Journal of Green Engineering (JGE)

Volume-10, Issue-12, December 2020

Sustainable Method of Estimation of Shear Strength of Concrete Beams Reinforced with GFRP Rebars

[1]R. Rajkumar and [2]N. Umamaheswari

[1]Assistant Professor, Department of Civil Engineering, SRM Institute of Science and Technology, Kattankulathur,Tamilnadu, India.
[2]Professor, Department of Civil Engineering, SRM Institute of Science and Technology, Kattankulathur,Tamilnadu, India.
E-mail: umamahen@srmist.edu.in

Abstract

Glass Fibre-Reinforced Polymer (GFRP) rebarsare nowadays used in construction industries because of good corrosion resistance and tensile strength properties they possess. The objective of the current research was to estimate ultimate shear capacity of concrete beams provided with GFRP rebars and conventional steel as reinforcement, using a sustainable method.In this case, shear reinforcement is eliminated to avoid flexural failure. Earlier research results show that ultimate shear capacity of concrete beams reinforced with FRP rebars is lesser than the estimated values using available standards for steel reinforcement. Hence the current study includes the re-evaluation of ultimate shear capacity of simply supported concrete beams reinforced with longitudinal GFRP and conventional steel rebars (omitting shear reinforcing bars) under four-point loading. Fifty-six numerical models of concrete beams have been developed during the simulation process. Analysis of all these beams have been executedby applysing Finite Element Analysis (FEA) software. The parameters varied in this numerical study are shear span to effective depth ratio, yield strength of conventional steel, compressive strength of concrete and diameter and arrangement of GFRP rebar in concrete beams. The observations such as ultimate load and load versus concrete and steel and GFRP reinforcement strain behavior are included in this paper. The shear strength of concrete beams under consideration was computed and compared with the estimations as per

Journal of Green Engineering, Vol. 10_12, 12948-12960.

available standards. The estimations based on equations suggested by previous researchers (as available in literature) was also included, for comparison purpose.

Key words: Finite Element Analysis; Shear strength; Concrete Beams;GFRP rebars

1 Introduction

The most frequently used structural material in building is steel reinforced concrete (SRC). However, steel corrosion in some conditions can lead to the degradation of structural components, resulting in high costs of repair and reconstruction. In order to prevent the buildings from these damages, the construction industry has been trying many measures to prevent steel corrosion, but they typically tend to be either costly or unsuccessful. The non-corrosive propertyof the material of Glass Fiber Reinforced Polymer (GFRP) has therefore been led to a generalized adoption of GFRP Reinforced concrete as a reasonable alternative. FRP provides a high strength non corrosive alternative to steel, thus providing the potential advantage of savings on maintenance costs and extended service life for bridge slabs, abutments, walls and other structure exposed to corrosive environments. Joseph R. Yost,et al. (2001) [1]. tested shear strength of normal strength concrete beams provided with deformed GFRP reinforcement and concluded that shear failure characteristics for beams with GFRP-reinforcement are identical to those of beams provided with steelreinforcement. For GFRP-reinforced beams, the shear strength is slightly lower compared to steel-reinforced beams. Ali S. Shanour et al. (2014) [2] analyzed GFRP reinforced beam and concluded that the overall strength would be improved by increasing the reinforcement ratio.Ali A.Hameed, Mohannad H, AL-Sherrawi (2018)[3]presented the effect of steel fiber on the shear capacity of a concrete beam under shear force test, the addition of steel fibers to reinforced concrete (RC) beams improved their ultimate shear strength upto 67.56% when compared with the control beam. Shawn P. Gross, et al. (2014) [4] studied the shear capacity of normal and high strength concrete beams provided with GFRP rebars and concluded that the high strength beams showed lesser shear capacity than the normal strength beams. Based on the experimental results, Monika Kaszubskaa et al (2017) [5] indicated while examining shear capacity of beams provided with single layer of reinforcement, there isonly less significant effect of the longitudinal reinforcement ratio. There is some improvement around 1.02 to 1.85%, with increase in the reinforcement ratio achieved with double layers of reinforcement. F.M. Wegian, H.A. Abdalla et al. (2015) [6]presented an investigation on shear strength of fiber reinforced polymers reinforced concrete beams. It was found that the concrete beams behave in a linear manner up to and after cracking also, but after cracking with reduced stiffness.

