CHAPTER-2

LITERATURE REVIEW

2.1. GENERAL

Retrofitting and Structural Health Monitoring of Structures is gaining importance on a large scale. On one hand, SHM helps in identifying the deficiency in the structural members while on the other hand, retrofitting helps in strengthening the members by the application of various available materials.

The literature survey has been done in these areas. The present chapter deals with the various researches that have been done in the related areas.

2.2. LITERATURE REVIEW

The literature survey has been done in the areas of health monitoring of structures and retrofitting of the structures. The studies have also been reported in the context of finite element modeling of the structures. The present section reports the research in this endeavor.

2.2.1. Strengthening of Structural Elements

(Jain 2006) reported about history of ferrocement. The first known example of reinforced concrete was a ferrocement boat. There are three different phases in the ferrocement history amongst the 1850’s, 1940’s, 1960’s. In 1850 began the concept of reinforced concrete and ferro cement, but only concrete construction, in its massive form, was done with great success, as a natural development of masonry architecture of that times. This phase had its duration for almost 100 years, with no substantial requirements. Ferrocement application went to decay after 1960’s as the labor cost increased and other competitors to thin walled components were developed. The most important property of ferrocement that emphasized it along its evolution is its high structural performance which facilitates application of the material in quite different constructions, from ship hulls to housing panels.

The effectiveness of externally bonded precast ferrocement plates in strengthening reinforced beams showing shear distress was studied (Kaushik et al. 1994). The relative efficacy of the bonding media used in bonding was studied. High tensile strength, low weight economy in long life of treatment and precise assessment of the additional strength gained by its use made it attractive for this application. Cement sand mortar bonding medium was found to be less effective than epoxy repaired beams, which showed a 20.5 % increase ultimate strength over original beams when subjected to identical loading. This specimen showed 25 % lower deflections than the original beams at the ultimate stage. The technique proved useful for rehabilitation of RC beams failing in shear.

The results of an experimental study of the feasibility of strengthening deficient RC cantilever slabs by bonding glass FRP (GFRP) strips / sheets were presented where the slab was deliberately made deficient through the mispositioning of tension reinforcement as the compression reinforcement with a 20-mm concrete cover, which may occur due to construction errors (Teng et al. 2000). As a result, the slab was made unable to resist the load intended for it to carry. The slab was positioned with its plane being vertical so that loading could be applied more easily using hydraulic jack fixed on floor. The experimental work included seven tests on cantilever slabs. The results demonstrated significant increase in ultimate load. GFRP strips provided a simple and efficient system to strengthen deficient cantilever slab Structures.

In another investigation, the strength of RC cantilever slabs bonded with GFRP strips was analysed (Lam and Teng 2001). Four model slabs composed of a wall segment supporting a cantilever slab were prepared. Slabs I and II were intended to have the same steel reinforcement ratio and position, but the former was loaded to failure before being strengthened to explore the effect of pre cracking. Slab III was designed with steel bars located farther away from the tension face. Slab IV had a higher steel reinforcement ratio than other slabs. The GFRP strips were formed by a wet lay-up process, using a woven fabric consisting of longitudinal glass fibres and transverse aramid fibres and a two component epoxy resin.

Initially, the behavior was linear. Thereafter, with the cracks appearing near the fixed end, the curve began to deviate from the linear path. After the GFRP strips reached their ultimate strength, the load dropped rapidly from the peak to a significantly lower load level. It was found that with the sufficient anchorage of the FRP strips to the cantilever slab by fibre anchors, debonding between the slab and the GFRP strips was less likely to occur and could be arrested by the fibre anchors if it does occur.

The results of punching shear tests on 31 square ferro cement slabs have been reported in the paper (Mansur et al. 200 1).The slabs were simply supported on all four sides and tested under a central concentrated load. The parameters investigated included mortar strength, volume fraction of reinforcement, depth of slab, and the effective span. They consist of testing a total of 31 simply supported, reinforced square slabs under a centrally applied load. Both cracking and punching shear strengths, in terms of load, resulted in significant increase.

A rehabilitation method that has gained widespread acceptance over the last decade involves externally bonding fibre-reinforced polymer plates onto the tension face of a concrete beam or slab, thus increasing the beam's or slab's flexural stiffness and load capacity. The research included the examination of four different specimens identified as free plate, thin-tape, thick-tape, and epoxy specimen (Luangvila, K. et al. 2002). The free plate specimen is simply a single, stress-free FRP plate that is not bonded to anything. The FRP plate was a 1 .2-mm thick, unidirectional, carbon fibre composite CarboDur S5 12. The thin-tape specimen consisted of the same FRP plate bonded to an aluminum half space with a 0.25-mm thick adhesive tape. The adhesive tape F-9473PC enabled bonding with a uniformly thick bond layer. The epoxy specimen composed of the same FRP plate that was bonded to a concrete half space with a 3.175-mm-thick epoxy bond layer as specified by the manufacturer. The research demonstrated that the combination of laser ultrasonic with the re assigned spectrogram was very effective in experimentally measuring the dispersion curves of FRP bonded components. The high-fidelity and broad-bandwidth nature of laser ultrasonic makes it possible to experimentally measure transient Lamb waves in FRP bonded components without any frequency biases.

Another paper represented the experimental results of the long-term deflection and cracking behavior of the concrete beams pre-stressed with carbon fibre-reinforced polymer CFRP tendons with a comparison to those with steel tendon (Zhou 2003). Six full-scale beams with rectangular cross-sections 300 mm deep by 150 mm wide and with spans of 6,000 mm were fabricated.

A particular type of CFRP tendon, lead line, with a slightly indented surface, 8 mm in diameter with a guaranteed tensile strength of 2,250 MPa and elastic modulus of 147,000 MPa was used in four of the beams. Seven-wire steel strand tendon, with smooth surface, 8 mm in diameter with the tensile strength of 1,860 MPa and elastic modulus of 200,000 MPa was used in the other two beams for comparison purpose.

When the beams remained uncracked under the sustained service load about 90% of the cracking load in this case, the long-term deflections of beams with CFRP were similar to those with steel tendons. The test results showed that the effect of concrete strength on the long-term behavior of the pre-stressed concrete beams is significant. With an increase of concrete strength, the cracking moment of the beam increases, and fewer cracks formed under the same level of loading. With an increase of concrete strength, the long-term creep strain reduces. Hence, beams with the higher concrete strength have lower curvature and lower deflection.

In an effort to assess the constructability and performance of bridges with fibre-reinforced polymer (FRP) composite decks, the short-term and long-term responses of a 207 m, five-span bridge retrofitted with four different FRP panel systems were monitored (Reiner et al. 2004).

All the panels were 20 cm thick. The ‘‘all FRP’’ panels covered the whole width of the bridge, resulting in a panel length of 14.6 m. The width of each panel was 2.44 m. The FRP 4 panels, on the other hand, only covered one bay between the girders. Their length was 2.4 m and their width was 46 cm. The concrete dominated the unit weight of these panels, and the deck was approximately five times heavier than the ‘‘all FRP’’ decks. Two of the FRP panel systems were found to perform considerably better than the other deck systems.

Based on the tests, long term data, and field observations, it was concluded that the deck system FRP 4 continued to exhibit the unintended composite action that was observed for the original RC deck. The layout of the panel cross sections has a major influence on the performance.

The small contact area between the core and the face sheets in sandwich-type decks could make such systems more susceptible to delamination, particularly in large panels. Internal insulation of the core material or horizontal dividing layers may result in large thermal gradients that influence the overall panel behavior, such as panel movements. The performance of the FRP 4 hybrid system was very satisfactory and least surprising. However, these systems lacked some of the benefits offered by ‘‘all FRP’’ deck systems, such as dead load reduction and reduced construction time.

In another research, the repair of slab-column connections using carbon fibre reinforced polymer (CFRP) sheets was made (Robertson and Johnson 2004).The models of interior slab-column connections were subjected to an increasing cyclic lateral load routine while supporting a slab gravity load equivalent to dead load plus 30% of the live load. During application of gravity load, slab cracking occurred adjacent to column. As increasing lateral displacements were applied, these cracks extended to the edge of the slab while additional flexural and torsion cracking occurred. All the specimens were reinforced with slab shear reinforcement to prevent punching shear failure. Epoxy repairs of cracks in slab-column connection were able to restore lateral load capacity. Because of the stroke limitation of the lead actuator, cyclic load reversals were only possible up to 5% lateral drift - beyond this drift, cycling continued in one direction only. Epoxy repair of cracks in a stab-column connection was able to restore the lateral load capacity, but did not restore the initial stiffness of the connection.

