

Textiles in Earth-Quake Resistant Constructions

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Abstract

The present paper reports some of the important developments in the field of application of textile materials in earthquake resistance constructions. Cement concrete reinforced with steel rods and rings are very popular in ordinary construction material. One major drawback of using steel is its susceptibility to environmental attack which can severely reduce the strength and life of concrete structures. Recent developments in the field of fiber reinforced cement (FRCs) composites have resulted in the development of highly efficient construction materials. The FRCs are unaffected by electro-mechanical deterioration and can resist corrosive effects of acids, alkalis, salts and similar aggregates under a wide range of temperatures. The fibers used in FRCs, their properties and their applications have been reported here. The various techniques of application of FRCs on the new and existing masonry structures to protect them from earthquake have been discussed here.

Keywords: Earthquake; Environmental attack; Fiber reinforced cement; Electro-mechanical; Masonry structure

Introduction

Many un-reinforced wood and steel reinforced masonry structures are widely present around the world. These structures are designed for gravity loads and are not able to withstand seismic forces during earthquake and caused wide spread damages. To conserve the historic structural heritage of the country it is necessary to develop innovative techniques for rehabilitating deteriorating structures. After earthquake other than life concern, the removal and transportation of large amounts of concrete and masonry material causes concentrations of weight, dust, excessive noise, and requires long periods of time to gain strength before the building can be reopened for service [1-3].

Repair of these structures with like materials is often difficult, expensive, hazardous and disruptive to the operations of the building. Most of these structures need strengthening or seismic upgrading work in order to ensure their conservation and functional use. Fiber Reinforced Cement (FRC) Composite materials, originally developed for the aerospace industry, are being considered for application to the repair of buildings due to their low-weight, ease of handling and quick implementation [2]. Review of literature indicates that numerous studies were conducted in the past to study the behavior of Fiber Reinforced Cement (FRC) Composite materials. Research and developments are going on to adapt these materials to the repair of buildings and civil structures. Appropriate configurations of fiber and polymer matrix are being developed to resist the complex and multi-directional stress fields present in building structural members. At the same time, the large volumes of material required for building repair and the low cost of the traditional building materials create a mandate for economy in the selection of FRC materials for building repair [1-6].

Structural damages due to earthquake

Earthquake is seismic vibration which generates ground motion both in horizontal and vertical directions. Due to the inertia of the structure this ground motion generates shear stress and bending moment in the structural framework. In earthquake resistant design it is important to ensure ductility in the structure, i.e. the structure should be able to deform without causing failure. Strength and ductility of structures depend mainly on proper detailing of the 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 forces, the beam-column joint region is subjected to horizontal and vertical shear forces whose magnitudes are many times higher than those within the adjacent beams and columns. Conventional concrete loses its tensile resistance after the formation of multiple cracks. So, the joints need to be more ductile to efficiently bear or dissipate the seismic forces. Most failures in earthquake-affected structures are observed at the joint. A construction joint is placed in the column very close to the beam-column joint. This leads to shear or bending failure at or very close to the joint as shown in Figure 1a. The high compressive stress in concrete may also cause crushing of concrete as shown in Figure 1b. If the concrete lacks confinement the joint may disintegrate and the concrete may spall, shown in Figure 1c. All concrete structure create a hinge at the joint and more will be the number of hinge higher will be the probability of collapse. If the shear reinforcement in the beam is insufficient there may be diagonal cracks near the joints, shown in Figure 1d. This may also lead to failure of the joint. Again the high bending moment may cause yielding or buckling of the steel reinforcements as shown in Figure 1e.

However, in many structures these details have not been followed due to perceived difficulties at site. In most of the structures lack of confinement and shear cracks have been found to be most common causes of failure. Rehabilitation and retrofitting strategy must alleviate these deficiencies from the structures [1,6-12].

