Analytical Study of RC Beam Externally Bonded With GFRP Sheets

Rajeshkumar K[1], Dr. G. Arunkumar [2]
[1]*PG Student Structural Engineering, Government College of Engineering Salem, India*
[2]*Associate professor, Dept of Civil Engineering, Government College of Engineering Salem, India*

Abstract: The use of externally bonded Fiber Reinforced Polymer (FRP) sheets is an effective method for enhancing the strength, stiffness, and service life of reinforced concrete (RC) structures. This study analyzes the structural behavior of RC plate girders strengthened with Glass Fiber Reinforced Polymer (GFRP) sheets under loading conditions. A finite element model (FEM) in ABAQUS is developed to evaluate improvements in flexural strength, deflection control, and stress distribution. The results indicate that GFRP strengthening enhances load-bearing capacity, mitigates deflection under service loads, and improves shear performance. This study provides insights into the effectiveness of GFRP sheets as a cost-efficient, lightweight, and durable strengthening solution, aiding in the development of practical design guidelines for deteriorating infrastructure.

Keywords: Reinforced Concrete, GFRP, Strengthening, Finite Element Analysis, ABAQUS

1. INTRODUCTION

Reinforced concrete (RC) plate girders are widely used in civil infrastructure such as bridges and industrial buildings. However, environmental degradation, increased service loads, and aging lead to structural deterioration, reducing their load-carrying capacity and service life. Traditional strengthening methods, such as steel plate bonding, are often labor-intensive and prone to corrosion. Glass Fiber Reinforced Polymer (GFRP) sheets provide a lightweight, corrosion-resistant alternative that enhances flexural and shear performance.

This study investigates the structural behavior of RC plate girders strengthened with GFRP sheets under static loading using a finite element model (FEM) in ABAQUS. The primary objective is to analyze the impact of different GFRP wrapping configurations on stress distribution, deflection, and ultimate load capacity.

2. FINITE ELEMENT MODEL DEVELOPMENT

2.1 MODEL DESCRIPTION

A three-dimensional finite element model (FEM) was developed in ABAQUS to analyze the behavior of RC girders before and after GFRP strengthening. Five configurations were considered:
Type 1: RC Beam without GFRP Wrapping
Type 2: GFRP Sheet Wrapping at Soffit
Type 3: GFRP Sheet Wrapping at Bottom Flange
Type 4: GFRP Sheet Wrapping at Bottom Flange and Web
Type 5: Fully Wrapped with GFRP Sheet.

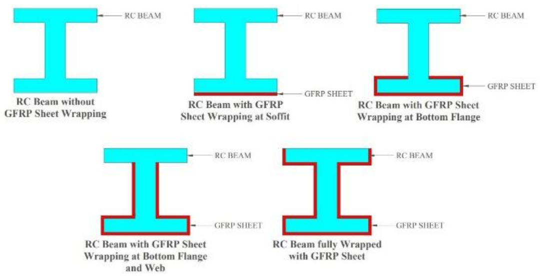

Fig.2.1. Model Types

2.2 MATERIAL PROPERTIES

Concrete was modeled using the Concrete Damage Plasticity (CDP) approach, while steel reinforcement was modeled as an isotropic hardening plastic material. GFRP was defined as an orthotropic material with the following properties:

- Elastic Modulus (E1): 90,000 MPa
- Elastic Modulus (E2): 900 MPa
- Shear Modulus: 3270 MPa
- Tensile Strength: 2300 MPa
- Poisson's Ratio: 0.26

2.3 BOUNDARY CONDITIONS AND LOADING

The girders were modeled with simply supported conditions and subjected to a two-point loading system. The applied load was increased incrementally until failure to evaluate the structural response under different GFRP configurations.

3. RESULTS AND DISCUSSION

3.1 LOAD-DEFLECTION BEHAVIOR

The load-deflection curves indicated that GFRP strengthening effectively reduced deflection while increasing load-bearing capacity. Table 3.1 summarizes the results:

Table.3.1. Ultimate Load and Maximum Deflection

Model Type	Ultimate Load (kN)	Maximum Deflection (mm)
Type 1	266.34	23.28
Type 2	292.93	20.08
Type 3	318.56	17.94
Type 4	334.49	17.15
Type 5	350.20	16.52

Fully wrapped girders (Type 5) demonstrated the highest strength, with an ultimate load increase of 31.5% compared to the unstrengthened girder (Type 1).

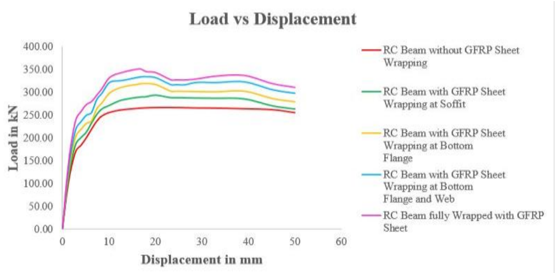

Fig.3.1. Load vs Deflection Comparison Graph

3.2 STRESS DISTRIBUTION

Membrane stresses (S_{11}, S_{22}, S_{33}) and shear stresses (S_{12}, S_{13}) were evaluated to understand stress distribution. The results showed that GFRP reinforcement reduced peak stress values and redistributed stresses more evenly across the girder sections.

