Chapter 41
Seismic Response of Composite Bridges: A Review

S. Bharani and M. N. A. Gulshantaj

Abstract Due to past recent earthquakes, bridge failure is more common due to the lack of strength. Extensive damage may occur not only in the substructures, which are expected to yield but also in the components of the superstructure involved in transferring the seismic loads. This leads to giving more importance to the strengthening of structural components using various innovative techniques. The recent techniques which improve the performance of the structures and environmental durability of the structures are likely to be adopted. The current research area is mainly focused on the use of alternative materials to conventional concrete such as fiber-reinforced plastic composites (FRP composites). The use of FRP composite in RC bridge components will increase the factors such as ductility, response factor, energy dissipation, etc. These also improve the adequate strengthening of structure and reduce the cracking pattern.

Keywords Composite bridges · FRP laminates · Seismic response · Bridge components · CFRP

41.1 Introduction

The seismic events create great devastation in terms of life, money, and failures of structures. The main cause of bridge failure is due to the extreme load during the earthquake. A properly designed bridge according to standards should also fail. That is because; it needs additional strengthening along with proper design. The structural strengthening of bridges can be done by following methods such as the post-cast shear wall, concrete jacketing of a column, Base Isolation, Mass Reduction Technique, Wall Thickening Technique and retrofitting using composites.

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Fig. 41.1 showing the composite bridge and its components. (Fang et al. 2019)

The main research needs associated with conventional strengthening methods is the optimization of the retrofit design to achieve a satisfactory structural performance level at a minimum cost based on reliably characterized seismic demand and structural capacity.

The FRP composites is a fibre reinforced polymer which belongs to the category as a composite material. The FRP Composites are mainly used to strengthening the structural components, which will replace the old construction technique. This forms a sequence of the network containing different types of material attached. This material is called anisotropic because it contains different types of fibre. The different types of material attached will form a sequence around them. The use of Fibre laminates in structural components improves the mechanical properties of the structure in the direction of placement of fibre (Bharani et al. 2021).

These composite material made of fibres has high corrosion resistance, high strength, and thermal properties. These composites are brittle, this affects the material at the increase of loading and due to change in environmental conditions. The temperature change will affect the mechanical properties. The main function of FRP is providing strength and stiffness in the direction of fibre placement. The fibre reinforcement will carry the load along the length of fibre placement. This composite material will replace the steel reinforcement in the structural system cordially but not fully. The use of FRP composite material will improve the cost reduction in the construction industry and make the construction more economical. The bridge and its damages are shown in Fig. 41.1.

41.2 Review of Research Findings

The timber wall made of DD timber frame which was infilled by using locally available stone and mortar. The five specimens of wall panel are cast and it was tested under monotonic loading in two-phase of testing. In the first one, the wall panel of five specimens was tested to observe failure patterns and the later phase was the retrofitting of the specimen at damaged areas/joints with Carbon Fibre Reinforced Polymer wraps and strips. The testing was done to obtain the load-displacement curve, ductility, energy dissipation capacity of the specimen and this result shows higher improvement compared to the conventional specimen in its seismic performance of using timber material in construction (Muhammad et al. 2020).

The STM method (i.e., Strut and Tie model) is used to Reinforced Concrete Deep beams bonded with Carbon Fibre Reinforced Polymer (CFRP) sheets. The new formation of the effectiveness factor of the concrete strut ad tie was formed in this investigation. The result obtained from the works of literature is compared with the results obtained from the RC deep beam bonded with this composite fibre sheets.in this testing, the proposed model has two modes of failure mechanism adopted, one is crushing strength of concrete and the other is diagonal splitting, and these two were later modified with ACI code and AASSHTO. This new model was compared with the already existing model and this shows significantly improved results compared to the existing one (Ammar N. Hanoon et al. 2017).

