American Journal of Engineering and Applied Sciences

Original Research Paper

Pre-Reinforcement Sprinkle FRP for Reinforced-Concrete Beams against Earthquakes, FRP: Consumption in Civil Engineering

[1]Moein Zargar, [2]Hossein Gholami, [3]Hossein Norouzi, [4]Morteza Soltani, [5]Shahide Dehghan, [6]Zahra Majidifar,[7]Majedeh Haeri-Hamedani, [7]Saeid Eslamian, [2]Kaveh Ostad-Ali-Askari and [8]Mohsen Ghane

[1]Department of Civil Engineering, Farzanegan Institute of Higher Education, Isfahan, Iran
[2]Department of Civil Engineering, Isfahan (Khorasgan) Branch, Islamic Azad University, Isfahan, Iran
[3]Department of Civil Engineering, Maybod Branch, Islamic Azad University, Maybod, Yazd, Iran
[4]Department of Architectural Engineering, Shahinshahr Branch, Islamic Azad University, Shahinshahr, Iran
[5]Department of Geography, Najafabad Branch, Islamic Azad University, Najafabad, Iran
[6]Department of Agronomy and Plant Breeding, Lorestan University, Lorestan, Iran
[7]Department of Water Engineering, College of Agriculture, Isfahan University of Technology, Isfahan, Iran
[8]Department of Civil Engineering, South Tehran Branch, Islamic Azad University, Tehran, Iran

Article history
Received: 28-01-2019
Revised: 14-02-2019
Accepted: 26-06-2019

Corresponding Author:
Mohsen Ghane
Department of Civil Engineering, South Tehran Branch, Islamic Azad University, Tehran, Iran
Email: greep.engineering@gmail.com

Abstract: Nowadays, the reinforcement is used by green concrete, coated steel sheet, reinforcement, fiber reinforced such as carbon, aramid, and glass as earthquake reinforcement methods for concrete structures. regard the reinforcing structures and buildings against earthquake forces in the future, only simple methods for lowering prices should not be considered and the earthquake behaviors should be completely transparent. In this article, after a brief description of the FRP and fibres that can be used into its, a simple, new and inexpensive way to reinforce concrete structures to increase the earthquake capacity of these buildings has been investigated. This method uses short fibres using vinylester to provide a new mix of materials for an earthquake reinforcement. The short fibres of carbon and glass with vinyl- ester resin is sprayed into the desired place in a concrete structure. This means that is called spraying the FRP.

Keywords: Composite Materials, Fibres, FRP Dispersion, Mechanical Properties, Utilization of Waste from Factories

Introduction

Since the mid-sixties, concrete structures in Europe, South Africa, the United States and the United States of America have been reinforced by fastening steel sheets to the bottom and side of the beams and slabs (Alcocer and Jirsa, 1993). Mayer and Kim *et al*. started the first scientific studies on using DFRP to reinforce bridge beams, especially suspended cable bridges (Prota *et al*., 2000) The first real use of composite materials has been attributed to Kaiser *et al*. to increase the carrying capacity of a concrete building (Ahmad and Khaloo, 1991). The word FRP abbreviation of the Fiber reinforced polymers (Ghobarah and Said, 2001). The actual of the word Latin componere, which means intermingling or combining with each other (ACI, 1995). From ancient times, humans combined different materials to get new material with better properties. Composite is a substance that has a distinct physical or chemical phase dispersed in a continuous phase and is essentially more important than any of the two components. The continuous phase is called the main phase and the spreading phase is usually called the strengthening phase. (Antonopoulos *et al*., 2001). The strengthening phase can be in the form of a particle, string or page. Polymer composite materials with reinforcing fibres, such as carbon, glass or aramid, are known as well-known engineering materials (Filiatrault and Lebrun, 1996). Due to their unique properties, composite materials have high environmental durability and remain in the environment (Prota *et al*., 2002). These materials can be found in the sport equipment factories and aerospace industry and in the astronaut industry, etc. (Prota *et al*., 2001). The use of factories waste and waste recovery is one of the most important fields of current research in the world (Alcocer and Jirsa, 1991). Multi-story reinforced concrete frames that were construct before the 1970's usually do not encounter current earthquake plan code needs (Biddah, 1997).

Table 1: Mechanical properties of common strengthening material

Material	Modulus of elasticity [Gpa]	Compressive strength [MPa]	Tensile strength [MPa]	Density kg/m^3
Concrete steel	20-40	5-60	1-3	2400
Carbon fibre	200-210	240-690	240-690	7800
	200-800	NA	2500-6000	1750-1950

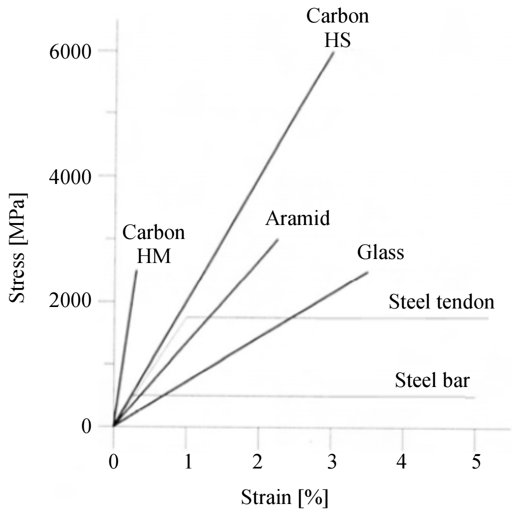

Fig. 1: Properties of different fibres and typical reinforcing steel. After ACI committee 440 (1996) and Dejke (2003). (Byars *et al*., 2003; Fashie Jalalie *et al*., 2005)

Fibres

Composite features are mainly influenced by the choice of fiber type. In civil engineering, three types of fibers are preferred (Pantelides *et al*., 1999). These fibers are carbon, glass, aramid and reinforced composites by these fibres called CFRP, GFRP, AFRP, respectively. For strengthening with high resistance, is suitable a carbon. of course, all fibres generally have a capacity of the high stress against usual steels in the elastic line until failure (Antonopoulos and Triantafillou, 2003). The most important features of these distinction three types of fibres is the stiffness and tensile strain of those (Prion and Baraka, 1995). Which compares these three fibres with different modes of steel (prestressed cable and rod) in a schematic form are in the Fig. 1 and Table 1. (ACI, 1991a).

