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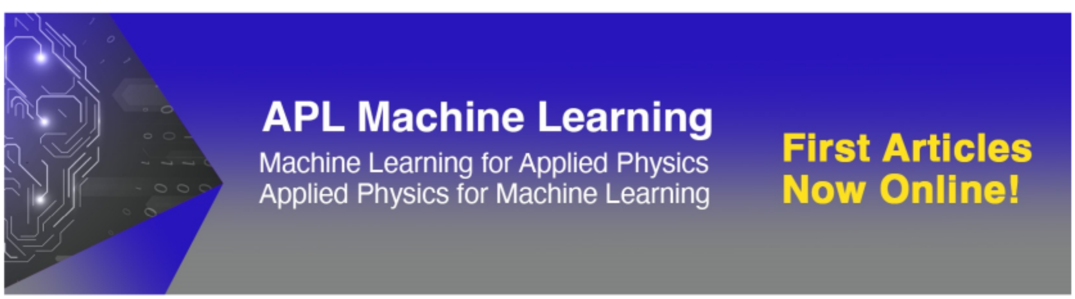

A Novel Proposed Method for Strengthening RC Beams Using FRP String and Geopolymer

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Abstract. The increasing environmental and economic concerns have instigated the demand for more sustainable construction materials. Civil structures are usually designed with particular service life, but then, unnecessary damages have been reported on reinforced concrete (RC) buildings prior to expiration. Therefore, a major maintenance objective to complement construction efforts tends to be achieved by strengthening. Research on RC beams retrofitted with Fiber Reinforced Polymer (FRP) strings has been applied for flexural strengthening, while little is known for shear strengthening, where the need to experiment on RC beams with FRP strings appears very imperative. Furthermore, confinements utilization from carbon fiber materials with higher tensile strength compared to steel reinforcement, allows for greater increase in concrete restraint. Also, the combination with geopolymer utilization indirectly tend to reduce environmental pollution. This is due to the ability to diminish CO2 gas emissions from cement industries, and subsequently, employs factory waste in the form of fly ash.

INTRODUCTION

The construction sector commonly take into consideration the intended service life in the design of structures. However, reinforced concrete (RC) buildings often experience damages prior to expiration. This tends to initiate degradation or decline in structural efficiency, as technical requirements, including strength, stiffness, stability, ductility, and durability are barely observed. The occurrences are probably due to design or construction errors, modifications in building functions to incur additional loads or impact, and varying conditions to match new regulations or adjust to scientific developments.

The use of Fiber Reinforced Polymer (FRP) provides a significant alternative towards the strengthening of RC elements. This material is generated from fiber synthetic sources, including glass, aramid, and carbon joined by a matrix substance, e.g. epoxy or polyester, and offers high tensile strength, light weight, corrosion resistance, inability to conduct electricity, easier installation, and excellent durability [1]. FRPs are distinguished by three categories, termed Glass Fiber Reinforced Polymer (GFRP), Aramid Fiber Reinforced Polymer (AFRP), and Carbon Fiber Reinforced Polymer (CFRP). Based on shape or size, the materials are potentially sheets, rods, strips, strings, and grids. Also, the functions in RC structural elements strengthening are similar to flexural or shear strengthening. Therefore, the rods, strips, and strings are widely employed in flexural strengthening, while the sheet forms are for shear strengthening.

Previous studies on shear strengthening of RC beams with FRP have been extensively reported. The most applied is the wrap type, using the EBR approach, as the setup is on both sides of the beam (side-bonded), on three sides (U-

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Wrap), and on the entire corners [2-4]. In addition, the installation is achieved by forming a specific angle to the horizontal axis based on the previous studies conducted previously [5-6], while another works combined U-Wrap with anchors [7, 8]. Research on shear strengthening of RC beams using FRP strips have been performed, by setting up U-strips combined with the use of anchors [9]. Based on an earlier investigation [2], the installation with side-bonded and U-Wraps showed majority of the failures occurred due to de-bonding, while for continuous (complete wrap), the FRPs were responsible.

The study on the strengthening of RC beams with FRP string has only been utilized for flexural strengthening, but not yet for shear strengthening. Therefore, there is need to propose this procedure for shear strengthening. FRP strings are applied by embedding using the Near Surface Mounted (NSM) method for all three sides of the specimens, while on the lower portion, geopolymer concretes were introduced. This allows for greater increase in concrete restraint. Furthermore, indirect utilization of geopolymer tends to also reduce environmental pollution, due to the ability to diminish CO2 gas emissions from cement industries, as well as utilize factory waste in the form of fly ash. Little has been employed for structural element designs and applications, despite the huge potentials of geopolymer materials [10]. Figure 1 shows a schematic diagram of the related research along with the proposed work.

