

INTISARI

Struktur beton bertulang yang telah dirancang dengan standar lama atau mengalami perubahan fungsi memerlukan perkuatan struktural untuk mempertahankan kapasitas dan umur layan bangunan. Salah satu metode perkuatan yang umum digunakan adalah penambahan *Glass Fiber Reinforced Polymer* (GFRP), karena sifatnya yang ringan, kuat tarik tinggi, dan tahan korosi. Namun, sebagian besar penelitian sebelumnya lebih fokus pada perkuatan balok beton bertulang skala kecil. Oleh karena itu, kajian eksperimental pada balok beton bertulang skala penuh dengan variasi jumlah lapisan GFRP menjadi penting, khususnya dalam memahami pengaruhnya terhadap kekakuan, kapasitas lentur, daktilitas, serta fenomena *debonding*.

Penelitian ini dilakukan dengan uji lentur empat titik terhadap lima spesimen balok beton bertulang skala penuh, yang diperkuat dengan satu hingga empat lapis GFRP pada zona tarik terluar penampang. Pengujian menggunakan metode pembebanan monotonic dengan skema *loading-unloading* untuk menangkap perilaku elastoplastik serta efek pemulihan selama pelepasan beban. Selain uji lentur, dilakukan juga uji tarik GFRP berdasarkan ASTM D3039/D3039M (2014) dan uji tarik tulangan baja berdasarkan SNI 2052:2017, serta analisis teoritis kekuatan lentur menggunakan pendekatan analisis penampang fiber, dan perhitungan kapasitas geser berdasarkan ACI 318M-14. Parameter yang diamati meliputi kekakuan awal, kuat leleh, kuat *debonding*, kuat ultimit, dan daktilitas.

Hasil eksperimen menunjukkan bahwa penambahan GFRP secara signifikan meningkatkan kekakuan dan kuat lentur awal sebanding dengan jumlah lapisan, terutama sebelum terjadi *debonding*. Meskipun fenomena *debonding* menyebabkan penurunan sementara kapasitas momen lentur pada rasio perpindahan terhadap bentang dengan rentang 0,67%-0,93%, balok yang diperkuat dengan dua hingga empat lapis GFRP tetap menunjukkan peningkatan kuat lentur ultimit kedua dengan rentang 14,35% hingga 39,22%. Penambahan GFRP juga mampu mempertahankan daktilitas balok akibat adanya *catenary action* dari GFRP yang terlepas di zona sendi plastis yang tetap berkontribusi terhadap ketahanan beban. Dengan demikian, penggunaan GFRP sebagai perkuatan lentur memberikan peningkatan kekakuan dan kekuatan akhir sekaligus mempertahankan daktilitas, sehingga potensial diterapkan pada balok sekunder yang mengalami momen lentur positif.

Kata kunci: Balok beton bertulang sekunder, *Glass Fiber Reinforced Polymer*, Perkuatan lentur, Daktilitas, Skala penuh, *Debonding*.

ABSTRACT

Reinforced concrete structures designed under obsolete standards or adapted to new functional demands often require structural retrofitting to ensure adequate load-bearing performance and service longevity. A widely adopted solution is the application of Glass Fiber Reinforced Polymer (GFRP), favored for its low weight, high tensile strength, and corrosion resistance. However, prior research has largely focused on small-scale specimens. Thus, experimental evaluation of full-scale beams with varying GFRP layers is essential to assess their effects on stiffness, flexural capacity, ductility, and debonding behavior.

This study conducted four-point flexural testing on five full-scale reinforced concrete beam specimens, each strengthened with one to four layers of GFRP applied to the outermost tension face. A monotonic loading protocol with a loading–unloading sequence was used to capture both elastic–plastic behavior and recovery characteristics during unloading. In addition to flexural tests, tensile tests on GFRP were conducted in accordance with ASTM D3039/D3039M (2014), while steel reinforcement was tested following SNI 2052:2017. Theoretical flexural strength was evaluated using the fiber section analysis approach, and shear capacity was determined based on ACI 318M-14 provisions. Key parameters included initial stiffness, yield strength, debonding load, ultimate strength, and ductility.

Experimental results showed that the addition of GFRP significantly improved both stiffness and initial flexural capacity, with enhancements proportional to the number of layers applied—particularly prior to the onset of debonding. Although debonding caused a temporary reduction in flexural moment capacity within a displacement-to-span ratio range of 0.67%–0.93%, specimens strengthened with two to four GFRP layers still exhibited a secondary increase in ultimate flexural strength, ranging from 14.35% to 39.22%. Moreover, the presence of GFRP contributed to the retention of ductility through catenary action in the plastic hinge region, even after debonding had occurred. Overall, GFRP strengthening proved effective in enhancing both stiffness and ultimate strength while preserving ductile behavior, making it a viable solution for retrofitting secondary beams subjected to positive flexural moments.

Keywords: Secondary reinforced concrete beam, Glass fiber reinforced polymer, Flexural strengthening, Ductility, Full-scale, Debonding.