There is an increase in strains and deflections of fiber reinforced polymers reinforced concrete beams. Maher A. Adam, et al. (2015) [7] observed that since elastic modulus is less,unlike steel, GFRP rebars will undergo brittle failure. Certain disadvantages can be overcome by adopting fibers of more tensile strength. B Benmoktane, et al.(1995) [8], found that adopting fiber-reinforced plastic FRP rebars as a substitute to steel rebars is an idea developed in recent years. If properly implemented in the field of infrastructure, FRP composites can offer considerable benefits, both in terms of overall cost and durability. O. Chaallal (1995) [9],found that FRP has higher corrosion resistance, more tensile strength and lighter weight compared to steel. They are non-magnetic. Therefore, use of FRP can be considered forunder water structures / structures constructed in or near corrosive environments, S.H. Alsayed et al. (2000) [10]. Mohamed Said, Maher A. et al. (2016) [11] conducted experimental and analytical studies on shear evaluation of GFRP reinforced concrete beams and found that shear capacity increases withi ncrease in concrete compressive strength. Michele Theriaule et al (1998) [12]studied the effects of FRP reinforcement ratio and concrete strength and it was found that the crack spacing is less influenced by concrete strength and reinforcement ratio. H. Y. Leung et al (2002) [13] discussed about use of steel and FRP rebars together in concrete beam and found that the results were better.

The aims of the current research work are, first, to conduct a Finite Element Analysis (FEA) to find the beam behavior using ANSYS software[18], second, to discuss the results of numerical study of concrete beams reinforced with GFRP and conventional steel rebars with respect to load-concrete and reinforcement strain behavior and ultimate load carrying capacity, third, to analyze the effect of concrete compressive strength, steel yield strength, diameter and orientation of GFRP rebars and shear span to effective depth ratio on behavior of concrete beams, fourth, to estimate shear capacity of concrete beams reinforced with GFRP rebars based on available equations. Four different sizes of GFRP reinforcement, two different yield strengths of conventional steel, two concrete compressive strength, two different lengths of concrete beams were used for this purpose. Initially, numerical models for evaluating the behavior of GFRPconcrete beams were validated with the available test results [1] for validation purpose.

2 Related Works

Francesco Micelli et al (2004) [14] reported on durability of concrete structures provided with FRP rods. It was identified that properties of resin used for adhesion will affect the durability of reinforcement. BiswarupSaikia, et al (2007) [15] concluded that less effect is only observed on the behavior of the GFRP reinforced beams after cracking, by adding polypropylene fibers. At serviceability and ultimate limit states, C.

Barris et al (2007) [16] conducted tests and used code formulations and other analytical models for comparisons. Wenjun Qu et al (2009) [17] investigated and concluded that the concrete beamswith combination of steel and GFRP rebars with normal effective reinforcement ratios, shown good performance with respect toload carrying capacity, ductility and serviceability.

3 Numerical Study

3.1 General

FEA software ANSYS [18] was used to simulate the shear behavior of RC beams provided with steel and GFRP rebars. Load–strain curves were developed to study the beam behavior including beam load carrying capacity and maximum strain. Created beam models were symmetric in geometry, loading and internal reinforcement. Each model was typically discretized using 3-D isoperimetric elements Solid65.

3.2 Properties of Materials used

Four different diameters of GFRP reinforcements (12 mm,10 mm,8 mm,6 mm)were used for this investigation. Ultimate tensile strength and modulus of elasticity of the GFRP bars were 689.5 MPa and 40,336 MPa respectively. Two different concrete grades (25 and 80 MPa) were used. Conventional Steel reinforcement of two different grades (Fe415 and Fe500) were used and analyzed as a control beam for comparison purposes and their yield strength and modulus of elasticity were taken as 415MPa, 500MPa and 200GPa respectively. Similarly,poisson's ratio of GFRP and steel bars were taken as 0.27 and 0.2 respectively. Ratio of shear span to effective depth considered were 2.56 and 2.93.