Carbon Fibre

The carbon fibre has a high modulus of elasticity is 200 to 800 Gigapascal. The length of their extension is between 0.3% and 2.5%, which is lower than the elongation, with high stiffness and vice versa (Saatcioglu and Yalcin, 2003). The carbon fibre does not absorb water and is resistant to chemical solvents. Their's stability is very good at fatigue. Tension does not cause gradual corrosion and they do not show any kind of creep and flexibility and have less flexibility than steel (Pantelides *et al*., 2000).

Glass Fibre

These fibers are considerably inexpensive from carbon fiber and aramid fibers. Therefore, glass fibre is most capable of public use such as boat industry. The modulus of elasticity is 70 to 85 Gigapascals and the elongation is 2-5%, which depends on the quality (Priestley *et al*., 1996). The glass fibre has a gradual tension and is sensitive to moisture, which protects the good selection of the field or the masonry against it (Katsumata *et al*., 1988; Fashie Jalalie *et al*., 2005.)

Aramid Fibre

Aramid is a short fibre aroma polyaromatic (chemistry) fiber, with its good brands called chlorine or the trademarks Twaron, Technora, svm. The modulus of elasticity is between 70 and 200 Gigapascal and has an elongation of 1.5 to 5%. Aramid has a high energy absorption or fracture that is used in protective masks and bulletproof clothing. These fibers are sensitive to ultraviolet and high humidity and high temperatures and there are also problems with the flexibility that is used less in civil engineering (Priestly *et al*., 1992; Fashie Jalalie *et al*., 2005).

Matrix

Two types of a matrix in civil engineering use, called polyester and epoxy, are presented in Table 2.

In the study by professors in Iran (Dr Mahmoud Mehrdad Shokriya, Associate Professor of the Iranian Composite Institute and the University of Science and Technology) on the use of factory waste powders resulting from the machining of glass fibers and polyester resins as additive to concrete components in the two combinations, the proportions of the components according to the ratios described in Fig. 2 and 3, are given below, which after 7 day compressive strength tests (Fig. 4) and 28 days (Fig. 5) and 28-day tensile strength Fig. 6) selected a first-order compound that was more than the second combination, which the results of the resistance tests are also given in Table 3 and 4 (Estrada, 1990).

Then, two types of powder, the first powder from the Nipco-Palstic Noorista company waste, which made of glass fibre and polyester resin, are added to the composition of the concrete in terms of the weight of the sand and with the weight percentages of the fibers which are: 5, 3, 2, 0, Concrete slabs were constructed and tested for resistance, with the results as follows. (Mosallam, 2000; Fashie Jalalie *et al*., 2005).

DOI: 10.3844/ajeassp.2019.259.269

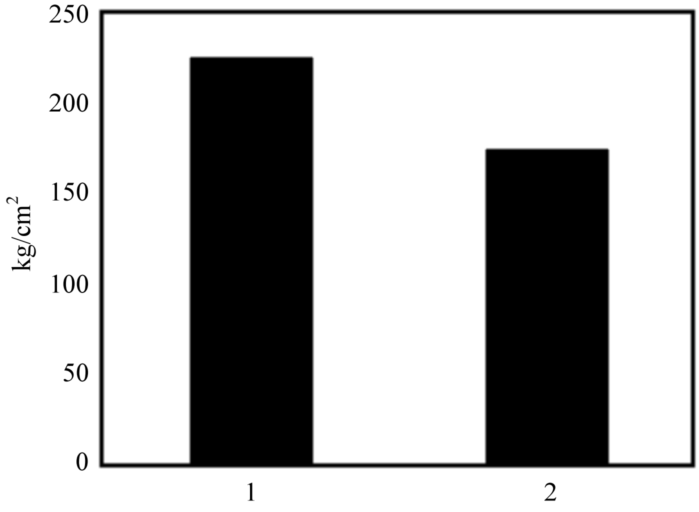

Fig. 2: Compressive strength of seven days compression ratio of one and two (Fashie Jalalie *et al*., 2005.)

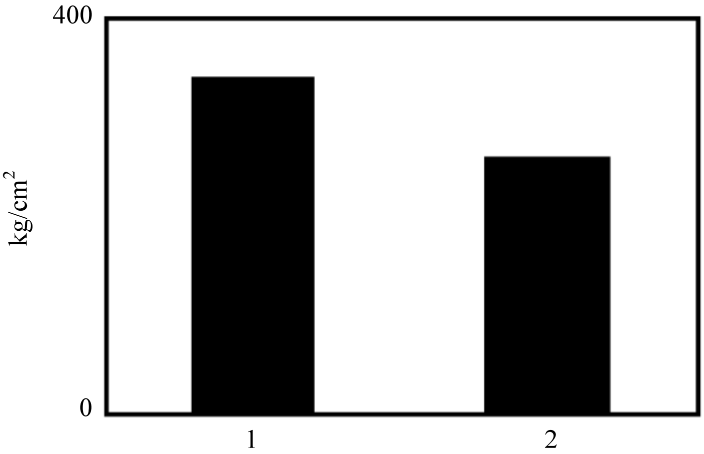

Fig. 3: Compressive strength of 28 days compression ratio of one and two (Fashie Jalalie *et al*., 2005)

