IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 20, Issue 5 Ser. III (Sept. – Oct. 2023), PP 19-38
www.iosrjournals.org

Enhanced Performance Of Isolated Footing Reinforced By Fiber Bars

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Abstract
*There is a growing concern with worldwide deterioration of traditional materials such asconcrete and steel. Recently, attention has shifted to use fiber reinforced polymer composites (FRPs) as alternative materials. FRP materials used in many structural engineering applications, especially in the reinforcement and strengthening of various structural elements in concrete buildings and in view of the many advantages of these materials, such as, high tensile strength, high strength and modulus values compared totheir density, low weight, thermal expansion, Non-corrosive nature material so they can be usedto replace steel and reinforced concrete in situations when they would be exposed to corrosion and ease for installation and excellent formability enable the fabrication of new elements and the structural rehabilitation of the existing parts made of traditional material. In this paper will be used two types of FRP (GFRP and CFRP) as an alternative to steel in reinforcingisolated footing, so twenty specimens of isolated footing (30.5*30.5*7.5) cm were tested under increasing load until failure .one of these specimens was reinforced with steel only and considered as a control specimen. The experimental results showed an improvement in the flexural behavior of the reinforced specimens compared to control specimen.*
The present study aims to assess the proposedtechnique under the effect of different variables for isolated footing reinforced by FRP (CFRP,GFRP) and compare it with isolated footing reinforced by steel. Moreover, a finite element models were developed by ABAQUS to simulate all the tested specimens.
Keywords: *Glass; Carbon; fiber reinforced polymer; Finite element analysis.*

Date of Submission: 16-10-2023 Date of Acceptance: 26-10-2023

I. Introduction

Steel was used as traditional material to reinforce concrete structures for a long time, but now the Fiber reinforced polymer composites (FRPs) offered an economical alternative in situations where steel is expansive reinforcement. Such FRPcan be used in a wide variety of end-useapplications. Carbon and glass fibers, which are so close to plastics in nature that you, might not believe that they could alternative to steel in construction.

The main reason for the delayed use of composite materials in many structural engineering applications has been its high cost, but in recent years the cost has decreased and newly developed composite materials are now being used extensively as never before.

In recent years, several studies have delved into various aspects of reinforced concrete structures. One such study conducted in 2023 by researchers El-Sayed A. El-Kasaby, Mahmoud Awwad, and et.al [1], explored the impact of biaxial geogrids on the flexural behavior of square footing foundations reinforced with glass fiber reinforced concrete (GFRC). Through experiments on five reinforced concrete square footings, they subjected them to area loading until failure, providing valuable insights.

Another noteworthy study led by El-Sayed A. El-Kasaby, Mahmoud Awwad, and et.al [2] presented the findings from eleven lateral pile loading tests. These tests were conducted on concrete piles reinforced with various materials, including FRP bars, geosynthetics geogrids, and composite materials. The objective of this study was to evaluate the effectiveness of these reinforcement methods in withstanding lateral loads.

HS Hadad, MT Nooman, and KA Saleh carried out a study [3],that focused on comparing the use of glass fiber reinforced polymer (GFRP) bars with traditional steel reinforcement in isolated

Furthermore, Elsayed El Kasaby and Mohammed F. Abd-Elmagied's study [4], investigated the performance of isolated footings reinforced with different ratios of glass fiber reinforcement. Through experiments conducted on both square and rectangular footings, they enhanced our understanding of the structural behavior influenced by glass fiber reinforcement. And other studies [5], have covered important topics within this field, including isolated footings reinforced with glass fiber, the utilization of GFRP bars for residential building foundation slabs, and the enhancement of foundation slab durability through strain monitoring and alternative reinforcement options. These studies collectively contribute to the ongoing advancements in understanding and improving reinforced concrete structures.

There are other researches [6] to [11] that have studied the effects of the use of fiber bars reinforcement rather than steel in other concrete elements, such as beams, slabs and columns.

All of those researches shown that, the using of FRP gave the best result than steel which made it the best choice to replace steel in many structural engineering applications especially in the reinforcement and strengthening.

II. Materials and Methods

In this study twenty specimens of isolated footing were used with square shape. FRPs CFRP &GFRP were employed instead of steel bars with a percentage of 100, 125, 150, 175, and 200% of area steel, Table (1). One of these specimens was reinforced with steel only with a percentage of 100%of area steel and considered as a control specimen.

Table (1) details of tested specimens

Type of reinforcement	Dim.	No. of bars
Steel Bars (Control specimen)	Ø 8mm	S-4b
Carbon Bars	Ø 8mm	C-4b
Carbon Bars	Ø 8mm	C-5b
Carbon Bars	Ø 8mm	C-6b
Carbon Bars	Ø 8mm	C-7b
Carbon Bars	Ø 8mm	C-8b
Glass Bars	Ø 8mm	G-4b
Glass Bars	Ø 8mm	G-5b
Glass Bars	Ø 8mm	G-6b
Glass Bars	Ø 8mm	G-7b
Glass Bars	Ø 8mm	G-8b
Carbon + Glass Bars	Ø 8mm	C-1b +G-3b
Carbon + Glass Bars	Ø 8mm	C-2b +G-2b
Carbon + Glass Bars	Ø 8mm	C-3b +G-1b
Steel + Carbon Bars	Ø 8mm	S-1b+ C-3b
Steel + Carbon Bars	Ø 8mm	S-2b+ C-2b
Steel + Carbon Bars	Ø 8mm	S-3b + C-1b
Steel + Glass Bars	Ø 8mm	S-1b + G-3b
Steel + Glass Bars	Ø 8mm	S-2b + G-2b
Steel + Glass Bars	Ø 8mm	S-3b + G-1b

Steel

In this study, mild steel bars diameter of 8 mm were used.

Fiber Bars (CFRPs &GFRPs)

CFRPs &GFRP bars are locally fabricated by use pultrusion process, in which braided strands are impregnated with polyester, then a separate preforming system and pulled through a heated stationary die where the polyester undergoes polymerization. The Mechanical properties of FRP bars (CFRP &GFRP) are given in Table (2), Fig. (1), (2)

Cement

Ordinary Portland cement has been used in all experimental work. The cement was a uniform color and free from any hard lumps.

Aggregates

The used fine and coarse aggregates were used form the availability local.

Water

Normal and clean water free from impurities (organic matter, silt, oil, sugar) was utilized to mix and cast the tested specimens.

Strain gauges

The applied strain gauges were branded as Tokyo Sokki Kenkyujo Co, Ltd, were used to estimate the strain in the tested specimens under different loads.

