The Behaviour of Reinforced Concrete Bridge Piers Using Different Types of Concrete Mix

Ali H Al-Mamoori1, Wajde S Alyhya1, and Hajir A Al-Hussainy1, 2
1 Department of Civil Engineering, University of Kerbala, Iraq
2 Corresponding author, email: hajerhmad204@gmail.com

Abstract. This paper investigates the behaviour of reinforced concrete piers produced from four different concrete mixes. All samples have identical dimensions of 200 mm in width, 200 mm in depth, and 600 mm in length with a column cross-section of 200 x 300 mm and 200 mm in depth. The four various concrete mixes were: Normal concrete (NC), Green concrete (GC) which used a recycled aggregate with a replacement ratio of 50% instead of normal aggregate, GC in addition to 2% volumetric ratio of recycled steel fibre (TRSF) and high strength concrete mix at pier cap region (THSC). Experimental tests have been conducted to determine the behaviour of the piers in terms of first cracking loading, load failure, crack width and deflection. Results showed that the ultimate load value of GC was less than the NC pier by 2.41%. Furthermore, there was a significant increase in the ultimate load of TRSF pier by 4.76% as compared with GC pier because of the recycled steel fibre in the pier cap that affects positively on crack width. The results also showed that the use of HSC in the pier cap region improved the failure load by 29.7% when compared with GC pier.

Keywords: Green Concrete, High Strength, Reinforced Pier, Steel fibre

1. Introduction

Piers are the parts of the bridge that provides vertical supports at intermediate points. The two main functions of piers are: transferring superstructure vertical loads to the foundations and resisting horizontal forces acting on the bridge[1]. With increasing the rate of demolition, it is imperative to reuse waste materials effectively to conserve non-renewable natural resources [2]. Several research studies were conducted on the use of recycled aggregate in order to be used in concrete to investigate the properties of the produced concrete. Most of the previous studies investigated the mechanical properties of the resulting concrete. However, limited works were concentrated to understand the durability aspects of emerging building materials most likely with concrete made from natural aggregates [3]. Recycled aggregates are largely used as fillers in low-level applications and road construction, whereas it is little used in structural construction due to its irregular shape, which can affect the feasibility of concrete as well as the large water absorption capacity [4]. The high paste content and high water absorption of the recycled aggregate resulted in poor operating capacity and significant loss of concrete strength [5]. Previous research indicated that the addition of an extra 5% of cement to a concrete mix containing recycled aggregates can compensate for the decrease in strength [6]. Furthermore, the variation in concrete properties, which used recycled aggregates were greater than those with normal aggregates because of its inconsistent surface [7].
Many researchers have studied the mechanical properties of recycled concrete. However, no researchers have studied the effect of using recycled concrete on structural units, especially piers. Therefore, the aim of this research is to investigate the behaviour of reinforced concrete piers using various concrete mixes.

2. Experimental Work

2.1. Details of the Tested Piers
All specimens have an identical geometry and reinforcement pattern as shown in Fig. 1 and Table 1. The cross-section of each reinforcement concrete piers is shown in Fig.2

![Cap Details](image)

**Figure 1.** The cross section details of the pier.

| Pier Case | Concrete type          | Cap Details | Column Details |
|-----------|------------------------|-------------|----------------|
|           |                        | Normal Aggregate | Recycled Aggregate | Normal Aggregate | Recycled Aggregate |
| NC        | Normal concrete        | 100         | 0              | 100         | 0              |
| GC        | Green concrete         | 50          | 50             | 50          | 50             |
| TRSF      | Green concrete +2% by vol. ratio of the recycled steel fibres | 50          | 50             | 50          | 50             |
| THSC      | High strength concrete | 50          | 50             | 50          | 50             |

2.1.1. Case No. 1 (NC)
It represents the reference which is cast by using normal concrete (NC) and reinforced with steel bar as shown in Fig. 2.
2.1.2. Case No. 2 (GC)
This case investigates the effect of using green concrete (GC), which is produced by replacing half natural aggregate (NA) by recycled coarse aggregate (RCA) and reinforcing with steel bar as shown in Fig. 2.

