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Behavior of eccentrically loaded high strength concrete columns jacketed with FRP laminates

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HIGHLIGHTS

- FRP strengthened eccentric HSC columns exhibited enhanced strength and ductility.
- FRP strengthening reduced the brittleness of failure of HSC eccentric columns.
- Partial and full wrapping enhanced strength by 12.5%–23%.
- Tension-side FRP plus transverse partial ones enhanced flexural capacity by 60%.
- Excessive tension-side strengthening coverts ductile failure mode into brittle one.

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ABSTRACT

This study is an experimental investigation into the performance of high strength concrete columns subjected to uniaxial eccentricity and strengthened by glass fiber reinforced polymer fabrics (FRP). The study aims to evaluate the potential enhancement in the structural performance of seven 200 × 200 × 1050 mm columns subjected to single eccentricity strengthened by external FRP fabrics, and to investigate the effect of arrangement and amount of FRP laminates to achieve optimal enhancement. The test parameters considered are the number and arrangement of fabric layers and the value of load eccentricity. The laminates are applied in single or double layers; in partial or full wrapping in small eccentricity loading. Longitudinal laminates are provided along tension side of specimens under large eccentricity loading then overlaid by transverse FRP wraps applied partially in single layer. In the present work, test results of seven large-scale concrete columns are presented and discussed. The study has experimentally proven the efficiency of FRP laminates in enhancing the strength of uniaxially loaded HSC columns through increasing flexural capacity (by up to 23% and 59% for small and large eccentricity loaded specimens, respectively). The ductility capacity of small eccentricity loaded columns was not objectively assessed due to early termination of small eccentricity tests for safety concerns; however, a significant ductility enhancement was achieved in large eccentricity specimens strengthened by fiber reinforced polymers.

1. Introduction

High strength concrete columns (with cube compressive strength between 59 MPa and 120 MPa) subjected to uniaxial eccentricity are common elements in many structures. The advances in earthquake engineering along with structural usage changes urge upgrading of some of the existing HSC elements constructed starting the 1980s. Upgrading HSC columns is required to enhance column load carrying capacity and/or ductility. Many researchers have investigated these two basic aspects either for axially loaded columns or using traditional strengthening techniques. Examples for these investigations are: Ghoneim [1], Khalil [2] which investigated strengthening high strength axially loaded columns, El-Afandy [3] which studied strengthening axially loaded rectangular columns, Hosotani, et al. [11] and Demers [4]. Few investigations have been conducted to study the behavior of normal strength concrete (NSC) columns upgraded using FRP laminates under uniaxial loading such as Nanni et al., [16], Parvin and Wang [17], Bencardino [5], Challal and Shahawy [6] and more recently El-Maaddawy [18] which investigated the performance of strengthened columns under single eccentricity. Fam et al. [14,15]

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Table 1
Concrete mix design.

Mix Constituents	Cement	Silica Fume	Crushed Dolomite	Sand	Water	Super Plasticizer
kg/m^3	475	47.50	1224	612	146.3	18.3

studied the behavior of concrete filled FRP tube under eccentric loading while Hady [19] investigated the subject for NSC circular plain concrete columns. However, no information is available on the behavior of non-circular HSC eccentrically loaded columns that are strengthened with FRP. The present work is attempting to fill this research gap.

2. Scope and objectives

The research work reported in this paper has been conducted to achieve the following objectives: evaluating the improvement in the structural performance of HSC short columns subjected to uniaxial eccentricity when strengthened by externally applied GFRP laminates, and investigating the optimum arrangement and amount of GFRP laminates to achieve potential enhancement in structural performance. The prime interests of the authors were the enhancement of the strength and ductility of the strengthened columns. An extensive experimental program has been conducted to achieve the target objectives. The experimental program consists of testing seven full scale high-strength concrete short columns strengthened by FRP laminates under the effect of axial load accompanied with small and large eccentricity uniaxial bending moments. The key variables were: number of layers of transverse FRP wraps, the arrangement of FRP wraps (partial or full wrapping), eccentricity condition (small vs. large eccentricity), and the number of layers of longitudinal tension side FRP laminates. The present work supplements (with single eccentricity tests) an investigation, carried out by Hassan [7], Hassan, et al. [12] and Hodhod, et al. [13], that covered the mechanical behavior of square RC columns strengthened with FRP under the effect of biaxial (double-eccentricity) bending moments.