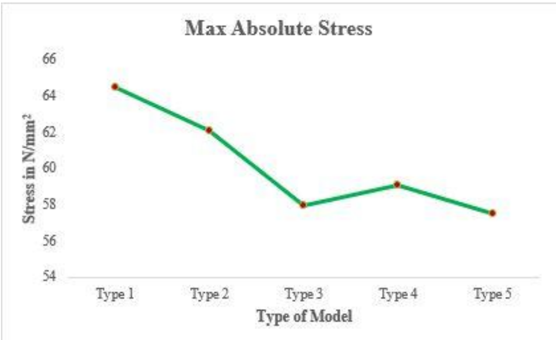

Fig.3.2.1. Maximum Absolute Stress

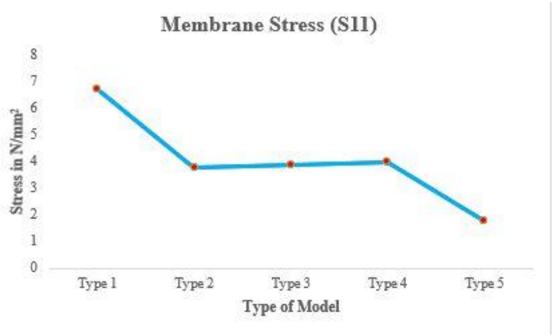

Fig.3.2.2. Membrane Stress (S_{11})

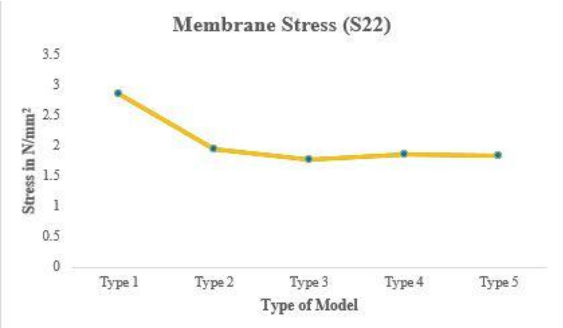

Fig.3.2.3. Membrane Stress (S_{22})

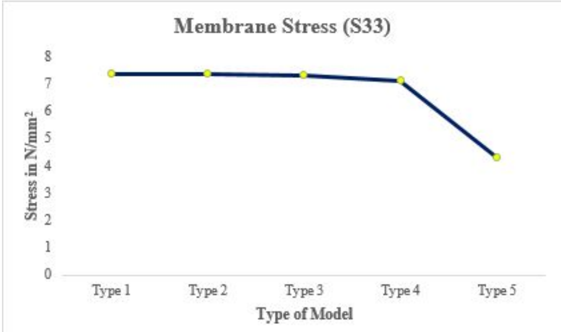

Fig.3.2.4. Membrane Stress (S_{33})

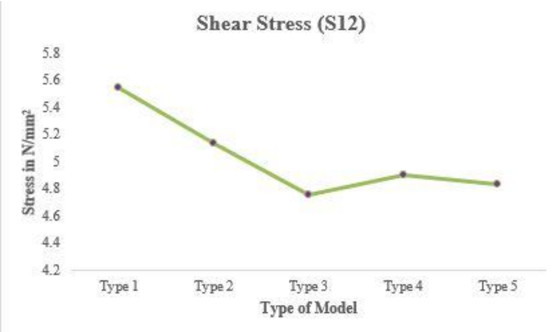

Fig.3.2.5. Shear Stress (S_{12})

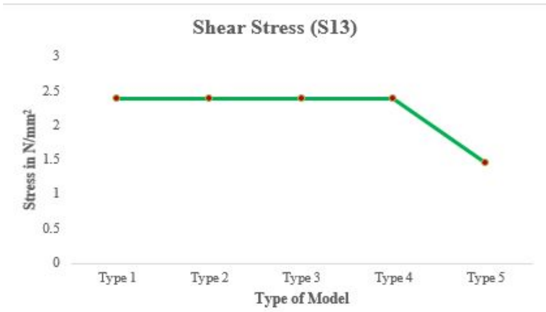

Fig.3.2.6. Shear Stress (S_{13})

3.3 FAILURE MODES

Unstrengthen girders exhibited flexural cracking at midspan, leading to failure. GFRP-strengthened girders showed improved performance with delayed crack propagation. Type 5 configurations exhibited the best structural integrity, minimizing stress concentrations and increasing ductility.

4. CONCLUSION

This study highlights the effectiveness of GFRP sheets in strengthening RC plate girders. The key findings include:

GFRP wrapping significantly enhances load-bearing capacity and reduces deflection.

