Expermental Study to Investigate the Green Concrete Piers of Bridge Using Different Types of Reinforcement

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Abstract

This paper investigates the behaviour of four concrete piers reinforced with different types of reinforcement. All piers have identical dimensions of 200mm in width, 200mm in height, and 600mm in length with a column cross-section of 200×300mm and 200mm in depth. Various concrete mixes were used among which are the normal concrete (NC) and the green concrete (GC) which use a recycled aggregate of 50% replacement ratio instead of normal aggregate. CFRP bars and GFRP bars are used for reinforcing pier cap at the top two layers .Experimental tests had been carried out to investigate the behaviour in terms of first cracking load, crack width, failure load, and deflection. The test results showed that the value of load failure of the GC pier was less than that for the NC one by 2.41% with an increase in deflection. Furthermore, CFRP and GFRP pier specimens showed opposite behaviour regarding the failure load. It has been found that the ultimate load of CFRP bars increased the ultimate load by 6.9%, while GFRP bars decreased the ultimate load by 6.7% in comparison to the pier with steel reinforcement.

Keywords: Green Concrete, Normal Concrete, Pier, Steel Reinforcement, CFRP Bars, GFRP Bars.

1. Introduction

Piers are the parts of the bridge that provide vertical supports at intermediate points. The Two main functions of piers are : transferring superstructure vertical loads to the foundations and resisting horizontal forces acted on the bridge[1]. The most usually used bridge piers are those made from concrete, which is considered a leading construction material for more than a century. Due to the fact that aggregates nearly form 70% of the produced concrete, their global consumption ranged between billion tons in 2010 [2]. Over 1 billion tons of construction and demolition (C&D) waste is globally generated every year [3] and could be used successfully in producing various concrete structures. Very limited studies have been carried out about experimental tests on pier cap that contain recycled concrete aggregates. [4]. In 2011, Al Hussainy [5] carried out an experimental study to produce self-compacting concrete (SCC) from recycled concrete aggregate (RCA). The percentages of coarse aggregate substitution by RCA were 0%, 25%, 50%, 75% and 100%. The results showed that the compressive and splitting tensile strength decreased with the increase in the RCA replacement ratio. In addition, the microstructure analysis and the quality of interfacial transition zone were better than that of the original paste resulting in weak adhered mortar, which determined the strength and behaviour. In 2013, Mjelde [6] conducted an experimental research to study weather recycled concrete aggregate (RCA) can be used effectively in new concrete pavements. The incorporation of a 20% substitution of cement is used in the mix. To conduct the experimental program, eight concrete batches are produced series of fresh and hardened concrete samples from each batch. The results indicated that the recycled coarse aggregate is suitable to be used as an aggregate source for concrete with a lower workability of the fresh concrete. The percentage of RCA substitution did not have an influence on the modulus of rupture and compressive strength.

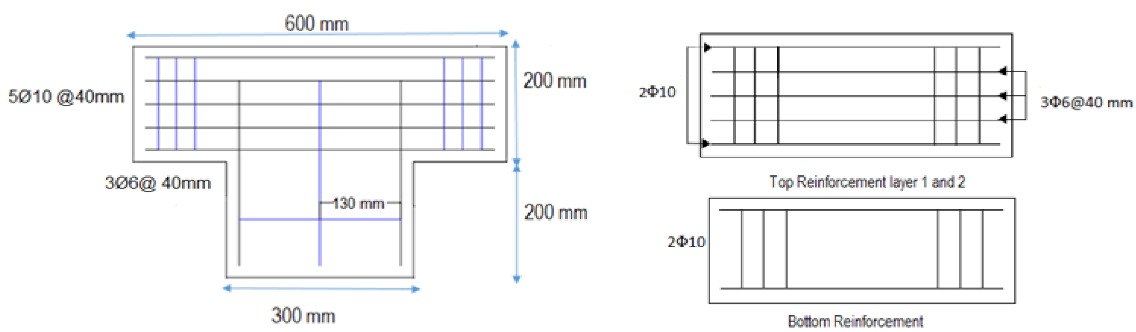
In 1990, Sami [7] conducted an experimental investigation that involves testing Six reinforced concrete pier caps. Varaible parameters in the specimens were the geometry of the pier caps, the amount and distribution of uniformly distributed reinforcement, and the anchorage details of this reinforcement. Results showed that yielding spreads to the distributed reinforcement after yielding the main tension tie reinforcement. Furthermore, the uniformly distributed reinforcement contributed significantly to the strength and played a key role in controlling cracks Denio et al. carried out an experimental study on pier caps to investigate the behaviour of the pier caps by using Six test specimens with five different reinforcing steel patterns used in the six specimens to examine the contributions of different reinforcing types to the pier cap strength. Eleven static load tests were conducted to failure on the Six pier caps. The result shows that the specimens with a greater quantity of horizontal reinforcing steel and adequate development of horizontal reinforcing had a greater capacity. The bearing capacity of the pier cap was increased by the confinement provided by the continuous loop around the end of the pier cap.