The RC frames are cast as per the ACI code(seismic provision). The numerical modeling and Experimental investigation were carried out to find the parameters of flange – web joints under quasi-static cyclic load test. In two specimens, one was not retrofitted and the other was retrofitted with CFRP Laminates. In Experimental investigation, the test was carried out at each drift applying full three scales of cyclic loading. The STM model was created and analysed by using ANSYS software. The result of both investigations shows that the specimen/model bonded with FRP laminates shows better results compared to the conventional specimen (Maheri et al. 2019).

The RC column with Previously damaged structures by seismic force and new RC column under Pseudo – seismic loading are used for testing. Both types of the model with lap-spliced bar are retrofitted with FRP sheets externally and finite element model was created to verify the results. The investigation is done by using the equation KANAPE and EC8.3 to get a better accuracy of results. The shear strength of a new column will be higher the damaged column strengthened by FRP because of obtaining less chord rotation parameter (Evgenia et al. 2019).

The Reinforced Concrete walls are bonded with Flax fibre Reinforced Polymer externally in the form of strips. The specimen with or without Flax-FRP results is compared to the CFRP specimen in the literature review. The results of the above specimen under cyclic seismic loading shows that the FFRP shown good performance equals to CFRP. This FFRP should be used as a good alternative as natural fibre reinforced polymer composites) (Luccio et al. 2017).

The seismic response of the retrofitted brick masonary house was tested. The different types of composite materials are used, and the models are tested under dynamic shake table test. Four types of one-fourth scale specimens were tested which are unreinforced brick masonary house model, brick masonary house model retrofitted with Polypropylene band, FRP composites and both FRP & Polypropylene band. The result shows that the Combination of FRP and PP band shows better results compared to all other types of specimen because of its good ductility and energy dissipation capacity (Umair et al. 2016).

The specimen of retrofitted and unretrofitted column are tested in a different direction under lateral loading. The CFRP wraps are used for retrofitting of RC columns. The test result shows that the loading direction plays an important role in the seismic performance of the specimen. The increase of loading decreases the shear resistance, lateral drift, and energy dissipation in the unretrofitted column. The retrofitted column will exhibit the failure mode in a different direction of loading (Daiyu et al. 2018).

The STM (strut and tie model) was developed and it is retrofitted with CFRP composites. The results of this STM model are compared with the result obtained from the two scales experimental model of RC beam-column retrofitted with CFRP jackets. This proves that STM was one of the best alternative methods in the aspect of seismic assessment of the Beam–column joint (Yasuteru et al. 2017).

The RC wall panels were initially damaged by applying cyclic lateral load and these seismically damaged panels are externally bonded with the CFRP composites. The use of glass and carbon fibre grid provides better confinement at the ends. The ATENA 2D software was used for numerical analysis to obtain the maximum lateral load. The result of all panels are compared with the numerical analysis shows that it improves the load-bearing capacity and displacements values (Todut et al. 2015).

The strut and tie model was developed to evaluate the shear strength of concrete deep beams. The deep beam was divided into two parts: uncracked and cracked parts. The experiment and numerical results of the existing deep beams are taken for parametric study, and the results show that the uncracked section is more interlock to the shear resistance (Chen et al. 2018a, b).

The comparison of two deep beams was taken into consideration. The carbon fabric reinforced cement-based mortar and carbon fibre reinforced polymer-based mortars are used to strengthen the deep beam. The maximum lateral loads of this beam are calculated by the strut and tie model method. The results show that the CFRP grid strengthening system is better compared to others (Rizwan et al. 2018).

The investigation of Engineering cementitious based Hybrid FRP steel-reinforced columns. The specimens of a steel-reinforced column, ECC provided at the plastic hinge, Steel – FRP Reinforced column were tested. The column with hybrid steel FRP shows less deformation compared to the conventional one. This method significantly improves the seismic behaviour of the Reinforced column and reduces the deformation and shrinkage of the column (Fang et al. 2019).

The seismic retrofitting technique of using ultra-high-performance FRP jackets to strengthen the RC piers. The FRP was wrapped around the RC piers and the specimen of various height was tested under cyclic loading. The FE modelling of the RC pier with FRP was analysed and the result of both experimental and FEM was validated. The RC pier with less height will have better results and shows high seismic-resistant behavior (Teng et al. 2019).