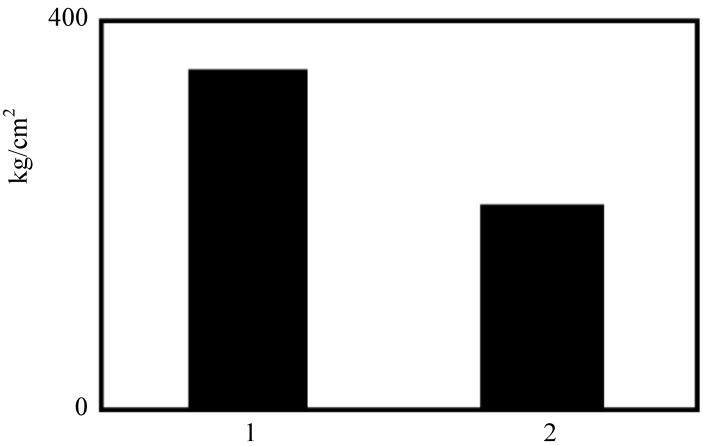

Fig. 4: Tensile strength of 28 days compression ratio of one and two (Fashie Jalalie *et al*., 2005)

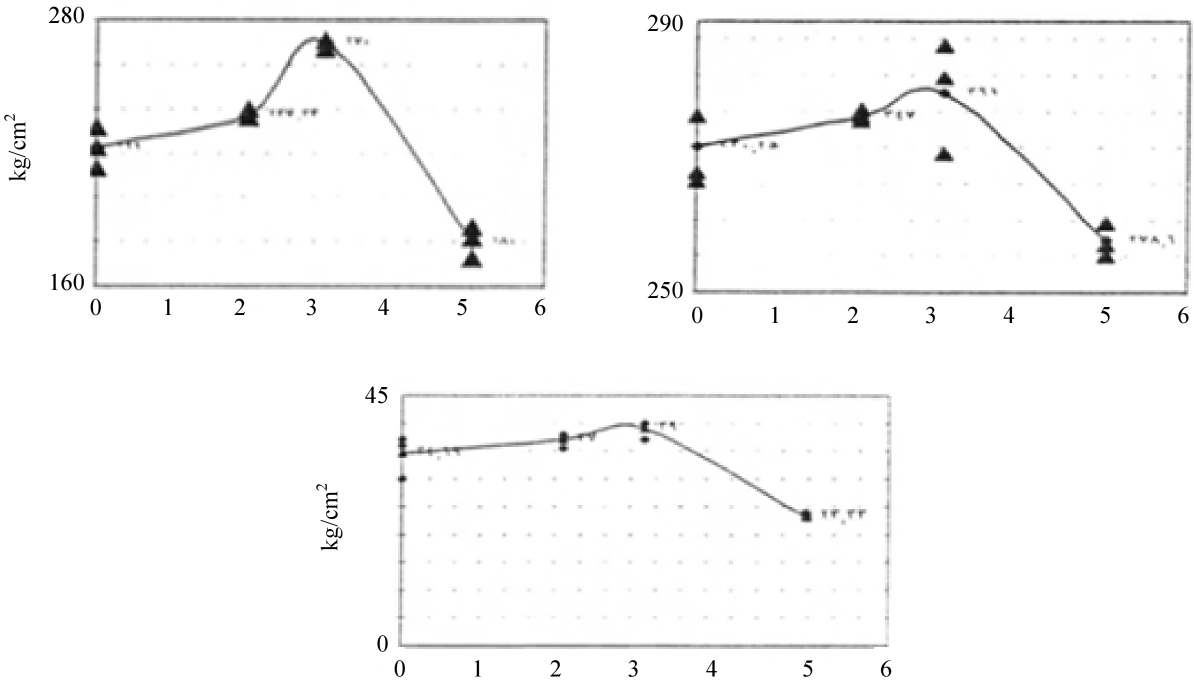

Fig. 5: 7-day compressive strength of the concrete in the first ratio of the composition,28-day compressive strength of the concrete in the first ratio of the composition, Tensile tests results (Fashie Jalalie *et al*., 2005)