Fiber reinforced polymers and composites

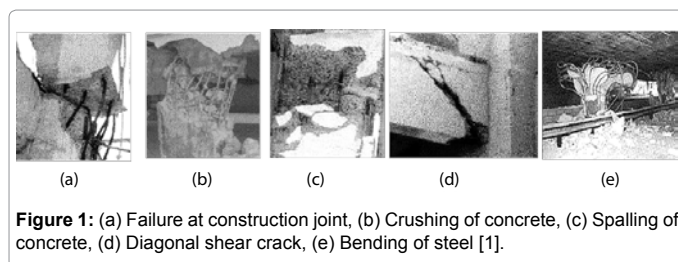
Fiber Reinforced Cement (FRC) Composite materials are widely used in many structural applications where their mechanical performances are of primary importance. The stiffness and the strength of composites are dependent upon the mechanical properties of the constituents, but also upon the stress transfer processes occurring at the fiber/matrix interface [13]. Fiber Reinforced Cement (FRC) or

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Concrete composites are generally defined as composites with two main components, the fiber and the matrix as shown in Figure 2 [13,14].

Fiber reinforced cement based composites have made striking advances and gained enormous momentum over the past four decades. This is due in particular to several developments involving the matrix, the fiber, the fiber-matrix interface, the composite production process, a better understanding of the fundamental mechanisms controlling their particular behavior, and a continually improving cost performance ratio.

The FRCs are unaffected by electro-mechanical deterioration and can resist corrosive effects of acids, alkalis, salts and similar aggregates under a wide range of temperatures. FRCs thus holds a very distinct advantage over steel as an external reinforcing device. Moreover, FRCs are available in the form of laminas and different thickness and orientation can be given to different layers to tailor its strength according to specific requirements Figure 3. Again, FRCs as post-reinforcements possess high specific strength (strength/weight ratio) as well as they are very light and easy to handle. The FRSc are available as unidirectional fibers of a huge length. Therefore, joints in the reinforcement can be avoided very easily. Moreover, the corrosion of the reinforcements can be avoided completely. Research work is gaining momentum on the application of composite materials as post-reinforcement. Some potential applications of FRCs in earthquake resistant construction are shown in Figure 4 [13-20].

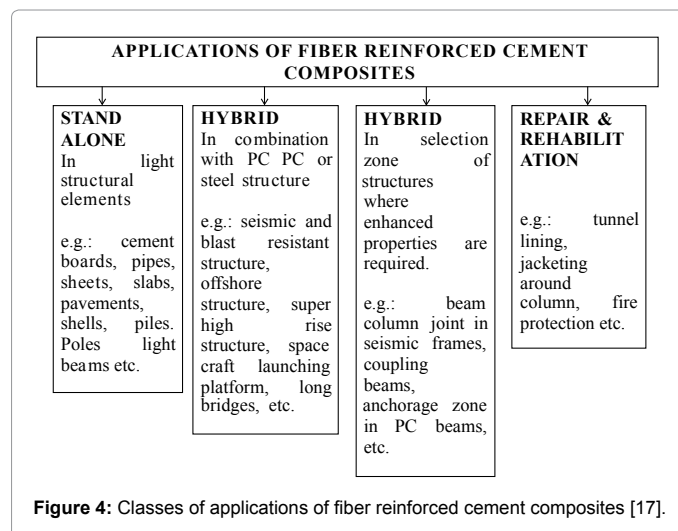
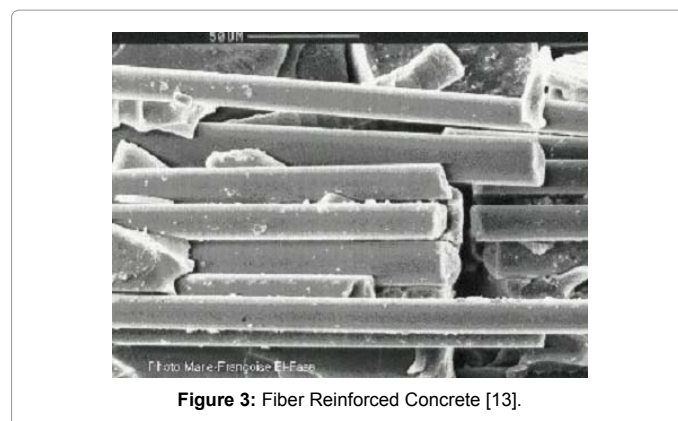
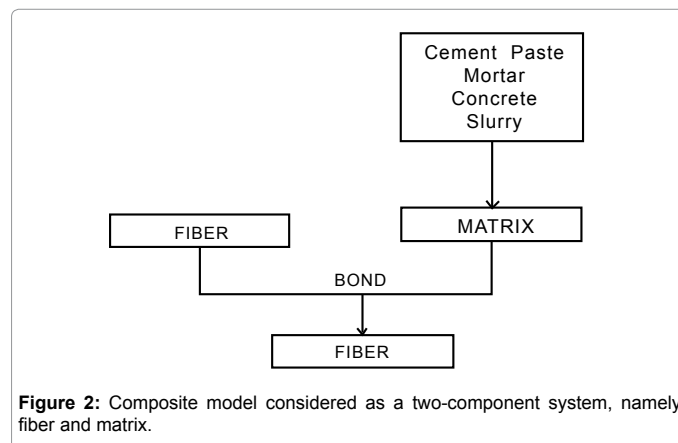
FRCs can be used in the concrete structures in the following forms:

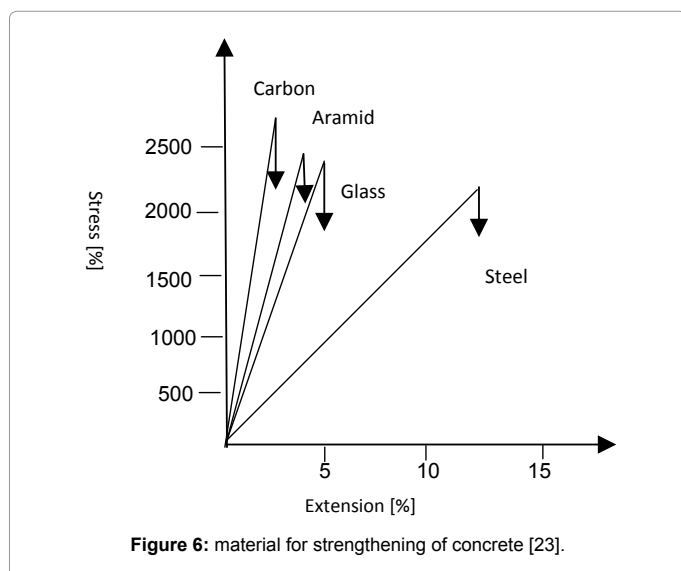
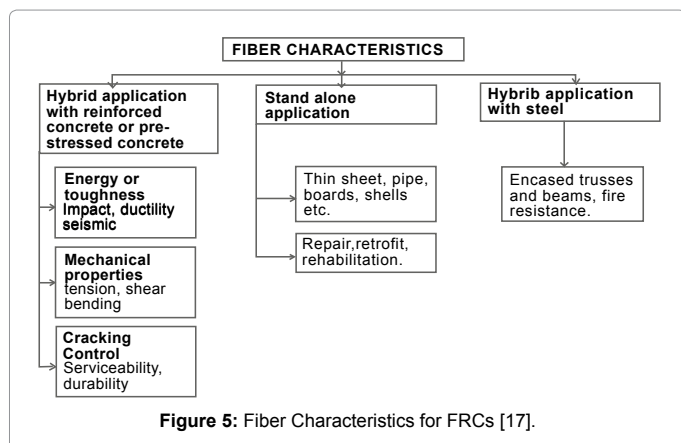
- Plates - at a face to improve the tension capacity.
- Bars - as reinforcement in beams and slabs replacing the steel bars.
- Cables - as tendons and post tension members in suspension and bridge girders.
- Wraps - around concrete members to confine concrete and improve the compressive strength

