



Behaviour of Reinforced Concrete Beams Confined with Uniaxial Polyester Geogrids

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Received: 10 June 2025 / Accepted: 6 September 2025
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Abstract

This study explores the structural performance of reinforced concrete (RC) beams confined internally with uniaxial polyester geogrids as partial replacements for traditional stirrups. Nine RC beam specimens with varying stirrup spacings (150 mm, 200 mm, and 350 mm) and geogrid confinement layers (0, 1, and 2 layers) were subjected to four-point static bending. The double-layer geogrid-confined beams demonstrated a ductility factor enhancement of 374%, an increase in ultimate load of up to 36%, and an improvement in energy dissipation of more than five times when compared to control specimens. The confinement transformed failure modes from brittle shear to more desirable ductile flexural failure. Initial stiffness improved by up to 60% with geogrid confinement. An analytical shear model, incorporating a confinement reduction factor ($\psi=0.95$), accurately predicted ultimate load with an average error of 6.2%, validating the model's applicability. These findings highlight the potential of geogrids as a cost-effective solution for improving the shear behaviour and ductility of RC beams, particularly in small-scale applications.

Keywords Geogrid · Confinement · Ductility · Analytical model

List of Symbols

V_n	Nominal shear capacity of the RC beam	f_{ys}	Yield strength of steel stirrups (MPa)
V_c	Shear contribution from concrete	s_{sw}	Spacing of steel stirrups (mm)
V_s	Shear contribution from steel stirrups	A_{gw}	Cross-sectional area of geogrid reinforcement (mm ²)
V_g	Shear contribution from geogrid reinforcement	$\epsilon_{g,eff}$	Effective strain in geogrid reinforcement
ψ	Reduction factor for geogrid (taken as 0.95)	E_g	Young's modulus of geogrid (MPa)
b	Width of the RC beam cross-section (mm)	s_{gw}	Spacing of geogrid confinement layers (mm)
d	Effective depth of the RC beam (mm)	d_s	Effective depth of steel stirrups from compression fiber (mm)
f_{ck} / f'_c	Characteristic / cylinder compressive strength of concrete (MPa)	d_g	Effective depth of geogrid layer (mm)
A_{sw}	Cross-sectional area of steel stirrups (mm ²)	α	Angle of geogrid orientation to beam axis (°)
		n	Number of geogrid layers
		t_g	Thickness of the geogrid (mm)
		w_g	Effective width of the geogrid layer (mm)
		ϵ_{gu}	Ultimate tensile strain of the geogrid
		μ	Ductility factor ($\Delta f / \Delta y$)
		Δ_y	Yield deflection (mm)
		Δ_f	Ultimate deflection at failure (mm)
		P_y	Yield load (kN)
		P_u	Maximum load (kN)
		P_f	Failure load (kN)
		EDI	Energy Dissipation Index (area under load–deflection curve)

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Abbreviations

RC	Reinforced Concrete
OPC	Ordinary Portland Cement
UD	Unidirectional (Geogrid)
BD	Bidirectional (Geogrid)
MD	Machine Direction (in Geogrid)
CMD	Cross-Machine Direction (in Geogrid)
w/c	Water-to-Cement Ratio
LVDT	Linear Variable Differential Transformer
IS	Indian Standard
ACI	American Concrete Institute
ASCE	American Society of Civil Engineers
FRP	Fiber Reinforced Polymer
CFRP	Carbon Fiber Reinforced Polymer
BFRP	Basalt Fiber Reinforced Polymer
FEM	Finite Element Method

1 Introduction

Reinforced concrete (RC) beams are prone to shear failures under high service loads, particularly when transverse reinforcement is insufficient. While conventional stirrups are effective in enhancing shear performance, their use can be labor-intensive and often results in reinforcement congestion. This congestion complicates the placement and compaction of concrete, potentially leading to poor-quality concrete and voids in critical regions (Siva Chidambaram and Agarwal 2015). To overcome these challenges, researchers are exploring alternative confinement methods that improve shear strength and ductility under static loading.

Geogrids, a specific type of geosynthetic material, are widely used in geotechnical engineering for reinforcing soils in retaining walls, embankments, and foundations (Demir et al. 2014). They provide tensile strength and improve the deformation behaviour of soil, making them ideal for use in flexible structures. Geogrids are manufactured in various materials, including polyester, polypropylene, polymer, and polyethylene. Based on their rib orientation, geogrids are classified into two types: bi-directional (BD) and unidirectional (UD) geogrids (Siva Chidambaram and Agarwal 2015). BD geogrids have equal tensile strength in both the machine direction (MD) and cross-machine direction (CMD), while UD geogrids exhibit different strengths in these two directions. Geogrids, polymeric mesh-like materials commonly used in geotechnical applications, have recently been investigated for structural use due to their high tensile strength, corrosion resistance, and ease of integration into concrete (Shokr et al. 2024a, 2024b).

Recent studies have explored the potential of using geogrids as reinforcement in RC structures (El Meski and

Chehab 2014), particularly in regions where high shear strength is required. Research has shown that using geogrid reinforcement in RC beams can significantly improve their flexural strength. In some cases, geogrids have been used as a substitute for conventional transverse reinforcement in RC members, providing comparable or even superior performance in terms of shear strength and ductility.