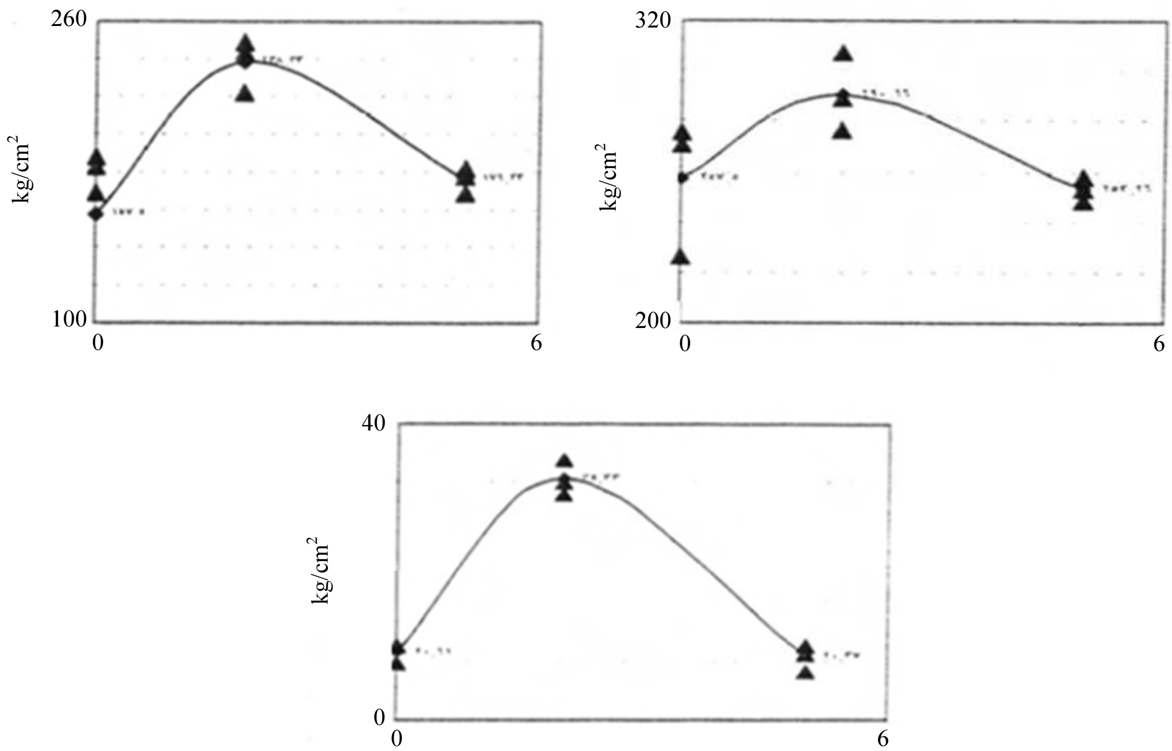

Fig. 6: 7-day compressive strength of the concrete in the Second ratio of the composition,28-day compressive strength of the concrete in the Second ratio of the composition, 28-day Tensile strength of the concrete in the Second ratio of the composition (Fashie Jalalie *et al*., 2005)

Table 2: Properties for matrix materials (Fashie Jalalie *et al*., 2005)

Material	Density kg/m^3	Tensile strength [MPa]	Tensile modulus [MPa]	Failure strain [%]
Polyester	1000-1450	20-100	2.1-4.1	1.0-6.5
Epoxy	1100-1300	55-130	2.5-4.1	1.5-9.0

Table 3: The ratio of the first combination

W/C	Water (kg)	Sand (Kg)	Gravel (Kg)	Cement (Kg)
0.494	195.2	1084.8	690.3	394.5

Table 4: The ratio of the Second combination

W/C	Water (kg)	Sand (Kg)	Gravel (Kg)	Cement (Kg)
0.437	175	800	1000	400

Carefully, in the above results, we find that adding more than 3% by weight of the composite to the concrete composition on the sand causes the loss of the measured properties and the graphs show the descending trend. In other words, 3% by weight is the optimal ratio compared to other proportions compared to pure concrete.

(Corley, 1993).

The second powder was obtained from Sadid Saba Power, which was originally prepregled in the form of fiber and powdered to blend with concrete. The material is made of glass fiber and epoxy resin. The results of resistance tests for this powder are shown below (Pantelides *et al*., 2001).

According to the following results, the best weight ratio is 3% by weight of sand, which is increased by 15-20% in this ratio of mechanical strength of concrete in all three cases of tensile, pressure and bending. As a computer model at 810 kg and a laboratory sample at 850 kg was broken. The reason for the strength of concrete in combination with these materials can be considered as the role of these materials in filling the porous of the concrete, which prevents the formation of microscopic cracks (Saadatmanesh *et al*., 1977).

After these definitions and knowledge about FRP, we come up with a method of the reinforcement of concrete by pre-reinforcing spraying is described briefly in the abstract (Corazao and Durrani, 1989).

In this study, a simple, new and inexpensive method to reinforce concrete structures to increase the earthquake capacity of these buildings has been investigated, using short fibers with vinyl ester, a new combination of materials for earthquake reinforcement (O'Rourke, 1999). Short fibers Carbon and glass with vinyl ester resin are sprayed into the desired location in concrete structures. This is called FRP dispersion. The advantages of using vinyl ester resins to epoxy resin are that this method for more strengthen requires less time to be taken and dried (Gamble *et al*., 1996). In addition, the mechanical properties of the resin and vinyl ester (T-shaped) are similar to those of the epoxy resin, in which case the results of this method and the results of the beam and concrete experiments with FRP loading are reported as asymmetry. In addition, the anchor and torsional and flexural behavior are reported between the use of slate (Saatcioglu *et al*., 1999).

Results of the FRP Spread Reinforcement Method

The figure shows a reinforcing idea with spraying FRP, Fig. 1 shows the construction workshop of the sprayed spray column samples. In this method, the resin is guided through a narrow tube by a compressor, the resin or short fibers, such as carbon or glass, are mixed at the tip of the sprayer, after which the reinforcing materials are sprayed directly to the desired surface, then the surface is smooth with a the rollers, the resin hardens and the entire sprayed part is reinforced by FRP materials, this method makes it possible to provide an earthquake reinforcement for all members of the various structures, which can be columns, beams, a wall, a slab that can be joined individually or in all structural parts of the interior.

The FRP spraying strengthening process is as follows:

Step 1: Prepare the Desired Level

At this stage, the surface of the concrete is cleaned with a mechanical fibre with air

Step 2: Cover the Initial Resin

At this stage, the primary resin is used to create a high viscosity between the concrete and the main resin on the surface.

Step 3: Prepare the Concrete Part

Stair areas or non-level surfaces are filled with concrete on the surface of the concrete and the surface is done to prevent local stress, FRP, single-hand exhaust. After it has dried, the surface is re-sanded.