Materials for strengthening of structures

Fiber reinforced cement composite is consist of high strength fibers embedded in a resin matrix. The fibers generally used in construction are Carbon (C FRCs), Glass (G FRCs) or Aramid (A FRCs). These fibers are sufficiently strong, even many times stronger than steel in the longitudinal direction but generally weak laterally. Typically these fibers show very less or no ductility. So the stress-strain behavior of most FRCs can be taken as linear elastic to failure. C FRC posses the highest Young's modulus, generally around 150–200 GPa, with some Ultra High Modulus C FRCs being available with moduli up to 600 GPa. Strengths are generally in the range of 2500–3500 MPa. FRCs not only have the advantage of very high strength over conventional materials, but are also light weight and highly durable in many environments. The properties of fibers for FRCs have been shown in Figure 5 [14-21].

Figure 6 and Table 1 present a comparison of mechanical behavior of materials that are available for strengthening of structures. It can be seen that the non-metallic fibers have strengths that are 10 times more than that of steel. The ultimate strain of these fibers is also very high. In addition, density of these materials is approximately one-third that of steel. Due to its corrosion resistance FRCs can be applied on the surface of the structure without worrying about its deterioration due to environmental attack. They in turn protect the concrete core from environmental attack. FRPC sheets, being malleable, can be wrapped





Material	Density g/m ³	Initial Modulus	Tenacity (mN/tex)	Decomposition melt (°C)
Aramid standard	1.44	55	2065	550
Carbon HT	1.78	134	1910	3700
Carbon HM	1.83	256	1230	3700
E-Glass	2.58	28	780	825
Steel cord	7.85	20	330	1600

Table 1: Properties of commercially representative reinforcement fibers [23].

around the joints very easily. The light weight makes rehabilitation techniques much easier as heavy handling equipment is not needed in constricted spaces. The strength and stiffness of a structure can be increased with very little increase in mass, distinctly advantageous from the seismic perspective. The high durability is attractive for applications where steel deteriorates rapidly. However, one drawback of FRCs is the susceptibility of the resin in exposure to ultraviolet light. The resin slowly becomes brittle – often seen in plastic objects as they weather over the years when exposed to sunlight. Thus, FRCs must be protected from exposure to direct sunlight. It can easily be achieved in indoors and with paint. New resin formulations are being developed which will not suffer from this problem [14-21].

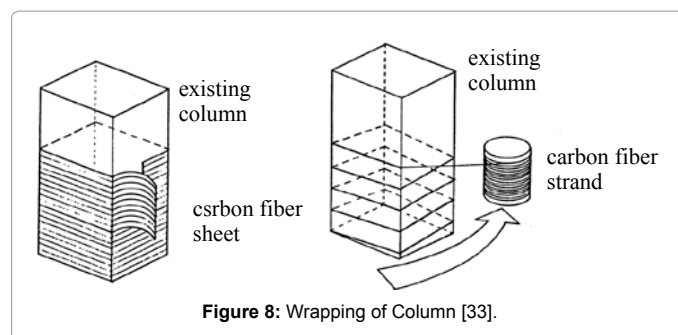
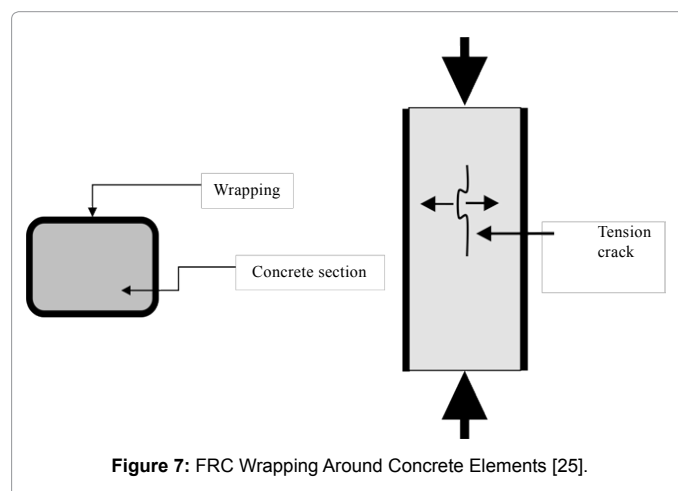
FRC plates as reinforcement to concrete beams

FRCs for strengthening of structures can be glued to an old and deteriorated concrete surface to improve its strength. This method is more convenient and durable than epoxy bonded steel plates. Meier (1987) has examined the suitability of carbon fiber reinforced epoxy laminates for rehabilitation of concrete bridges [22-23].