Retrofit of three-span reinforced slab bridge with fibre reinforced polymers systems were also studied (Shahrooz and Boy 2004). The material properties of steel bars and concrete were assumed, as no samples were available for testing. The bridge had minor cracks on the underside of the slab in the mid-span mostly along the joint. The bridge was instrumented and tested before retrofitting, shortly after installation of retrofitting systems and after one year of service. The retrofitted bridge achieved rating factors and load limits larger than the corresponding values for original bridge. Retrofitting with FRP system led to 22% increase in load carrying capacity of the bridge.

The investigation of the field performance of an FRP slab bridge was done where the in-service performance, and impact and dynamic characteristics of the first fibre reinforced polymer composite bridge superstructure built in New York State in late 1998 were documented (Alampalli 2005). This was also the first such bridge to use high skew angle, integral barrier, and deck cross slope. A detailed test program of periodic testing and visual inspections was used to monitor its in-service performance, characterize its dynamic properties, and obtain data to calibrate theoretical analyses.

The test data indicated that the superstructure was structurally performing well. The maximum strains recorded were well below those predicted during the design stages. Low strains and deflections observed in the field, compared to those predicted, were attributed to assumptions made regarding the boundary conditions during the design.

These also showed the need for better optimization of the deck to make these more cost effective in the future. Higher modal damping values were observed and reflect the vibration absorbing capacity of FRPs, compared to steel structures. The dynamic behavior also confirmed that the longitudinal joint is working well and the structure is behaving as a single unit.

The evaluation of the effective width and distribution factors for GFRP bridge decks supported on steel girders was done (Moses et al. 2005). They performed a number of in situ load tests of three steel girder bridges having the same GFRP deck system to determine the degree of composite action that may be developed and the transverse distribution of wheel loads that may be assumed for such structures. Current design practice treats GFRP deck systems in a manner similar to no composite concrete decks. Specifically the effective width of the GFRP deck was lower than that of an equivalent concrete deck. This decrease resulted from increased horizontal shear lag due to the less stiff axial behavior of the deck as compared to concrete and increased vertical shear lag due to the relatively soft in-plane shear stiffness of the GFRP deck. The engaged effective width showed some evidence of degradation with time, a condition most likely related to reduction in the shear transfer efficiency required for composite behavior.

The history of ferrocement was reported in an investigation where the author discussed the rehabilitation technique for reinforced concrete structural beam elements using ferro cement (Tomar 2006). Reinforced concrete beams were strengthened with hexagonal chicken wire mesh and skeletal steel combined by ordinary plastering considering the amount of wire mesh applied, its geometrical configuration and the degree of distress in the beams. The test results were in good agreement with the original design capacity of the beams.

This technique of strengthening offers several advantages such as, it doesn’t require any specialized labor or equipment or any formwork. The author also reported that Ngoro, a wooden ferry in New Zealand has been preserved as a historical artifact and moored in an inner harbor location at which she recently sank. Subsequent examination of the hull showed severe damage by gribble worm. Re-planking of the hull was estimated to cost US$ 120000 and would have required annual maintenance for repainting and antifouling treatment for increasing its life span. The ferro cement retrofit was estimated to cost US$ 15000 to US$ 16000 and would in contrast to the other options, provide long term durability.

The author (Tomar 2006) further stated that in 1991, behavior and performance of composite ferrocement brick reinforced slab without ferrocement panels especially to be shaped into simple geometric forms was studied. There are various advantages of this building technique: product quality is assured using prefabrication by optimizing aggregate grain, the water cement ratio binder and may entail deduction in cost, while the simplicity of the operation to be performed to obtain a structural element from the semi-finished product make the process ideally suitable for self-help activities, enabling even unskilled workers to participate in the construction of their homes. The author described that the detailed study on thin ferrocement sheets of 10mm thickness was carried out in 1991 and their cracking and strength characteristics were determined. Cement replacement by 50% to 70% fly ash and inclusion of super plasticizer can produce mixes of excellent flow characteristics and adequate early strength that can further ease the construction process and enable incorporation of short discrete fibres without difficulties of fabrication. The inclusion of fibres increases stiffness, decrease deflection and shows large ductility at failure. Small opening meshes controls cracking better than large opening meshes.

The author also compared that the durability of polymer-ferrocement with conventional ferrocement. Using styrene-butadiene rubber latex, the polymer-ferrocement is prepared by varying the ratios of polymer and cement, and is tested for accelerated carbonation, chloride ion penetration and accelerated corrosion. It is concluded that the carbonation and chloride ion penetration depth of polymer ferrocement decreases markedly with an increase in polymer-cement ratio regardless of exposure and immersion periods, and are strongly affected by polymer-cement ratio and water-cement ratio. With the increase in polymer-cement ratio, corrosion inhibiting property of polymer-ferro cement is improved remarkably.

Furthermore, the advantages and application of ferro cement for low-cost housing especially in Pakistan were presented. As a result a cheaper and durable solution was obtained using ferrocement roof and wall system and also a more permanent look to the structure is obtained as compared to other low-cost materials with a reasonable amount of economy. Successively, the effectiveness of the repair primarily depends on how effectively the diagonal tension cracks in the shear-damaged beams were trapped. Flexural mode of failure was observed surpassing shear capacity for only those specimens where full encasement of the shear zone was carried.

Another experimental work was conducted in which the FRP strips, reinforced with a combination of carbon and Glass unidirectional fibres and continuous strand mats, were fastened to the concrete beams with steel powder-actuated fasteners (Bank and Arora 2006) and were tested to different failure mode. The strengthened RC beams were designed to fail in a ductile manner. Test results implied that the strengthened beams showed increases in yield and ultimate moments of up to 25% and 58%, respectively over an un-strengthened beam. All strengthened beams failed, as intended, in a ductile manner with the ultimate failure mode due to concrete compression failure at large deflections with the FRP strip still firmly attached.

In recent years, the use of externally bonded fibre-reinforced polymers (FRP) has become increasingly popular for civil infrastructure applications, including wrapping of concrete columns. Significant research has been devoted to circular columns retrofitted with FRP. The use of externally bonded FRP composite for strengthening and repair can be a cost-effective alternative for restoring or upgrading the performance of existing concrete columns. The paper (Kumutha et al. 2007) was directed towards this endeavor. A total of nine reinforced concrete columns were tested. The columns were cast horizontally in steel forms and compacted using a needle vibrator. The length 750 mm and the cross sectional area of 15625 mm^2 was kept constant for all the specimens. From the results, it was seen that the confinement of columns with GFRP wrap increases load carrying capacity of reinforced concrete columns. For most wrapped columns, the failure of GFRP wraps was observed at or near corner in all the specimens mainly due to stress concentrations. In order to avoid stress concentration, attempt should be made to round off sharp corners. The ultimate load predicted from the proposed analytical model was compared. It was found that a good correlation was obtained between the experimental results and those got from the theoretical model. The maximum error was found to be only less than 7%. The load carrying capacity of the column decreased, with increase in aspect ratio of the cross-section. The test results show a clear overall linear relationship between the strength of confined concrete and lateral confining pressure provided by FRP. Based on the analysis of the experimental results, a simple model has been proposed for the prediction of the ultimate load of FRP confined columns, and a good correlation was obtained between experimental and analytical results.

The experimental investigation of ferrocement overlay as a repairing material for distressed masonry in filled RC frame under lateral loading condition was carried out to have an idea about regaining load carrying capacity after distressed condition (Amanat et al.2007).The masonry in filled RC frame was tested by applying monotonic lateral load at the top of the RC column up to initiation of failure. The surface of masonry in-fill and all sides of column were colored white and yellow to facilitate the viewing of cracks. Load was increased stepwise at the rate of 1 ton per step until the failure occurred by recording it from machine dial gauges simultaneously. Ferro cement technique was adopted to repair the distressed RC frame and masonry in-fill wall. It was concluded that the capacity of the in filled frame will be significantly higher if ferrocement overlay is applied to any existing un-distressed in-fill.

FRP composites are light-weight and easy to install on site, they are considered to be the most favored material in many strengthening applications. The state-of-the-art of the FRP composites for strengthening of existing civil structures in Europe was presented (Motavalli and Czaderski 2007).

The use of FRP in civil and building structures is not uncommon anymore. The structures have successfully been strengthened or retrofitted with FRP materials in many European countries. FRP composites are readily used for strengthening applications mainly due to the relative ease of installation. Strengthening with FRP composites have mostly been either at the lowest tendered price or the only plausible solution available. The material costs of the FRP composites are several times more than that of conventional materials (e.g. steel and concrete). However, the life-cycle cost, including fabrication, application, protection and projected maintenance costs, is comparable and can be less than that of conventional materials (Motavalli and Czaderski 2007).

