JEAS
Journal of Economics and Administrative Sciences
E-ISSN: 2148-1792 P- ISSN: 1302-2024
Volume 3, Supplement Issue 2
www.jeasweb.org

Improving the seismic performance and reinforcing steel structures using CFRP plates

*Reza Amiri **
Department of Civil Engineering, Faculty of Engineering ,University of Rouzbahan, Sari, Iran.
**Corresponding Author*

Mohammed Mosavi
Faculty member Civil Engineering, Tonekabon Branch, Islamic Azad University, Tonekabon, Iran.

ABSTRACT
Choosing the type of materials used in the structure is one of the most sensitive decisions that made by a structural designer. This decision often depends on the type of structure, financial issues, as well as the experience and skill of the designer. The main objective of designing is to obtain optimal economic structures. Generally, reinforcing steel joints suffered from untimely cracks or retrofitting beams to insufficient columns caused by inadequate arming is very difficult. Therefore, CFRP plate as a retrofitting method is used to reinforce and improve the seismic performance. In this study, the improvement of seismic performance was focused.
Keywords: Steel, Structural Reinforcement, CFRP

Introduction

Bridges improvement usually is much less expensive than their replacement. In addition, duration of the work and consequently the traffic disruption in bridges improvement is less than the reconstruction. Welding the reinforcement plates to the upper tensile wing of continuous steel plate girder in negative anchor areas has been common in the construction of old steel bridges. These sheets were welded to the plate girder due to the greater amount of bending anchor in these areas and were cut in the positive anchor areas ().

According to the NBI, steel bridges were recommended mainly to be improved. Corrosion, poor maintenance and fatigue-sensitive details are major problems of steel bridges. In addition, many of these bridges need to be improved to withstand larger loads and more traffic.

According to the statistics and conditions of roads and bridges in our country, Iran caused floods in the past year, beam bridges are in ultimate condition and need to be improved and reinforced.

Various improvement methods have been presented from two perspectives. In the first view, hammering, re-melting of the metal by electric arc, lathe and drilling are applied directly to the weld at the end of the retrofitting plates. These methods are not always successful (). In the second view, a steel plate is screwed to the upper wing at the crack to restore the bending capacity (). In all the improvement methods listed above, the upper surface of the tensile wing must be accessed except for the drilling method. One of the most important components of steel structures is connections between structural members which result in forces in transmission between the members and the supports. Therefore, the performance of all steel structures is affected by the connections between structural members and should be concerned in the general analysis of the structure. The failure of most steel structures under different loads indicates that weak connection can be a very determining factor in the failure of steel structures (). This study aims to examine improvement of seismic performance and retrofitting steel structures using CFRP plates.

Seismic Retrofitting of Steel Connections

The purpose of the retrofitting is to improve the behavior of the structure against the forces caused by the earthquake; so that, damage to building components can be expected within the performance level at different levels of risk after the retrofitting operation. For example, the total damage to a building with a moderate level of safety performance is predicted; i.e. the remaining stiffness and strength is expected to exist in all classes and gravity force resisting system will operate (). Also at this performance level, the dangers of objects collapsing are prevented, but many building installations and architectural elements are damaged.

Technical Criteria in Retrofitting

One of the main criteria in any retrofitting plan is to reduce the stress on the structural members; so that, no member is subjected to stresses beyond its capacity. Since many existing buildings are designed to withstand gravity loads. In this case, if lateral loads are applied, most members will be loaded beyond the regulations limits. Such a problem in bending members causes phenomena such as the formation of plastic joints, bending deformations and secondary torsions, local shear failure and local and partial buckling in compressive members.

Therefore, it is necessary to model and analyze the solution of increasing the lateral load of the structure at first and then, gravity and lateral loads on each member in different loading as well as the degree of failure would be determined. In this case, in order to increase the member strength in steel structures, strategies such as adding reinforcing sheets, hardening sheets in critical points and replacing members with stronger sections can be used, and in concrete structures, methods of modifying reinforcement details at critical points, post tensioning using external post tensioned reinforcement etc. can be used ().