The Reinforced concrete bridge column was tested under uniaxial cyclic loading. The ECC was used mainly because of its Strain hardening behaviour. The RC column, a column with ECC plastic hinge and wrapped with PP - ECC jackets were tested under cyclic load. The results show the Column with wrapping jackets improves structural performance (Zhanga et al. 2019).

The investigation of the retrofitting behaviour of beam-column joints under the shear test. The beam-column joint specimen was damaged by applying cyclic load and the specimen was retrofitted using the CFRP sheet at a critical section. This retrofitting technique improves the structural performance of the beam-column joints (Khaled et al. 2019).

The FRP composite vehicular bridge was designed and on a small scale and it was tested under static and dynamic loads. The Finite element model of this bridge was developed and the flexural behaviour was analysed in numerical modelling. The result was used to develop the design procedure to develop the composite bridge (Tomasz et al. 2019).

The innovative bridge column model incorporating ECC with Aluminium – magnesium – copper (superelastic alloys) bar were tested under seismic loads. The experimental data are compared with the numerical data and it is validated. The result of the numerical modelling provides the data that cannot be obtained through the experiments (Farshid et al. 2019).

The seismic behaviour of the RC shear wall was analysed under seismic load to determine the structural performance of the wall. The RC wall represents the existing shear wall of a five-storeyed building and the specimen was strengthened by CFRP composites. The shear strength of the CFRP specimen was improved with other parameters (Samiullah et al. 2019).

The gravity railway bridge pier is retrofitted with carbon Fiber-reinforced polymer. The pier model of the 1/8th scale was tested to obtain the seismic performance of gravity bridges. The results show that the use of CFRP and steel materials will improve the performance of bridge piers in seismic prone areas (Xingchong et al. 2018b).

The bridge decks were constructed using FRP composite and the FEM model of the bridge was created to analyse both theoretical and experimentally. The static and dynamic test was conducted and the bridge was continuously monitored by using the optical sensor. The sensors are used to monitor the long time performance of FRP of bridges (Xingchong et al. 2018b).

Numerical modelling of Cable-stayed Bridge was analysed under seismic loading using SAP 2000 software. The base isolation has been created for heavy earthquake and it has been executed in the Bridge. The 3D finite element model was created and the nonlinear dynamic time history analysis of the cable-stayed bridge has been carrying out. Deck Displacement, acceleration, base shear, base moment, bending moment, the response of tower and performance of the cable and isolators was investigated (Siwowski et al. 2018).

The structural behaviour of the original bridge for earthquake forces. The bearing made of rubber is equipped with a cable-stayed bridge and it is investigated. This was done by using the nonlinear dynamic time history analysis method. In this system, they conclude that the bearing system will improve the structural performance of the bridge and transmit the seismic force to the superstructure (José et al. 2017).

The FRP composites are used to retrofit the RC bridge piers for seismic collapse assessment. The analysis reveals the conditional probability of earthquake intensity at a particular damage stage. In a circular pier, the fragility curves are developed and

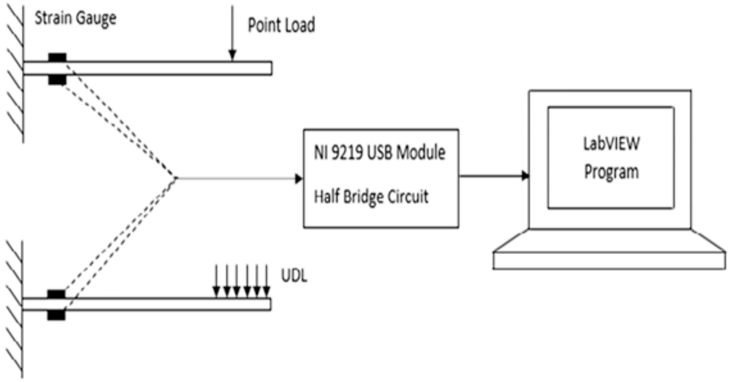

Fig. 41.2 showing the experimental setups interfaced with LabVIEW (Hamel et al. 2020)

the various parameters are taken into performance analysis to investigate the non – linear behaviour (Parghi et al. 2016).