Step Four: Resin Coating

In this step, the resin will first be sprayed on a surface by a sprayer to make it more viscous.

Step Five: The Main Action of the Spray

The resin and short fiber are split into concrete at the same time. The length of carbon fibre and glass fibre is 2 and 1.5 inches, respectively.

Step Six: Saturation

At this stage, the trapped air goes out with a roller.

In this paper, to compare the structured features of spraying FRP with regard to the reinforcement of continuous fibre sheets, preliminary preparations such as steps 1 to 3 are carried out, although the goal of achieving a suitable earthquake resistance is from 4th step steps.

Mechanical properties of Spraying FRP

Five samples of FRP sprayed material are prepared as samples A(JISK7.54), the conditions for preparing the samples are exactly the same as the original conditions. The FRP thickness with a spray time control of 3 mm was considered to have the same hardness as the carbon fiber sheet 200 gr/mm, regrad to the tensile testing for plastic strength materials from glass fibre of tensile test was also used for these specimens.

The Table 5 summarizes the results of tensile tests. The parts of the sections include the resin in the stress calculated. The tensile strength of FRP is about 70 MPa and the resistance throughout the unit is also about 270 $^{N}/_{mm}$. The elasticity coefficient is 8 Gpa and its hardness is 24 $^{KN}/_{mm}$. This value is approximately the same as the values of carbon fiber sheets to the specifications of 200 $^{Kg}/_{mm}$. and 26 $^{KN}/_{mm}$.

Bending Test between FRP and Concrete

Sprayed FRP brings a lot of flexibility for concrete columns in construction sites. The structural behavior of the beams affected by reinforced fiber sheets has been shown to be affected by the anchor conditions of sheets in the corners of the join of the beam and the slab (Kuan, 1991). In this paper, it is considered that the sprayed FRP is anchored in the corners of the intersection with the use of fillers of the gap (Geng *et al*., 1998).

Table 5: The results of tensile tests

Width (mm)	Thickness (mm)	Tensile (Mpa)	Elastic Modulus (Gpa)	Elongation (%)
24.8	3.99	67.2	8.02	1.24

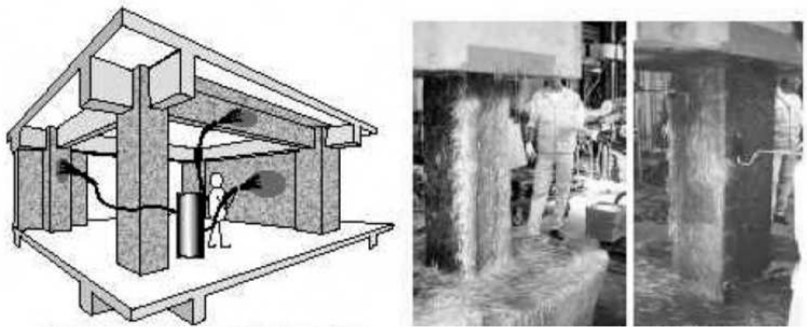

Fig. 7: Sprayed-up FRP Strengthening, Construction site of sprayed-up FRP (Mechanical Properties of Sprayed-up FRP)

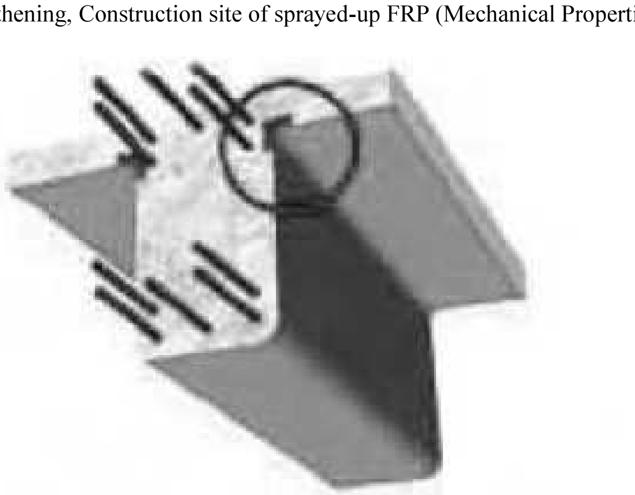

Fig. 8: FRP filled gap anchoring

DOI: 10.3844/ajeassp.2019.259.269

The Fig. 7 shows A recent correction and fortifying procedure by sprinkling carbon or glass chopped fiber with vinyl ester resin upon concrete structures is presented. This procedure is organized systematically for the aim of modification and fortifying ofconcrete structures applying sprayed-up FRP composites (Parvin and Granata, 2000). The Fig. 8 shows how sprayed FRP is used at two levels of intersection. In this method, there is a presumption that there are no steel materials (Chambers, 1992). In this paper, the bending test is performed using double-sided samples to examine the effect of the FRP filler gap and to test the variables of the size of the gaps.(ACI, 1991b)

Sample Drop and Maximum Loading

The sample No. 1 without gaps was destroyed by separating bend the concrete from the FRP and samples 2 to 4 were damaged by the breakage of the FRP or the shear drop of the concrete ordinary pest samples are shown in the Fig. 9 (Beres *et al*., 1992).

The maximum load for the number one of the specimens between FRP and sprayed concrete in the average of three samples is 20.6 KN. By comparing this with the flexural strength of carbon fiber sheets, they find the same hardness, the bending strength have been about 80% of the analytical flexural strength (Yamakawa and Kamogawa, 2000).