Factors Influencing the Choice of Seismic Retrofitting Solution

There are many seismic retrofitting solutions depending on the type and condition of the structure. Therefore, choosing retrofitting manner is a complex process and is influenced by both technology, economic and social conditions. The following are the factors that influence the choice of retrofitting solutions:

- The cost of reinforcement and the importance of the structure
- Existing manpower
- Duration of run or being obsolete
- Completion and reinforcement based on the desired performance of the employer
- Paying attention to the appropriateness of architecture and completing the existing structure
- Reversibility interference
- Performance level quality control
- Cultural and historical significance of the structure.
- Compatibility of retrofitting method with existing structural systems.
- Lack of order in hardness, strength and ductility.
- Proportionality of hardness, strength and ductility.
- Control of damage to non-structural components and parts.
- Suitable bearing capacity of the foundation system.
- Existing improvement materials and technology.

Generally, there are two methods to increase the seismic performance of existing structures. The first is structural surface reinforcement, which includes general structural system modifications. Common general modifications include the addition of structural walls, steel braces or base partitions. The second method is local strengthening. In this method, the capacity of members who have insufficient ductility to meet the limit is increased. Local strengthening includes methods such as adding concrete, steel or armor to columns with composite polymer fibers to limit local deformations and rotations ().

Application of New Materials

Applying new technologies in seismic retrofitting of structures should be concerned by structural engineers as a new approach. The main features of polymer composites include optimal corrosion resistance, ease of installation and light weight.

Fiber-Reinforced Polymer (FRP)

FRP systems have been used worldwide as exterior coatings to increase the strength and improve existing concrete structures since the mid-1895s. The number of projects used in connection with FRP systems worldwide has increased dramatically. Over the past 15 years, it has grown from a small number to several thousand projects now.

Structure of CFRP Materials

FRP materials consist of two basic components; Fiber (fibers and resins) of the binder material (fibers that are mainly elastic, brittle and very strong, are the main component of the carrier in FRP material. Depending on the type of fiber, its diameter is in the range of 5 to 25 microns. ()

The final strain of the mentioned fibers is about 1 to 4% without yielding before failure. Also, their final resistance range is about 5700 to 3300 MPa and the elastic modulus is from 69 to 269 GPa (Ghafouri, 2012)

Carbon Fiber Fibers (FRP) are made by polyacrylonitrile (PAN) method and FRP composite rebars and FRP composite profiles are produced by Pultrusion method. In this method, the bundles of fibers, after being impregnated in the resin are put together after passing through a mold, to create the desired profile. Polymer products used in structures are available in the form of FRP composite polymer plates, FRP rebars or FRP reinforcement, FRP meshes and FRP profiles (Tavakolzadeh 2003). These polymeric materials and FRP composites are used to build and strengthen structures. The specifications of each of these fibers are as follows:

Generally, 4 kinds of FRP fibers are used for FRP reinforcement system, which include carbon fiber reinforcement, glass fiber reinforcement, aramid fiber reinforcement and basalt fiber reinforcement (Tavakolzadeh 2003)

Carbon fiber reinforcent polymers (CFRP)
Glass fiber reinforced polymers (GFRP)
Aramid fiber reinforced polymers (AFRP)

Improving the Seismic Performance of Corroded Steel Beams

Corrosion is the most common cause of breakdown of steel structures. FRP repair method can be used to increase the load-bearing capacity of the eroded member. Kachlakio (2012) repaired and tested a beam cut from a damaged bridge by FRP. Both beams have similar dimensions of 755mm span length, 10mm depth and 220mm wing width. There was uniform corrosion along both axes, most of which focused on the tensile wing. Due to that, 50% reduction in the level of the tensile wing has been observed, which leads to a 20% reduction in the stiffness of the beam. Since the corrosion in the beam core is small, only the lower wings of the beam have been repaired, so that a layer of CFRP tape 0.5 mm thick and 38 mm wide has been used along the entire length of the beam. The repaired beams are loaded and the load is gradually increased to local buckling in the beam compression wing (due to the lack of concrete slab on the compression wing). Because the corrosion of the first beam was more severe than the corrosion of the second beam, the elastic stiffness of the first beam increased by 10% and the hardness of the second beam by 37%.

Also, the final capacity of the first and second beams will increase by 17 and 25 percent, respectively. These increases indicate the ratio predicted for unrepaired beams. It is believed that the final capacity obtained for the beams can be increased by preventing local buckling of the compressive filament. In addition, it has been shown that at the same amount of load, the plastic strain of the reinforced beam tensile wing is reduced by 75% compared to the strain of the unreinforced beam.

Composite Systems

Composite systems consisting of concrete columns and steel beams have been proposed for several years as a new and efficient structural system that provides sufficient hardness through reinforced concrete columns and energy dissipation capacity through steel beams. In recent decades, a lot of research has been done on the resistance of concrete and steel composite against lateral forces, including systems such as flexural frame systems including concrete columns and steel beams ().