GFRP sheets are effectively used as a retrofitting material as it has high strength-to-weight ratio, good corrosion and fatigue resistance. E-glass is mostly used of all the glass fibres as it has low cost, high temperature resistance. E-glass and Epoxy were used for creating sheet bonded specimens (Mukherjee and Arwikar 2007). The specimens consisted of beams without any internal reinforcement. The beams were reinforced with E-glass fibre sheet. Bracket-assembly was used to load the beams and the loads were controlled by monitoring the spring length during tightening of bolts. It was seen that the deflection in original beams was more than the conditioned beams. The beams failed at higher loads and less deflection. The ultimate deflection came down from 2mm to 0.5mm. Compressive strength increased by 22% due to conditioning.

The degradation of bond between FRP and RC beam was studied (Silva and Biscaia 2007). The effects of cycles of salt fog, temperature and moisture as well as immersion in salt water on the bending response of beams externally reinforced with GFRP or CFRP, especially on bond between FRP reinforcement and concrete was considered. Temperature cycles and moisture cycles were associated with failure in the concrete substrate, while salt fog cycles originated failure at the interface of concrete adhesive. Immersion in salt water and salt fog caused considerable degradation of bond between the GFRP strips and concrete. No significant differences were detected on the behavior of the systems strengthened with GFRP and CFRP.

The experimental and theoretical studies on the effect of structural topping on shear capacity of hollow core slab were done (Girhammar 2008). The testing program included construction of composite slabs 950 mm in width, 6400 mm in length and 280 mm in thickness. Plain concrete and steel fibre reinforced concrete were used as topping material. The beams were cast at both ends of slabs to prevent cracking during transport. Pull-off test for tensile strength and compression strength test was done. Fibre reinforcement increased compressive strength of concrete topping by 20% whereas there was a slight increase in tensile / bond strength of fibre-reinforced concrete. When analytical evaluation of failure modes and ultimate load carrying capacities was made, it was seen that the predicted failure mode was shear tension failure in all cases. The observed load bearing capacities were on an average 30% and 37% higher than from analytical results.

The seismic behavior of a full-scale RC structure retrofitted using GFRP laminates was studied (Ludovico et al. 2008). The experimental program aimed at two main objectives of improving the understanding of the plan-irregularity influence on the seismic response and the effectiveness of different retrofit methodologies.

The experimental activity highlighted that the retrofitting intervention provided the structure with an enhanced ductility with respect to the "as built" configuration, which suffered significant damage under the excitation. The experimental results showed that the deformation capacity of the structure has likely been increased since the damage of the retrofit structure was significantly less than the damage of the "as-built" structure under the same seismic input. Moreover, FRP retrofit allowed the structure to withstand a level of excitation, in the two directions, 1.5 times larger than that applied to the "as built" structure.

The GFRP laminates provided a considerable increase of the structural global deformation capacity without significantly affecting its strength. The laboratory work showed that the use of composites could represent a sound alternative to traditional methods, as it allows improving considerably the seismic performance of an existing RC structure by increasing its deformation capacity without significantly affecting its stiffness.

Another research aimed at examining the potential use of mechanically-anchored unbonded FRP (MA-UFRP) system to upgrade RC slabs deficient in flexural strength (Maadway and Soudki 2008). MA-UFRP system does not require surface preparation, adhesive application, or skilled labor. The structural performance of RC slabs strengthened with MA-UFRP system was studied and compared to that of slabs strengthened with EB-FRP system. The effect of varying the number and location of anchors along the slab span on concrete compressive strain, FRP strain, and overall flexural behavior was investigated.

All the slabs were tested under four-point bending with an effective span of 1500 mm and a shear span of 500 mm. Load was applied monotonically at the mid-span of the slab using a servo-hydraulic actuator having a capacity of 156 kN. The slab was supported on two steel pedestals, 1500 mm apart on center. The pedestal rested on the rigid floor of the concrete laboratory one linear variable differential transducer (LVDT) was placed under the mid-point of the slab to measure the deflection while a calibrated load cell was used to record the load. LVDTs were also used to measure the slip between the concrete and the CFRP strip at the end anchors. Two strain gauges, each of 30 mm length, were bonded to the surface of the CFRP strip, one strain gauge at the mid-span and one strain gauge at a point mid-way between the support and one of the loading points.

The slabs strengthened with MA-UFRP had higher yield and ultimate loads relative to those of the control but the strength gain was less than that obtained by the use of EB-FRP system. The yield load of the slabs strengthened with MA-UFRP was on average about 13% lower than that of the slabs strengthened with EB-FRP but was still 20% higher than that of the control. MA-UFRP strengthening system resulted in about 33% average strength gain relative to that of the control with a minimum and a maximum of 20% and 43%, respectively. The strength of the slabs strengthened with MA-UFRP was on average 18% lower than that of specimen B-MA-2 and only 10% lower than that of specimen B-NA. The mid-span deflection at ultimate load of the slabs strengthened with MA-UFRP system was on average 56% higher than that of specimen B-NA, 5% higher than that of specimen B-MA-2, and only 15% lower than that of the control.

The flexure behavior of slabs with pre-stressed and non-pre-stressed CFRP sheets was studied (Kim et al. 2008). In this research, flexural behavior of the tested slabs, including the load-deflection response, strain distribution, crack propagation, and crack mouth opening displacement were found for four large-scale flat plate slabs 3,000 mm×3,000 mm ×90 mm having span length of 2700 mm. The slabs were subjected to a monotonic patch load at center of span with the help of plate. One slab was kept as a control slab and other three were strengthened with CFRP sheets out of which one was strengthened with non-pre-stressed CFRP sheet and two were strengthened with pre-stressed CFRP sheets. After applying load, an increase in the flexural load-carrying capacities of up to 25 and 72% was achieved for the slab strengthened with non-pre-stressed and pre-stressed CFRP sheets, as compared to the un-strengthened control slab. Failure pattern of the control slab was very ductile but for strengthened slabs it was step wise failure.

Study of acoustic emission on concrete slab strengthened with CFRP was monitored (Degala et al.2008).Three different approaches to analyze the data, namely, parameter analysis, intensity analysis and principal component analysis. A total of nine slabs were tested in a monotonic load-to-failure protocol under displacement control and monitored using an AE instrumentation suite. The slabs had four different CFRP width-to-spacing ratios. Each slab was tested in four points bending over a span of 1220 mm. The load was applied in monotonic manner to failure. For one of the specimen, significant acoustic activity was detected in two instances around 8.90 kN and 22.2 kN. At 53.5 kN, the density of AE events increased. At 59.8 kN, the strip deboned from the concrete substrate. Event amplitudes falling between 40-5 9 db and 60-100 db were distinguished. The more heavily loaded slab failed at 75.6 kN due to a concrete shear failure. All AE amplitudes were below 60 db. Shear failure of the third specimen occurred at 97.9 kN that was confirmed by parametric analysis. This study showed that cumulative energy correlates well with the degree of damage sustained by specimens.

(Honickman and Fam 2009) investigated a structural form system for concrete girders using commercially available GFRP sheet-pile sections. Specimens incorporating either adhesive to wet concrete bond or bonded aggregates systems had a bond failure at the concrete-GFRP interface, within a thin layer of cement paste. The specimen incorporating additional non headed studs achieved only a modest increase, 24%, in strength; as failure occurred by studs pull out from the concrete flange. Flexural stiffness was not affected by bond system. Adhesive bonding to wet concrete was the simplest and quickest to apply, while resulting in a comparable strength to other systems.

In general, 47–75% of the ultimate strains of concrete and GFRP materials were reached at bond failure. In most practical applications, however, where shear span-todepth ratios are likely greater than the 4.2 used in this investigation, flexural failure will likely precede bond failure

In wet adhesive or bonded aggregate girders, excellent monolithic composite action was observed prior to bond failure, as evident by a consistent lack of slip between concrete and GFRP throughout the loading history. Increasing concrete strength had insignificant effect on stiffness or the bond failure load. It, however, increased flexural strength, when governed by concrete compression failure. Increasing the thickness of the GFRP flanges increased flexural strength and stiffness significantly, but had a negligible effect on the bond failure load.

Investigation of the effects of FRP on slabs was done (Smith and Kim 2009). For the research, six simply supported one-way spanning RC slabs were made. All slabs were prismatic, rectangular in cross section and were 3400 mm long, 160 mm deep with a clear span of 3200 mm. Two of the slabs were control specimens and two of the slabs were without cut outs. Slabs were strengthened by bonding high-strength, light-weight, non-corrosive fibre reinforced polymer (FRP) composites to the tension face of the slab. When load was applied to the slabs it was observed that the three control slabs were loaded until the deflection increased without a substantial increase of load. At this stage the tension steel reinforcement had yielded and cracking had stabilized. The test was stopped when the mid span deflection was at most 100 mm due to the maximum stroke of the actuator being reached. Slabs strengthened with FRP failed after debonding of FRP from the concrete surface after this the behavior of the slabs approximately resorted to that of plain un strengthened slabs and the application of load stopped when the mid-span deflection reached at most 100 mm. The maximum average load of control Slabs was 50.6 kN, 45.6 KN and 49.3 KN and the FRP-strengthened slabs debonded at an average load of 76.4, 70.5 and 80.8 kN, so they concluded that all FRP-strengthened slabs failed by debonding, and the extent of debonding and the ability of the slab to sustain load post-initiation of debonding was dependent on the position of the load.