3.3 Numerical Program

Fifty-six GFRP and conventional steel reinforced concrete beams were analyzed for two different spans, with adequate amount of longitudinal reinforcement.In this study, only members without transverse (shear) reinforcement were investigated. Four RC beams with two different grades of conventional steel (Fe415 and Fe500) were analyzed as control beams for comparison purpose.The developed rectangular concrete beam model along with the meshing and boundary condition for the beam model is shown in Fig.1. The models were allowed to undergo four-point bending, with1800 and 2000 mm as overall span, the distance between loads was taken as 260 mm, as shown in Fig.2.FEA was conducted to simulate the shear behavior of RC beams provided with conventional steel and GFRP rebars. The different cross-sections used in beam models for varying diameter and orientation of GFRP rebars were shown in Table 1.The beam designations were given accordingly, for example if it is M25-S12S12S12-Fe415, it indicates M25 grade concrete has been used in a rectangular beam of conventional steel reinforcement of grade Fe415 of 12 mm diameter. Likewise, GFRP reinforcements were mentioned as ‘G’. Combinations of steel and GFRP reinforcements as bottom reinforcements of beam was also considered in this numerical investigation. The observations made were ultimate load and load versus concrete and reinforcement strain behavior.

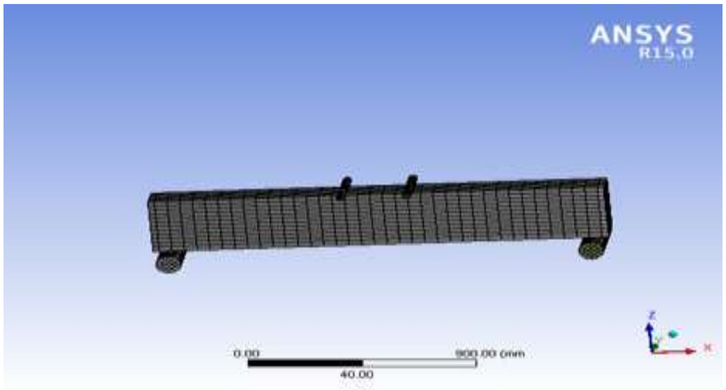

Figure 1 Rectangular Concrete Beam model

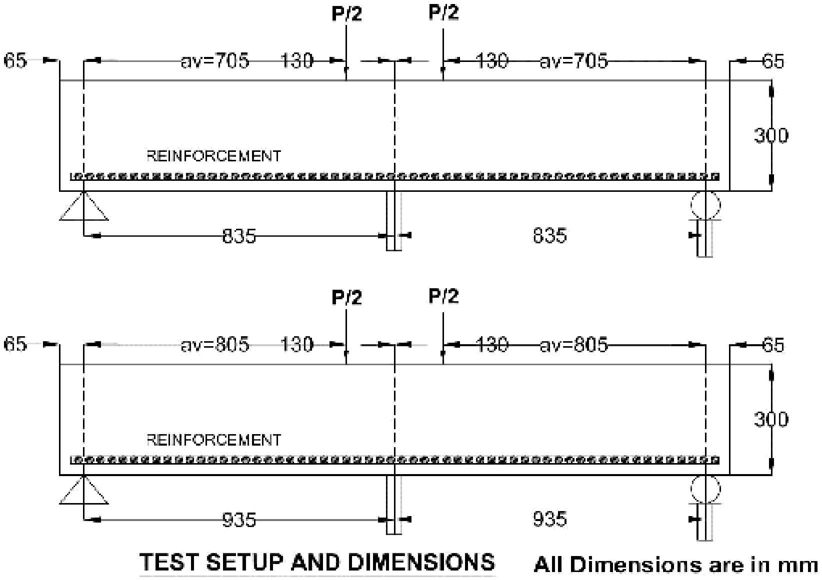

Figure 2 Four Point Bending Test

3.4 Validation of Models

The numerical models created for analyzing the behavior of steel and GFRP-reinforced concrete beams were validated using the experimental results available in literature [1]. The load versus midspan deflection behavior of concrete beams presented in literature [1] was compared with that of the results obtained using current numerical study done by authors. The percentage difference in peak load was found to be 8.3 even though there was marginal difference in initial stiffness. The comparison of load versus midspan concrete and GFRP strain was also executed. The percentage difference in GFRP strain was found to be 11.