In recent years, many studies focus on the behavior of concrete members reinforced with fiber reinforced polymer (FRP) bars. Most of these studies focus on studying FRP bars in strengthening only. Therefore, it is the aim of this paper to examine the behavior of various reinforced concrete piers using various types of reinforcement as well as a recycled aggregate mix originated from destroyed building waste.

2. Experimental Work

2.1. Details of the Tested Piers

Four reinforced concrete piers were tested to represent the variables of this work. All specimens have identical geometry and reinforcement pattern and all details are given in Fig.1. The details of the specimens were as follows:



Cap Details

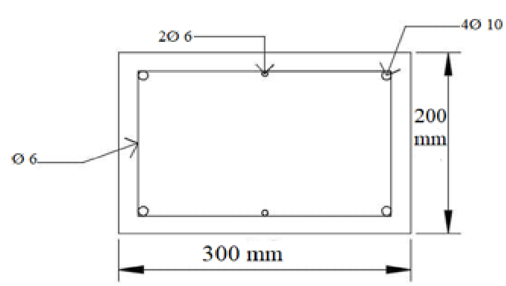


Figure 1: Details of the Reinforced Concrete Pier.

2.1.1. Case No. 1 (NC)

This case represents a reference pier that was cast using normal concrete (NC) and reinforced with an ordinary steel reinforcement as shown in Figure2.

2.1.2. Case No. 2 (GC)

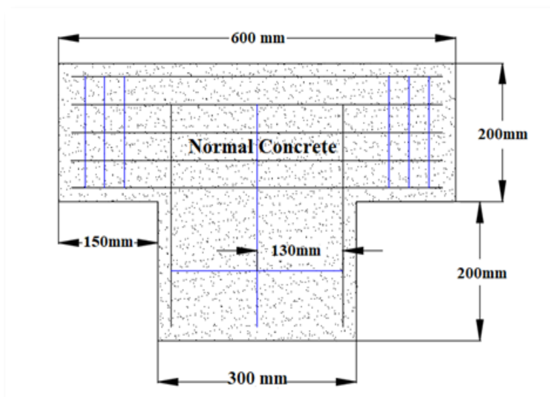
This case investigates the effect of using a type of concrete known as a green concrete (GC), which is produced by replacing 50% of the natural aggregate (NA) by recycled coarse aggregate (RCA). This pier also used the same ordinary steel reinforcement as in the reference pier model.

2.1.3. Case No. 3 (T1CFRP)

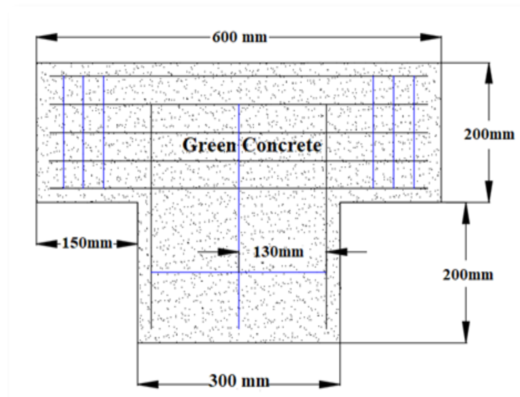
This case studies the effect of CFRP bars that are used to reinforce only the Two upper layers. Other layers were reinforced with ordinary steel reinforcement and cast with GC.

2.1.4. Case No. 4 (T1GFRP)

Study No. 4 was similar to study No. 3 except using GFRP bars are used instead of CFRP ones.



Case no.1



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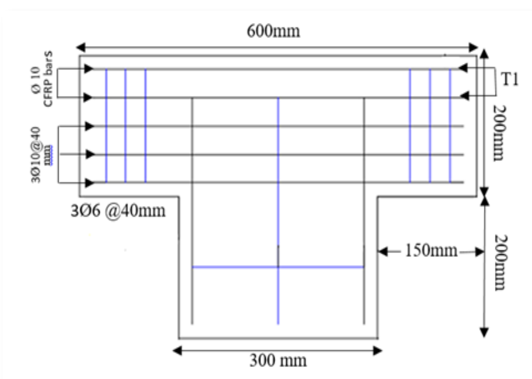
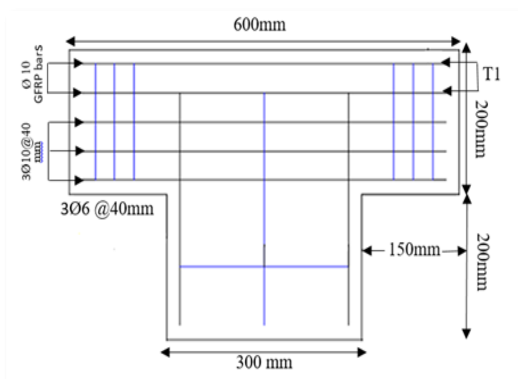


Case no.3



Case no.4

Figure 2. Details of the Tested Pier.