Researcher(s)	Year	Specimen Geomerty		FRP Material			FRP Geometry				Strengthening Method							Installation Tecgnique						Type of Study	
		Rectangular Beam	T-Beam	Carbon	Glass	Basalt	Wrap	Grid	String	Strip	Side-bonded	U-wrap	Continuous	U Wrap + Anchorage	angle to longitudinal	CFRP-Matrix Geopolimer	BFRP-ECC composite	NSM	EBR	EBRIG	EBR - Bolts	Embeded	Anchorage technique	Experimental	Numerical
Sinan Altin	2010		■	■						■		■			■				■					■	
Abdeldjelil Belarbia	2013	■	■	■			■				■	■	■						■						■
Daniel Baggio	2014			■	■		■					■		■					■					■	
Weiwen Li,	2016	■		■						■		■							■					■	
G.M. Chen, Z. Zhang, Y.L. Li, X.Q. Li, C.Y.	2016		■			■				■		■							■				■	■	
Nino Spinella	2019		■	■			■					■							■						■
Amir Shomali	2020	■		■			■				■				■					■				■	■
Yingwu Zhou,	2020	■		■			■				■	■	■						■						■
Yu-Zhou Zheng	2020	■				■		■			■						■				■			■	■
Ali Saribiyik	2020	■				■	■				■	■	■		■				■		■			■	
Xu Yang	2020	■		■		■		■			■						■		■					■	
Ahmed Godat, Farah Hammad, Omar Chaallal	2020		■	■			■				■	■	■										■		■
E. Moradi, H. Naderpour	2020	■		■			■				■	■	■									■		■	
Sudibyo	2020	■		■					■				■			■		■						■	

FIGURE 1. Schematic diagram of the related research and proposed work

EXPERIMENTAL PROGRAM

Material Mechanical Properties Testing

This examination is critical in determining the mechanical properties of potential materials to apply in this study, including normal and geopolymer concretes, steel reinforcements, and FRP strings. Steel reinforcements, both main and stirrups, undergo tensile test, using Universal Testing Machine (UTM), as shown in Figure 2, according to the referred standard. This process is expected to obtain relevant data on yield strength (f_y), yield strain (ε_y), ultimate strength (f_u), and ultimate strain (ε_u). The quality of steel reinforcement is required to fulfill the criteria for reinforced concretes based on the code.

In normal concrete planning, a job mix design is initially performed in order to ascertain quality. The objective is to determine the composition of the constituent mixture, comprised of sand, split, and cement. Furthermore, the entire samples were obtained locally, based on stated requirements. Also, resources for the geopolymer blend were also analyzed for material properties.

FIGURE 2. Universal Testing Machine

Beam Design

Based on Kani's Valley [11], ultimate bending moment (M_u) and failure modes depended on the ratio of the shear span and the effective depth of the beam (a/d), as shown in Figure 3. The decline in reinforcement ratio (ρ) tends to enhance relative ultimate bending capacity (M_u/M_f), and also either decreases or increases the a/d ratio, marking the transition points for separate beam types. These beams are further divided into four groups, termed:

1. Type I (Long Beams), attained the maximum bending capacity ($M_u = M_f$), but failed in bending. A long beam with $a/d > 6.0$ and ρ value of 1.8% indicated a shear capacity higher than the maximum bending capacity.
2. Type II (Normal Beams of Intermediate Length), is unable to obtain maximum bending capacity (M_f). This parameter is equal to the diagonal cracking capacity. Under normal condition where $2.5 < a/d \leq 6$ and a ρ value of 1.8%, the ratio (M_u/M_f) decreases as the ratio a/d reduces to the minimum value, dependent on ρ. This occurred as the lowest point in Kani's Valley.
3. Type III (Short Beams), does not achieve the maximum bending capacity. A short beam with $1 < a/d \leq 2.5$ and a ρ value of 1.8% exhibited a higher ultimate shear capacity compared to cracking. The M_u/M_f ratio increased as a/d ratio decreases, until $M_u = M_f$ is attained.
4. Type IV (Deep Beams), is a beam with $a/d \leq 1$ and a ρ value of 1.8% with higher shear.