The anchor resistance of the gaps filled with FRP due to non-linearity is not known, because specimens 2 to 4, which have these conditions, have been lost due to FRP tear or concrete shear drop. However, the depth of the gap is 5 mm which itself has been effective in creating FRP tear alone. The average maximum load of three samples is 97% of the tensile strength obtained from the tested samples. (Saadatmanesh *et al*., 1996).

Explain FRP Strain

The Fig. 10 shows the FRP strain expression for five samples (Ghobarah and Said, 2002). The X-axis represents the distance between the center and the center of the samples. Gaps are between 80 mm and 120 mm in specimens 2 to 4 and in sample 1, it is observed that in a section of the gradient, the strain distribution moves from the center to the end of sample with increasing load. This effect is due to exit of the bending of the FRP material (Migliacci *et al*., 1983). Figure 11 shows on the shear fortifying of Reinforced Concrete (RC) beams by outwardly bonding fiber-reinforced polymer (FRP) composites. A recent strength pattern is then expanded.

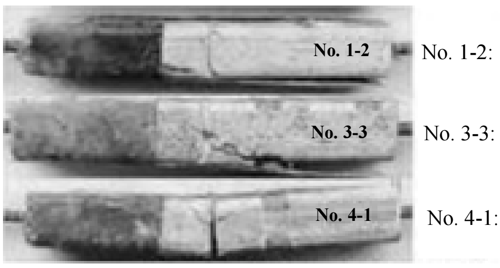

Fig. 9: Bond specimens after loading (No 1-2: Bond Failure, No 3-3: Concrete Shear, No 4-1: FRP Rupture)

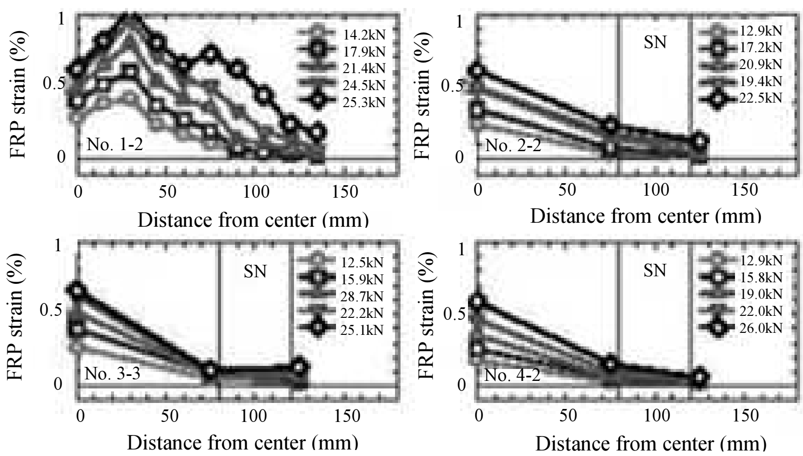

Fig. 10: Strain distribution of FRP

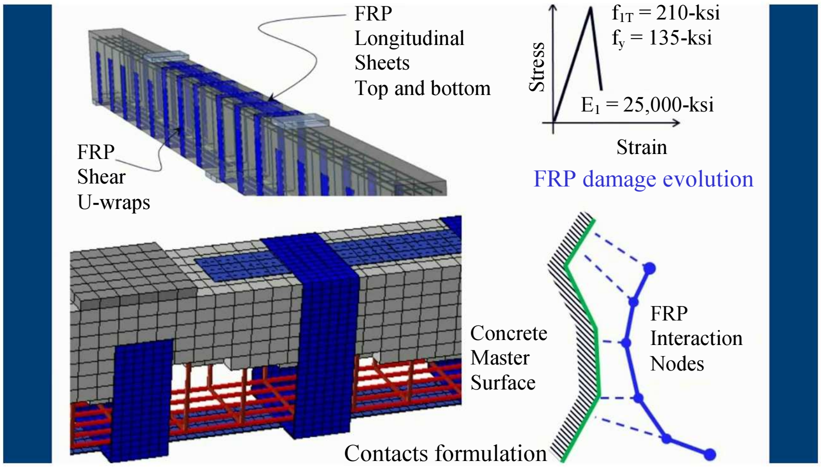

Fig. 11: Permissible moment redistribution limits for continuous FRP-strengthened RC beams

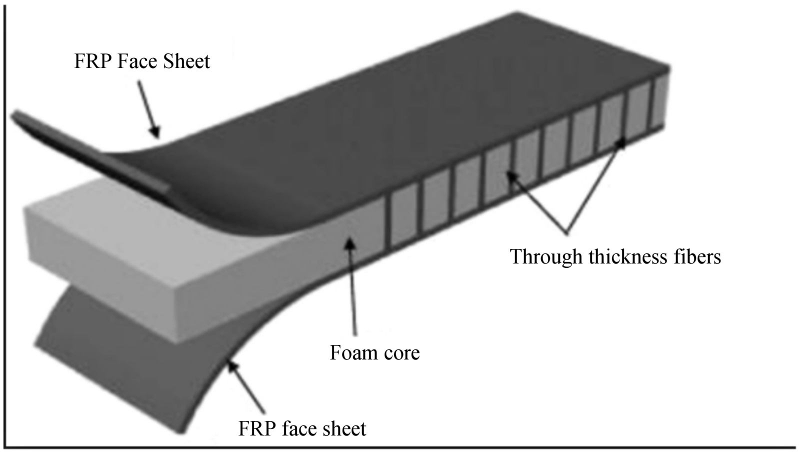

Fig. 12: State-of-the-art review on FRP sandwich systems for lightweight civil infrastructure

Fig. 13: FRP Floor Grating| FRP Engineering

The pattern is accredited against empirical information accumulated from the available literature. Finally, a recent plan suggestion is introduced. Figure 12 Shows Fiber-Reinforced Polymer (FRP) sandwich methods as main load-bearing components are fairly recent notions in lightweight civil infrastructure. These methods suggest a mixture of lightweight, high stability, thermal insulation for some sorts and service-life privileges. This Fig. 13 shows a recent notion for an FRP-Concrete composite floor method. The empirical consequences demonstrate that this kind of shear connection can prepare hardiness and appropriate flexibility to the process.