The first repair work of a concrete bridge using CFC laminates has been carried out at Ibach Bridge, Lucerne, Switzerland. The 228 m long bridge was designed as a continuous beam of span 39 m several pre-stressing tendons of the bridge were accidentally severed preventing the bridge to operate at its full capacity. The bridge was repaired with a 2 mm thick 150 mm wide C FRC laminate. It was found that the repair work became particularly easy due to the use of composite materials. Owing to its light weight 175 kg steel could be replaced by only 6.2 kg of CFC. As a result the work could be carried out from a traveling hydraulic lift and the cost of scaffolding could be avoided. The composite is held in position by means of a vacuum bag, thereby avoiding pressers required in case of steel plates. Although CFC was 40 times more expensive than steel plates, it was estimated that the process saved 20% in cost [24-27].

FRCs as wrapping on concrete elements

The tensile strength of concrete is much less in comparison to its compressive strength. As a result, even the compression members often fail due to the tensile stress that develops in the perpendicular direction of the compressive load as shown in Figure 7. If such a concrete element is confined using a wrapping (Figure 8), the failure due to tensile crack can be prevented. The compressive strength of the wrapped concrete element is several times higher than the unwrapped



concrete element. Although this is known for a long time effective application of confinement could not be achieved due to a lack of suitable wrapping material. If the wrapping is torn the capacity of the element reduces dramatically. Therefore, the durability of the wrapping material is of utmost importance. In addition, the wrapping material remains exposed to environmental attack. Therefore, steel is unsuitable for this purpose. FRCs due to their non-corrosive nature offers an attractive alternative. Moreover, the light weight FRC fibers can be very easily wrapped around an old concrete column. However, typical stress-strain curve of cylindrical specimens wrapped with FRC of varying number of layers is presented in Figure 9. It may be noted that with one layer of FRC wrap the ultimate strength of the specimens increased by a factor of 2.5. The ultimate strength went on to increase up to 8 times when 8 layers of the wrap were used. [24-25,28-32]

The ultimate strain increased by 6 times with one layer of wrap. This feature is particularly attractive for earthquake resistant structures. Due to higher ultimate strain the ductility of the structure also increases. It may be noted that the ultimate strain of the specimens is insensitive to the number of layers of wrap. Therefore, for earthquake resistance a thin wrap that offers high ultimate strain but low stiffness is desirable. Glass fibers that have considerably lower stiffness than the carbon fibers and higher ultimate strain is desirable. The unfavorable creep behavior of glass fiber poses little adversity in earthquake resistant applications as earthquake forces are seldom encountered. Moreover, glass fiber is much less expensive than carbon fiber [16-20,25,33].

Glass fiber retrofitting to protect bridge from earthquake

Older concrete columns are reinforced with ring and rods of steel. These concrete columns crack and spall during seismic vibrations. They are also vulnerable to corrosion. Seismic upgrades have traditionally involved retrofits with concrete or steel jackets, but these techniques are expensive and time-consuming, and the jackets also require maintenance over time. An easier, more cost-effective technology for strengthening concrete columns has recently been developed, the Snap Tite Composite Column Reinforcement. Snap Tite consists of an external composite fiberglass jacket, approximately 1/8 inch thick, that literally “snaps on” to the concrete column as shown in Figure 10. This composite is comprised of glass fibers and corrosion resistant isopolyester resins, manufactured into a single-seamed cylindrical jacket that encloses the column, which must be even and uniform in shape. The jacket contains the column, preventing the concrete from expanding due to seismic stress or temperature variations. Thousands of bridges columns in California are to be wrapped with jackets containing high performance glass fiber in order to protect the structure from severe earthquakes. The jacket are made from industrial glass fibers & isotophthalic polyester resin in contrast to the conventional sheet steel wraps and are designed to reduce the risk of serious seismic damage. [7,9,29,31,32,34].