4 Results and Discussions

This section includes discussion on the results obtained from numerical study, such as ultimate load, type of failure, load versus concrete and reinforcement strain behavior. The analysis of results such as effect of concrete compressive strength, steel yield strength, diameter and orientation of reinforcement and ratio of shear span to effective depth was included. Estimation of shear capacity using various equations was also included.

4.1 Ultimate Load and Type of Failure

Diagonal tension failure is observed in all beams since the beams were designed to avoid flexural failure. The ultimate load obtained from each FEA is noted. It is shown in Table 1(a) and Table 1(b) for beams of span 2m and 1.8m respectively.

Table 1(a) Shear Strength of Concrete Beams-Span 2m

Beam Designation	Span of Beams-2m			
	Failure load kN	F_{FEA} kN	F_{FEA}/ $F_{ASCE-ACI426}$	F_{FEA}/F_{DEITZ}
M25-S12S12S12-F415	105	53	2.28	1.88
M25-S12S12S12-F500	112	56	2.43	2.00
M25- G12G12G12	56	28	1.22	1.00
M25-G10G10G10	63	34	1.37	1.13
M25-G8G8G8	56	28	1.22	1.00
M25-G6G6G6	49	25	1.06	0.88
M25- S12G12S12	91	46	1.98	1.63
M25-S10G10S10	98	49	2.13	1.75
M25-S8G8S8	77	39	1.67	1.38

M25-S6G6S6	63	34	1.37	1.13
M25- G12S12G12	63	34	1.37	1.13
M25-G10S10G10	70	35	1.52	0.61
M25-G8S8G8	63	34	1.37	1.13
M25-G6S6G6	63	34	1.37	1.13
M80-S12S12S12-	105	53	1.28	1.05
M80-S12S12S12-	105	53	1.28	1.05
M80-G12G12G12	70	35	0.85	0.70
M80-G10G10G10	77	39	0.91	0.77
M80-G8G8G8	70	35	0.85	0.70
M80-G6G6G6	70	35	0.85	0.70
M80 S12G12S12	98	49	1.20	0.98
M80-S10G10S10	105	53	1.28	1.05
M80-S8G8S8	98	49	1.20	0.98
M80-S6G6S6	77	39	0.91	0.77
M80 G12S12G12	77	39	0.91	0.77
M80-G10S10G10	84	42	1.02	0.84
M80-G8S8G8	77	39	0.91	0.77
M80-G6S6G6	77	39	0.91	0.77

Table 1(b) Shear Strength of Concrete Beams-Span 1.8 m

Beam Designation	Span of Beams-1.8m			
	Failure load, kN	F_{FEA} kN	F_{FEA}/ $F_{ASCE-ACI426}$	F_{FEA}/F_{DEITZ}
M25-S12S12S12-	119	60	1.30	2.13
M25-S12S12S12-	105	53	1.14	1.88
M25- G12G12G12	63	32	0.69	1.13
M25-G10G10G10	70	35	0.76	1.25
M25-G8G8G8	70	35	0.76	1.25
M25-G6G6G6	70	35	0.76	1.25
M25- S12G12S12	105	53	1.14	1.88
M25-S10G10S10	105	53	1.14	1.88
M25-S8G8S8	84	42	0.91	1.50
M25-S6G6S6	77	39	0.84	1.38
M25- G12S12G12	77	39	0.84	1.38
M25-G10S10G10	91	46	0.99	1.63
M25-G8S8G8	70	35	0.76	1.25
M25-G6S6G6	70	35	0.76	1.25

M80-S12S12S12-	112	56	0.69	1.12
M80-S12S12S12-	105	53	0.64	1.05
M80-G12G12G12	70	35	0.43	0.7
M80-G10G10G10	77	39	0.47	0.77
M80-G8G8G8	70	35	0.43	0.70
M80-G6G6G6	70	35	0.43	0.70
M80 S12G12S12	98	49	0.60	0.98
M80-S10G10S10	119	60	0.73	1.19
M80-S8G8S8	91	46	0.56	0.91
M80-S6G6S6	84	42	0.51	0.84
M80 G12S12G12	77	39	0.47	0.77
M80-G10S10G10	91	46	0.56	0.91
M80-G8S8G8	77	39	0.47	0.77
M80-G6S6G6	77	39	0.47	0.77