In samples 2 to 4, the strains are far away from the gaps. These results suggest that the filled gaps with FRP have the ability to anchor FRP.

Loading System and Measurements

Each sample has a non-symmetrical bending momentum in a recursive form, the transition angles range from $^1/_{400}$ Rad to $^1/_{20}$ Rad variables. Measuring these cases was the horizontal and vertical displacement between the upper and the lower sections and the strains of the main Bar, Stirrups and FRP.

Conclusion

With the use of various industrial waste and resistance tests, materials could be found inside the country, which saved the currency and strengthened the buildings at a low cost and the generalization of the problem of earthquake resistance by the general population.

The reinforcement method is made of glass fibers with vinyl ester resin, which can be used to reinforce reinforced concrete beams. Summaries are as follows:

All of the bending and beam test results indicate that the grooves filled with FRP are effective for the transfer of anchor from FRP to concrete.

The depth of the groove is 5 mm sufficient to create a tear state in the FRP alone.

The FRP drop in the collision surfaces between the beam in the use of the transition moment with the grooves filled with FRP and the slab was not observed and, finally, the FRP starts to tear at the angle of twist 1.5 Rad along the edges of the beam.

Acknowledgment

This research was supported by the Isfahan University of the Technology. We thank our all authors who provided insight and expertise that greatly assisted the research.

Author's Contributions

All authors contributed to design the study, write and revise the manuscript.

Ethics

The present Study and ethical aspect were approved by the Isfahan University of the Technology. The present study was approved by the Isfahan University of Technology.

References

ACI, 1991a. Design of beam-column joints for seismic resistance. ACI Special Publication, SP-123, American Concrete Institute, Detroit, MI, USA.

ACI, 1991b. Recommendations for design of beam-column joints in monolithic reinforced concrete structures. ACI 352R-91, ACI Committee 352, American Concrete Institute, Detroit, MI, USA.

ACI, 1995. Building code requirements for reinforced concrete. Detroit, MI, USA.

Ahmad, S.H. and Khaloo, 1991. Behavior of concrete spirally confined by fiberglass filaments. Magazine Concrete Res., 43: 143-148. DOI: 10.1680/macr.1991.43.156.143

Alcocer, S.M. and J.O. Jirsa, 1991. Reinforced concrete frame connections rehabilitated by jacketing. PMFSEL Report No. 91-1, P. M. Ferg. Str. Eng. Lab., University of Texas at Austin.

Alcocer, S.M. and J.O. Jirsa, 1993. Strength of reinforced concrete frame connections rehabilitated by jacketing. ACI Struct. J., 90: 249-261.

Antonopoulos, C.P. and T.C. Triantafillou, 2003. Experimental investigation of FRP-strengthened RC beam-column joints. J. Comp. Construct., 7: 39-49. DOI: 10.1061/(ASCE)1090-0268(2003)7:1(39)

Antonopoulos, C.P., T.C. Triantafillou and C.G. Papanicolaou, 2001. Experimental investigation of FRP-strengthened RC beam-column joints. Non-Metallic Reinforcement for Concrete Structures-FRPRCS5, Cambridge.

Beres, A., S. El-Borgi, R.N. White and P. Gergely, 1992. Experimental results of repaired and retrofitted beam-column joint tests in lightly RC frame buildings. Technical Report NCEER-92-0025, National Centre for Earthquake Engineering Research, State University of New York at Buffalo.

Biddah, A., 1997. Seismic behaviour of existing and rehabilitated reinforced concrete frame connections. Ph.D. Thesis, McMaster University, Hamilton, Ontario, Canada.

Byars, E.A., P. Waldron, V. Dejke, S. Demis and S. Heddadin, 2003. Durability of FRP in concrete – deterioration. Int. J. Mater. Product Technol., 19: 28-39. DOI: 10.1504/IJMPT.2003.003554

Chambers, R.E., 1992. Composites performance in infrastructure. Proceedings of the ASCE Material Science Conference, (MSC' 92), Atlanta, Georgia, pp: 532-545.

Corazao, M. and A.J. Durrani, 1989. Repair and strengthening of beam-to-column connections subjected to earthquake loading. NCEER Technical Report No. 89-0013, National Center for Earthquake Engineering Research, State University of New York at Buffalo.

Corley, W.G., 1993. Ductility of column, wall and beams-how much is enough? Special Publication, SP-157, American Concrete Institute.

Estrada, J.I., 1990. Use of steel elements to strengthen a reinforced concrete building. M.Sc. Thesis, University of Texas at Austin, TX, USA.

Fashie Jalalie, F., N. Rezapour and F. Shakorie Nia, 2005. Sprayed-up FRP strengthening for concrete structure. Proceedigns of the 12th National Conference of Civil Engineering Students, (CES' 05), Iran University of Science and Technology.

Filiatrault, A. and I. Lebrun, 1996. Seismic rehabilitation of reinforced concrete joints by epoxy pressure injection technique. Seismic Rehabilitation of Concrete Structures, SP-160, American Concrete Institute, Farmington Hills.