Snap tite technology for column reinforcement

The Snap Tite Composite Column Reinforcement strengthens a concrete column by confining it in an external composite jacket, which prevents the concrete from expanding during seismic activity or prolonged freeze-thaw cycles. The pre-manufactured fiberglass jacket is comprised of glass fibers and corrosion resistant isopolyester resins. The resin completely encapsulates the reinforcing fiber network, which, for most applications, is conventional E-glass woven roving and bi-directional fabric. Each Snap Tite component is a single-seamed, cylindrical jacket that snaps on the column as shown in Figure 11. The column is cleaned and prepared with a high performance urethane

adhesive before the first jacket is applied. More jackets are applied until the desired thickness for the job is achieved. Adhesive is applied between layers, and the vertical and horizontal jacket seams are symmetrically alternated. A typical column will require 3 to 4 layers of jackets, with a

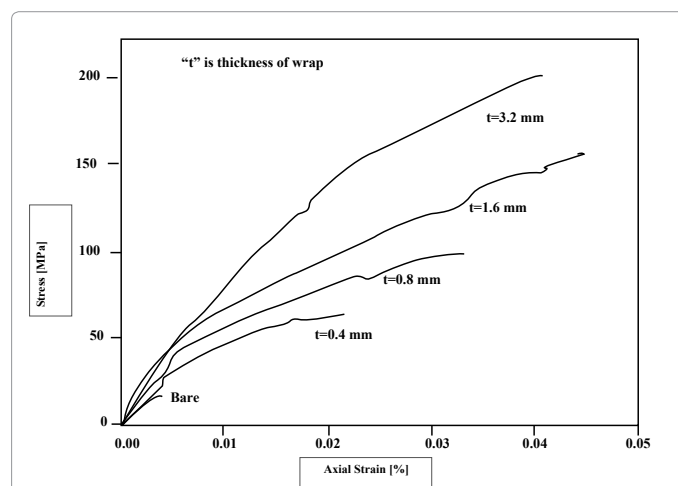


Figure 9: Axial strength of circular columns with different levels of confinement [25].

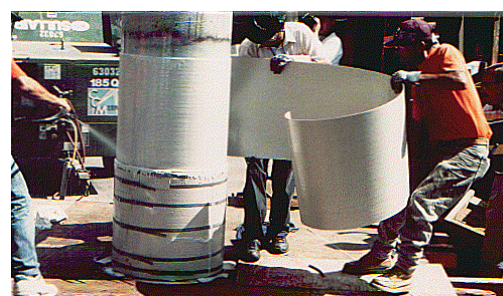


Figure 10: Installing Prefabricated Fiberglass jacket [34].



Figure 11: Snap tite applied beam surface [14].

nominal jacket thickness of around 1/8 inch thick. Each nested jacket is bound with belt clamps until the adhesive cures [7,9,14,33].

Benefits of snap tite

Snap tite is recognized as one of the most cost effective and user friendly solutions for rehabilitating or upgrading existing steel reinforced concrete columns or structures. Snap Tite replaces steel, the conventional material used for column reinforcement, reducing installation and long-term maintenance costs. For example, Snap Tite, because of its light weight, can typically be installed in three hours vs. three days for steel, and can be lifted in place by workers using only a few pieces of light, mobile equipment. Snap Tite won't rust and never needs to be painted, even when installed in corrosive environments.

The other market challenge to Snap Tite is the epoxy resin composite column wrap. Although this composite does meet performance requirements, it is much more expensive to manufacture. The current manufacturer of this resin also uses extensive equipment for installation, Snap Tite does not. Full-scale tests at two major universities have verified that columns reinforced with Snap Tite withstand three-to-eight times the deflection of columns without reinforcements. Preliminary tests indicate that Snap Tite can improve earthquake capability three times beyond that of a steel jacket. Snap tite jackets work by increasing the resistance to the phenomenon of spalling which occurs when an earthquake causes the concrete columns to shatter. This expose the steel reinforcement bars which then bend outward. The jacket also allow for greater deflection when a bridge column bends, so reducing the risk shear failure [7-9,17,24,25].