Fig (1) Fiber glass bars (GFRPs)

Fig (2) Fiber carbon bars (CFRPs)

Table (2) Dimensional and mechanical properties of FRP bars

Property	GFRP bars	CFRP bars
Diameter of barsArea of bars Fiber ratio by area Tensile strength of fibers Modulus of elasticity of fibers Strain at failure	8 mm 50 mm2 30% 13700 kg/cm^2 900000 kg/cm^2 15000 x 10^{-6}	8 mm 50 mm2 26% 14000 kg/cm^2 2100000 kg/cm^2 6600 x 10^{-6}

Table (3) Strain gauges characteristics

Type	PL-60-11-1L JC-F
Gauge Length	60 mm
Gauge Factor	2.12 ± 1%
Gauge Resistance	120 ±0.5Ω
Transverse Sensitivity	0.1%

Concrete footing specimens

Specimens of square footings of (30.5 x 30.5 x 7.5) cm were considered. One specimen reinforced by mild steel without using any fiber, Fig.(3) as a control specimen. The other specimens divided into groups reinforced by fiber glass, carbon and mix between fiber and steel bars with different percentage of number of bars. Fig from (4) to (8).Before placing concrete, the specimen moulds were painted with a layer of oil before casting and checked for dimensional accuracy and well cleaned. After casting concrete in the mould, the concrete was vibrated and the excess concrete at the top of the moulds was struck with a straight and the top surface was finished then after 24 hr, the specimens were submerged in water, Fig (9) After 28 days the specimens were tested under increasing load until failure. Strain gauge was connected to data acquisition system.

Fig (3) Control specimen

Fig (4) Carbon bars

Fig 5) Glass bars

Fig (6) Carbon & Glass bars

Fig (7) Carbon& Steel bars

Fig (8) Glass &Steel bars

Fig (9) Top surface of the specimens

Test procedures

The concrete footing was placed in center of container with a dimension of (1.50 x 1.50 x1.50) m and filled by compacted course aggregates soil ensuring horizontal alignment for uniform stress distribution, and a hydraulic jack of steel frame used to apply the load, Fig. (10), the strain gauges were installed in all specimens to collect readings were recorded and saved in an excel sheet on computer. The load was applied in regular interval by a hydraulic jackof 100 ton capacity and increases the load until failure, Fig. (11, 12). Failure load and strain were recorded simultaneously.

Fig (10) Steel Container and loading frame

Fig (11) Loading specimens

III. Results and discussion

Strain-Load Relationship

The results of all reinforced footings are depicted in Figs from (13) to (18). Fig. (19) shows failure load at all specimens.

For Reference group, the control specimen was reinforced by only steel bars 4Ø8 and compared its results with other groups' results Fig. (13).

Fig. (12) Failure of some tested specimens

1. First group, five specimens reinforced bycarbon fiber bars (4, 5, 6, 7 and 8 bars) were compared with the control specimen, and it was shown that compared at failure load, an increase in maximum load was achieved in the carbon specimens 10.7%, 22.7 %, 35.4%,48.9% and 56.4%, respectively of that recorded for the control specimen, Fig. (14).
2. Second group, five specimens reinforced byglass fiber bars (4, 5, 6, 7 and 8 bars) was compared with the control specimen, and it was shown that compared at failure load, an increase in maximum load was achieved in the carbon specimens 5.4%, 9.5 %, 11.3%,18.5% and 30.4%, respectively of that recorded for the control specimen ,Fig. (15).
3. In third group, three specimens were reinforced with mixture of carbon and glass fiber bars (C-1b +G-3b, C-2b +G-2b, C-3b+G-1b), and it was shown that, with an increase in carbon bars and decrease in glass bars in the specimens, there was an increase inmaximum load values 8.7%, 11.1% and25.6% compared to the control specimen, Fig. (16).
4. In fourth group, three specimens were reinforced with mixture of steel and carbon fiber bars (S-1b +C-3b, S-2b +C-2b, S-3b +C-1b), and it was shown that, with an increase incarbon bars and decrease in steel bars in the specimens, there was an increase in maximumload values 24.03%, 8.46% and 4.28% compared to the control specimen ,Fig. (17).
5. In fifth group, three specimens were reinforced with mixture of steel and glass fiber bars (S-1b +G-3b, S-2b +G-2b, S-3b +G-1b), and it was shown that, with an increase inglass bars and decrease in steel bars in the specimens, there was an increase in maximumload values 8.7%, 3.1% and 1.4% compared to the control specimen, Fig. (18).
6. The failure mechanism of concrete footings under the moment effect involves the development of cracks in the tension zone of the footing due to the applied bending moment. These cracks start to widen and propagate from the bottom surface of the concrete to the top surface. As the moment increases, the cracks can extend further and eventually lead to the failure of the footing, Fig. (12).