The main concern in these systems is the connection area of the beam and column. In recent years, due to similarities of new editions of steel, concrete and loading design standards, the design of mixed systems has become simpler and the tendency to use this structural system is increasing. Extensive studies conducted over the past decades have shown that these systems are especially suitable for use in medium to tall buildings in areas with low to medium seismic risk and also is convenient and economical for use in short to medium buildings in areas with medium seismic risk. (Tang 2015)

The advantage of composite connection with integrated beam compared to conventional metal frame is that due to the whole entire of steel beams, the beam is continuously passed through the column and the beam-to-column welding is minimized and this results in preventing the weaknesses in the structure and eliminating the failure in the steel connection.

Ductility Coefficient

The connection of beams to the columns of structures, especially concrete structures, is one of the most sensitive areas in the structure, and not paying enough attention to its precise design can lead to the destruction of the entire structure. Usually in the design stage, special stirrup is used to provide sufficient strength and ductility in the connections, and steel plates and FRP are used in their reinforcement.

The purpose of seismic improvement of concrete columns is to achieve a level of ductility that can absorb and dampen the energy entering the structure during an earthquake, before one of the failure modes has been named. FRP displacement ductility is one of the criteria for evaluating the seismic performance of members and structures (Fisher 1997)

According to Slim (2010) and Tang (2025), GFRP materials lose their properties when exposed to extreme heat and humid environments. Gangrao [5] investigated the effects of heat and humidity on carbon composites. The samples were tested under different humidity and temperature. Temperatures ranged from -20F to 120F and relative humidity ranged from 0 to 100%, and some samples were immersed in 3% sodium chloride. The results show less than 7% reduction in the strength and hardness of the samples and show that the carbon sheets do not decrease in substantial strength for 180 days after exposure to different environmental conditions.

Force Transmission between Composite Materials and Steel Using Adhesive

A strong and durable adhesive is required for the effective use of composite sheets in steel bridge repair. Damage and corrosion of the substrate must be thoroughly cleaned and the surface free of any grease and contamination before gluing the sheet. This can be done by spraying sand along with the use of fat-soluble solutions.

The force transmission between FRP and steel is controlled by the adhesive between their joint surface. Various factors such as bonding surface, type of fibers and resin, surface preparation, adhesive thickness and FRP layer thickness affect the adhesive performance.

Doske (1980) investigated double lap joint behavior using SM-CFRP and HM-CFRP plates. According to this study, HM-CFRP plates with low final strain is less resistant than SM-CFRP plates with higher final strain. In addition, the use of a GFRP layer between the steel surface and the HM-CFRP layer causes a gradual force transmission (better shear stress is transferred) and increases the bearing capacity of the adhesive by up to 20%.

The study also tested the behavior of double lap joint at CFRP. In this experiment, two CFRP plates with a length of 557mm and a width of 37mm were glued and stretched on two sides of a steel plate with a length of 015mm. As shown in Figure 1, the transmission was approximately 08% of the total force took place in the initial 100mm of the connection (FHWA2001 Bridge Program).