Fully wrapped girders exhibit the best performance in terms of stress distribution and failure resistance.

The application of GFRP mitigates flexural and shear stresses, improving structural durability.

These findings support the adoption of GFRP as a viable retrofitting technique, providing practical design insights for engineers involved in infrastructure rehabilitation.

ACKNOWLEDGEMENT

We want to thank our colleagues and mentors for their helpful suggestions and constructive feedback which added significantly to the quality of this study. We would also like to acknowledge the contributions of previous researchers, whose efforts paved the way for this

REFERENCES

[1] ACI 440.2R-17. Guide for the design and construction of externally bonded FRP systems for strengthening of concrete structures. Michigan: American concrete institute, ACI Committee 440; 2017.

[2] Coronado, C. A., & Lopez, M. L. (2006). Sensitivity analysis of reinforced concrete beams strengthened with FRP laminate. Cement and Concrete Composites, 28, 102–114.

[3] Camata, G., Spacone, E., & Zarnic, R. (2007). Experimental and nonlinear finite element studies of RC beams strengthened with FRP plates. Composite Part B, 38, 277–288.

[4] Galal, K., & Mofdi, A. (2009). Strengthening of RC beams in flexure using new hybrid FRP sheet ductile anchor system. Journal of Composite for Structures, 13(3), 217–225.

[5] Kim, H. S., & Shin, V. (2011). Flexural behavior of reinforced concrete beams retrofitted with hybrid fiber reinforced polymer under sustained loads. Composite Structures, 93, 802 811.

[6] Kara, I. F., & Ashour, A. F. (2012). Flexural performance of FRP reinforced concrete beams. Composite Structures, 94, 1616–1625.

[7] Attari, N., Amziane, S., & Chemrouk, M. (2012). Flexural strengthening of concrete beams using CFRP, GFRP and hybrid FRP sheets. Construction and Building Materials, 37, 746 757.

[8] Ceroni, F., Marisa, P., Bilotta, A., & Nigro, E. (2012). Bond behavior of FRP NSM system in concrete element. Composite Part B, 43, 99–109.

[9] Choi, E., Utai, N., & Kim, H. S. (2013). Experimental and analytical investigations on debonding of hybrid FRPs for flexural strengthening of RC beams. Composite Part B, 45, 248–256.

[10] Dong, J., Wang, Q., & Guan, Z. (2013). Structural behavior of RC beams with external flexural and flexural-shear strengthening by FRP sheets. Composite Part B, 44, 604–612.

[11] Skuturna, T., & Valivonis, J. (2016). Experimental study on the effect of anchorage systems on RC beams strengthened using FRP. Composite Part B, 91, 283–290.

[12] Triantafyllou, G. G., Rousakis, T. C., & Karabins, A. I. (2017). Corroded RC beams patch repaired and strengthened in fexure with fber-reinforced polymer laminate. Composite Part B, 112, 125–136.

[13] Raoof, S. M., Koutas, L. N., & Bournas, D. A. (2017). Textile-reinforced mortar (TRM) versus fiber-reinforced polymers (FRP) in flexural strengthening of RC beams. Construction and Building Materials, 151, 279–291.

[14] Renyuan, Q., Zhou, A., & Lau, D. (2017). Effect of reinforcement ratio on the flexural performance of hybrid FRP reinforced concrete beams. Composite Part B, 108, 200–209.

[15] Chellapandian, M., Praksh, S. S., & Sharma, A. (2018). Experimental and finite element studies on the flexural behavior of reinforced concrete element strengthened with hybrid FRP technique. Composite Structures, 208, 466–478.

[16] Kashi, A., Ramezanianpour, A. A., Moodi, F., & Malekitabar, H. (2019). Effect of aggressive marine environment on strain efficiency factor of FRP-confined concrete. Construction and Building Materials, 222, 882–891.

[17] Siddika, A., Al-Mamun, M. A., Alyousef, R., & Amran, Y. H. M. (2019). Strengthening of reinforced concrete beams by using fiber-reinforced polymer composite: A review. Journal of Building Engineering, 25, 100798.

[18] Moradi, E., Naderpour, H., & Kheyroddin, A. (2020). An experimental approach for shear strengthening of RC beams using a proposed technique by embedded through-section FRP sheets. Composite Structure, 238, 111988.

[19] Chen, C., Yang, Y., Jinbo, Y., Yu, J., Tan, H., Sui, L., & Zhou, Y. (2020a). Eco-friendly and mechanically reliable alternative to synthetic FRP in externally bonded strengthening of RC beams: Natural FRP. Composite Structures, 241, 112081.

[20] Raza, A., El Ouni, M. O., Zaman Khan, Q. U., & Berradia, M. (2021). Structural assessment of eccentrically loaded GFRP reinforced circular columns: experiments and finite element analysis. Composite Structures, 275, 114528.

[21] Abaqus/Explicit User’s Manual, Version 6.3. Hibbitt, Karlson and Sorenson, Inc. Pawtucket, RI. 2002.