4.2 Load versus Concrete Strain Behavior

Representative load versus concrete strain (observed at mid span) plot is shown in Fig.3.The ultimate strains of concrete were in the range of 0.0013. The change in compressive strain in concrete at midspans till the formation of first crack was minimal. After this stage, strains were increased and reached the maximum. This showed that theincrease in concrete strain was rapid. This might be due to the formation of the diagonal tension crack thus causing collapse of beams.

4.3 Load versus GFRP Reinforcement Strain Behavior

Representative load versus GFRP reinforcement strain (observed at mid span) plot is shown in Fig.4.The ultimate strains of GFRP rebars were in the range of 0.0098. The change in tensile strain in longitudinal GFRP reinforcement till the formation of first crack was minimal. After this stage, strains were increased and reached maximum. This showed that the increase in strain in GFRP rebars was rapid. This might be due to the formation of the diagonal tension crack thus causing collapse of beams.It was found that there is considerable increase in strain occurred after crackingbecause stress in concrete is transferred to the reinforcement, resulting in large strains.

4.4 Load versus Steel Reinforcement Strain Behavior

Representative load versus steel reinforcement strain (observed at mid span) plot is shown in Fig.5.The ultimate strains of steel rebars were in the range of 0.0099. The change in tensile strain in longitudinal steel reinforcement till the formation of first crack was minimal. After this stage, strains were increased and reached maximum. This showed that the increase in strain in steel rebars was rapid. This might be due to the formation of the diagonal tension crack thus causing collapse of beams. It was found that there is considerable increase in the strain occurred after crackingbecause stress in concrete is transferred to the reinforcement, resulting in large strains.

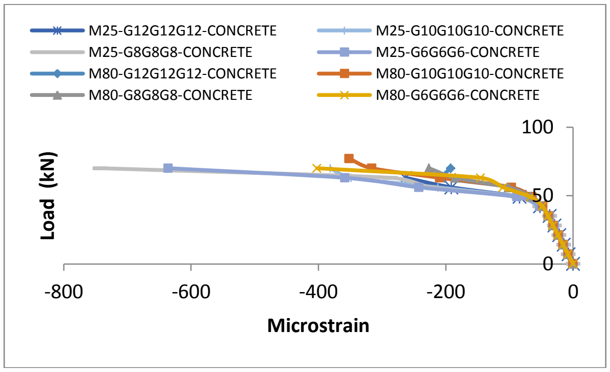

Figure 3 Load vs Concrete Strain Behaviour

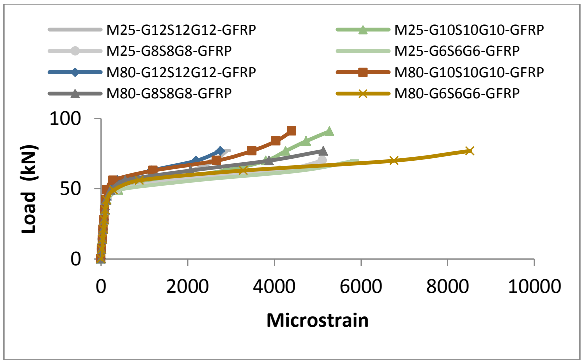

Figure 4 Load vs GFRP Reinforcement Strain Behavior

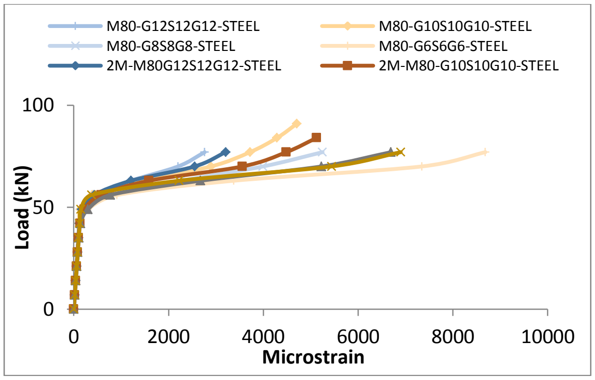

Figure 5 Load vs Steel Reinforcement Strain Behavior

4.5 Shear Capacity of RC Beams

Shear capacity of reinforced concrete beams under consideration were calculated from the failure loads obtained from FEA (F_{FEA}), for span 2m and 1.8m and were shown in Table 1(a) and Table 1(b) respectively.