Retrofitting walls for seismic loads using aramid fibers

High strength fibers and elastomeric polymer bonded to walls can significantly strengthen walls against wind, seismic and blast loads. This System uses woven aramid fiber sheets as the reinforcing material. Aramid fibers are arranged to the axial direction of the sheets as shown in Figure 12. Aramid fiber sheets are characterized by light weight, high strength, no corrosion, and non-conductivity.

High strength aramid fiber can be applied to the inside (i.e., non blast loaded side), or to both sides of masonry walls. In the case of load bearing walls, high strength aramid fibers must be attached to both sides of the wall to prevent wall failure during rebound. Figure 13 shows a typical construction procedure of aramid retrofitting system. Epoxy resin is used for matrix of the sheets. Figure 14 shows a test wall with aramid matting. Aramid fibers are encased in a 0.03 inch thick layer of resin and placed parallel to the direction of the wall span between supports. E-glass or carbon fibers are optional high strength fibers that can be used in place of aramid [1,25].

Developments in fiber reinforced concrete for earthquake resistance

Significant progress in research and development in fiber reinforced concrete has been seen. Generally, concrete is strong against compressive force, but weak against tensile force. As a result conventional concrete elements tend to suffer brittle shear failure. The beam columns joints are critical region for the seismic safety of buildings as discussed before. A new FRC has been developed with embedded polyvinyl alcohol (PVA) fiber in the matrix, which is called PVA-ECC [7]. It has been claimed that this concrete realized unprecedented ductility by way of optimization of matrix, fiber, and fiber/matrix interface through a micromechanical approach. Controlling the interaction between PVA fibers and calcium ions

in the cement is important to obtaining the optimal frictional bond, which leads to excellent strain hardening behavior. The PVA-ECC has superior ductile property as compare to conventional FRCs as shown in Figure 15, which makes it more suitable for creating earthquake proof buildings. The PVA-ECC wall itself absorbs energy from the

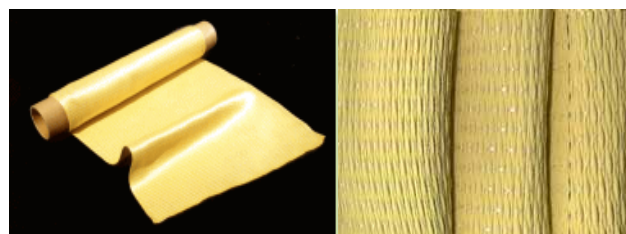


Figure 12: Aramid fiber sheet [16].

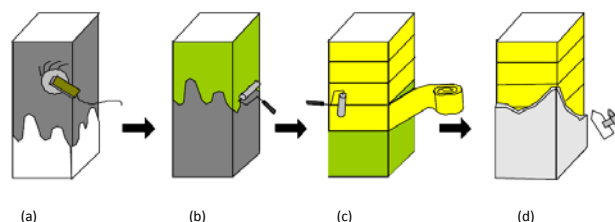


Figure 13: Typical construction procedure: (a) Surface treatment, (b) Coating primer and epoxy resin, (c) Wrapping sheet and removing air with roller, (d) Coating epoxy resin Finishing with mortar or painting [25,33].



Figure 14: Attachment of Kevlar Mat with Epoxy [25,33].

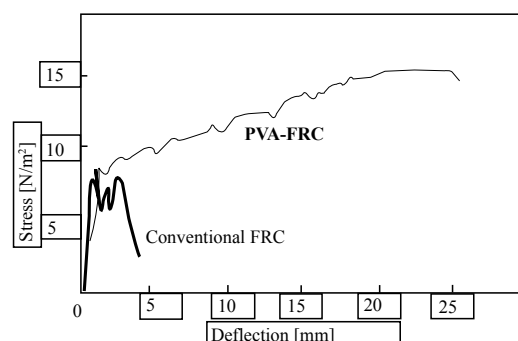


Figure 15: High-flexural deformability of PVA-ECC [17].

earthquake and save buildings from seismic force. Again PVA offers cost effectiveness compared to other aramide and carbon fibers. And it has good workability as well [17,35-41].