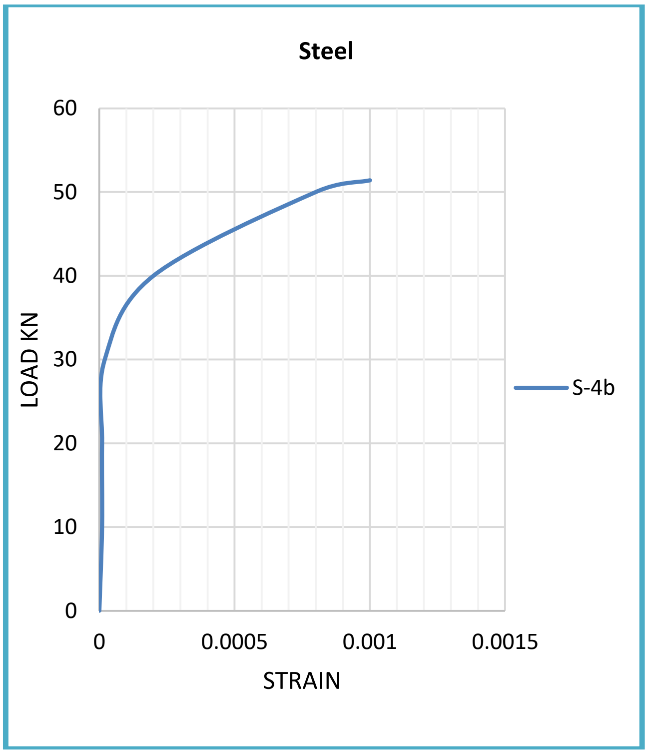

Fig. (13). the control specimen

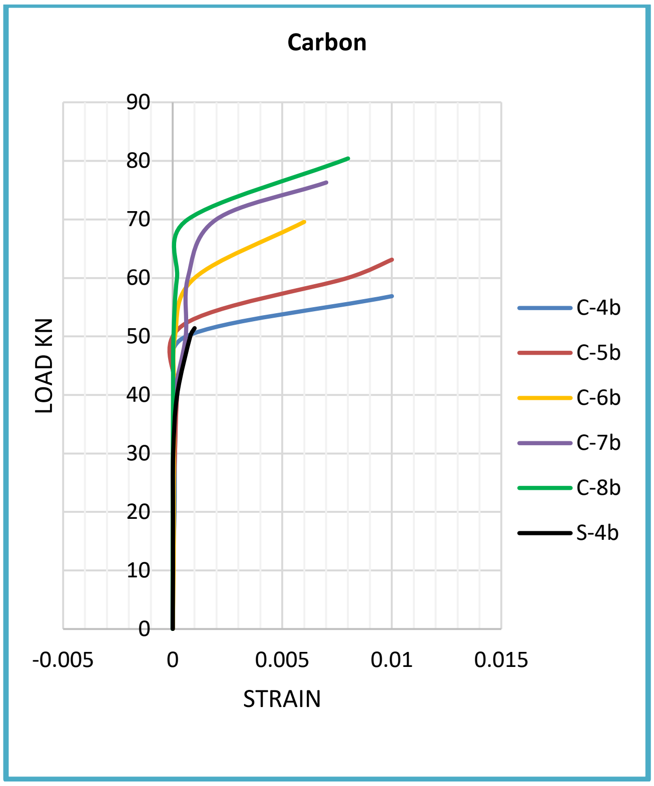

Fig. (14). Comparison between load of steel and load of carbon groups

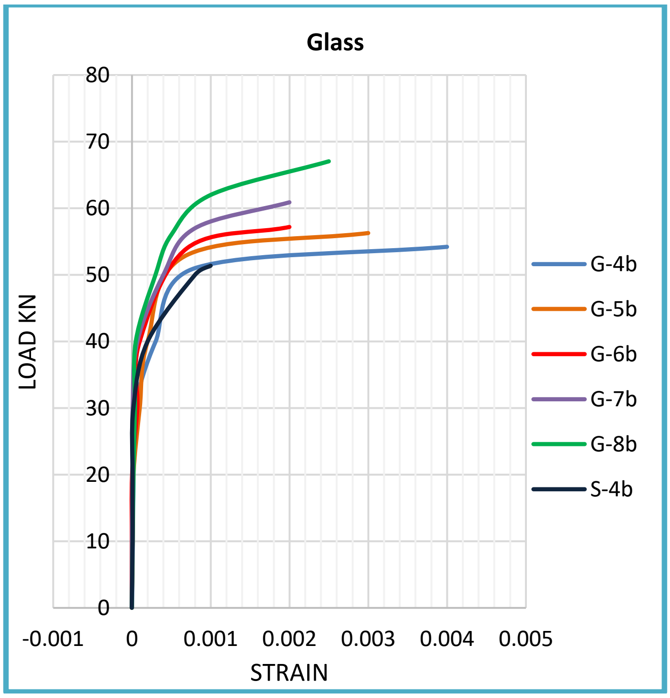

Fig. (15). Comparison between load of steel and load of glass groups

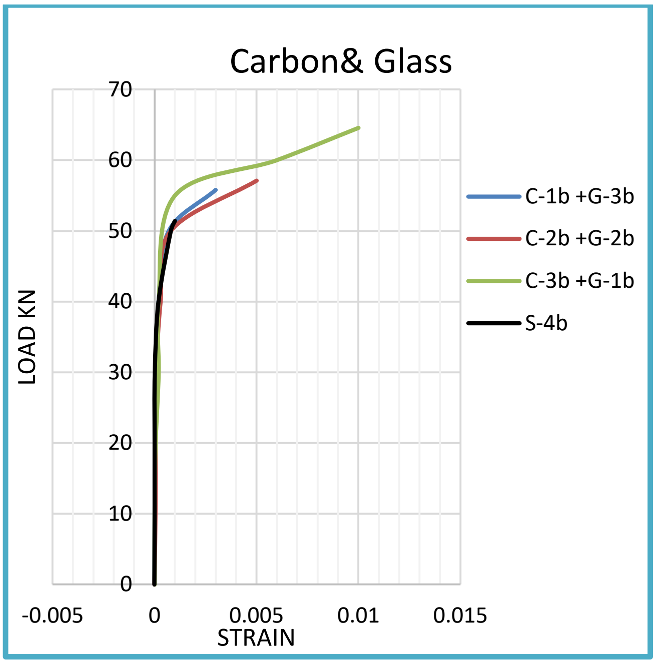

Fig. (16). Comparison between load of steel and load of mixture of carbon &glass

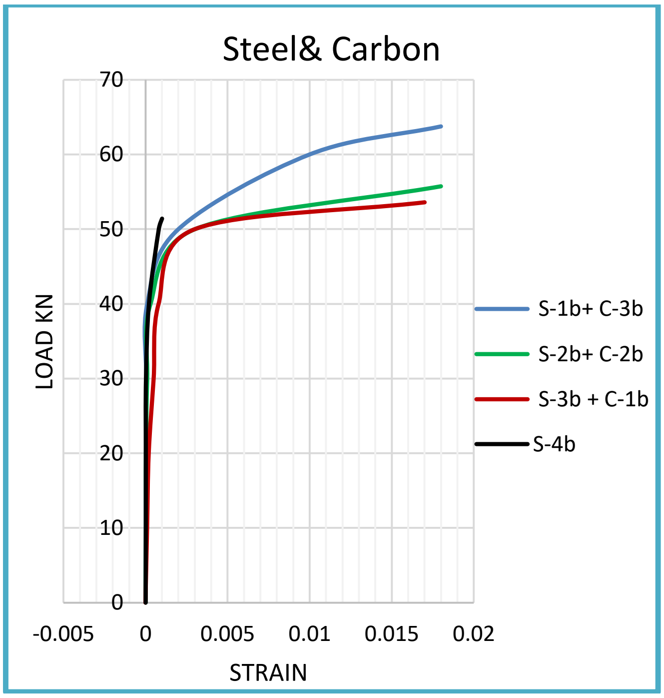

Fig. (17). Comparison between load of steel and load of mixture of steel &carbon

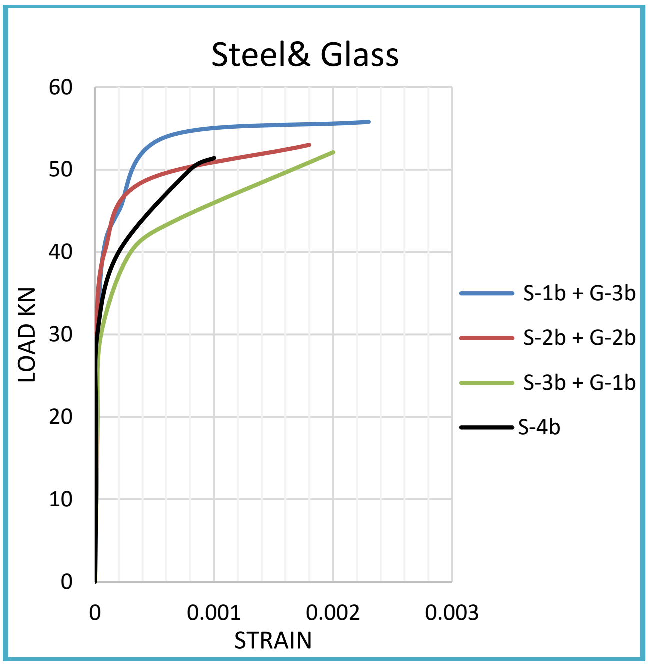

Fig. (18). Comparison between load of steel and load of mixture of steel &glass

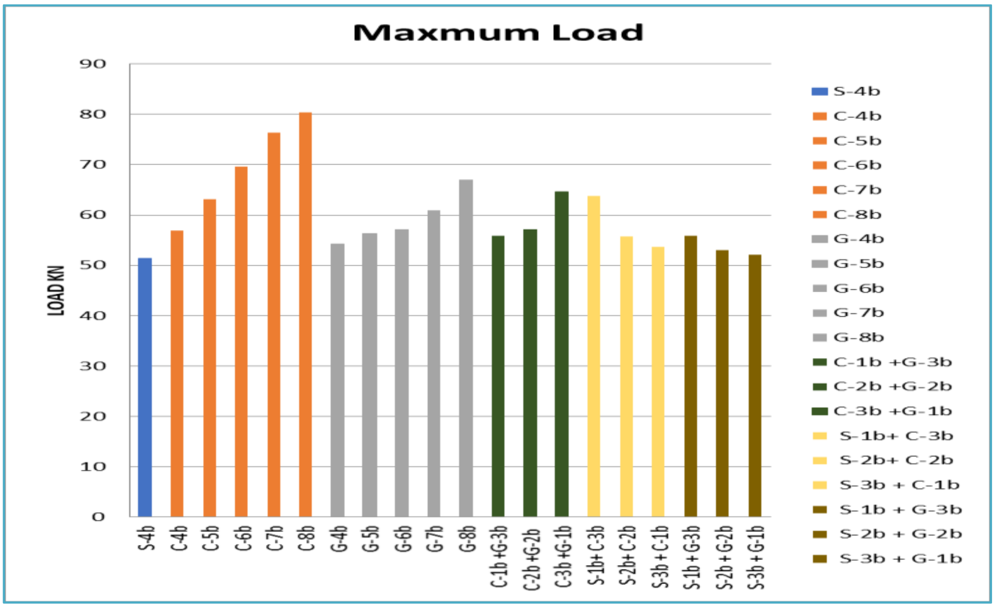

Fig (19) Failure load at all specimens

Finite element analysis

In civil engineering, Abaqus is a computer program used for analyzing and modeling various structural and geotechnical problems. It can simulate the behavior of structures under different loads, such as buildings, bridges, dams, and tunnels. Abaqus enables engineers to perform finite element analysis to determine stress distribution, deformation, and stability of structures. It also allows for studying soil-structure interaction, slope stability, and foundation design. Additionally, Abaqus can be used for simulating dynamic and seismic analysis to assess the response of structures to earthquake loads.

In this part, the tested specimens were simulated using the (FEA) program ABAQUS. The numerical results of the simulated foundation were compared with the experimental results, many materials were used in modeling the specimens such as concrete, steel reinforcement, CFRP bars, and GFRP bars. The compressive stress-strain relationship of concrete is considered to be linear from zero