In another investigation, the strengthening the RC beams deficient in shear by using GFRP sheets was carried out (Sundarraja and Rajamohan 2009). In this study the response of RC beams strengthened in shear using bi-directional GFRP fabrics was found out. The retrofitting was done by using inclined side GFRP strips and by providing inclined U-strips of GFRP.

This experiment was aimed at understanding the best wrapping style for retrofitting the deficient beams. In his study five control beams were taken having cross-sectional dimensions of 100 mm ×150 mm and 1000 mm length. From these five beams one beam was fully strengthened. But the other four beams were so designed such that they were shearing deficient. For testing three sets of beams were casted in which one set was of control beam, second set was of beams which were externally bonded with inclined GFRP strips on the sides of shear span and third set of beams were those which was given inclined U-wrap of GFRP strips. The failures that were observed comprised of shear failure due to GFRP rupture, and shear failure without GFRP rupture, crushing of concrete at the top and flexure failure. Beams retrofitted with GFRP inclined U strips had flexure cracks caused due to rupture of FRP. The retrofitted beams when tested for their ultimate loads were found to have greater load carrying capacity than their corresponding control beams. Maximum percentage of increase in ultimate strength of 50 % was observed in the beams retrofitted with GFRP Inclined strips. The ultimate loads of beams retrofitted with U-wrapping were greater than the beams retrofitted by bonding the GFRP strips on the sides alone. The load carrying capacity of the retrofitted beams were found to be greater than that of the control beams, thus the externally bonded FRPs were able to help in taking more load.

The investigation on the bond strength of FRP fabrics and flexural behavior of FRP strengthened reinforced concrete beam using cement based adhesives was conducted (Hashemi and Mahaidi 2010). The specimens were 245 ×75 ×75 mm^3 concrete prisms. The surface of the specimen was sand blasted to achieve a high level of bonding between mortar and concrete. CFRP material was applied in two different shapes including fabric and textile. The anchored prisms showed higher levels of load carrying capacity compared to the unanchored ones. One beam was retrofitted with 2 strips of

CFRP fabric using normal epoxy adhesive. The failure was characterized by a combination of mid-span and end deboned. The load carrying capacity was 61.7 kN which was 35 % higher than the control beam capacity. Cementitious mortar adhesive was used to attach 2 layers of CFRP fabric strips to the soffit. The load was progressively increased, a flexural shear crack developed near the point load. As the load was further increased, most of the fabric was unbonded on one side of the beam and the beam started to exhibit a response similar to that of the control beam. The ultimate load which was achieved by using CFRP textile-cement mortar is around 80%.

A research paper on Field Monitoring and Repair of a Glass Fibre-Reinforced Polymer Bridge Deck was presented (Berman and Brown 2010). The deck deflections were monitored periodically over a 10-month period and were found to increase significantly over that time. The GFRP deck was an adhesively bonded assembly of GFRP tubes and top and bottom plates. After 9 months of service, wearing surface cracking was observed, and upon closer inspection, the top GFRP plate was found to be delaminated from the tubes over a fairly large area. Deck deflections in the area of delamination were found to be considerably larger than those observed during previous monitoring in undamaged locations. A retrofit solution was employed where the top plate was reconnected to the tubes using screws coated with a two-part epoxy that mixed when they were driven. At the time of writing the retrofit was successful in reattaching the delaminated top plate.

Field monitoring of the Getchell Road Bridge was performed over nine months to determine the feasibility of using a GFRP deck for the retrofit of the larger Granite Falls Bridge. The results indicated the deck displacements increased significantly between each monitoring date. The static displacements recorded on July 31, 2007 were more than twice those recorded on October 18, 2006 due to top plate delamination. Cracking of the wearing surface and top plate delamination were observed at multiple locations. The calculations showed that the deck moment of inertia decreased by 50% when the top and bottom plates have completely delaminated.

(Nam et al. 2010) experimentally evaluated the effectiveness of GFRP against blasts pressures. The concrete damage model represented dynamic hardening-softening non-linear behavior. The slab made was doubly reinforced with welded wire-mesh. The slabs were retrofitted with two laminates of GFRP in crossed form. The blast was assumed as a spherical burst which was converted into 27.4 kg of TNT by conversion factor of 0.82.

The shell elements of GFRP were attached to the solid elements of concrete. The analysis was in good agreement with experimental data. There was a minute difference between debonding and perfect bonding models which indicated energy absorption capacity of perfect bonding between GFRP and concrete. The results of displacement of non-retrofitted slab were compared and it was seen that the maximum displacement was reduced by 20% by GFRP retrofitting. In non-retrofitted slab, the central region has large out-of-plane displacements. There were slight localized material failures when the stresses of GFRP exceeded the material strength and debonding failures were observed when local GFRP strains exceeded maximum strain capacity.

Generally the material used in construction of pedestrian bridges consists of steel, wood and Reinforced concrete. The materials mainly comprises of fibre reinforced polymer (FRP), self-compacting concrete (SCC), GFRP and CFRP, fibre reinforced steel compacting concrete (FRSCC). The influence of height and thickness of GFRP profiles and effect of additional layer of pre-stressed carbon fibre sheet was evaluated (Mendes et al. 2011). The length was half of length of original bridge. For the loaded length of 12m, the deflection limit was 48mm.

The investigation on the three FRP bolt types and their behavior was compared with two previously tested slabs: SB 1 without shear reinforcement and SB4 with steel shear bolts. (Lawler and Polak 2011). To analyse slab's behavior and failure, the comparisons were also done with the ACI code predictions. They concluded that FRP rods work well as a retrofit method provided the anchorage is strong enough to carry tensile forces opening the internal shear cracks.

Study on reinforcement of simply supported beams with Carbon and Glass fibres was reported (Tokgoz et al. 2011). The weakest points of reinforced concrete beams are the regions where tension and shearing stress concentrate. Nine moulds of poplar wood were used. A total of one hundred and fifty three stirrups were used in each beam samples. Reinforcement was applied by using CFRP and GFRP textiles. Two transducers were attached at tension and pressure zones. Linear Variable Differential Transformer (LVDT) was used for the measurement during loading of all beams. Control beams consumed 15% less energy than the beams reinforced with GFRP. Lowest energy consumption was in the beams reinforced with CFRP. Cracks occurred at end point of material adhered in two layers. Use of GFRP strips were more effective in strengthening of structures in shear. The displacement of beams was 43.8 mm, 22.8 mm and 32 mm for control, CFRP and GFRP beams.

Bond strength is an important factor on which strength of whole member depends. The failure of bond may be within concrete or at FRP / concrete interface. The glass FRP / concrete interface was characterized (Biscaia et. al 2012). The failure criterion of GFRP/Concrete interface was established based on double shear tests. Two steel rods were used to exert pressure and two pressure cells were used to control pressure. The specimens consisted of unidirectional GFRP laminates bonded on opposite faces of standard concrete cube. The compression stress showed a relative increase of 43.1% and 12.8%. Cohesive rupture of concrete and adhesive rupture at interface between GFRP and concrete were the modes of failure observed.

Most recently, the assessment of the performance of flat plate structures by non-linear static and dynamic analysis by using program code opensees was carried out (Shin and Kim 2013). The various retrofit schemes that were applied comprised of steel braces and jacketing of steel columns. It was seen that by considering the stiffness reduction factor, the results obtained matched well with the results of beam elements. The cyclic behavior of the non-linear element was compared with the connection behavior using non-linear fibre elements. The non-linear model exhibited brittle behavior due to shear failure. The modeling of jacketing columns was done by non-linear fibre section.

The braces were connected to the steel columns. Also, the beams were retrofitted with steel plates to improve the resistance to shear failure. It was found that the steel braces did not significantly improve the strength due to their less contribution towards resisting lateral load. The jacketing of columns significantly improved the strength with the steel plate.

The study on the fatigue performance of GFRP placed concrete bridge decks that were supported by precast girders was done (Richardson 2013). In one of the two systems of bridge decks, the flat panels were joined by splicing. In the second system, the corrugated sheet-pile sections were joined through connections. The two types of surface treatments were done for each system. In the first test, GFRP acted as a permanent formwork replacing the bottom reinforcement. In the second testing type, the GFRP rebar was provided for cracking control.