2.2. Materials

2.2.1. Cement

Portland cement (type V) was used in this experimental work, which is produced by Karbala factory and it conforms to Iraqi specification limits No. 5/1984 [7].

2.2.2. Fine Aggregate (Sand)

Natural sand from Al-Ukhaidher was used for producing various concrete mixes with a particle size of (4.75 mm) as a maximum. Results of physical and chemical properties showed that this type of sand complies the Iraqi specification No. 45/1984 [8].

2.2.3. Coarse Aggregate (Gravel)

A natural aggregate was used in producing various concrete mixes with a (19 mm) as maximum particle size. It has been rinsed with water to remove dust and is then left to dry in the air before being used [8].

2.2.4 Recycled Coarse Aggregate

Old concrete samples, which were available in the laboratory were collected to be used as a recycled coarse aggregate (RCA). These samples have been broken down into smaller particles using a hand hammer. They are then taken to the sieving process to be within the Iraqi specifications' limits No. 45 /1984.

2.2.5. Steel Reinforcement

Ukrainian deformed bars with two sizes of (6, and 10 mm) diameter have been used in reinforcing all concrete piers. From each size three samples have been tested. The results are found to confirm to the ASTM A- 615-15[9].

Table 1. Properties of Steel Reinforcement Bars

Bar size (mm)	Actual diameter (mm)	Yield stress (MPa)	Ultimate stress (MPa)
Ø6	5.963	583.3	597.1
Ø10	9.852	541.8	669.7

2.2.6. Carbon Fiber Reinforcement Polymers (CFRP) Bars

Aslan 200 carbon fiber reinforcement polymers (CFRP) and glass fiber reinforcement polymers GFRP bars have been used in this work with a nominal diameter of (6 mm) and (10mm) .The properties of this type as supplied from the manufacturer are shown in Table 2 . The test results were acceptable with the standard specification ASTM D 7205[10].

Table 2. Properties of FRP Bars [11]

Properties	Type			
	GFRP (6mm)	**GFRP (10mm)**	**CFRP (6mm)**	**CFRP (10mm)**
Nominal diameter (mm)	**6**	**10**	**6**	**10**
Nominal area (mm)2	**31.67**	**71.26**	**31.67**	**71.26**
Ultimate tensile load (kN)	**28**	**59**	**71**	**154**
Guaranteed tensile strength (MPa)	**896**	**827**	**2241**	**2172**
Modulus of elasticity (GPa)	**46**	**46**	**124**	**124**
Weight (g/m)	**77.4**	**159**	**/**	**/**
Transverse shear strength (MPa)	**150**	**150**	**/**	**/**

2.4. Concrete mix proportions

Normal strength concrete was used for casting pier specimens using recycled coarse aggregates at 50% replacement ratio by normal aggregates as green concrete. All concrete mixes consist mainly of cement, fine aggregate, coarse aggregate, recycled aggregate concrete, and water. Different concrete mixes were produced based on the replacements of natural aggregate with recycled aggregate, which were (25%,50%,75% and 100%)of normal coarse aggregate. Many trail mixes had been carried out for each of them to find the best mix of concrete according to the results that were obtained from the laboratory tests including slump test and compressive strength .Several empirical mixes have been carried out in the laboratory to select the final mix proportions (1: 1.4: 2.2) with w/c ratio of 0.43. A replacement level of 50% was used to replace the natural coarse aggregate by recycled coarse aggregate to produce the green concrete mix. The quantities of materials are presented in Table 3. Using a rotary mixer of 0.1 m3, the mixing process was performed.

Table (3)Properties of Trail Mixes

	Materials (kg/m3) Mixes	Cement	Fine Aggregate	Coarse Aggregate	Recycled Coarse Aggregate	w/c	Compressive strength (MPa)
	NC	465	651	1023	0	0.43	30
Recycled Aggregate Concrete	25% of Coarse Agg. Weight	465	651	767.25	225.75	0.43	29.4
	50% of Coarse Agg. Weight	465	651	511.5	511.5	0.43	28.5
	75% of Coarse Agg. Weight	465	651	225.75	767.25	0.43	25.7
	100% of Coarse Agg. Weight	465	651	0	1023	0.43	21

Although the concrete mix with a replacement ratio of 25% gave better results than the mix of a 50% substitution ratio in terms of the compressive strength, the mix of 50% substitution ratio was adopted for economic considerations.

2.5. Casting of Concrete

Prior to the casting process, the wooden moldings were prepared and all surfaces were lubricated to prevent adhesion of the concrete after hardening. All the materials were mixed to obtain a homogenous mix and the mixture was poured into the wood molds .The compaction was applied using an electric vibrator. After One day of casting, the molds were opened and the pier specimens were placed in special treatment basins.