The girder collision at the abutment and wing wall due to seismic force was investigated. The ABAQUS is used to create the 3D FEM model of 2-span concrete girder bridge and it is examined for different approaches. The results show that the structural parameters were affected by the displacement restriction (Desy et al. 2016).

The LABVIEW software is used to record or monitor the vibration in an MDOF system. The active dynamic vibration absorber is used by the LABVIEW to continuously monitor the frequencies and it consolidates the result from the various frequency (Ismail et al. 2012).

The LABVIEW is used to detect the crack in a conductive material. It is the non-destructive testing method to detect the crack pattern without damaging the material. The eddy current test is used to detect the crack on the material and it is continuously monitored by using the wires that connect the automatic test and the materials (Hamel et al. 2020).

The flexural formula for cantilever beam can be calculated by using Ni-LabVIEW software. The ANSYS software is used for numerical modelling of the same to get the results. The experimental setup of this model is shown in Fig 41.2 (Anirban et al. 2018).

41.3 FRP Composites

41.3.1 Fiber Reinforced Polymer Composites

Fibre Reinforced Polymer (FRP) composite is a composite material made of polymer and fibre. It is the form of two materials and it is artificially made in the industry. The FRP composites are made up of different types of fibres combined to form

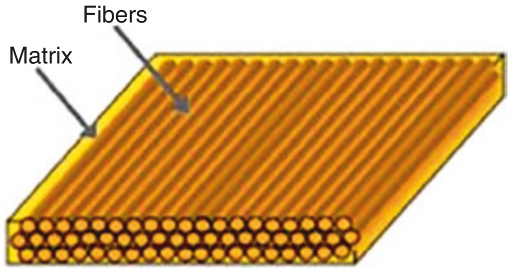

Fig. 41.3 Formation of FRP (Abbood et al. 2021)

a network. This is mainly used to replace the existing construction material. They are not brittle compared to the other materials. The use of fibre in the FRP will distribute the load equally and improves the properties of the composites. The FRP used in the building construction proves that it will be safer and economic because of its properties. The use of steel and aluminum will lead to corrosion and this can be avoided by using FRP composites. The FRP is used in the construction of boats, parts of the instruments and many other applications.

41.3.2 Components of Composites Materials

Fibres The fibres are the materials that are obtained from natural and artificial sources. The various fibers from the artificial sources are steel and glass. The fibres extracted from the natural sources are jute, coir, aramid, sisal and many other fibres. In these fibres, some are used for composite materials. The type of fibre used defines the properties of composite materials.

Matrices The matrices are the resin used to form the polymer by using fibre. The most used resins are epoxy and vinyl ester and it is used at different temperature. This improves the bonding strength and it is resistant to chemicals. The formation of the FRP matrix is shown in Fig. 41.3.

41.4 Types of Fibre Reinforced Polymer (FRP) Composites

41.4.1 Glass Fibre Reinforced Polymer (GFRP)

The limestone, silica sand, folic acid, and another compound are mixed and it is melted under high temperature. The strands obtained from the molten glass are cooled to drawn the fibres in a platinum plate. The obtained glass fibres are converted to various forms to get the composites. The polymer reinforced with the glass fibre to form the glass fibre reinforced polymer. The resin is used as a polymer

Fig. 41.4 Various types of FRP (Abbood et al. 2021)

matrix. These composites will have high mechanical strength, low moisture, and high electrical insulating properties. It has good impact resistance compared to other fibre. The various forms of GFRP are shown in Fig 41.4.

41.4.2 Carbon Fibre Reinforced Polymer (CFRP)

Carbon fibres are having high stiffness, elastic modulus, and lower elongation and vice versa. They are water resilient in nature and resistant to chemicals. They are resistant to creep and corrosion and can withstand fatigue. The carbon fibre laminates are shown in Fig. 41.5.