Cyclic loading was applied and linear potentiometers were used to measure deflections. It was observed that up on completing 3 million loading cycles, there was 9% reduction in the slope of load-deflection curve. The crack propagation was observed with the increase in strain in the GFRP rebar. The GFRP ribbed panels or corrugated panels survived with excellent performance up to 3 million cycles. Thereafter, the degradation occurred up on punching shear. There was tearing between GFRP flange and web occurred in the corrugated-form deck.

2.2.2. Health Monitoring of Structures

It is often necessary to test concrete structure to determine its suitability for which it is designed. Ideally such testing should be done without damaging the concrete. The tests available for concrete range from the completely non-destructive to partially destructive tests.

Various researches that have been done on the damage detection of structures are summarized below:

The vibration frequency analysis to evaluate the global condition of the structure was used (Pandey et al. 1994). When the structure was dynamically excited, the resulting mechanical vibrations comprise different modes of vibration. The damage imparted to the structure results in a change in the natural frequencies of vibration.

Thereafter, the natural frequencies of vibration were accurately tracked while a concrete specimen was subjected to test loading (Subramaniam et al. 1998). In this study, prismatic concrete beams with 46 cm length were used. The experimental setup consisted of a 4.75 mm diameter ball, two accelerometers, a digital oscilloscope and a personal computer.

The experimental results demonstrate the capability of nondestructive evaluation techniques that have been developed at Center for Advanced Cement Materials. Through thickness ultrasonic measurements were much more sensitive to the presence of micro cracks in the concrete structures than to the ultrasonic velocity measurements. Self-calibrating test measurement scheme was used for an unprepared concrete structure by applying one-sided mechanical wave signal transmission. The relationship between reduction in vibration frequency and imparted damage could be used to predict the fatigue life of a structure, assuming an appropriate and sensitive vibrational mode of a structure is identified, isolated, excited, and monitored over a portion of its fatigue life.

The techniques that can detect, localize, and characterize damage in concrete that may take the form of distributed micro cracks, such as that caused by freeze-thaw action, or distinct large cracks that extend significant distances within the structure (Shah et al. 2000). The ultrasonic tests were applied to a series of prismatic concrete specimens. To perform an ultrasonic test, the test specimen was immersed in a water bath, in between a pair of 500 kHz, 2.5 cm diameter ultrasonic transducers. Ultrasonic pulse transmission measurements were found to be sensitive to the presence of microscopic damage in concrete.

An ultrasonic non-destructive investigation technique for bonding evaluation in external FRP strengthening was performed (Bastianinni et al. 2001) and it was observed that the technique was similar to the usual pulsed echo ultrasonic analyses, but bonding defects were located through the amplitude of the reflection echo rather in its delay time. They successfully tested the effectiveness of the above named technique with different composite materials (CFRP and GFRP).

From the detailed investigation it was suggested that the technique was applicable when the FRP strengthening was applied in a more heterogeneous material acting as an "acoustical black body" at some ultrasonic frequencies. The limited surface roughness allowed a good contact coupling between the transducer and the material under test.

A wide research on an experimental study on the behavior of flat slabs containing openings at different locations was presented (Tayel et al.2004). 12 square plates (1.5 m x 1.5 m and 4.0 or 6.0 cm in thickness) models having different opening sizes, shapes, and locations were casted, treated, and tested under the effect of concentrated load. Also two models without openings were tested under the same conditions for comparison. In this work each plate was rested on four corner supports and loaded in increments up to failure. The slabs to be tested were classified in four groups and each of which is further designated by four characters. First group was plate with central opening, second group was plate with eccentric opening, and third group was a solid plate without any opening. Every plate model had a side length of 150 cm. All the plate models were tested using the steel frame supported on four corner supports; each was a steel plate 5 x 5 cm. Each plate model was loaded up to failure using the steel frame applying the load by a hydraulic jack. The load increments achieved by increasing hydraulic jack compression, each load increment was 250 kg for the 6 cm thickness plate models and 125 kg for the 4 cm thickness plate models. After each load increment, the strains, deflections, first cracking loads and failure loads were recorded, also cracks propagation were marked.

The main conclusions drawn from the experiments included that the presence of openings in flat slabs decreased the strength and rigidity of the flat slabs depending on the sizes, shapes, and locations of these openings. The bigger the dimension of the opening, the higher the deflection values were. The deflection values of the slabs with square openings were about 125% higher than those of slabs with circular openings having diameter equal to the square opening side length. So, the most suitable shape of an opening in the slab is the circular shape and the most preferable location was away from the corner supports.

Some of the available non-destructive evaluation methods may be used in the field or in the laboratory to assess the properties and physical conditions of structural materials (Yaqub, M. (2007). The paper presented the results of a case study carried out on fire affected and unaffected concrete structural components in sixteen storey reinforced concrete building damaged in Pakistan. Non-destructive testing technique was used to obtain information about the properties or the internal condition of the building without damaging. Semi destructive tests were also carried out on fire affected concrete and unaffected concrete. Thirty three core-samples were taken. Out of which eleven samples were taken from the unaffected portion of the building and remaining twenty two from beams and six samples from slab were taken. It was observed that fire affected concrete core wall, beams and slabs compressive strength were 34 MPa, 13 MPa and 16 MPa while unaffected concrete core wall, beams and slabs compressive strength were 44 MPa, 27 MPa and 22 MPa respectively.

Fifteen ultrasonic pulse velocity tests were carried out from basement to top floor on fire affected concrete and unaffected concrete. It was observed that in slabs the average strength of unaffected floors was 39 MPa and average strength of affected floors was 32 MPa. In beams the average strength of unaffected floors was 37 MPa and average strength of affected floors was 16 MPa. Similarly the average column strength of unaffected floors was 28 MPa and the average column strength of affected floors was 16 MPa. Fifteen Rebound Hammer tests were conducted on different floors of fire affected concrete and unaffected concrete.

Based on the destructive and non-destructive test results obtained in this study, it was observed that the concrete compressive strength was higher for unaffected floor than fire affected floors and that it has not significantly affected up to rise in temperature

300^0C. But when the temperature rises above 300^oC the concrete compressive strength decreased significantly. The cement paste tend to contract due to loss of water while the aggregate expanded at high temperatures, the bond between the aggregate and the paste was weakened, thus reducing the concrete strength. Ultrasonic pulse velocity method showed greater compressive strength of concrete both in affected and unaffected concrete as compared to core testing and Schmidt Hammer Rebound Test methods.

The engineering assessment of fire damage to a concrete slab provided the opportunity to compare the results of in situ, non-destructive evaluation techniques and laboratory testing of specimens taken from cores extracted from the fire damaged slab (Dilek and Leming 2007).The paper discussed and compared results of in situ pulse velocity and impact-echo testing with dynamic elastic modulus and air permeability index test results of 25 mm (1 in.) thick disks sawed from concrete cores removed from selected areas of damaged slab. Both the NDE techniques and the laboratory testing of thin disks identified the presence of damage as a result of fire. Compressive strength results were consistent with the results of other tests but largely inconclusive by themselves. Impact-echo testing was available to identify the presence of a severely demonstrated concrete layer but could not identify the extent or depth of damage or clearly identify less damaged areas. A distressed layer of concrete was found by subsequent laboratory testing to be limited to a near surface zone in some areas as suggested by the pulse velocity based analysis resulted in an overestimate of the depth of damage.

In the National Workshop at Delhi, the operation of Rebound Hammer (also called Schmidt's hammer) and ultrasonic pulse velocity methods was reported (Bhattacharjee 2008). Concrete absorbed a part of the energy which enabled one to use the rebound number as an indicator of concrete properties. Thus, more energy was absorbed by a low strength, low stiffness concrete than high strength, high stiffness concrete and gave a lower rebound number.

In another investigation, the non-destructive testing and evaluation of Concrete Parking Garages was reported in Montgomery County, Md. when Public Works Department needed strategies for inspection of local infrastructure and cost effective methods for testing of existing concrete garages (Stergiopoulou et al. 2008).

The investigation involved the measurement of ultrasonic pulse velocities using the indirect transmission method on the concrete floor slabs for each level of 20 public parking garages of Montgomery County. The measurements were not performed on obviously defective parts of the structure, i.e., those characterized by scaling, spalling, or cracking. In addition, they were carried out on locations that were far from the beams of the structure and other locations where densely reinforced zones existed. The age of concrete influences the ultrasonic velocity. For the data from the Montgomery County garages, the age of the concrete was as long as 42 years. Therefore, the effect of age on velocity was evaluated, as the age of much of United States infrastructure was much greater than 1,000 days.

As membranes were used to protect concrete slabs, a study of the effect of membranes on UPV measurements was undertaken. It is noteworthy that to make pulse a velocity measurement, each level that was covered by a membrane was paired with the nearest garage level in the garage that was not covered by a membrane, which was always the deck immediately below the membrane covered deck. Ultrasonic pulse velocities in steel can be 1.4-1.7 times faster than those in concrete and because public parking garages are reinforced, the potential effect of the reinforcement in the Montgomery Country garages on estimated velocities needed to be assessed.