to one-half the ultimate compressive strength, and the strain at the ultimate compressive strength ranges from 0.002 to 0.003. Reinforcement bars and shearconnectors were modeled as a nonlinear and isotropic material. CFRP bars and GFRP barswere modeled as linear isotropic material Table.4 presents the properties of the used material.

The experimental results obtained from testingof the tested specimens are compared with those obtained from the finite element modeling. The experimental and numerical results of load versus strain are compared foreach specimen, Figs from (21 to 40).Table 5 presents a comparison between the numerical and experimental ultimate loads. It can be noticed that the ratio of the numerical ultimate load to experimental one ranged from1.025 to 1.113. It can be observed that ABAQUSalmost predicts a higher ultimate load compared to the load observed during experiments.

Table. 4. The properties of the used materials

Material	Compressive strength (MPa)	Tensile strength (MPa)	Poisson`s ratio	Modulus of elasticity (GPa)
Concrete	25	2.8	0.16	20
Steel bars	--	340	0.3	200
GFRP bars	--	1370	0.3	90
CFRP bars	--	1400	0.3	210

Table. 5. Comparison of experimental and numerical results

Specimens code	$P_{u, exp.}$	$P_{u, num.}$	$\frac{P_{u, num.}}{P_{u, exp.}}$
S-4b	51.4	54.4	1.058
C-4b	56.9	62.7	1.102
C-5b	63.1	68.1	1.079
C-6b	69.6	73.9	1.062
C-7b	76.3	80.7	1.058
C-8b	80.4	85.6	1.065
G-4b	54.2	57.5	1.061
G-5b	56.3	59.4	1.055
G-6b	57.2	62.2	1.087
G-7b	60.9	67.8	1.113
G-8b	67.05	70.5	1.051
C-1b +G-3b	55.8	57.2	1.025
C-2b +G-2b	57.1	60.4	1.058
C-3b +G-1b	64.56	66.8	1.035
S-1b+ C-3b	63.75	67.2	1.054
S-2b+ C-2b	55.75	58.1	1.042
S-3b + C-1b	53.6	55.7	1.039
S-1b + G-3b	55.8	59.3	1.063
S-2b + G-2b	53	57.6	1.087
S-3b + G-1b	52.1	55.2	1.060