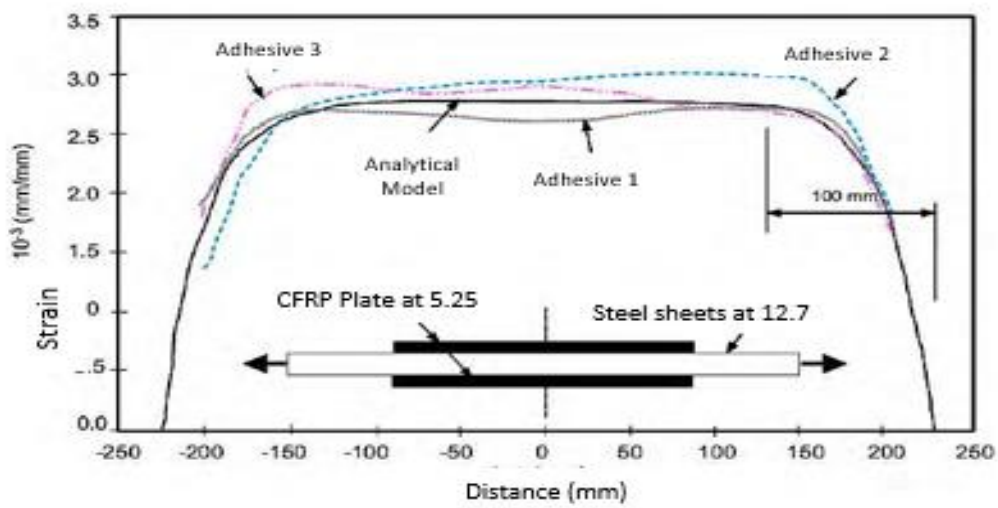

Figure 1: Strain Distribution along the Longitudinal Double Lab Joint

Literature review

- ✓ Lee Hong et al. (2017), conducted a study entitled "Repair of steel-concrete columns using: FRP concept and behavior". By comparing the results of the analysis in the models in which the seismic improvement has been done by changing the seismic system on the lateral load of the steel joints and other studied reinforcement methods, seismic behavior of the improved frames is suggested. The present study confirms that in braced steel frames, by observing some scientific, technical and executive points, replacing the lateral force resisting system from converging steel braces to thin steel shear wall plates can be a suitable method for retrofitting and improving a wide range of available steel frames.
- ✓ Rashed et al. (2017), in a study entitled " Lateral-torsional buckling of rectangular steel beams with FRP coating under bending" examined the behavior of reinforced metal beams using FRP plates in bending and the effect of increasing the length of the FRP plate on increase in beam strength. In this study, metal beams with I-shaped cross-section with a length of 200 mm were tested. Out of six beams, whole length two beams and in two other samples a part of length was retrofitted with composite sheet. Two other samples selected as control group without any retrofitting. Control and reinforced beams were subjected to static loading, which, while preparing the force-displacement diagram, yield strength of the beams and the load failure of the composite sheets were determined and studied.
- ✓ Pierluigi Colombi. (2016) conducted a study entitled "Improving the growth of fatigue cracks in steel columns reinforced by CFRP strips" In this study, they used carbon fiber reinforced polymers (CFRP) through experimental and analytical methods and examined crack growth and fatigue caused by load. In this study, they tested the double lap joint behavior of CFRP; two CFRP plates with a length of 457 mm and a width of 37 mm were glued and stretched on two sides of a steel plate with a length of 914 mm. The samples were tested under a four-point flexural configuration. Then an analytical model is proposed to predict the strain redistribution in the reinforcing strips and the fatigue crack.
- ✓ Kian et al. (2016) conducted a study entitled "Fatigue durability of cracked steel beams with high strength materials and founded the steel structures under dynamic loading are prone to fatigue damage and a significant number of metal infrastructures in the world are structurally deficient. The fatigue

behavior of imperfect steels of mechanical steel using different materials with high strength was investigated experimentally in this work. In this study, the results show that the failure modes of CFRP used in the reinforcement of steel bending beams are: shear load splitting (BS), back load point (BD), and laminate (EDL) and (ED). The event and outcome of the CFRP failure modes depended on the reinforcement program. The structural performance of CFRP reinforced steel also varied according to the reinforcement characteristics studied in this study.

- ✓ Agcakota et al. () specified the CFRP required to ensure the intended behavior of reinforced concrete composite beams. They obtained reinforced beams using a High Modulus CFRP (CFRP) at the lower wing of a steel beam forming a composite section; and the beam was loaded with 4 points. HM-CFRP strips were failed.
- ✓ In the study conducted by Dzyilmaz, the effect of CFRP plates on steel-concrete composite beams was investigated experimentally under 4-point loading tests. In a study conducted at the University of South Florida, the possibility of using CFRP in the repair of steel-concrete composite bridges was examined. They tested a total of six beams with a length of 6.10 meters of 11 * W203 steel section connected to a concrete slab 711 mm wide and 115 mm thick. The CFRP plates used in the study were 3.65 m long, 150 mm wide and had two different thicknesses of 2 and 5 mm. According to the evidences, CFRP plates can significantly improve the final capacity of composite beams.
- ✓ Due to the limited research on the effectiveness of epoxy bonding of CFRP plates to the tensile wing of steel concrete composite beams, this study was conducted to evaluate the effectiveness of this method. Experimental results were also compared with conventional analytical methods. In a separate article, the authors discuss the importance of galvanic corrosion when CFRP is used in conjunction with steel (Tavakolizadeh and Saadatmanesh 2001). The results of this study showed that galvanic corrosion is not significant and can be reduced by providing a thin layer of adhesive or a non-metallic composite layer between steel and CFRP.