2.6. Tests for Hardened Concrete

2.6.1 Compressive Strength Test

According to the ASTM C39/C39M-05 the compressive strength test was conducted on cylinder specimen dimensions of (100 mm diameter and 200 mm length). The average value of three specimens was considered to represent each mix.

2.6.2. Splitting Tensile Strength Test

The splitting tensile strength governs the cracking behavior and affects other properties, such as the durability of concrete. This test was carried out according to the ASTM.

3. Tests Setup and Instrumentation of Piers

The pier specimens were tested after the curing had been finished. By using Two points of concentrated load with a 75mm distance from each side of the pier cap, the load was applied on the piers. The distance between points load was (450mm) from centre to centre. The layout of applied load and the deflection gage for piers are illustrated in Figure 3.

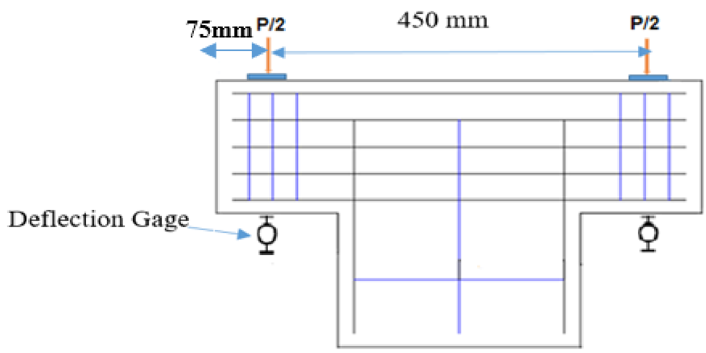


Figure 3. The layout of Points Loads and The Deflection Gauges for Pier Specimens

Using hydraulic testing machine all pier specimens were tested. To measure the deflection, two of (20 mm) LVDT settlement capacity was used, which linked to a computer. The process of testing is shown in Plate 1.

Plate 1. The Hydraulic Testing Machine of Concrete Pier Specimens

4. Experimental Results

4.1. Mechanical Properties of Concrete

The mechanical properties of concrete samples tested in this study included compressive strength, splitting tensile strength, absorption, and density. The average values of the Three samples were recorded to represent each mechanical property, as shown in Table 4.

Table 4. Mechanical Properties of Concrete

Mix Notation	fc′ (Cylinders) (MPa)	ft (Splitting) (MPa)	Absorption %	Density (Mg/m3)
N C	**29.5**	**3.47**	**3.707**	**2.485**
G C	**29.1**	**3.25**	**4.423**	**2.343**

4.2. Results of Tested Piers

4.2.1. Crack Pattern and Failure Modes

When the tensile stress reached the ultimate strength of concrete, the cracks started to occurre in the reinforced concrete piers. Several types of cracks were observed in the pier specimens under load. These cracks ware shear, flexural shear, and flexural cracks. The results of all piers including the first cracking load, ultimate load, crack width, and the deflection at failure stage are illustrated in Table 5.

Table 5. The First Cracking Load, Ultimate Load, Crack Width, and Deflection at Failure Stage

Piers Notation	First crack, Pcr (kN)	Ultimate load, Pu (kN)	Crack Width (mm)	Deflection. (mm)
NC	**200**	**538**	**2.3**	**6.59**
GC	**180**	**525**	**3.5**	**7.81**
T1CFRP	**243**	**548**	**2.7**	**5.52**
T1GFRP	**175**	**502**	**3.2**	**7.78**

From the results it can be noticed that the cracks started at the top of the pier, then propagated downward and became wider with the increasing applied load. Plate 2 shows the cracks patterns of the pier specimen.