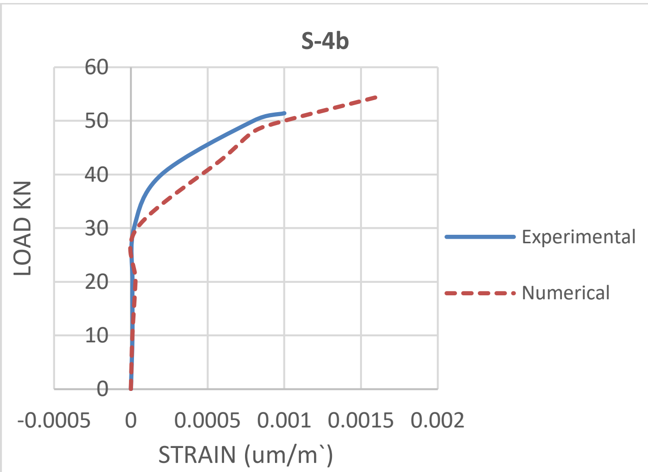

Fig (21) Comparison between experimental & numerical load-strain curves of tested specimen (S-4b)

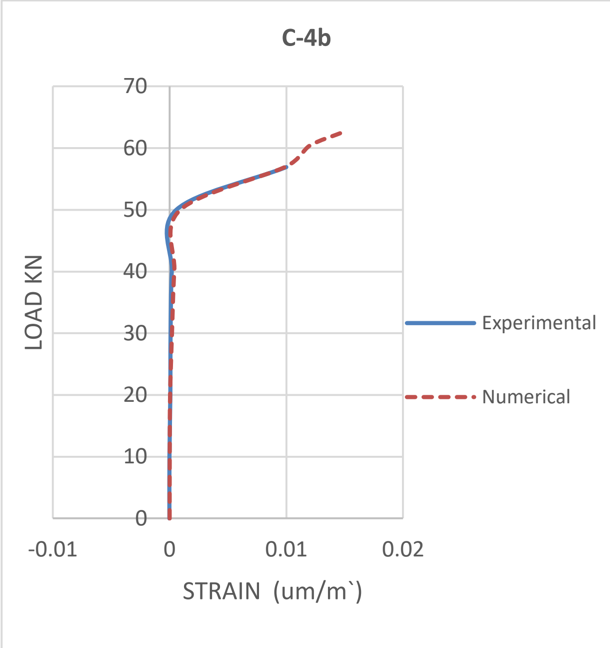

Fig (22) Comparison between experimental & numerical load-strain curves of tested specimen (C-4b)

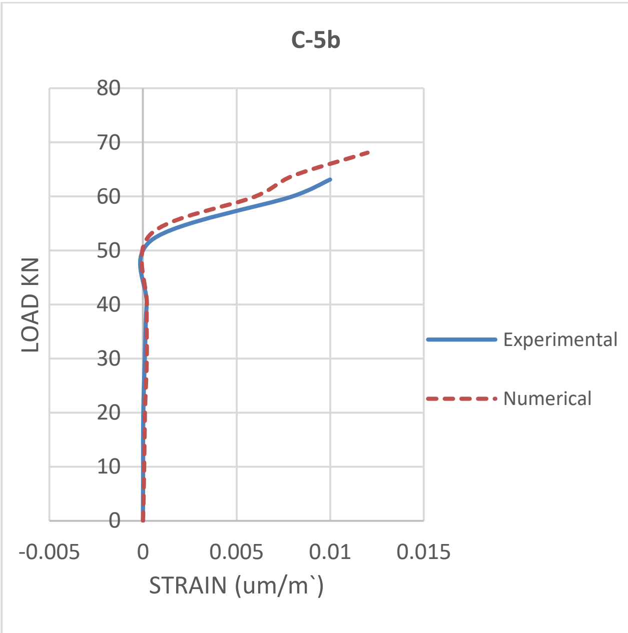

Fig (23) Comparison between experimental & numerical load-strain curves of tested specimen (C-5b)

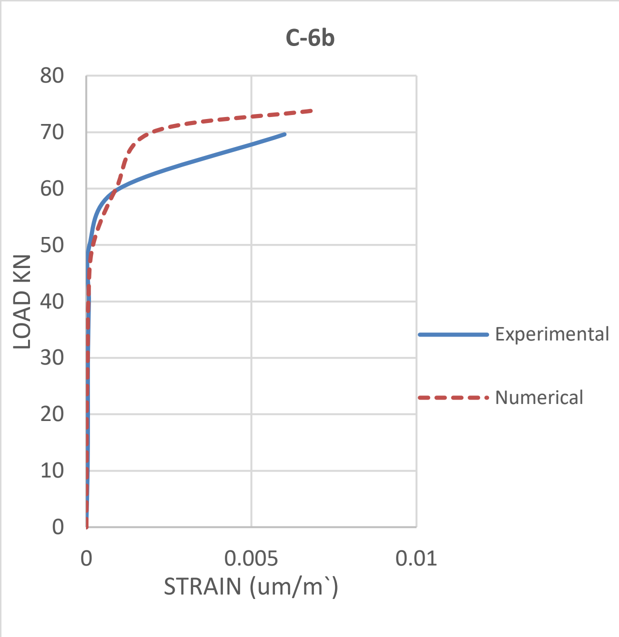

Fig (24) Comparison between experimental & numerical load-strain curves of tested specimen (C-6b)

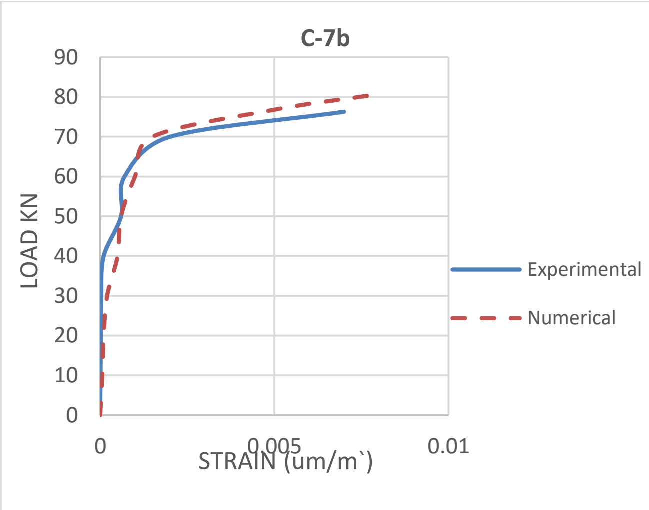

Fig (25) Comparison between experimental & numerical load-strain curves of tested specimen (C-7b)