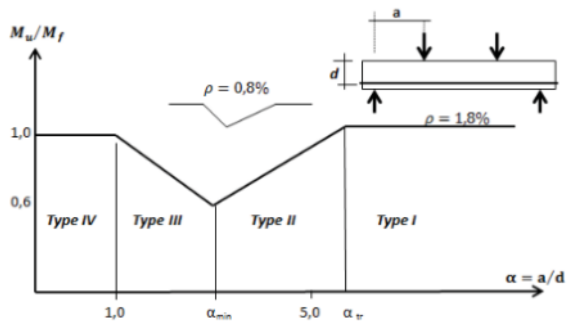
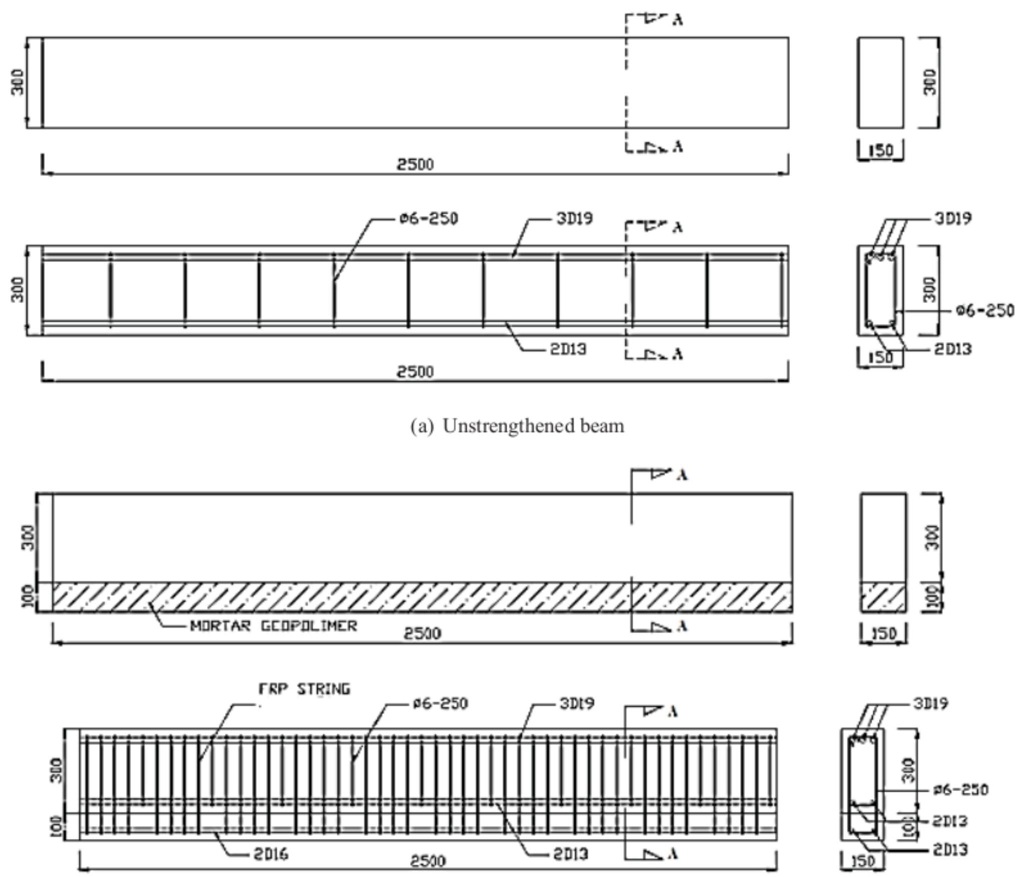


FIGURE 3. Classification of beams according to Kani's Valley

The beam specimens were designed with a size of 150 x 300 mm and a span length of 2.50 m. Figure 4 represents the cross-section, while Figure 5 displayed the illustration for the installation of strengthening systems. Table 1 shows the specimen variation.