Conclusion

Seismic retrofitting and improvement of structures in Iran located on earthquake faults, is important and inevitable. A retrofitting plan can be appropriate and optimal when, in addition to meeting the aforementioned criteria, it also complies with the facilities and executive capabilities and other constraints on implementation. Unfortunately, the average quality level of construction is not very optimal in Iran and it is not possible to use methods in the structural reinforcement plan that do not have an experienced executor in practice or the equipment needed to do it. New and modern methods and technologies are applying in the developed countries of the world to improve seismic performance of buildings. Unfortunately, in our country, there is no technology, equipment or technical manpower. Any project that meets various improvement criteria cannot be useful, unless it can have used ().

Advanced composite materials have been used in the world to improve and strengthen worn-out infrastructure. Conventional techniques for reinforcing damaged (non-standard) structures such as bridges, buildings with important uses, as well as the members of these structures, such as beams, columns, foundations, etc., are usually costly, time consuming and laborious. Today, many new techniques have solved the disadvantages mentioned in the old techniques. In many of these new techniques, light, high-strength, corrosion-resistant layers (sheets) of various materials, especially FRP-reinforced polymers, have been used for modification and reinforcement.

Based on the aforementioned explanation, it is better to provide an improvement or retrofitting plan after assessing the vulnerability of a building or structure against earthquakes and identifying weaknesses. For meeting the goal, it is necessary to review any improvement or retrofitting plan carefully and in accordance with the current condition of the building in order to ensure that the acceptance criteria in the valid regulations are met in structural and non-structural members. The criteria considered in an improvement plan are based on the general principles of design of earthquake-resistant buildings, with the difference that in this case design process faces more problems due to the limitations such as situation of structure, architecture, type of use etc. Therefore, it is needed to introduce more diverse solutions ().

References

[1] M. Tavakkolizadeh, H. Saadatmanesh, strengthening of steel-concrete composite girders using carbon fiber reinforced polymers sheets, J. Struct. Eng. 129 (1) (2003) 30–4
[2] E. Ghafoori, M. Motavalli, J. Botsis, A. Herwig, M. Galli, Fatigue strengthening of damaged metallic beams using prestressed unbonded and bonded CFRP plates, Int. J. Fatigue 44 (2012) 303–315
[3] D. Kachlakev, T. Miller, Finite Element Modeling of Reinforced Concrete Structures Strengthened with FRP Laminates, Final Report – SPR 316 – Oregon Department of Transportation Research Group and Federal Highway Administration (2001).
[4] Teng J. G., Fernando D. and Yu T., "Finite element modeling of bonding failures in steel beams flexural strengthened with CFRP laminates", Engineering Structures, 86: 213-224, (2015).
[5] Seleem M.H., Sharaky I.A. and Sallam H.E.M., "Flexural behavior of steel beams strengthened by carbon fiber reinforced polymer plates three dimensional finite element simulation", Materials & Design, 31(3): 1317- 24, (2010).
[6] Fisher, J. W. (1997). ''Evaluation of fatigue resistant steel bridges.'' TRB Record 1594, Transportation Research Board, National Academy Press, Washington, D.C.
[7] Dussek, I. (1980). ''Strengthening of the bridge beams and similar structures by means of epoxy resin-bonded external reinforcement.'' TRB Record 785, Transportation Research Board, Washington, D.C., 21– 24.
[8] FHWA Bridge Program Group. (2001). ''Count of deficient highway bridges.'' ^http://www.fhwa.dot.gov/bridge& (March 20, 2002), The Office of Bridge Technology, The Federal Highway Administration, Washington, D.C
[9] M. Tavakkolizadeh, M. ASCE, and H. Saadatmanesh, M. ASCE," Strengthening of Steel-Concrete Composite Girders Using Carbon Fiber Reinforced Polymers Sheets", (2003).
[10] Ağcakoca E., and Aktaş M., "HM-CFRP ile güçlendirilmiş kompozit I-kirişlerde HM-CFRP'nin sıyrılmaması için faydalı mesafenin belirlenmesi", EJournal of New World Sciences Academy, 7(2): 47-59, (2012). •
[11] Özyılmaz E.," Karbon Lifler İle Güçlendirilmiş Kompozit Kirişlerin Eğilme Ve Kesme Kuvveti Altında Davranışlarının Deneysel Olarak İncelenmesi", Master's Thesis, Ege University, Institute of Science and Technology, (2016)