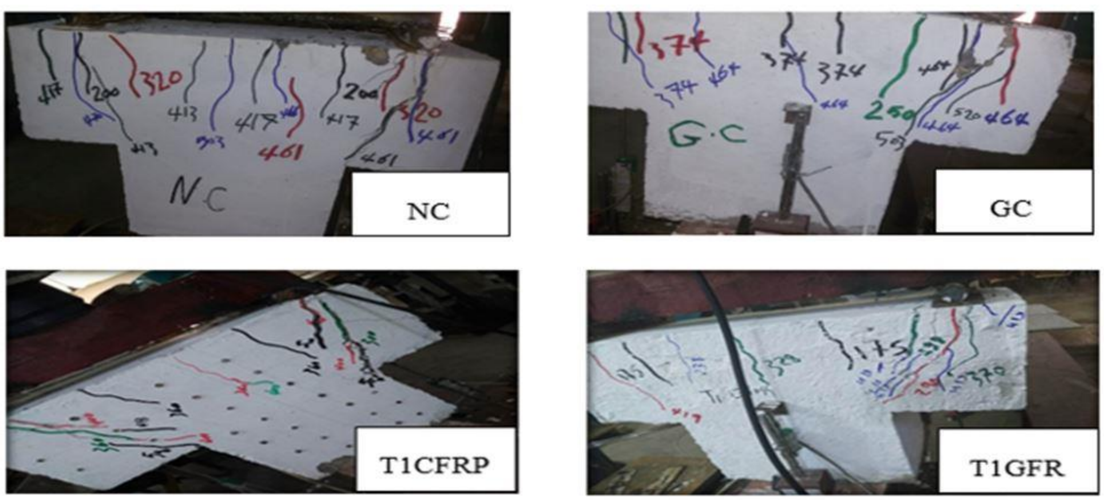


Plate 2. The Crack Pattern of Tested Piers

4.2.2. First crack and Crack width

The propagation of cracks has been noticed and the crack width was recorded for each 40 kN of specimens loading. This monitoring was continued until the failure loads were reached. For reference pier (NC), the first crack was recorded at load of 200 kN with 0.1 mm wide flexural crack, which was closed to the middle of pier cap propagated from the top surface. At service load (70% of the ultimate load), this pier recorded a crack width of 1.22 mm. A load of 417 kN, the cracks widened to 1.33 mm. Further loading to nearly 530 kN resulted in further cracks with a maximum crack width of 2.3 mm. Pier GC recorded a first crack at 180 kN with a crack width of 0.1 mm, a maximum crack width of 3.5 mm at 520 kN, and a crack width of 1.7 mm at the service load.

On the other hand, the first crack width was 0.09 mm for T1CFRP. Then, cracks were propagated to reach a value of 1.5 mm at the service load. Piers reinforced with GFRP showed a little effect on the first crack and crack width as well as results showed that the first crack width was 1.10 mm for T1GFRP. Fig. 4 showed the load –crack width relationship of tested pier.

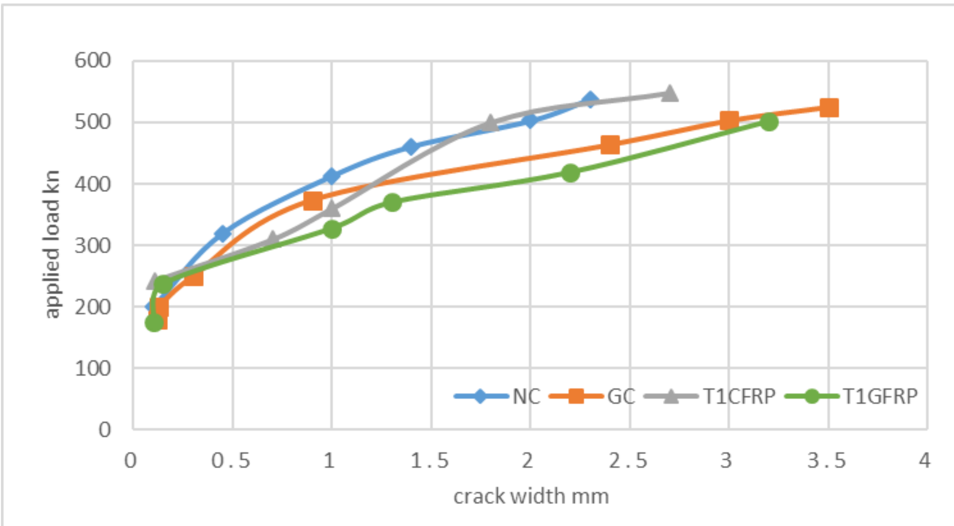


Figure 4. Load-Crack Width Curve of Tested Piers

4.2.3 Load-Deflection Behaviour

The load-deflection curves for all tested pier specimens included the reference pier (NC) and other piers, which will be illustrated in Fig. 5. Deflections have been measured at the cantilever part of the pier cap for each load increment. Generally, piers behaved elastically at early loading stages, with no visible cracks. At further stages, piers have a tendency to change the elastic behaviour and cracks become visible with a nonlinear behavior. At the Third stage, shear and the flexural shear cracks continued to propagate downward, and the piers behaved plastically, after yielding of steel reinforcement.