Shear capacity was found to increase by upto 25% as compressive strength of concrete increased from 25 to 80 MPa and decreased by upto 5% as steel yield strength increased from 415 to 500 MPa.Shear strength variation was found to be minimal with respect to diameter of steel rebars but it decreased by upto 23 and 35% as percentage replacement by GFRP rebars increased from 67 to 100%.Shear strength decreased by upto 24% as ratio of shear span to depth increased from 2.56 to 2.93 (for M25 grade concrete). The effect was seemed to be minimal for M80 grade concrete.

4.6 Estimation of Shear Strength of RC Beams

The currently available standards/equations for shear strength estimation were framed for beams reinforced with conventional steel rebars. Shear strength was found to be considerably lesser for GFRP reinforced beams compared to that of steel reinforced beams.ASCE-ACI426[19] and Deitz et al.[20] were referred for estimation of shear strength of beams under consideration. The results are provided in Table 1(a) and Table 1(b) respectively, for beam span 2m and 1.8m. ASCE-ACI426[19] equation for shear strength estimation yields unconservative results for beams reinforced with GFRP. Equation suggested by Deitz et al.[20] yields comparatively an acceptable estimate of shear strength of concrete beams reinforced with GFRP rebars without web reinforcement, (but only for beams with lesser f_{ck})

5 Conclusions

Numerical investigation was carried over on the behaviour of simply supported concrete beams reinforced with longitudinal GFRP and conventional steel rebars when no shear reinforcement is provided. A total of fifty-six numerical models of concrete beams have been created and analysed using FEA software.

The following conclusions were arrived according to the results obtained from thecurrent numerical investigation. Simply supported RC beams provided with GFRP rebars behave in a bilinear manner upto and after cracking with reduced stiffness.Shear capacity of concrete beams reinforced with GFRP rebars was lesser than that of beams reinforced with steel rebars. Shear strength increases by upto 25% as concrete compressive strength increases from 25 to 80 MPa.The available standards and equations slightly overestimate the shear capacity of beams reinforced with GFRP rebars.

References

[1] Joseph R. Yost, Shawn P. Gross, and David W. Dinehart: “Shear Strength of Normal Strength Concrete Beams Reinforced with Deformed GFRP bars”, Journal of Composite for Construction, Vol.5, no.4, 2001.

[2] Ali S. Shanour, Ahmed A.Mahmoudand Maher A. Adam “Experimental Investigation of Concrete Beams Reinforced With GFRP Bars”, International Journal Of Civil Engineering and Technology (IJCIET), Vol. 5, no. 11, pp.154-164, 2014.

[3] A.Hameed,Mohannad H, AL-Sherrawi, **“**Effectof steel fiber on the shear strength of a concrete beam”. Civil Engineering Journal, Vol.4, no.7, 2018

[4] Shawn P. Gross, Joseph Robert Yost, and David W. Dinehart, “Shear Strength of Normal and High Strength Concrete Beams Reinforced with GFRP Bars”, High Performance materials in Bridges, 2014.

[5] Monika Kaszubskaa,RenataKotyniaa, Joaquim A. O. Barrosb, “Influence of longitudinal GFRP reinforcement ratio on shear capacity of concrete beams without stirrups”, Procedia Engineering, Vol. 193 , pp.361 – 368, 2017.

[6] F.M. Wegian, H.A. Abdalla: “Shear Capacity of Concrete Beams Reinforced with Fiber Reinforced Polymers”, Composite Structures, Vol. 71, pg.130-138, 2005.

[7] Maher A. Adam, Mohamed Said, Ahmed A. Mahmoud, Ali S. Shanour “Analytical and experimental flexural behavior of concrete beams reinforced with glass fiber reinforced polymers bars”, Construction and Building Materials, Vol. 84, pp. 354-366 , 2015.