Experimental investigations on the use of geosynthetics for strengthening both brick masonry (Khan and Nanda 2020) and RC structures have shown promising results. For example, geosynthetics, such as geotextiles and geogrids, have been tested for retrofitting applications. When applied to RC beams, geogrids have indicated superior performance in terms of confinement and crack control compared to traditional materials like wire mesh. Studies focusing on shear strengthening through the external bonding of geogrids have also shown that geogrid reinforcement leads to significant improvements in both the strength and stiffness of RC beams, as well as their overall shear capacity (Majumder and Saha 2020a).

In beam-column joints, where seismic forces are concentrated, external bonding of geosynthetic materials has been shown to enhance seismic performance by improving the ductility and energy dissipation capacity of the joint (Majumder and Saha 2020b). These findings highlight the potential of geosynthetics to be used in a wide range of structural applications, from retrofitting existing structures to improving the performance of newly constructed RC elements.

Compared to conventional strengthening systems such as CFRP sheets, steel plates, or wire meshes, geogrids offer distinct practical and economic advantages. Shi et al. (2024) noted that while advanced fiber reinforced polymer (FRP) systems like BFRP with carbon nanotube-modified epoxy can enhance flexural performance, their application requires careful surface preparation, controlled curing conditions, and high material costs. Maglad et al. (2023) demonstrated that embedding steel fibers in recycled aggregate concrete significantly enhanced fracture toughness, ductility, and post-cracking energy absorption. Their findings highlighted the effectiveness of internal reinforcement in improving structural performance and reducing brittle failure, particularly through mechanisms that restrain crack propagation and enhance load redistribution. Similarly, Baggio et al. (2014) observed that FRP-strengthened RC beams can be effective in shear but are often limited by debonding failure and the need for skilled labor during installation. In contrast, geogrids, particularly when internally integrated, are lightweight, corrosion-resistant, and easy to install during casting without specialized adhesives or anchorage. Their high chemical durability and low embodied energy also make

geogrids are lightweight, non-corrosive, and easier to handle on-site, reducing labor effort and placement time. Their resistance to corrosion provides a durability advantage in aggressive environments, potentially lowering long-term maintenance costs. While a direct cost analysis was not part of this study, qualitative comparison indicates that geogrids offer a sustainable and cost-effective alternative to steel stirrups, particularly in small- to medium-scale construction where ease of placement and reduced steel congestion are significant considerations.

5 Conclusion

An experimental study was conducted to investigate the performance of RC beams internally confined with geogrids as a supplementary shear reinforcement strategy. Under static four-point bending, geogrid-confined beams exhibited significantly improved structural behaviour compared to unconfined control specimens. Beams with double-layer geogrid confinement demonstrated marked enhancements in ultimate load capacity (up to 36%), ductility (up to 374%), and energy dissipation (over fivefold), along with a clear transition from brittle shear failure to more ductile flexural cracking patterns. These improvements were especially prominent in specimens with reduced stirrup spacing, where the contribution of the geogrid became more pronounced. The geogrid loops effectively restrained diagonal shear cracks, delayed their propagation, and improved post-peak load resistance. Additionally, the initial stiffness of geogrid-confined beams increased by up to 60%, and crack widths at failure were significantly reduced.

Experimental results were compared with analytical predictions of ultimate load and failure mode. The proposed analytical model closely aligned with the experimental outcomes, with an average deviation of only 6.2%, validating its applicability for predicting shear-enhanced performance.

This study was conducted on small-scale RC beams with a span of 1200 mm under static loading conditions. Although geogrid confinement yielded improvements in strength, ductility, and energy absorption, the findings are limited to lab-scale conditions with controlled reinforcement detailing. The effectiveness of this technique in practical applications involving longer spans, seismic or dynamic loads, and complex reinforcement layouts remains to be confirmed.

A preliminary cost comparison suggests that polymer-based geogrids may reduce overall reinforcement costs by 15–20%, primarily by minimizing labor associated with stirrup bending and placement. However, this potential economic benefit must be further validated under real-world site conditions. Future research should include full-scale testing

of geogrid-confined RC members under cyclic and seismic loading to assess their practical feasibility. Additional studies are needed to examine the influence of geogrid tensile strength, anchorage methods, and confinement spacing on structural behaviour. Investigations into long-term durability under environmental exposures such as wetting–drying, freeze–thaw cycles, and chemical attack are also essential. Furthermore, bond behaviour studies will be critical for understanding stress transfer mechanisms and anchorage requirements. These efforts will support the broader adoption of geogrid-based confinement as a sustainable, efficient reinforcement strategy in RC construction.

Author Contributions V. Selvapriya: Conceptualization, Methodology, Experimental Investigation, Data Analysis, Writing—Original Draft Preparation, Supervision, Project Administration. K. Ramadevi: Validation, Formal Analysis, Writing—Review & Editing, Resources, Visualization. N. Divyah: Experimental Setup Assistance, Data Curation, Literature Review, Writing—Initial Draft Assistance.

Data Availability No datasets were generated or analysed during the current study.

Declarations

Conflict of interest The authors declare no competing interests.

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