3. Experimental program

3.1. Materials

Local concrete constituent materials have been used to manufacture the test specimens including type (I) cement. The proposed mix was designed to develop characteristic cube strength of 80 MPa. Silica fume was added to cement with a ratio of 10% in accordance with the recommendations of Canadian Code CAN/CSA to avoid long-term negative effects [8]. Mix proportions are given in Table 1. The specimens' main reinforcement is high strength deformed steel bars (Grade 400) while the steel hoops are mild smooth bars (Grade 240).

Wrapping material is "SIKA Wrap Hex-430G (VP)" which is E-Glass fabric of 0.17 mm fiber thickness and 2.25 GPa fiber tensile strength. Fiber tensile modulus of elasticity is 70 GPa. Sikadur-330 adhesive was used to bond external FRP laminates to concrete surface. The flexural modulus, tensile strength, and adhesion strength

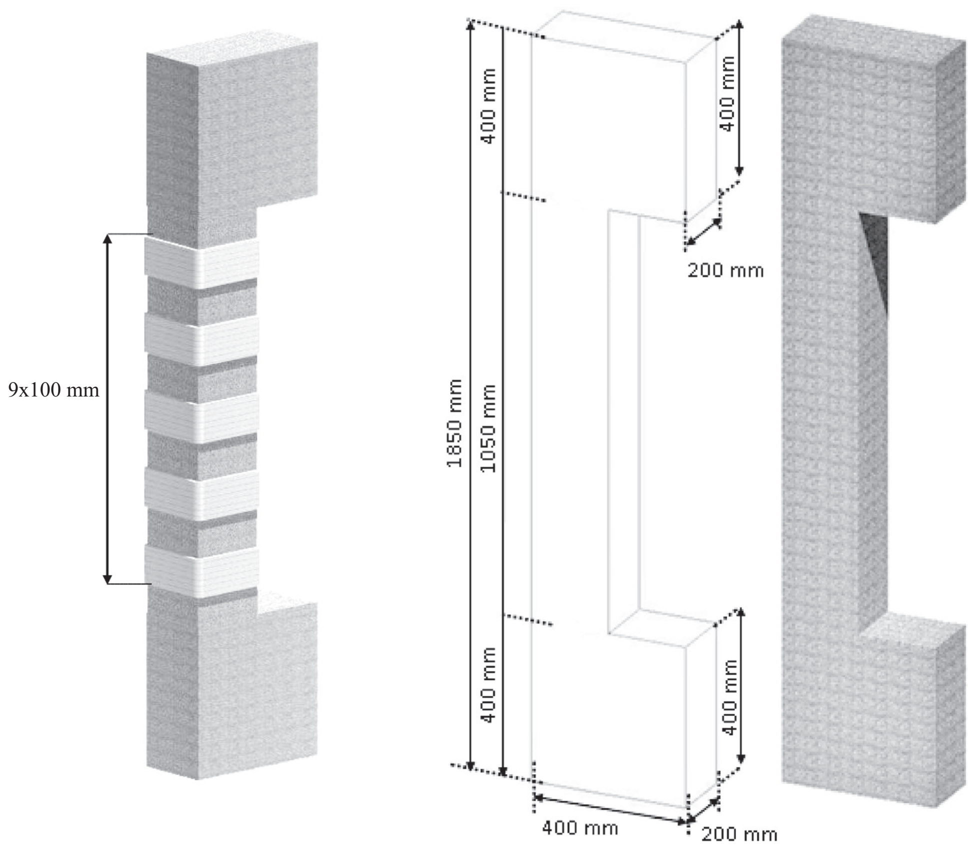

Fig. 1a. Test specimens dimensions.