2.1.3. Case No. 3 (TRSF)
This case investigates the behaviour of green concrete that has recycled steel fibres of 2% by volume in the pier cap part with GC in the column part as shown in Fig. 2.

2.1.4. Case No. 4 (THSC)
This case investigates the effect of using high strength concrete (HSC) in the pier cap while the green concrete mix is used for the column as shown in Fig. 2.

![Diagram of tested piers](image)

**Figure 2.** Details of the tested piers.

2.2. Materials

2.2.1. Cement
CIM V is used, which is produced by Karbala factory according to the Iraqi specification No. 5/1984 [8].

2.2.2. Fine Aggregate
Natural sand from Al-Ukhaidher is used for producing various concrete mixes with a maximum particle size of (4.75 mm). The physical and chemical properties were according to the Iraqi specification No. 45/1984 [9].
2.2.3. Coarse aggregate
Natural aggregate is used with a (19 mm) as maximum particle size, which is washed by water and then left to dry in the air before using [9].

2.2.4 Recycled coarse aggregate
Old concrete samples, which are available in the laboratory are collected to be used as a recycled coarse aggregate (RCA) is broken down into small size particles by hand hummer and sieved according to the Iraqi specifications’ limits No. 45/1984 [9].

2.2.5. Recycled steel fibres
The steel fibres used in this investigation was a recycled one produced and extracted from old cars tires. The tires have been burned and then the steel fibres were extracted and cut into small pieces of 2 cm length. The diameter and length of the recycled steel fibre were 1 mm and 20 mm respectively with a dry density of 6740 kg/m$^3$.

2.2.6. Steel reinforcement
Ukrainian deformed bars with two sizes of 6- and 10-mm diameter was used in reinforcing all concrete piers. From each size, three samples have been tested. The tensile strength was tested according to ASTM A- 615-15[10].

2.2.7 Superplasticizer
High-range water-reducing admixture was used to produce high strength concrete (HSC) mix only, which is produced by Sika Company and known commercially as SikaViscoCrete®-5930.

2.3. Concrete mix proportions
Normal and high strength concrete mixes were used for casting pier specimens using recycled coarse aggregates at 50% replacement ratio by normal aggregates as green concrete. All concrete mixes consisted of cement, fine aggregate, coarse aggregate, recycled aggregate concrete, and water. Several empirical mixes have been carried out in the laboratory to select the final mix of (1: 1.4: 2.2) with w/c ratio of 0.43 for the normal and green concrete mix and (1: 0.97: 1.23) with w/c ratio of 0.38 for high strength mix. The green concrete mix was produced by replacement of 50% of natural coarse aggregate with recycled coarse aggregate. The mixing process was performed by using a rotary mixer of 0.1 m$^3$ and the mix proportions are shown in Table 2.

| Table 2. Mix proportions of different types of concrete. |
|-----------------------------------------------|
| Materials                        | Normal | Green concrete | High-strength |
|-----------------------------------------------|
| Cement                                   | 465    | 465          | 500          |
| Fine Aggregate                           | 651    | 651          | 485          |
| Coarse Aggregate                         | 1023   | 511.5        | 615          |
| Recycled Coarse Aggregate                | 0      | 511.5        | 615          |
| w/c                                       | 0.43   | 0.43         | 0.38         |
| Superplasticizer                         | 0      | 0            | 1            |

2.4. Casting of Concrete
All moulds were prepared and all their internal surfaces were oiled. After mixing, the concrete was poured into the moulds and the compaction was applied using an electric vibrator. After one day, the moulds were opened and the pier specimens were placed in special treatment basins.
2.5. Testing
After curing, the pier specimens transferred from the water tank. In order to clarify cracks, the surfaces have been dried and painted by white colour. To measure the deflection, the load was applied by using two points load on the specimens in which the distance from centre to centre was 450 mm.