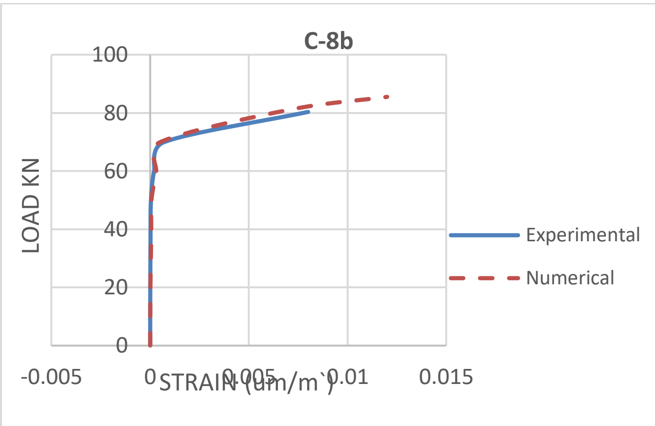

Fig (26) Comparison between experimental & numerical load-strain curves of tested specimen (C-8b)

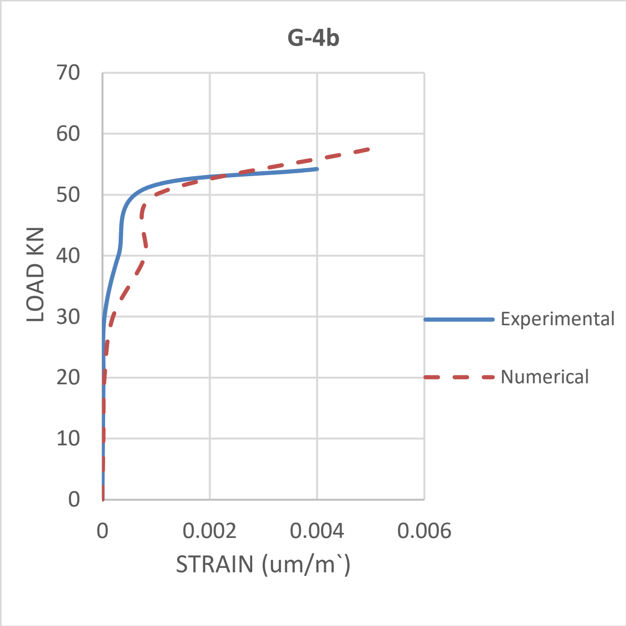

Fig (27) Comparison between experimental & numerical load-strain curves of tested specimen (G-4b)

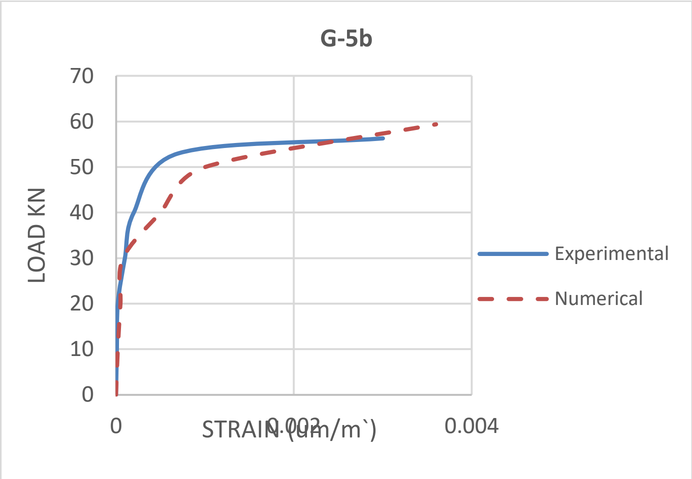

Fig (28) Comparison between experimental & numerical load-strain curves of tested specimen (G-5b)

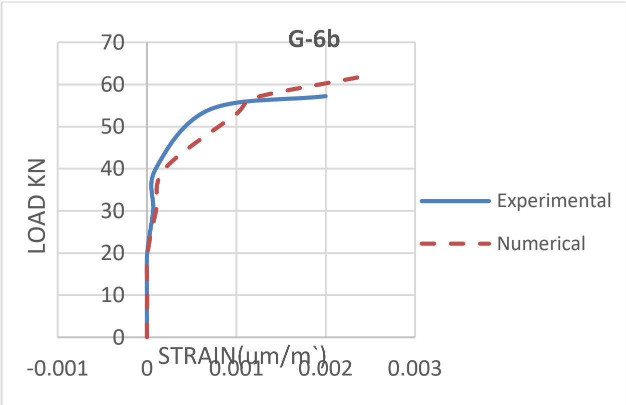

Fig (29) Comparison between experimental & numerical load-strain curves of tested specimen (G-6b)

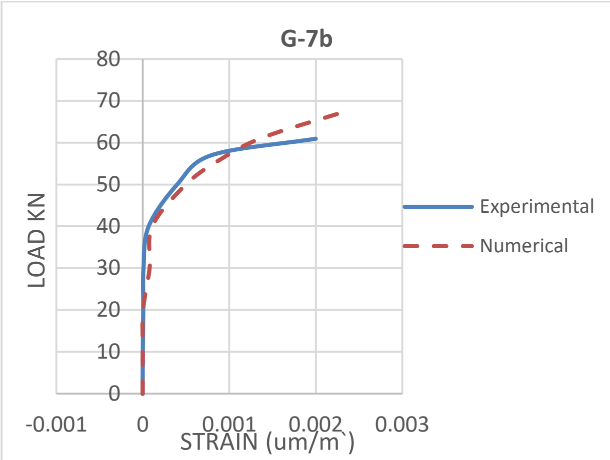

Fig (30) Comparison between experimental & numerical load-strain curves of tested specimen (G-7b)

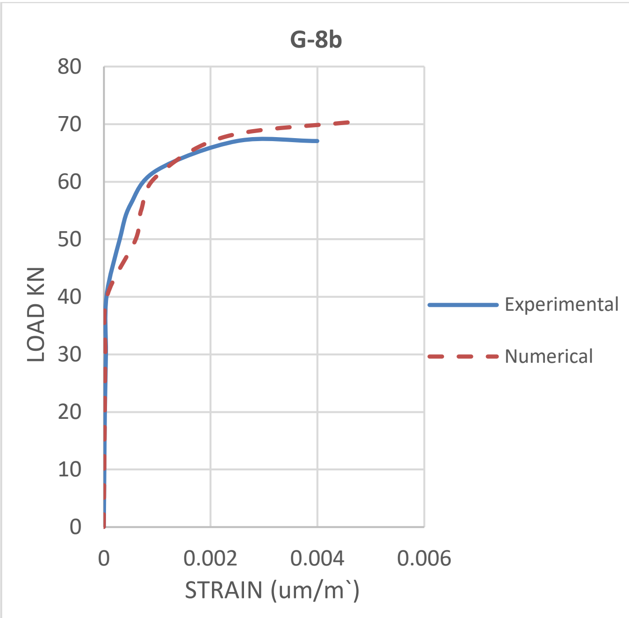

Fig (31) Comparison between experimental & numerical load-strain curves of tested specimen (G-8b)

