



Research Article

Effect of waste steel tire wired concrete on the mechanical behavior under impact loading

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ABSTRACT

In this experimental study the effect of waste steel tire wire was investigated on the concrete bollards of mechanical behavior under impact loading. Concrete bollards were produced using three different dimensions with three different volumes of waste steel tire wire (0%, 5% and 10%). The concrete was 30 MPa strength. The concrete bollards were cast into molds with a size of 100x100 mm, 150x150 mm and 200x200 mm and standard length of 1100 mm prism. Nine cube specimens of three different dimensions are tested. 84 kg of an impact load is used with the drop height of 400 mm in this study. Compressive strength tests were achieved. Concrete bollards were kept in laboratory standard conditions. According to the results of study compressive strength of the concrete vary between 25-30 MPa. The use of waste steel tire wire in the concrete bollards contributes to the less crack, less deflection, more acceleration and more energy dissipation at the end of the specimens. The experimental test aimed to research the effect of waste steel tire wired concrete on the mechanical behavior under impact loading as a possible environmentally friendly and sustainable solution. It can be said that the results provide the potential usage of waste steel tire wire manufacturing friendly to nature and sustainability of the concrete bollards. Generally, the usage of waste steel tire wire in concrete could be an innovative method in the construction industry.

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1. Introduction

Rapid technological developments, industrialization and population growth made the humankind face to face with problems that have not encountered before, very quickly. The increment in the amount of waste product is one of the important consequences of this. With the increment in the amount number of wastes, the rapid pollution of nature and the environment threatens bios in terms of health. For this reason, researches on recycling of wastes are intensively carried out and implemented. Significant achievements can be acquired by recycling waste tires that have reached the end of span. Protecting the nature and keeping it clean is the most important achievement. The product with high added value obtained by recycling can be used as a raw material in the production of different products. With the decrease in

imports, it can be beneficial to close the current account deficit and to employment by creating a new business branch.

It is the main duty of humankind to leave a cleaner, more sustainable environment and nature to posterity. Developed countries constitute millions of waste tires every year in consequence of the rapid enhancement of vehicles. Approximately 1.4 billion tires are sold out globally every year and accordingly many of them fall into decay and became waste. These tires waste generate one of the most important problems of waste, as it is large in volume and because of their durability (Lo Presti 2013). By recycling waste tires, rubber and steel wire can be obtained.

Concrete which has low tensile strength but on the contrary, high compressive strength is a well-known building material. In order to improve these properties,

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lots of researches have been done and new components have been developed. The most common is fiber-reinforced concrete. The idea of using fibers is to increase the tensile strength of concrete by enhancing the load bearing capacity by bridging cracks. It has been proved that the usage of steel fibers controls the crack attitude and changes it to ductile (Faghiih 2017). The main purposes of modern engineers by adding fiber to concrete can be written as to improve the plastic crack properties of fresh concrete, tensile and flexural strengths, impact strength and toughness, and durability of concrete. It is also to control the failure mode and crack formation with post-crack ductility (Hannat 2003). Recently, many researches about the usage of rubber and steel wires recycled from waste tires in concrete have been done. It has been proven that the concrete acquired by adding waste steel tire wires has acceptable improvements especially in toughness and post-crack behavior. Consequently, waste steel tire wired concrete seems to be a promising candidate for both structural and non-structural executions (Aiello et al. 2009).

Zeynal (2008) conducted an experimental study to investigate the effect of steel fiber and water/cement ratios on the impact strength and mechanical properties of steel fiber concrete. With the usage of only 0.4%, 0.8% and 1.2% long steel fibers by volume in concrete; it can be increased by 2% to 10% in compressive strength, 13% to 42% in split tensile strength, and 14% to 115% in flexural strength. He concluded that an increase in the value of impact number that causes fragile ranging from 3.5 to 23.9 times to be obtained. Şengül (2016) researched to examine the mechanical properties of concrete containing steel wires obtained from waste tires. Concrete was produced by using different ratios of steel fibers obtained from waste tires with an average diameter of 0.3, 0.6, 1.4 mm and an average length of 5 cm. It was observed that the splitting tensile strength slightly increased as the steel wire content increased. The use of steel wires obtained from waste tires in concrete did not significantly affect the compressive, flexural and splitting tensile strength of the concrete. Concrete containing steel wires recovered from waste tires show the similar behavior in the descending part of the load-deflection curves that is of residual strength and toughness, compared to concrete containing standard steel fibers acquired in bending. Test results showed that steel wires recycled from waste tires can be used in concrete instead of standard steel fibers. Senesavath's (2021) experimental study investigated the effect of steel wires recycled waste tire on concrete properties. By using the waste steel tire wire, a more ductile behavior was obtained after the first crack formation and an increase in energy absorption capacity was observed. Flexural toughness showed an increasing trend with the addition of waste tire steel wire. Siraj (2009) investigated the mechanical behavior of steel wire obtained from waste tires in concrete. The experimental study used 0.5, 1.0 and 1.5% waste steel tire wire by volume. The test specimens were produced in the dimensions of 150 mm cube specimen, 150 mm diameter with 63.5 mm height cylindrical specimen and 100x100x500 mm beam. With the addition of steel wire recycled waste tire, enormous in-