It was concluded that as the concrete ages, the rate of decrease in velocity increases with each year. A relationship between the ultrasonic velocity and the age of the concrete was fitted using the data from the garages. Elastomeric membranes provide protection for concrete decks.

While they can increase the life of a deck by about 10%, as indicated by our measurements, they change the ultrasonic test velocities. This result could be useful as a part of an economic or risk study for the public facilities.

The three methods of ultrasonic testing that comprised of pulse echo method, transmission method and two transducer method were discussed and interpreted (Garima 2008).

In a Pulse echo method, a piezoelectric transducer is used to transmit and receive ultrasonic energy. The ultrasonic waves are reflected by the opposite face of the material or by discontinuities, layers, voids, or inclusions in the material, and received by the same transducer where the reflected energy is converted into an electrical signal. The computer display can show the relative thickness of the material, depth into the material where flaws are located.

In the transmission method, an ultrasonic beam transmitter is placed on one side of the material and a receiver is placed on the other side. Scanning of the material using this method resulted in the location of defects, flaws, and inclusions in the X-Y plane.

The direct damage detection and indirect damage detection approaches of structural health monitoring were reported in a study (Xue et al. 2008). Damage detection methods can be categorized on local level and global level. Local-based damage detection methods monitor structures components or subcomponents by using non-destructive testing method like ultrasonic inspection. Global-based damage detection uses numerical means to take into account the global vibration attributes of a structure to identify damage. Structures due to the changing environment and operational loadings sometimes need large number of sensors to detect damage. Hence, cheap wireless sensor network technology makes realize SHM economically.

Three kinds of Electronic Sensors were used to measure the changes and the long-term variation trends with temperature. Thermal couples were installed to measure the temperatures of the air, track, and concrete. Extensometer was used to measure the displacement of the free end of the track. Whereas, the variation of the gap distance of the concrete bridge was measured by the linear variable differential transformer (LVDT). A structural condition monitoring platform was developed to acquire, analyze, and manage the data from sensors. The sensors were used to develop a real time track-monitoring system that was not traditional. The proposed system recorded the long-term data on the changes in the rail as the season and the temperature changed, hence provided complete and accurate data.

The two rectangular reinforced concrete slab specimens using two non-destructive testing techniques: the measurement of electrical resistivity and the transmission of ultrasonic surface waves were tested (M. Goueygou 2008).

Each method was used to detect, locate and characterize the crack pattern i.e. its width and depth. The specimens were reinforced with 10 mm bars with 150 mm spacing and 25 mm thick cover. Two same specimens were casted for every arrangement, one reference slab and one to be submitted to mechanical damage. During testing, ultrasonic technique proved to be fetching more data than the electrical methods because of its smaller spatial sampling as compared to that used in the electrical technique.

A case study on health assessment of reinforced concrete structures was reported (Kulkarni and Sudhakar 2009). As based on the assessment of in place concrete strength of R.C.C residential buildings of different age groups and elevated storage reservoirs of ages 25 years and 30 years respectively, it was found that the use of NDT techniques were much reliable and fit to assess the quality of concrete structures. In this paper the field investigation for strength assessment was made and resolved the doubts of quality of construction of an existing structure based upon non-destructive testing.

Eight cylindrical specimens (160 mm length and 60 mm diameter) were extracted from a concrete slab and evaluated under damage (Antonaci et al. 2010). A specific damage process was induced by applying a mono-axial compressive load along the longitudinal direction of the specimen through a 250 kN Mechanical Testing System, working under controlled displacement velocity. All specimens were tested by means of linear and nonlinear ultrasonic NDT at the end of each load level and in their undamaged state. For each specimen, rupture load was reached through a number of loading steps at increasing intensity. The failure load of each specimen ranged between 100 kN and 120 kN

The NDT (Non Destructive tests) on an existing reinforced slab of laboratory was conducted to find out the loss of strength of concrete decreases after using it for about a decade (Muftah and Sani 2012).

Equipments used in this research were Rebound Hammer and UPV (Ultrasonic Pulse Velocity). The Rebound Hammer test was used to determine the current strength while the UPV test was used to investigate the pulse velocity, presence of crack and also properties of concrete. The grids were marked on the slab to be tested and the points were darkened on each grid. The distance of all points near to the wall was kept 0.5m. Likewise the spacing between the points was kept 0.5m.

The results of Rebound Hammer on the slab were analyzed by determining the average value of each point. The results of these tests showed that only 1% of the total area in the laboratory slab was classified as fair in condition of quality while 99% of total area was considered as good quality layer. From the result of UPV test, integrity of concrete on the slab was classified as moderate and defected. From the observation, the reinforcement in the slab could have influenced the reading of the UPV test.

From the both above stated results of Rebound Hammer and UPV test equipment it was concluded that the result of combination of these two tests was not sufficient because of high variations obtained. This was because the equipment had result on the surface of the concrete structure.

Recently, the non-destructive testing for concrete structures was performed in which Rebound Hammer test and Ultrasonic Pulse Velocity test was conducted to assess the quality of concrete (Jain and Vishwanath 2013).Various other methods employed were half-cell potentiometer test, cover meter test, carbonation test and chemical analysis on samples of concrete. The beams and the columns were selected at random and UPV test was performed. The hardness of slabs was assessed by Rebound Hammer test. The thickness of the cover concrete was assessed by cover meter test. The various NDT methods, when followed with caution, could normalize the deficient R.C. footings and columns.

2.2.3. Finite Element Modeling

Six full-scale reinforced concrete slabs were tested of which five slabs were with various arrangements of openings in the vicinity of the column (El-Salakawy et al. 1 999).The openings in the prototypes were square with the sides parallel to the sides of the column; and there were two opening sizes, one of which was the same size as the column and the other was 60% of the column size. It was reported that the results of finite element analysis on larger and smaller opening sizes led to reduction in ultimate strengths of 30% and 12% respectively.

A technical paper on Finite Element Analysis of slab and its comparative Study with analytical solution was presented (Bari et al. 2004). The observations revealed that the displacements and moments were deviating by an order of 20% than the analytical results. The analysis also increased the confidence of site-in charge; and therefore an investigation for reliability estimate was recommended.

The analysis of RC beams strengthened with fibre reinforced polymer was done (Perera et al. 2004). The authors discussed the effect on bonding between reinforced concrete and composite plates (CFRP) when epoxy adhesive was used and compared the analytical and experimental results. The nonlinear response of the strengthened members was determined through the development of material nonlinear constitutive models capable of simulating what happens experimentally. At the mid span of the concrete blocks, debonding started and propagated to the intermediate areas of the blocks. In general, the model performs reasonably well in predicting the behavior of the FRP strengthened beam.

The analysis of the retrofitted reinforced concrete shear beams using CFRP composites was studied presenting the numerical approach to simulate the performance of retrofitted reinforced concrete shear beams (Santhakumar et al. 2004). The experiments were performed on control RC beam and retrofitted RC beams using carbon fibre reinforced plastic (CFRP). The influence of retrofitting on pre-cracked and uncracked beams was also studied. Finite element software ANSYS was used for this study. The load deflection graphs obtained from this study were close to the experimental plots. There was no significant difference between the behavior of uncracked and precracked retrofitted beams at initial or ultimate stage. Hence this numerical modeling predicted the behavior of retrofitted beams more precisely as it helped to track crack pattern and propagation which was quite difficult in case of experimental study due to wrapping of CFRP composites.

The non-linear finite element analysis of reinforced concrete beam strengthened with externally bonded FRP plates was studied (Supaviriyakit et al.2004). The correct material models of concrete, steel and FRP were the key for success of the analysis. The concrete and reinforcing steel were modeled together by 8-node 2-D isoparametric plane stress RC element. The RC element considered the effect of cracks and reinforcing steel as being smeared over the entire element. The FRP plate was modeled by 2D elastic element. The stress-strain properties of cracked concrete consisted of tensile stress model normal to crack, compressive stress model parallel to crack and shear stress model tangential to crack. Considering the bond between concrete and steel bars, stress strain property of reinforcement was assumed to be elastic-hardening. FRP was modeled as elastic-brittle material. The objective of the test was to investigate the effect of the bonded length on peeling mode of FRP. The results obtained from this analytical method worked that the finite element analysis accurately predicted the load deformation, load capacity and failure mode of the beam.

The finite element prediction process for simply supported reinforced concrete slabs under uniformly distributed load for development of charts for exact peak load determination was established (Hossain and Olufemi 2005).