(a) Unstrengthened beam

(b) Strengthened beam

FIGURE 4. Beams design

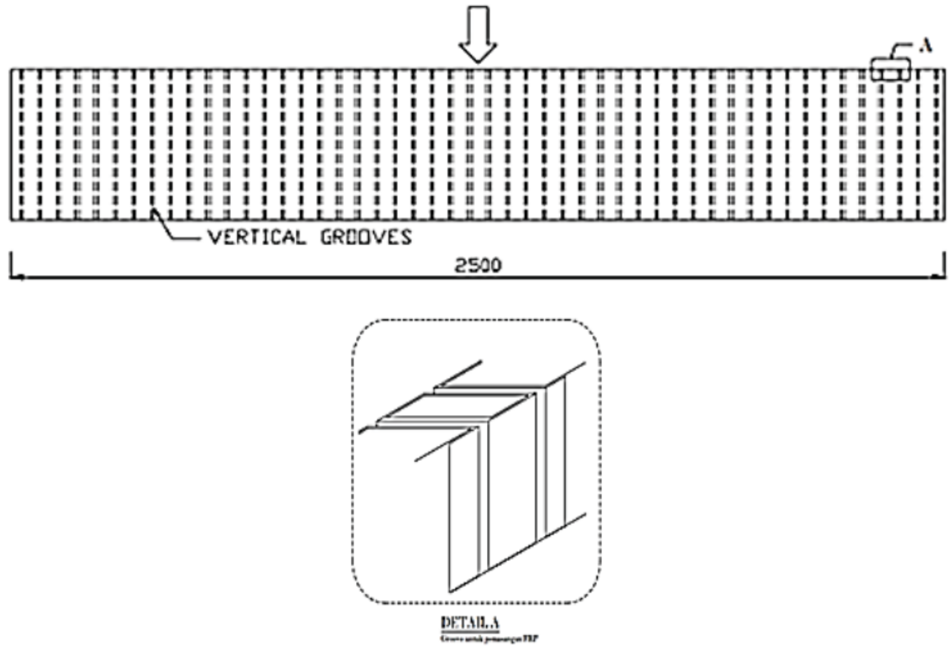


FIGURE 5. Strengthening systems

TABLE 1. Specimen variation

No	Specimen	Treatment	Sample
1	Type 1	Reinforcement Beams of FRP Strings and Geopolymer Concrete Stirrups	3
2	Type 2	Reinforcement Beams of Reinforcing Steel and Geopolymer Concrete Stirrups	3

Data Collecting

Complete instrumentation was used to capture data for each assessment, including concrete and steel reinforcement's strain at various locations and deflections along the specimen, as well as the magnitude of applied force. The strain gauge was installed prior to casting, in order to measure the strain response under loading conditions. Also, the device was attached to the compressed side of the beam, using a special strain gauge adhesive glue. Linear Variables Displacement Transducers (LVDTs) were also mounted on the upper and lower sections in a longitudinal direction.

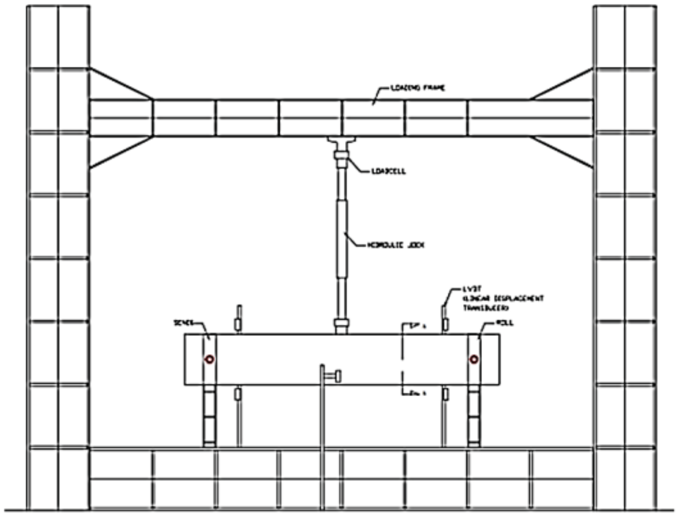


FIGURE 6. Experimental setup

This set up, with maximum gauge length of 100 mm, was intended to evaluate the horizontal beam displacement, subsequently used to determine the curvature. Vertical displacement obtained a gauge length value of 300 mm, above the horizontal. Furthermore, LVDT was also positioned in close proximity to the support to ascertain the relative rotation angle, due to applied load. Entire attachments to the specimen were actualized, using a magnetic base placed on the LVDT loading frame above 3 (three) pieces per assessment. The data from the instrument measurement include load cell and actuator recordings, LVDT deformations, and strain gauge reading attached to reinforcing steel and concrete. Figure 6 represents the setup during testing process, as the data were logged. The results provided significant insight for calculating other deformation equations, termed drift ratio, curvature, moment, or specimen rotation. Based on this data, the relationship curves between variables are processed and described in terms of force-displacement and moment-curvature.

CONCLUSIONS

This paper proposed a modern method of reinforced concrete beam strengthening, using FRP strings. In addition, near surface mounted (NSM) technique was applied on all three sides, with the bottom side was combined by the use of geopolymer concretes. Therefore, the method allowed for greater increase in concrete restraint. The application of geopolymer tends to indirectly reduce environmental pollution, due to the ability to decline CO2 gas emissions from cement industries and also utilizes factory waste in the form of fly ash. Finally, the complete results will be reported in the future work.

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