4. Using fully FRP U wrap is more effective than CFRP strips with higher torsional strength and ductility.

5. All strengthened beams represent higher stiffness compared to the control beam in the three regions of the load-deflection curves.

6. The control beam shows a faster rate of diagonal crack propagation than the strengthened beams. This is due to the lack of CFRP wrapping along the beam. The failure occurred after substantial wide diagonal cracks and concrete crushing followed by CFRP rupture.

References

1. Kongjian, Shen, Shui Wan, Y.L. Mo, Zhengwen, Jiang. Theoretical analysis on full torsional behavior of RC beams strengthened with FRP materials. Composite Structures. 2018. 183(1). Pp. 347–357. DOI: 10.1016/j.compstruct.2017.03.084.
2. Jariwala, V.H., Patel, P, Purohit, S.P. Strengthening of RC beams subjected to combined torsion and bending with GFRP composites. Procedia Engineering. 2013. 51(1). Pp. 282–289. DOI: 10.1016/j.proeng.2013.01.038
3. Amulu, C.P., Zeagu, C.A. Experimental and analytical comparison of torsion, bending moment and shear forces in reinforced concrete beams using BS 8110, euro code 2 and ACI 318 provisions. Nigerian Journal of Technology. 2017. 36(3). Pp. 705–711. DOI:10.4314/njt.v36i3.7.
4. Meyyada, Y. Alabdulhady, Lesley, H. Sneed, Christian, Carloni. Torsional behavior of RC beams strengthened with PBO-FRCM composite–An experimental study. Engineering Structures. 2017. 136(1). Pp. 393–405. DOI: 10.1016/j.engstruct.2017.01.044
5. Gonzalez-Libreros, J.H., Sneed, L.H., D'Antino, T., Pellegrino, C. Behavior of RC beams strengthened in shear with FRP and FRCM composites. Engineering Structures. 2017. 150(1). Pp. 830–842. DOI: 10.1016/j.engstruct.2017.07.084
6. Shraddha, B. Tibhe, Vijaykumar, R. Rathi. Comparative Experimental Study on Torsional Behavior of RC Beam Using CFRP and GFRP Fabric Wrapping. Procedia Technology. 2016. 24(1). Pp. 2212–0173. DOI: 10.1016/j.protcy.2016.05.020
7. Rahal, K.N., Collins, M.P. Combined torsion and bending in reinforced and prestressed concrete beams. ACI Structural Journal. 2003. 100(2). Pp. 157–165. DOI: 10.14359/12479
8. Hii, AKY, Al-mahaidi, R., Asce, M. Torsional capacity of CFRP strengthened reinforced concrete beams. Journal of Composites for Construction. 2007. 11(1). Pp. 71–80. DOI:10.1061/(ASCE)1090-0268(2007)11:1(71).
9. Ghaidak Al-Bayati, Riadh Al-Mahaidi, M. Javad Hashemi, Robin Kalfat. Torsional strengthening of RC beams using NSM CFRP rope and innovative adhesives. Composite Structures. 2018. 187(1). Pp. 190–202. DOI: 10.1016/j.compstruct.2017.12.016
10. Ameli, M., Ronagh, H.R. Analytical method for evaluating ultimate torque of FRP strengthened reinforced concrete beams. Journal of Composites for Construction. 2007. 11(4). Pp. 384–390. DOI: 10.1061/(ASCE)1090-0268(2007)11:4(384).
11. Aravind, N., Samanta, A.K., Roy, D.S., Thanikal, J.V. Retrofitting of reinforced concrete beams using fiber reinforced polymer (FRP) composites–a review. Journal of Urban and Environmental Engineering. 2013. 7(1). Pp. 164–175. DOI: 10.4090/juee.2013.v7n1.164175.
12. Meyyada Y. Alabdulhady, Lesley H. Sneed, Omar I. Abdelkarim, Mohamed A. ElGawady. Finite element study on the behavior of RC beams strengthened with PBO-FRCM composite under torsion. Composite Structures. 2017. 179(1). Pp. 326–339. DOI: 10.1016/j.compstruct.2017.07.079