An acceptable guaranteed solution was established by setting optimum parametric values and computational conditions by conducting a series of parametric studies using simple concrete model and simulation of tests on four simply supported slabs as basis. The reliability of parameter values was verified by direct simulation of 11 other slabs. As the reliability was verified, the charts were developed by analyzing 270 computer model slabs using finite element model. These charts serve a speedy determination of reliable peak loads for arbitrary simply supported slabs. Idealization of slabs was done with 3D and 9-node element. A symmetric quarter of slab was divided into 9 elements. A tactic was set up for displacement determination with same accuracy within 4% of test results as chart prediction and the paper discussed possible practical applications of the developed finite element system.

The procedure for nonlinear analysis of reinforced concrete slabs using finite element analysis was given (Phuvoravan and Sotelino 2005). It combined the two node beam elements for the steel reinforced bars with a four nodes shell element for concrete. A rigid link was used to connect concrete shell element and reinforcement beam element and beam nodes were eliminated from final mesh of the structure by using alteration method for rigid link. Thus from obtained experimental results a good harmony was established between analysis results and these values.

The investigation on the propagation of ultrasonic guided waves in a two layered structure was done theoretically and experimentally and it composed of a solid steel rod and a semi-infinite layer of concrete (He et al.2006). A semi-analytical FEM (SAFEM) model was used to calculate the high-frequency theoretical wave structures for a rod embedded in concrete. At higher frequency, there was little energy leakage into the concrete. However, when using a lower frequency, large amounts of energy leaked into the concrete due to the large displacement at the interface.

In another research, the numerical modeling for FRP-concrete delamination was studied (Ferracuti et al. 2006). A non-linear bond-slip model was used for presenting the phenomenon of delamination. The study showed that under both short term as well as long term loadings FRP retrofit could be very useful to improve the behavior of RC structures. A non-linear interface law was adopted where the bonding between FRP plate and concrete was modeled by a non-linear interface law. A non-linear system of equations was then obtained via finite difference method. The numerical results agreed well with the experimental data. A non-linear shear stress–slip law was adopted for the interface which takes non-linear behavior of concrete cover into account. It was shown that, by adopting classical delamination test setup, the load-displacement curve occurred for bonded plate lengths greater than the minimum anchorage length.

The experimental and analytical investigation of the brittle failure modes of RCC members strengthened by FRP plates in flexure was explained (Camata et al 2007). Both mid span and plate end failure modes were investigated. In the experimental work, four RC members were cast, two slabs and two beams. Out of these four members, one slab and one beam were tested as an unstrengthen member and the other one slab and one beam were tested as a strengthened member. Same work could be done analytically. These RC members were modeled and analyzed using finite element method. Model considered actual crack pattern from the tests. The concrete continuum was modeled using a smeared crack model. The smeared crack model was based on rotating crack concept and thus allowed the cracks to traverse in principle strain directions. It followed the principles such that principle stress exceeds the tensile strength.

The strengthening of the RC beams was done with both CFRP and GFRP and noticed the difference between these two materials. The results of numerical and experimental work concluded that the crack propagation inside the concrete resulted in debonding and concrete cover splitting failure modes. For short FRP plates, failure started at the plate's end, while the longer FRP plates, failure started at the mid span. A comparison between CFRP and GFRP strengthening with the same axial stiffness but different contact area showed that increasing the plate width increased greatly the peak load and the deformation level of the strengthened beam.

The theoretical evaluation of the effects of opening on ultimate load-carrying capacity of square slabs was studied (Ng et al.2008). The authors studied the simply-supported and fixed-end, square slabs with opening at ultimate limit state.

For simply-supported slabs, the analytical study on the ultimate load capacity of the slab showed that the ultimate total load decreased with the size of the opening. However, when the ultimate total load was converted to ultimate area load, the results showed otherwise. In the study of fixed-end slabs, the results showed that the opening had insignificant effect on the ultimate area load capacity for a small opening size of up to 0.3 times the slab dimension. For opening size of more than 0.5 times the slab dimension, the ultimate area of load capacity increased drastically. The ultimate total load of a fixed-end slab with opening up to 0.3 times the slab dimension was also not affected by the opening. However, the ultimate total load increased drastically for opening size of 0.5 times or more of the slab dimension.

The behavior of reinforced concrete beam using non-linear three-dimensional finite element model was investigated (Al-Shimmari et al.2008).

The authors theoretically investigated that reinforced concrete and composite construction might be suitably combined to give a new structural material: composite reinforced concrete. To study theoretically the composite beam, they used nonlinear three-dimensional finite elements to analyze the tested beam. The 8-node brick elements in ANSYS were used to represent the concrete. The steel bars were modeled as discrete axial members connected with concrete elements at shared nodes assuming perfect bond between the concrete and the steel. The results obtained by finite element solution showed good agreement with experimental results. It was concluded that the composite reinforced concrete was a viable structural form. Flexural cracks up to the working load stage remained very fine and the calculation of their width was unlikely to be necessary in design.

The experimental work for strength modeling of reinforced concrete beam with externally bonded fibre reinforcement polymer was done (Pannirselvam et al. 2008). Three different steel ratios with two different Glass Fibre Reinforced Polymer (GFRP) and two different thicknesses in each type of GFRP were used during this study. 15 beams were casted for this work in which 3 were used as a control beam and the remaining were fixed with the GFRP laminate on the soffit. The performance of FRP was studied by flexural testing of simple beam with two-point loads which governed internal flexural strength, deflection, ductility and then was compared with unplated beams. The results obtained from this experiment showed that the beams strengthened with GFRP laminates exhibited better performance.

The possibility of using a top ferrocement slab to improve the behavior of space trusses was investigated (Anen et al. 2009). To construct space trusses with top ferrocement slab, decking plates were used to support the wet concrete.

The experimental models of ferrocement slab were casted with and without steel sheeting and their numerical models using the finite element method were presented. Finite element models were developed to simulate the behavior of the slab through nonlinear response and up to failure, using the ANSYS package. A finite element package "solid 65, and solid 45" was used to simulate the behavior of ferrocement slabs.

The ultimate load predicted by the theoretical model was higher than the experimental one with only 7.89 %.

The results of both experimental and analytical investigations to examine the composite action between the ferrocement slabs and steel sheeting were reported and discussed as an initial step towards using ferrocement slabs to improve the behavior of compression member in spaced trusses. Mainly two types of ferrocement slabs with and without steel sheeting were tested. The behavior of these slabs was modeled using finite element ANSYS. The ANSYS model accommodated material non-linearity, cracking and crushing of concrete (or mortar) and yielding of the steel sheeting and wiring meshes. The analytical results were in good agreement with the experimental results for ferrocement slabs without steel sheeting but for specimens with steel sheeting, the comparison was good only until the failure of the bond between the slabs and the steel sheeting.

The study on reinforced concrete beams externally reinforced with fibre reinforced polymer (FRP) laminates using finite elements method adopted by ANSYS was presented (Ibrahim 2009). The finite element models were developed using a smeared cracking approach for concrete and three dimensional layered elements for the FRP composites. The finite element analysis results for six beams with different conditions obtained from ANSYS were compared with experimental data. The comparisons were made for load-deflection curves at mid-span; and failure load. The results from finite element analysis were calculated at the same location as the experimental test of the beams. The experimental results as well as load-deflection curves were in good agreement with the results obtained from finite element analysis.

The study on finite element modeling of reinforced concrete beams retrofitted with fibre reinforced polymers presenting a simple and efficient two-dimensional frame finite element to estimate the load-carrying capacity of reinforced concrete beams strengthened with externally bonded fibre reinforced polymer strips and plates (Barbato 2009). The load-carrying capacity and the applied load mid span deflection response of RC beams subjected to three and four point bending loading were predicted. The numerically simulated responses agreed remarkably well with the corresponding experimental results. The major features of frame FE include simplicity, computational efficiency and weak requirement in terms of FE mesh refinement. Hence FEM was appropriate for effective and precise modeling and analysis of flexural strengthening of RC frame structures with externally bonded FRP sheets/plates.

A commendable research on nonlinear finite element analysis of the steel-concrete composite beam to concrete-filled steel tubular column joints was done (Wang et al. 2010).

The authors selected a suitable model as the concrete under low-cycle reversed loading. ANSYS program was used to establish nonlinear 3D finite element models (FEM). The authors demonstrated that the hysteretic curves and skeleton curves from FEM under low-cycle reversed loading agreed well with those of the cyclic loading tests. The authors analyzed the stress-strain relationship of concrete under cyclic loading conditions with the stress-strain relationship of concrete under monotonous loading conditions and established the 3D finite element model of the steel-concrete composite beam to concrete-filled steel tubular column joints. It was revealed that the load-displacement curves of FEA matched well with the corresponding experimental result of different types of joints.

An experimental model to predict the shear capacity of RC slabs was analysed by using a three dimensional (3D) nonlinear finite-element program named 3D CAMUI, which was developed at the Laboratory of Engineering for Maintenance System of Hokkaido University (Farghaly et al.201 1). The Newton Raphson method was used for nonlinear solutions. Iteration was continued until the convergence for residual displacement caused by unbalanced force was satisfied.