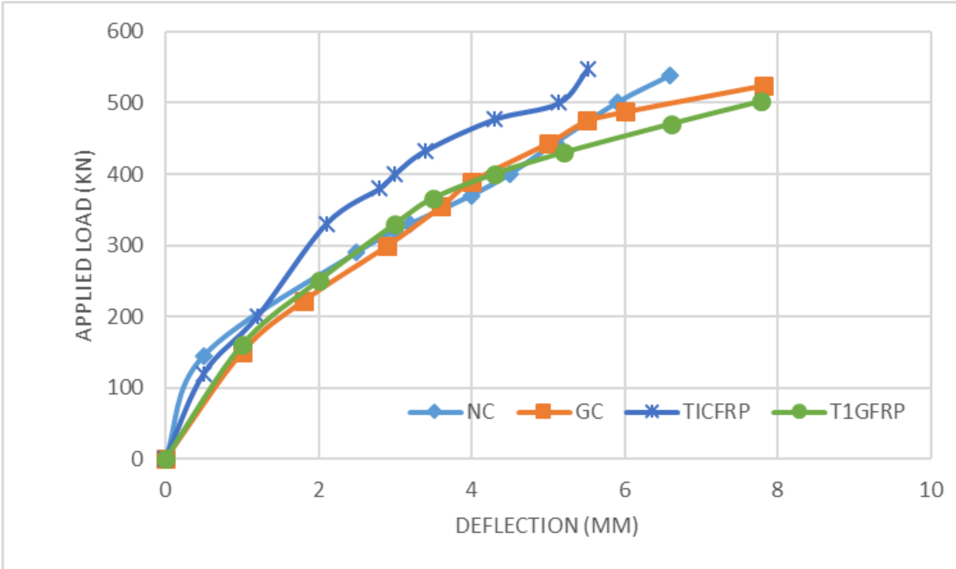


Figure 5. load-Deflection Behavior of Tested Piers

It can be seen that the failure load of the NC pier was greater than GC pier by 2.4%, and the deflection of NC pier was lower than GC pier by 18.5%. The ultimate load has been improved by changed the reinforcement type by CFRP bars that changing the two top layers only for specimen T1CFRP. This led to the increase ultimate load by 0.95 %, and decreased deflection by 29.32 as compared with GC pier. This reduction in deflection may be attributed to the increase of pier stiffness and rigidity. GFRP bar are also used in this research by changing the two top layers only for specimen T1GFRP were the ultimate load decreased by about 4.38% while the deflection increased by 4.19%, compared to GC pier. From these results, GFRP bars do not increase strength in compression. And do not reduce the effects of concrete creep of GFRP reinforced concrete flexural members due to the limited compressive strength and modulus of GFRP bars

4.2.4. Concrete Strain*s*

The strain of concrete was measured by Vernier calliper at an accuracy of 0.02 mm. At different loading stages. Ten pairs of demec discs were used to observe the strain concrete. Figure 6 shows the arrangement of these demec discs on the pier specimen. Figures 7 to 10 shows the load-strain curves for all piers.