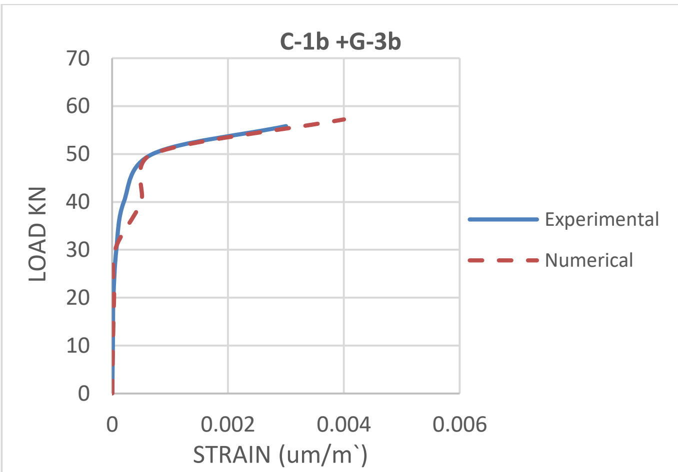

Fig (32) Comparison between experimental & numerical load-strain curves of tested specimen (C-1b +G-3b)

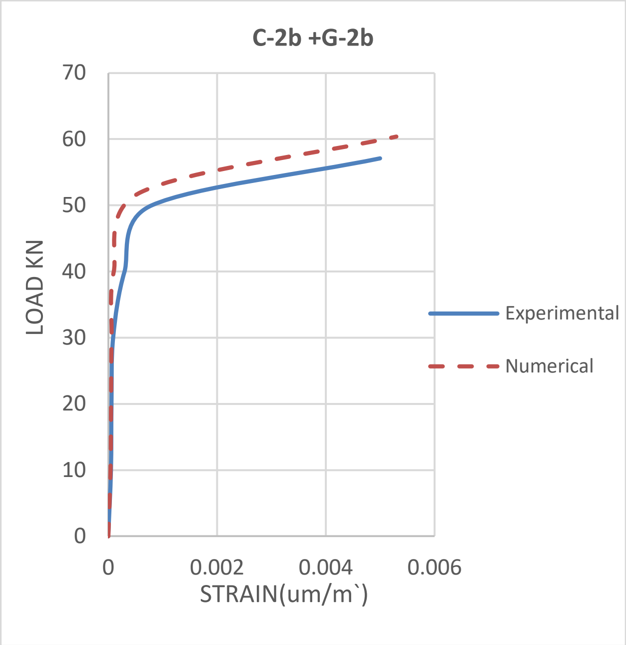

Fig (33) Comparison between experimental & numerical load-strain curves of tested specimen (C-2b +G-2b)

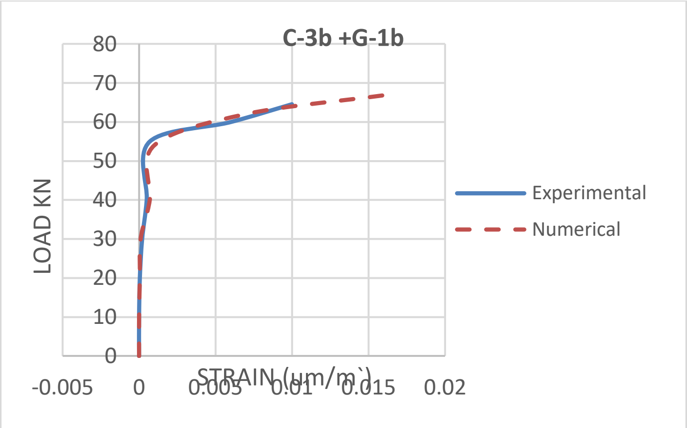

Fig (34) Comparison between experimental & numerical load-strain curves of tested specimen (C-3b +G-1b)

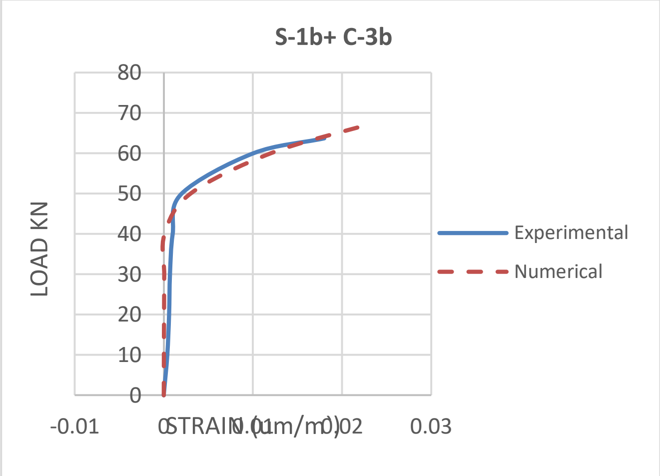

Fig (35) Comparison between experimental & numerical load-strain curves of tested specimen (S-1b+ C-3b)

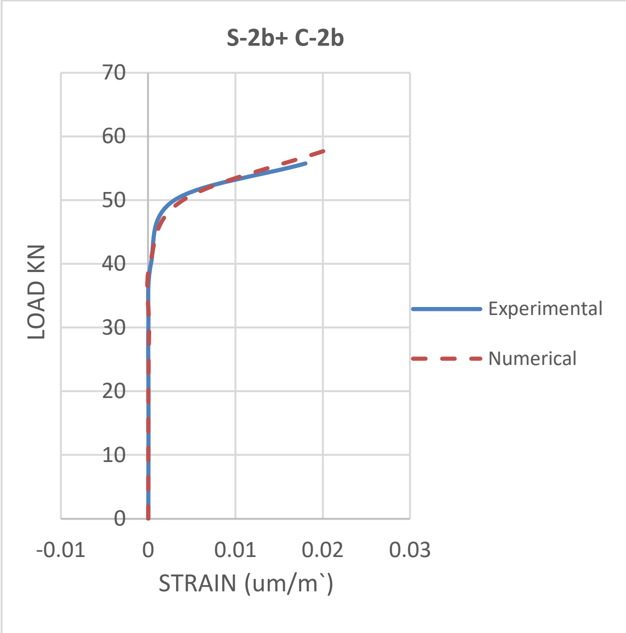

Fig (36) Comparison between experimental & numerical load-strain curves of tested specimen (S-2b+ C-2b)