The authors carried out finite-element analysis to simulate the nonlinear behavior and failure mechanism for two-way slabs of reinforced concrete externally strengthened with FRP sheets.

From the experimental and analytical results, it was seen that using FRP increased the stiffness and improved the punching shear strength of the slabs. Attaching the FRP or increasing the amount of attached FRP increased the tensile force in a slab to resist against the bending moment, increasing the compression force.

The numerical simulation tool could predict the ultimate load and deformation of the strengthened slabs with reasonable accuracy. By increasing the FRP sheet width, more uniform stresses were transferred between the FRP and the concrete substrate. This resulted in lower slip values at the FRP concrete interface. In regions where the FRP laminates overlapped, reductions in the slips were observed.

The investigation on the response of spherical ferro cement slabs under flexural loading was carried out (Mohammed 2011). The major factors taken for analysis were vertical and horizontal diameters, thickness of slab and the impact of number of wire mesh layers on the behavior of spherical Finite Element Model. The behavior of ferrocement slabs was simulated by using finite element package ANSYS.

Solid 65 was one of the solid isoperimetric elements used for plane elements. It has eight nodes, each having three degrees of freedom, translations in x, y, and z directions respectively. This element had one solid material and can have up to three rebar materials in three directions. It had iso parametric properties and could handle plasticity, creep, swelling, stress stiffening, large deflection and large strain. Using finite element software ANSYS, the spherical of simply supported slabs with dimensions 500x500x20 mm 0.7 mm wire mesh were used for analysis.

The salient features that were observed were that the spherical slabs showed less deflection than straight slabs by about 69 % with two wire mesh layers, 64% with four wire mesh layers and 60 % with six wire mesh layers. By changing the curvature from 60 to 70 mm, the deflection improved by 10 %. The stiffness increased with the increase in the thickness of slab from 20 to 40 mm resulting in 20 % decrease in deflection. There was increase in section capacity and decrease in deflection by increasing the wire mesh layers. The ferrocement members had load carrying capacity close to the prediction of proposed finite element analysis.

The opening in new slabs was usually required for plumbing, fire protection pipes, heat and air conditioning. The finite element method approximated the slab behavior by subdividing the plate continuum into a mesh of discrete finite elements (Daham 2011).

The plate or shell elements were typically employed to represent the behavior of slabs by deformations at the mid-surface. Solid-65 was used for the modeling of solids with or without re-bars. The solid was capable of cracking in tension & crushing in compression. This 8-Node brick element was defined by the isotropic material properties and used to stimulate the behavior of concrete layer. Link 8 was used as a spar (or truss) element is a uni-axial tension-comp. element with 3-degrees-offreedom at each node. To ascertain the validity of the used element, slab with opening was experimentally analyzed. This slab was tested by others & sufficient experimental data is available for their proper modeling by the finite element method. It was seen that experimental and analytical results were in good agreement with each other.

A research paper on multi-level optimization of input parameters for modeling of fibre reinforced concrete beams was presented (Pukl et al. 2011).

In order to improve modeling of the FRC tensile behavior material laws with special forms of the tensile descending branch more suitable for FRC were formulated and implemented. Two models were designed especially for steel fibre reinforced concrete (SFRC). The tested beams were casted with concrete C 55 / 67 and fibres of length 60 mm and diameter 0.8 mm.

From their research the authors concluded that the nonlinear finite element analysis was an efficient tool for investigation and design of the fibre reinforced structures. Advanced material models for numerical simulation of fibre reinforced concrete were available, but determining appropriate input material parameters suitable for realistic analysis lies above the usual testing methods.

The structural members made from RC and SFRC were investigated (Pukl et al. 2011). The research program included laboratory tests of full scale tunnel segments made from RC and SFRC under various loading conditions, and also accompanying material tests on SFRC beams.

The testing was supported by an extensive nonlinear numerical study modeling the RC and SFRC segments under various loads by using nonlinear package Atena 2D and

Atena 3D. Thereafter, the results from the experimental and numerical investigations for both RC and SFRC segments were presented and compared. They successfully proved that using of SFRC for production of tunnel segments was a prospective option. The authors observed that numerical model exhibited a more detailed evaluation of structural response as compared to experiments.

The investigation on the opening effects on the behavior of concrete beams without additional reinforcement in the opening region was done using FEM method (Amiri 2011).

Using ANSYS 10.0, the author employed finite element analysis software to simulate the simply supported concrete beams consisting of circular openings with varying diameters. The author's research mainly involved investigating the effects of circular opening size on the behavior of such beams. Two cases were carried out for verification study. Subsequently, numerous models of simply supported reinforced concrete rectangular section beams with circular and square opening were loaded monotonically with two incremental concentrated loads. The beams were simulated to obtain the load-deflection behavior and compared with the solid concrete beam. All beams had an identical cross section of 100 mm × 250 mm and 2000 mm in length with the circular opening in seven diameters: 150 mm, 130 mm, 120 mm, 110 mm, 100 mm, 80 mm and 60 mm and an equivalent square opening with 133 mm in width. The results obtained from this study showed that the performance of the beams with circular openings with diameter less than 0.48 D (D is depth of the beam web) had no effect on the ultimate load capacity of the RC rectangular section beams. On the other hand, introducing the circular opening with diameter more than 0.48D reduced the ultimate load capacity of the RC rectangular section beams at least 26 %.

Recently, making a move towards Finite Element Modeling, the fibre reinforced polymers in the research were presented (Aravind et al. 2013). The review of the properties of GFRP and CFRP and other reinforcing materials like steel plates was done. RC beams were strengthened by single layer of FRP composites. A mathematical model was tested for flexural strength in relation with the thickness of FRP laminates. Finite Element Analysis was carried out using ANSYS. The singly reinforced beam was of size (100 x 150 x 1200) mm and the mid-point loading was applied to the mild steel plate. It was observed that RC beam with rectangular corrugated profile showed an increase in load by 21.43 % as compared to the plain layer beam.

2.3. DAMAGE INDEX

Damage Index (DI) is defined as the measure of the response of the structure before damage and after damage expressed in terms of a fraction. A damage index is used as a tool for performing a damage assessment for a building (Rodriguez and Aristizabal 1999). A damage index is defined as a ratio of stiffness before damage and stiffness in a damaged state.

A structure is said to be in a damage state on different lines that includes (a) a binary damage state which classifies the damage state as failure or no failure state (Gunturi 1996). (b) a discrete valued damage state where indicators classifies the state as minor damage, moderate damage, severe damage and collapse state as shown in Table 2.1.

Table 2.1. Proposed Damage Index for different states of damage

Damage Level	Damage Index	Damage State
0	0 - 0.15	Minor Damage
1	0.15 - 0.3	Moderate Damage (repairable)
2	0.3 - 0.8	Severe Damage (irreparable)
3	> 0.8	Collapse

In the present investigation, the non-destructive testing was done before the loading test and after the loading test to determine the damage index of the slab. This value of damage index was used to determine the state of damage of the slabs and subsequently the decision for retrofitting process.

2.4. COMMENTS ON THE PRESENT STATE OF ART

The literature survey related to the field of strengthening of structural members and health monitoring of structures along with their finite element modelling showed that the researchers have tried GFRP, CFRP, ferrocement or other laminates like steel plates on members like beams, columns, slabs, joints and so on. Most of the failure modes were due to the de-bonding of laminates from the surface of concrete, tearing of the flanges of the bridge decks and rupture failure.

The finite element analysis carried out by the researchers gave results that were found to be in good agreement with experimental results.

2.5. RESEARCH SIGNIFICANCE

As studied in the available literature, although various properties of a member retrofitted with laminates have been discussed till now, very few studies have been devoted to the non-destructive testing and retrofitting of reinforced concrete slabs comprising with different materials.

A review of published literature indicates that although some amount of the study had been done on the retrofitting of the slabs, the research on their health monitoring was on an inadequate level. The inter study on the materials was also deficient. Moreover,

the study on application of more than one retrofit material on slabs was also scarce. The non-destructive testing and retrofitting on slabs by using more than one material at a time was also narrow. The present research was directed towards health monitoring of simply supported reinforced concrete rectangular slabs when retrofitted with glass fibre reinforced polymer, ferrocement and mild steel plate.

2.6. CLOSURE

To overcome the problem of lesser investigations on the slabs, in the proposed work, the health monitoring of the slabs have been carried out by Rebound Hammer Test and Ultrasonic Pulse Velocity Test. The slabs have been strengthened by the application of laminates like Glass Fibre Reinforced Polymer, Ferrocement and Mild Steel plate. The experimental behavior of the slabs under uniformly distributed load has been compared with analytical finite element modeling. The results have been compared and the interpretations made.