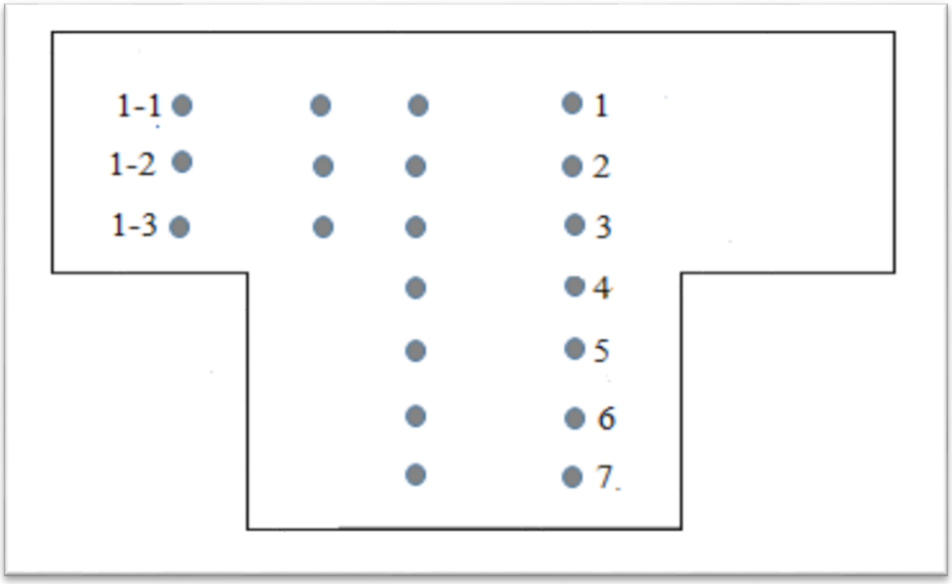


Figure 6. Arrangement of Demec Point

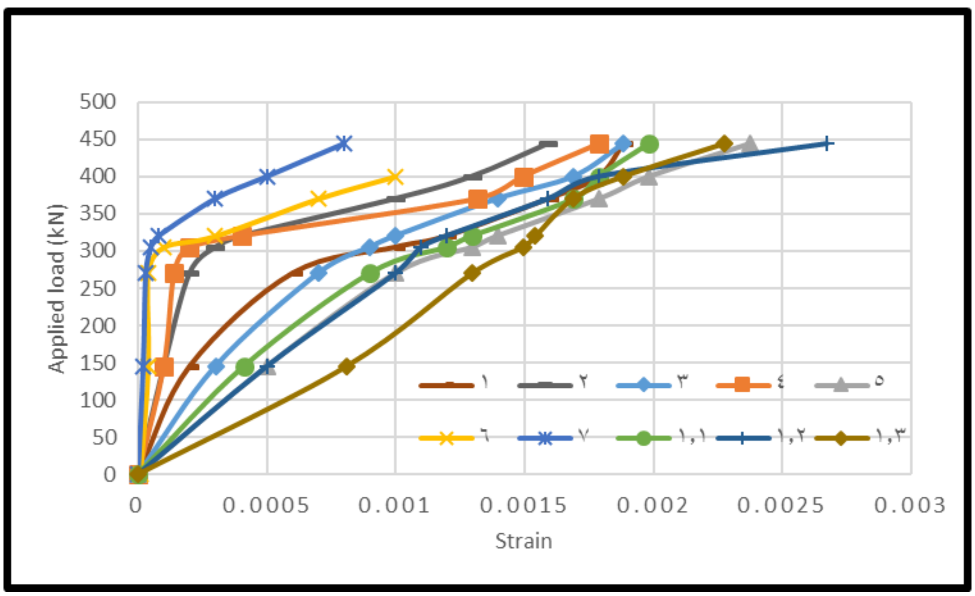


Figure 7 Load – Lateral Deflection Behavior of NC Specimen

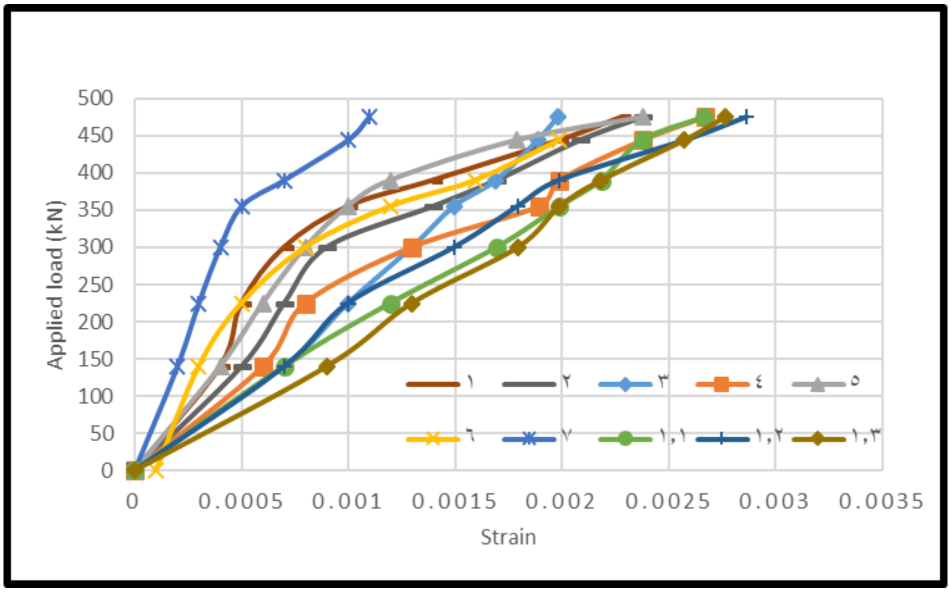


Figure 8 Load – strain Behavior of GC Specimen

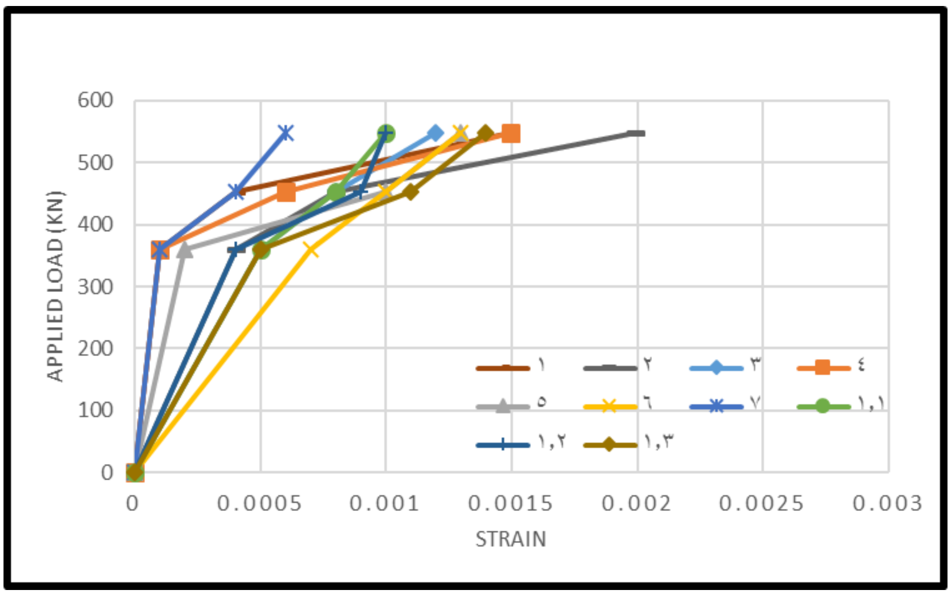


Figure 9 Load – strain Behavior of T1CFRP Specimen

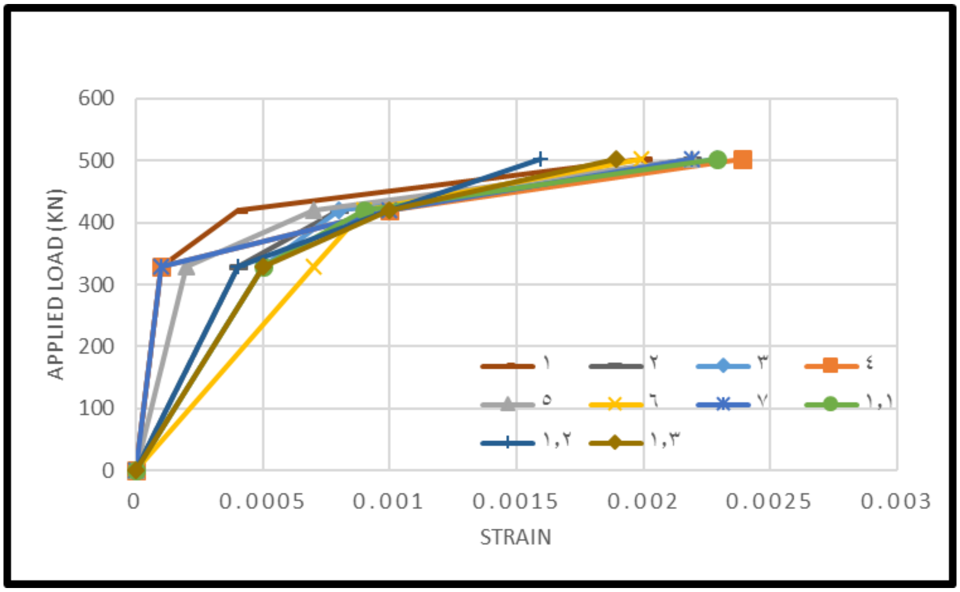


Figure 10 Load – strain Behavior of T1GFRP Specimen

5. Conclusions

1. There is a small difference in ultimate load between normal and green concrete of about 2.4%. This means that the green concrete is suitable to use for different purposes.
2. The deflection under the ultimate load of the GC pier was 18.5% bigger than that of NC pier.
3. The use of CFRP bars in the two top reinforcement layers of pier led to the improvement of the ultimate load by 4.19% and decrease deflection by 29.32%.as compared with a green concrete pier reinforced with steel reinforcement.
4. It was noticed that replacing steel reinforcement by GFRP bars at the top two layers of the pier cap led to a decreased ultimate load and an increase deflection by about 4.38% and 0.38%, respectively as compare to the GC pier that reinforced with steel reinforcement.