![Deflection Gage](image)

**Figure 3.** The deflection gages and point loads for pier specimens.

![Hydraulic Testing Machine](image)

**Figure 4.** The hydraulic testing machine of concrete pier specimens.

2.6. Concrete tests

2.6.1. Compressive strength test
The compressive strength test was carried out according to ASTM C39M-05 standard test method using cylindrical specimens [11]. The cylinder was with a diameter of 100 mm and 200 mm in length to determinate the compressive strength at age 28 days.

2.6.2. Splitting tensile strength test
The splitting tensile strength was carried out according to the ASTM C496 [12]. For each mix, three cylinders with a 100 mm in diameter and 200 mm in length were used to determinate the splitting tensile strength at age 28 days.
3. Experimental results

3.1. 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 three samples were recorded to represent every single property as shown in Table 3.

| Mix Notation | $f_{c'}$ (MPa) | $f_t$ (MPa) | Absorption (%) | Density (g/cm$^3$) |
|--------------|---------------|-------------|---------------|-------------------|
| NC           | 29.5          | 3.9         | 3.7           | 2.485             |
| GC           | 29.1          | 3.5         | 4.4           | 2.343             |
| RSF          | 35.0          | 4.5         | 1.5           | 2.343             |
| HSC          | 47.2          | 5.5         | 1.8           | 2.412             |

3.2. Crack pattern and first cracking load

When the tensile stress of concrete reaches the ultimate strength, the cracks occurred in the reinforced concrete piers. Due to the applied load, different types of cracks appeared in pier specimens. These cracks include flexural, flexural shear and shear cracks. The results of all piers are presented in Table 4, which includes the first cracking load, crack width, ultimate load and the deflection at failure stage.

| Piers Notation | First crack Per (kN) | Ultimate load Pu (kN) | Crack width (mm) | Deflection (mm) |
|----------------|----------------------|-----------------------|------------------|-----------------|
| NC             | 200                  | 538                   | 2.3              | 6.6             |
| GC             | 180                  | 525                   | 3.5              | 7.8             |
| TRSF           | 238                  | 550                   | 2.2              | 5.3             |
| THSC           | 320                  | 681                   | 3.7              | 4.5             |

From the results, it can be noticed that the cracks started at the top of the pier then propagated downward and become wider with increasing the applied load. Fig. 5 shows the cracks patterns of the pier specimen.
3.3. Crack width

The propagation of cracks has been observed and the crack width was recorded for each 40 KN of specimens loading. This monitoring was continued until reaching the failure loads. Using a microscope type AEM40X with an accuracy of 0.05 mm, the crack width was determined. For NC pier, the first crack load was 200 kN with 0.1 mm wide flexural in type, which was close to the middle pier cap and it propagated from the top surface. At service load, 70% of the ultimate load NC specimen recorded a crack width of 1.22 mm at a load of 417 kN which increased to 1.33 mm at 461 kN load. Further loading to nearly 530 KN resulted in further cracks with a maximum crack width of 2.3 mm.

On the other hand, the GC specimen recorded the first crack at 180 kN with a crack width of 0.1 mm which was increased to 3.5 mm at 520 kN. For TRSF specimen, the first crack width was 0.08 mm which increased to 1.4 mm at 361 kN. The maximum crack was 2.3 mm at 550 kN. It has been noticed that the use of recycled steel fibre has minimized the crack width. HSC pier found to have a first crack width of 0.1 mm. Moreover, at 70% of the ultimate load, the width of the cracks developed to reach a value of 1.5 mm. The maximum crack width of 3.65 mm at 680.7 kN as shown in Fig. 6.

![Figure 5](image1.png)  
**Figure 5.** The Crack pattern at the failure stage of all tested piers.

