conditions. Novel construction approaches can be developed with such materials that may lead to substantially higher strength, seismically resistant, durable and ductile concrete, in addition to construction also being faster and cost effective.

IV. Prospective Construction Benefits

HPLWAFRC has better thermal properties, fire rating and reduced autogenous shrinkage. It also possess excellent freezing & thawing durability, less micro cracking as a result of better elastic compatibility and has more fire resistance and better shock & sound absorption. In addition to its improved structural characteristics, HPLWAFRC has less cracking and improved skid resistance and is readily placed by the concrete pumping method. The use of structural high performance light weight concrete reduces the dead load by about 25 to 35 percent as compared to normal weight concrete thereby offering substantial cost saving by providing less dead loads, improved seismic response, longer span, thinner sections, less reinforcing steel and lower foundation cost. Reduced trucking and placement cost further make this material more versatile for its applications. Study of HPLWAFRC structural systems like beam column and beam-column slab junction is therefore observed as a grey area of investigation in this chain.

High performance concrete (HPC) mix of higher grades designed on the basis of standard methods available in literature may be utilized in beam column and beam-column slab joints considering variables discussed in the literature and the gap areas observed. Light weight aggregate obtained from different sources may also be utilized to study influence of type of aggregate, in strength and serviceability characteristics. These parameters will form part of further study in the subsequent paper.

V. Conclusions

The cost of civil infrastructure constitutes the major portion of the national wealth. Its rapid deterioration has created an urgent need for the development of novel, long lasting & cost effective methods for new construction, repair and retrofit. Promising way of resolving this problem is to selectively develop advanced composites such as high performance light weight aggregate fibrous concrete (HPLWAFRC) .Exhaustive overview of the published literature illustrated several gap areas in the research work pertaining to high performance light weight aggregate fibrous concrete structural systems, as discussed earlier. Recently it has been emphasized that the specific provision to evaluate quantitatively the increased bar-concrete and shear strength of beam-column joints is also not given in current design codes. Novel construction approaches can be developed with such materials that will lead to substantially higher strength, seismic resistance, durability and ductility, while construction also been faster and more cost effective than conventional methods. Most of the investigations reviewed in the study are limited to investigating behavior of structural members independently using normal weight concrete only. Since, beam-column, slab-column and beam-column-slab junctions are vulnerable locations which are subjected to high horizontal and vertical forces, use of fibre reinforced concrete with low fibre volume fraction like SFRC was found to be inadequate. In order to reduce the dead loads on structural members, HPLWAFRC would prove to be an efficient and noble material to withstand high horizontal & vertical shear forces in beam-column junctions under cyclic loading.

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