Conflict of Interests.

- There are no conflicts of interest.

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الخلاصة

تبحث هذه الورقة في سلوك أربعة ركائز خرسانية مسلحة بأستخدام انواع مختلفة من التسليح. جميع الركائز لها أبعاد متماثلة بعرض 200 ملم، وعمق 200 ملم، وطول 600 ملم مع مقطع عرضي للعمود يبلغ 200 × 300 ملم وعمق 200 ملم. تم استخدام خلطات خرسانية مختلفة: الخرسانة العادية (NC) ، والخرسانة الخضراء (GC) بأستخدام الركام المعاد تدويره بنسبة استبدال 50 ٪ بدلاً من الركام العادي. قضبان CFRP و GFRP تم استخدامها لتسليح الطبقتين العلويتين من التسليح الخاص بسقف الركيزه. تم إجراء الاختبارات التجريبية لتحري سلوك النماذج من حيث حمل التكسير الاول وعرض الكراك وحمل الفشل والانحراف. أظهرت نتائج الاختبار أن قيمة حمل الفشل للركيزه GC التي استخدمت الخرسانة الخضراء في صبها كانت أقل من قيمة الركيزه NC بنسبة 2.41٪ مع زيادة في الانحراف. علاوة على ذلك، أظهرت عينات CFRP و GFRP سلوكاً معاكسًا فيما يتعلق بحمل الفشل، فقد وجد أن الحمل النهائي لنموذج CFRP زاد الحمل النهائي بنسبة 6.9٪ ، بينما في نموذج GFRP انخفض الحمل النهائي بنسبة 6.7٪ مقارنةً بـــ الركيزه ذات حديد التسليح الاعتيادي .

الكلمات الدالة: الخرسانة الخضراء، الخرسانة العادية، الركائز، حديد التسليح الاعتيادي، قضبان CFRP ، قضبان.GFRP