Base isolation for earthquake resistance

During earthquake the building which have fixed bases tends to be displaced in opposite direction of the ground motion due to their inertia. So, the inertia forces acting on a building are the most important of all those generated during an earthquake. Figure 16 shows three different possible cases of deformation in the building frame whose bases are fixed. Due to these deformations the building may collapse during earthquake.

To mitigate these kinds of deforming force of inertia base isolation method has been introduced. The concept of base isolation is explained through an example building resting on frictionless rollers. When the ground shakes, the rollers freely roll, but the building above does not move. Thus, no force is transferred to the building due to the shaking of the ground. Simply, the building does not experience the earthquake. Now, if the same building is rested on the flexible pads as shown in Figure 17, that offer resistance against lateral movements, then some effect of the ground shaking will be transferred to the building above. If the flexible pads are properly chosen, the forces induced by ground shaking can be a few times smaller than that experienced by the building built directly on ground, namely a fixed base building. The flexible pads are called base-isolators, whereas the structures protected by means of these devices are called base-isolated buildings. The main feature of the base isolation technology is that it introduces flexibility in the structure [34,41].

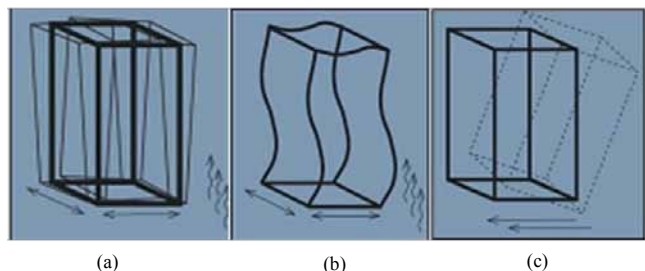


Figure 16: (a) shock & vibration to a stiffened frame: (b) shock & vibration to a bolted frame: (c) shock & vibration to a unbolted frame [42].

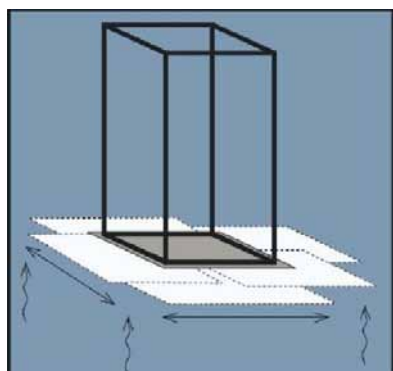


Figure 17: Base isolation system [42].

Due to the flexibility in the structure, a robust medium-rise masonry or reinforced concrete building becomes extremely flexible. The isolators are often designed, to absorb energy and thus add damping to the system. This helps in further reducing the seismic response of the building. Many of the base isolators look like large rubber pads, although there are other types that are based on sliding of one part of the building relative to other. Also, base isolation is not suitable for all buildings. Mostly low to medium rise buildings rested on hard soil underneath; high-rise buildings or buildings rested on soft soil are not suitable for base isolation [34-41].

Conclusion

Textile materials are successfully applied for earthquake resistant construction. The actual choice of fiber type, composite type, and number of layers of composite tiles for an earthquake resistance construction particular depends on the collaborative expertise of textile technologist and structural engineers. Fiber reinforced cement composites are found effective in construction and rehabilitation of masonry structures. Fibers used are high performance fibers such as aramid, carbon or glass. These fibers are judged more efficient than steel. Developments in resins are also going for getting long lasting effectively with performance. Various methodologies are also tried for applications of textile reinforced composites to strengthen the existing beams, columns and walls to protect them from seismic force. Base isolation method has been proposed for mitigating the effect of seismic shaking on low rise building.

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