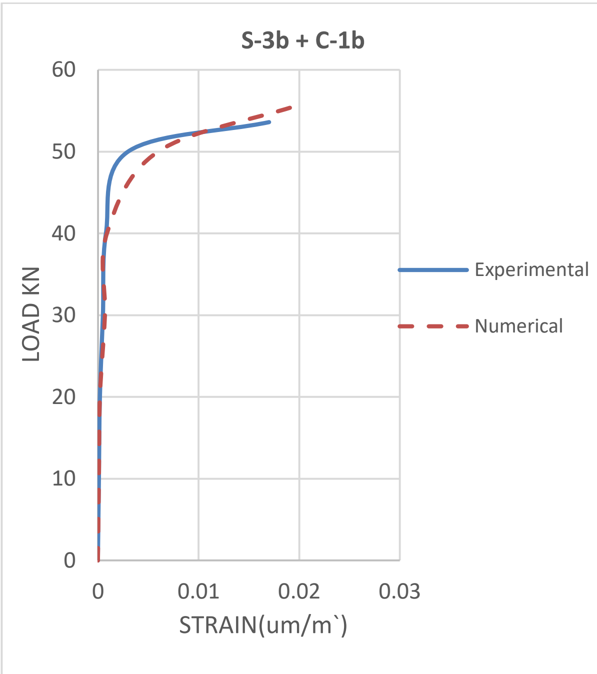

Fig (37) Comparison between experimental & numerical load-strain curves of tested specimen (S-3b + C-1b)

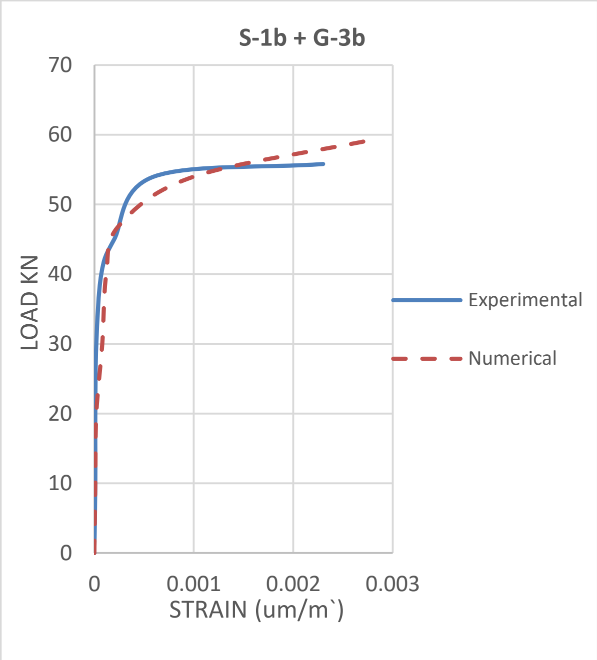

Fig (38) Comparison between experimental & numerical load-strain curves of tested specimen (S-1b + G-3b)

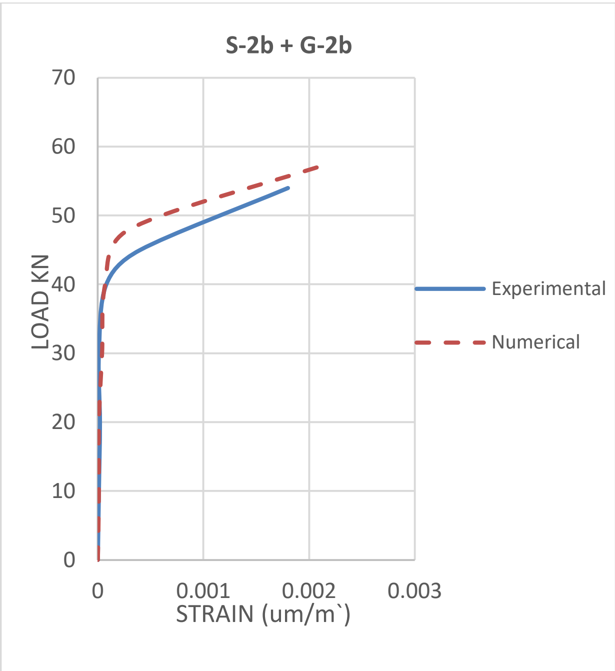

Fig (39) Comparison between experimental & numerical load-strain curves of tested specimen (S-2b + G-2b)

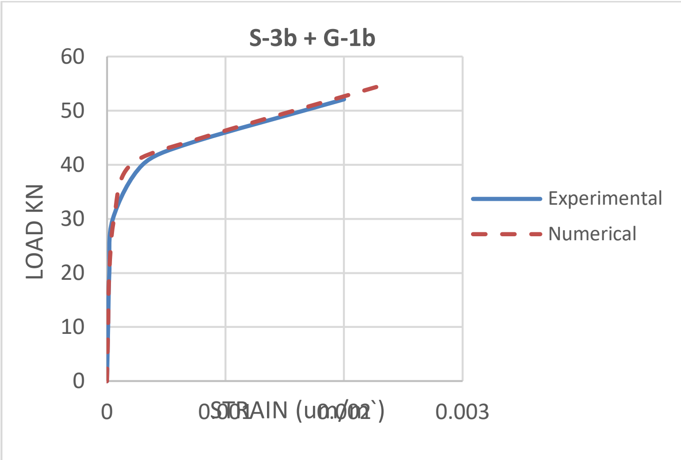

Fig (40) Comparison between experimental & numerical load-strain curves of tested specimen (S-3b + G-1b)

IV. Conclusion

In this study isolated footings are reinforced by different percentage by two types of fiber bars (carbon& glass) have been evaluated. Based on experimental results and theoretical analysis, it is concluded that,

- The experimental results showed an improvement in the flexural behavior of the reinforced specimens compared to control specimen.
- Use of fiber bars as reinforcement instead of steel increases the carried load of footing.
- The footings reinforced with Carbon FRP bars gave the greatest results of load, then that reinforced with Glass FRP bars, and finally footing reinforced with steel bars.
- In specimens reinforced with FRP, an increasein load values was observed as the number of bars increased.
- When more than type of reinforcement was used, recorded specimens (Carbon+ Glass), (Steel+ Carbon) and (Steel+ Glass) an increase in load values of 25.6%, 24.3% and 8.56%, respectively, compared to the control specimen.
- The specimen which reinforced by three bars of carbon and one bar of glass was the largest one, which recorded the highest load value, then which reinforced by one bar of steel and three bars of carbon compared to the control specimen and the specimens which reinforced with the same number of bars (4 bars).
- Specimens simulated using the finite Elements program (ABAQUS) were comparable to those of the experimental test and gave similarresults, where the ratio of the numerical load and experimental one ranged between 1.025 to1.113.

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