![Figure 6](image2.png)  
**Figure 6.** Load-crack width curve of various tested piers.
3.4. Ultimate load and deflection

The load-deflection curves for all tested specimens are shown in Fig. 7. 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. With increasing the load, the behaviour of the samples modified from elastic to non-linear and the cracks became clear. At the third stage shear and the flexural shear, cracks continued to propagate downward and they behaved plastically, after yielding of steel reinforcement.

![Load-deflection curves](image)

**Figure 7.** Load-deflection behaviour of all tested piers.

Results showed that the failure load of the NC pier was greater than that of GC pier by 2.4% and the deflection of NC pier was lower than GC specimen by 18.5% this reduction due to the higher air content of recycled coarse aggregate in the green concrete mix. By adding recycled steel fibre the load-deflection curve and the ultimate load increased significantly due to increased stiffness. The results of such improvement showed that the ultimate load of TRSF pier was greater than those without recycled steel fibre by 4.7 %, and the deflection was less by 29.6% in comparison with GC pier. Using high strength concrete mix (HSC) has improved the mechanical and physical properties of the specimen. For THSC, (pier with high strength concrete at pier cap only), the ultimate strength was greater than GC pier by 29.7%. Also, the deflection decreased by about 43% in comparison with the GC pier. These results may be due to the effect of using high strength concrete.

4. Conclusions

This study revealed several important points in the philosophy of green concrete piers as follows:

1. The ultimate strength of the pier cast using green concrete (GC) was less than those for NC by 2.4%, which means that GC is an effective alternative to be used for structural purpose.
2. The deflection under the ultimate load of the GC pier was higher by 18.5% than that of NC pier.
3. Adding recycled steel fibre to the pier cap increased the ultimate load by 4.8%. However, it caused a decrease in the deflection by 29.6 compared to GC. Use of high strength concrete (HSC) increased the ultimate load by 29.7% while the deflection decreased by 42.9% when compared with GC pier.
4. Generally, the increase in the ultimate current capacity of all pier model was conjugated by an increase in the first crack load and a decrease in the crack width corresponding to the applied load.
References

[1] G. Fu, Bridge Design LRFD and LRFR. John Wiley & Sons, Inc., 2013.

[2] A. K. Padmini, K. Ramamurthy, and M. S. Mathews, “Influence of parent concrete on the properties of recycled aggregate concrete,” Constr. Build. Mater., vol. 23, no. 2, pp. 829–836, 2009.

[3] F. T. Olorunsogo and N. Padayachee, “Performance of recycled aggregate concrete monitored by durability indexes,” Cem. Concr. Res., vol. 32, pp. 179–185, 2002.

[4] S. Hasaba, M. Kawamura, K. Toriik, and K. Takemoto, “Drying shrinkage and durability of the concrete made of recycled concrete aggregate,” Trans. Japan Concr. Inst., vol. 3, pp. 55–60, 1981.

[5] N. Su and B. L. Wang, “Study on the engineering properties of recycled aggregate concrete and recovered aggregate from demolished concrete,” J. Chinese Inst. Civ. Hydraul. Eng., vol. 12, no. 3, pp. 435–444, 2000.

[6] S. Frondistou-Yannas, “Waste concrete as aggregate for new concrete,” in Journal Proceedings, 1977, vol. 74, no. 8, pp. 373–376.

[7] C. De Pauw, “Fragmentation and recycling of reinforced concrete some research results,” in Adhesion problems in the recycling of concrete. Springer, pp. 311–319, 1981.

[8] Iraqi Specification, No. 5/1984, “Portland Cement”.

[9] Iraqi Specification, No. 45/1984, “Aggregate from Natural Sources for Concrete and Construction”.

[10] ASTM A615/A615M-15a, “Standard Specification for Deformed and Plain Billet-Steel Bars for Concrete Reinforcement,” ASTM Int., 2015.

[11] ASTM C39/C39M-05, “Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens,” ASTM Int., p. 8, 2004.

[12] ASTM Standard C496, “Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens,” ASTM Int., pp. 1–5, 2004.