Gamble, W.L., N.M. Hawkins and I.I. Kaspar, 1996. Seismic retrofitting experience and experiments in Illinois. Proceedings of the 5th National Workshop on Bridge Research in Progress, (BRP' 96), National Center for Earthquake Engineering Research, pp: 245-250.

Geng, Z.J., M.J. Chajes, T.W. Chou and D.Y.C. Pan, 1998. The retrofitting of reinforced concrete beam-to-column connections. Comp. Sci. Technol., 58: 1297-1305. DOI: 10.1016/S0266-3538(98)00014-1

Ghobarah, A. and A.M. Said, 2001. Seismic rehabilitation of beam-column joints using FRP laminates. J. Earthquake Eng., 5: 113-129. DOI: 10.1080/13632460109350388

Ghobarah, A. and A.M. Said, 2002. Shear strengthening of beam-column joints. Eng. Structures, 24: 881-888. DOI: 10.1016/S0141-0296(02)00026-3

Katsumata, H., Y. Kobatake and T. Takeda, 1988. A study on strengthening with carbon fiber for earthquake-resistant capacity of existing reinforced concrete columns. Proceedings of the 9th Conference on Earthquake Engineering, (CEE' 88), Tokyo, Japan, pp: 517-522.

Kuan, S.Y.W., 1991. Response of epoxy-repaired R/C exterior beam-column joints. Proceedings of the Annual Conference of Canadian Society for Civil Engineering, (SCE' 91), Vancouver, BC, Canada, pp: 335-344.

Migliacci, A., R. Antonucci, N.A. Maio, P. Napoli and A.S. Ferretti *et al.*, 1983. Repair techniques of reinforced concrete beam-column joints. Final Report of IABSE Symposium on Strengthening of Building Structures-Diagnosis and Therapy, Venice.

Mosallam, A.S., 2000. Strength and ductility of reinforced concrete moment frame connections strengthened with quasi-isotropic laminates. Composites, 31: 481-497. DOI: 10.1016/S1359-8368(99)00068-2

O'Rourke, T.D., 1999. The Turkey, Taiwan and Mexico city earthquakes: Lessons learned. Hearing of the Subcommittee on Basic Research U.S. House of Representatives Committee on Science.

Pantelides, C.P., C. Clyde and L.D. Reaveley, 2000. Rehabilitation of R/C building joints with FRP composites. Proceedings of the 12th World Conference on Earthquake Engineering, (CEE' 00), New Zealand Society for Earthquake Engineering, New Zealand.

Pantelides, C.P., C. Clyde, C.P. Lau and L.D. Reaveley, 2001. Seismic rehabilitation of reinforced concrete building corner joints. in Non-Metallic Reinforcement for Concrete Structures-FRPRCS5, Cambridge.

Pantelides, C.P., J. Gergely, L.D. Reaveley and V.A. Volnyy, 1999. Retrofit of RC bridge pier with CFRP advanced composites. J. Struct. Eng., 125: 1094-1099. DOI: 10.1061/(ASCE)0733-9445(1999)125:10(1094)

Parvin, A. and P. Granata, 2000. Investigation on the effects of fiber composites at concrete joints. Composites, 31: 499-509. DOI: 10.1016/S1359-8368(99)00046-3

Priestley, M.J.N., F. Seible and G.M. Calvi, 1996. Seismic Design and Retrofit of Bridges. 1st Edn., Wiley, New York, ISBN-10: 047157998X, pp: 686.

Priestly, M.J.N., F. Seible and E. Fyfe, 1992. Column seismic retrofit using fiberglass/epoxy jackets. Proceedings of Advanced Composite Materials in Bridges and Structures, (MBS' 92), Canadian Society for Civil Engineering, pp: 287-298.

Prion, H.G.L. and M. Baraka, 1995. Grouted steel tubes as seismic retrofit for beam to column joints. Proceedings of the 7th Canadian Conference on Earthquake Engineering, (CEE' 95), Montreal, pp: 871-878.

Prota, A., A. Nanni, G. Manfredi and E. Cosenza, 2000. Seismic upgrade of beam-column joints with FRP reinforcement. L'Industria Italiana del Cemento.

Prota, A., A. Nanni, G. Manfredi and E. Cosenza, 2001. Selective upgrade of beam-column joints with composites. Proceedings of the International Conference on FRP Composites in Civil Engineering, (CCE' 01), Hong Kong, pp: 919-926.

Prota, A., G. Manfredi, A. Nanni and E. Cosenza, 2002. Capacity assessment of GLD RC frames strengthened with FRP. Proceedings of the 12th European Conference on Earthquake Engineering, Sept. 9-13, London, UK.

Saadatmanesh, H., M.R. Ehsani and L. Jin, 1977. Seismic retrofitting of rectangular concrete columns retrofitted with composite straps. Earthquake Eng. Res. Inst. J.

Saadatmanesh, H., M.R. Ehsani and L. Jin, 1996. Seismic strengthening of circular bridge piers with fiber composites. ACI Struct. J., 93: 639-647.

Saatcioglu, M. and C. Yalcin, 2003. External prestressing concrete columns for improved seismic shear, resistance. ASCE J. Structural Eng., 129: 1057-1070. DOI: 10.1061/(ASCE)0733-9445(2003)129:8(1057)

Saatcioglu, M., D. Mitchell, R. Tinawi, N.J. Gardner and A.G. Gillies *et al*., 1999. Kocaeli (Turkey) earthquake-damage to structures. Canad. J. Civil Eng., 28: 715-737.

Yamakawa, T. and S. Kamogawa, 2000. Seismic performance and design of RC columns retrofitted by PC bar prestressing as external hoops. AIJ J. Structural Construct., 537: 107-113.