41.4.3 Aramid Fibre Reinforced Polymer (AFRP)

The aramid fibres (aromatic polyamide) are obtained from the trademark Kevlar. They are having high elastic modulus and elongation capacity. The application of these fibres are helmets, bulletproof, etc. They cannot be used in high temperature, and it does not work well in ultraviolet radiation. It has the property of resistance to steel corrosion.

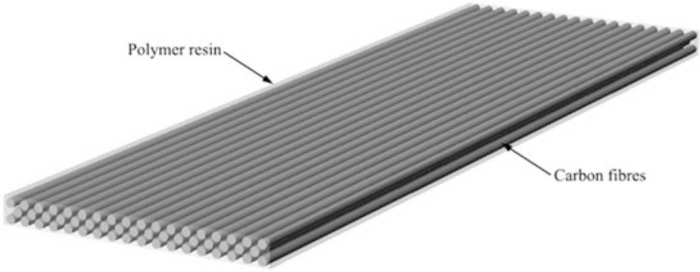

Fig. 41.5 Carbon fibre reinforced polymer (Liu et al. 2015)

41.5 Strengthening of Bridge Components by Using FRP

The strengthening of Bridge components is needed when the bridges are prone to seismic areas and it needs to be strengthened to avoid damages by an increase of loads and nearby activities. The individual bridge components are strengthened by FRP laminates externally or internally using FRP bars with the replacement of reinforced steel bars. The conventional concrete method will not be able to meet the seismic requirement, this cause damages to the bridge components and even leads to failure. This technique will enhance to development of a new concept in the civil Engineering field to adopt the structure resistant to earthquakes. According to the type of FRP composite used, it will improve both shear and durability capacity of the structure. The epoxy resin is used to bond the bridge components and FRP together. The FRP laminate is used in the form of sheets, wraps, strips, and laminated boards. The types of FRP are used based on the requirement of the bridge components.

41.6 Conclusion

(a) The Retrofitting of walls using FRP composites improves the ductility and load-carrying capacity of walls with a significant level (Muhammad et al. 2020)
(b) The strengthening of Bridge components using FRP laminates improves the stiffness and strength of the structure (Xingchong et al. 2018b).
(c) Nonlinear static pushover analysis (NSPA), and incremental dynamic analysis result of bridge piers strengthened by FRP improves its stability and shows improvement in other parameters (Todut et al. 2015).
(d) While investigating seismic behaviour, the normal column having low lateral strength, deformation, degradation compared to column retrofitted with FRP composites (Evgenia et al. 2019).
(e) In a beam-column joint, the use of the CFRP joint improves the shear strength of the retrofitted specimen. The use of wraps is quite useful in improving its shear strength (Yasuteru et al. 2017).

(f) The ultra-high performance of fiber-reinforced jackets used in the bottom of the pier improved the flexural behaviour of the pier (Parghi et al. 2016).
(g) The crack pattern and the seismic response should be easily analyzed experimentally using LabVIEW software. This software will process the data obtained during testing and shows better result compared to other software (Anirban et al. 2018).

41.7 Discussion and Future Scope

The innovative materials such as CFRP, GFRP, AFRP, etc, can be used as a replacement of steel and aluminium. They are used to eliminate the corrosion, fatigue failure, shear failure in the seismic prone areas (Bharani et al. 2021). These materials used in the concrete structural component such as beams, column and beam-column joint as a retrofit. These materials will improve the mechanical and durability properties.

They can be able to withstand the harsh environmental conditions and it improves the corrosion resistance of the element. These innovative materials help the Engineers to complete the project without difficulty. In repair works, the damaged structure can be easily retrofitted by using these composites. They can be used for strengthening the structural element while construction. They can be a good replacement for traditional materials.

These new designs will reduce the size of the structural element with the same loading condition. In the future, it will be used to retrofitting the existing bridge pier, decks, and other elements. The future scope of using FRP composites is mainly focused on the analysis of its response to seismic loading and categorizes its performance according to the environment.

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