13. Al-Bayati, G., Kalfat, R., Al-Mahaidi, R., Hashemi, J. Experimental study on crack propagation of CFRP-strengthened RC beams subjected to torsion. Australian Journal of Structural Engineering. 2018. 19(4). Pp. 279–297. DOI: 10.1080/13287982.1523293.
14. Al-Bayati, G., Al-Mahaidi, R., Kalfat, R. Experimental investigation into the use of NSM FRP to increase the torsional resistance of RC beams using epoxy resins and cement-based adhesives. Construction and Building Materials. 2016. 124(1). Pp. 1153–1164. DOI: 10.1016/j.conbuildmat.2016.08.095.
15. Al-Bayati, G., Al-Mahaidi, R., Kalfat, R.. Torsional strengthening of reinforced concrete beams using different configurations of NSM FRP with epoxy resins and cement-based adhesives. Composite Structures. 2017. 168(1). Pp. 569–581. DOI: 10.1016/j.compstruct.2016.12.045
16. Deifalla, A., Ghobarah, A. Strengthening RC T-beams subjected to combined torsion and shear using FRP fabrics: Experimental study. Journal of composites for construction. 2010. 14(3). Pp. 301–311. DOI: 10.1061/(ASCE)CC.1943-5614.0000091.
17. Vishnu, H. Jariwala, Paresh, V. Patel, Sharadkumar, P. Purohit. Strengthening of RC Beams Subjected to Combined Torsion and Bending with GFRP Composites. Procedia Engineering. 2013. 51(1). Pp. 282–289. DOI: 10.1016/j.proeng.2013.01.038
18. Ghobarah, A., Ghorbel, M.N., Chidiac, S.E. Upgrading torsional resistance of reinforced concrete beams using fiber-reinforced polymer. Journal of Composites for Construction. 2002. 6(4). Pp. 257–263. DOI: 10.1061/(ASCE)1090-0268(2002)6:4(257).
19. Deifalla, A., Ghobarah, A. Full torsional behavior of RC beams wrapped with FRP: analytical model. Journal of Composites for Construction. 2010. 14(3). Pp. 289–300. DOI: 10.1061/(ASCE)CC.1943-5614.0000085
20. Mahmood, M.N. Nonlinear analysis of reinforced concrete beams under pure torsion. Journal of Applied Sciences. 2007. 7(22). Pp. 3524–3529. DOI: 10.3923/jas.2007.3524.3529
21. Prabaghar, A., Kumaran, G. Theoretical study on the behavior of rectangular concrete beams reinforced internally with GFRP reinforcements under pure torsion. International Journal of Civil and Structural Engineering. 2011. 2(2). Pp. 570–594. DOI: 10.6088/ijcser.00202010134.
22. Elwan, S.K. Torsion strengthening of RC beams using CFRP (parametric study). Journal of Civil Engineering. 2017. 21(4). Pp. 1273–1281. DOI: 10.1007/s12205-016-0156-7.
23. Zojaji, A.R. znd Kabir, M.Z. Analytical approach for predicting full torsional behavior of reinforced concrete beams strengthened with FRP materials. Scientia Iranica. 2012. 19(2). Pp. 51–63. DOI: 10.1016/j.scient.2011.12.004.
24. Ameli, M., Ronagh, H.R., Dux, P.F. Behavior of FRP strengthened reinforced concrete beams under torsion. Journal of Composites for Construction. 2007. 11(2). Pp. 192–200. DOI: 10.1061/(ASCE)1090-0268(2007)11:2(192)
25. Gesund, H., Schuette, F.J., Buchanan, G.R., Gray, G.A. Ultimate strength in combined bending and torsion of concrete beams containing both longitudinal and transverse reinforcement. Journal of the American Concrete Institute. 1964. 61(12). Pp. 1509–1522. DOI: 10.1680/macr.1968.20.64.155.

Contacts:

Rajai Al-Rousan, +962799887574; rzalrousan@just.edu.jo
Isra'a Abo-Msamh, +96227201000; iabomsamh@gmail.com