[8] Benmoktane, 0. Chaallalt and R. Masmoudi “Glass fibre reinforced plastic (GFRP) rebars for concrete structures”, Construction and Building Materials, Vol. 9, pp.35-364 ,1995.

[9] O. Chaallal “Fiber-reinforced plastic rebars for concrete applications”, Composites Part B, Vol. 27B, pp. 245-252 ,1996.

[10]S.H. Alsayed, Y.A. Al-Salloum, T.H. Almusallam, “Performance of glass fiber reinforced plastic bars as a reinforcing material for concrete structures”, Composites: Part B 31, pp.555-567, 2000.

[11] Mohamed Said, Maher A. Adam, Ahmed A. Mahmoud: “Experimental and Analytical Shear Evaluation of Concrete Beams Reinforced with Glass Fiber Reinforced Polymers Bars”, Construction and Building Materials,volume 102, pg.574-591, 2016.

[12] Michele Theriaule and BrahimBenmokrane “Effects of FRP reinforcement ratio and concrete strength on flexural behavior of concrete beams”, Journal of composites For Construction, 1998.

[13] H. Y. Leung, S. Kitipornchai, R. V. Balendran and A. Y. T. Leung, "Analytical Behaviour of Concrete Beams Reinforced with Steel Rebars And FRP Rods, Advances in Building Technology, Vol.1,

[14] Francesco Micelli , Antonio Nanni , "Durability of FRP rods for concrete structures" Construction and Building Materials, Vol. 18, pp. 491–503, 2004

[15] BiswarupSaikia, Phanindra Kumar, Job Thomas, K.S. Nanjunda Rao, Ananth Ramaswamy, "Strength and serviceability performance of beams reinforced with GFRP bars in flexure", Construction and Building Materials, Vol. 21, pp.1709–1719, 2007.

[16]C. Barris a, Ll. Torres, A. Turon , M. Baena , A. Catalan. "An experimental study of the flexural behaviour of GFRP RC beams and comparison with prediction models", Composite Structures, Vol. 91 pp.286–295, 2009.

[17] Wenjun Qu, Xiaoliang Zhang and Haiqun Huang, "Flexural Behavior of Concrete Beams Reinforced with Hybrid(GFRP and Steel) Bars", journal of composites for construction, 2009.

[18]AvailableOnline:http://research.me.udel.edu/~lwang/teaching/MEx81/ansys56manual.pdf

[19]ASCE-ACI Committee 426: Suggested revisions to shear provisions for building codes, ACI Journal, Vol. 75, no. 9, pp 458-469,2006.

[20]Deitz DH, Harik IE, Gesund H., "One way slabs reinforced with glass fiber reinforced polymer reinforcing bars", IEEE ACI 4th Intl. Symposium.Detroit ACI,1999.

Biographies

R.Rajkumar is currently working as an Assistant Professor in Department of Civil Engineering, SRM Institute of Science and Technology, Kattankulathur, Tamilnadu, India. He completed B.E in Civil Engineering from Arulmigu Kalasalingam College of Engineering,Tamilnadu, India. He obtained M. Tech in Structural Engineering from Karunya University, Coimbatore, Tamilnadu, India. His Ph.D. work is related to investigation on concrete reinforced with Glass Fiber-Reinforced Polymer rebar.He has published few journal and conference papers.

N. Umamaheswari iscurrently working as a Professor in Department of Civil Engineering, SRM Institute of Science and Technology, Kattankulathur, Tamilnadu, India.She completed B.E(Civil) and M.E(Structures) from M.K. University, Madurai, Tamilnadu, India. She obtained Ph.D. from SRM Institute of Science and Technology (formerly known as SRM University), Kattankulathur, Tamilnadu, India in 2012.She is a Fellow of Institution of Engineers India (IEI), Fellow of Association of Consulting Civil Engineers ACCE, Chennai, Life Member of The Indian Society of Technical Education (ISTE) andLife Member of Indian Concrete Institute (ICI). She was invited as key note speaker and conference chairperson for international conferences and reviewer of journals. She has authored a book on Prying Force and published 60international/national journal and conference papers.