creases in the flexural strength and post-crack energy absorption capacity of concrete were achieved. In addition, it was observed that the first crack and final failure impact strength increased significantly in the repeated drop weight test. Mastali (2018) conducted a study in which the properties of steel wire recycled waste tire concrete were determined. In the experimental study, samples with varying fiber content by volume (0.5, 0.75, 1.0, and 1.5) were produced. When examining the first crack and the final crack resistance depending on the waste steel tire wire usage, the impact resistance increases by creating bridging. In addition it is stated that waste steel tire wire gives the superlative productivity when compared to industrial steel fibers in terms of the optimum mechanical properties, impact resistance and minimum cost. And also Mastalli (2019) conducted another study on high-strength concrete in which the effects of steel wire recycled waste tire were compared. The experimental study has a miscellaneous comparison that as the volume of waste steel tire wire increases, the initial impact resistance, the final impact resistance, the drop weight number after crack initiation until failure, the deformation ability, the energy absorption capacity, and the impact energy increase.

The data obtained from the experimental study on the effect of waste tire steel wire by recycling waste tires under impact loading of concrete are examined in this article. There are lots of studies about industrial steel fiber or steel wire recovered from waste tire on concrete, but a few about impact loading or blasting. In this research paper on concrete bollards that are often faced to impact loading, differently from other researches, waste steel tire wire is added for the purpose of examine impact loading.

2. Experimental Study

A total of 9 square based prismatic concrete specimens, with and without waste steel tire wire were designed for impact load. The specimens represent a prototype of concrete bollards that help guide traffic flow of vehicular. These concrete bollards are characterized by low to moderate waste steel tire wire by ratio and cross section. Geometry and waste steel tire wire ratio details of the specimens indicated in Table 1. All the specimens had 1100 mm height. The columns were divided into three sets. All sets had three specimens. Each set had a square cross section of 100 mm, 150 mm and 200 mm by respectively. All the collected data were achieved with the help of LabView SignalExpress program by National Instruments during the experimental study. Also all the collected data processed with the help of DIAdem program by National Instruments.

2.1. Materials

Three types of concrete mix with waste steel tire wire were used with volume ratio of 0%, 5% and 10% for the concrete bollards. The steel wire was obtained from waste tire is shown in Fig. 1. The waste steel tire wire were added to the concrete mixing machine by desired

volume ratio and waited three minutes for an adequate mixture in each time. Then by sufficient time for curing and gaining strength, all the testing of specimens was completed in 7 days. Two piece of 150 mm test cubes were used to obtain the cube strength of concrete for specimens and the mean strength was recorded 30 MPa. The cubes were tested at the age of 28 days, at the same time first specimen was tested in the laboratory. Because of understanding the effect of steel wire recovered waste tire, three concrete mix (0%, 5% and 10%) used for concrete bollards.

2.2. Method

A total of 9 square based prismatic specimens were casted using appropriate moulds and prepared at the same time. The columns were divided into three sets. All sets had the ratio of the area of longitudinal steel bar to the area of the specimen same as 0.5%. The concrete cover was provided in all the columns 8 mm. The concrete thickness of about 50 mm was cast between ends of the longitudinal bars on both the top and bottom surfaces of the specimens. The specimens cured in the la-

boratory conditions. Three different types of specimens for tests were casted in 100x100 mm, 150x150 mm and 200x200 mm cross section area and the length of 1100 mm were produced. The casting and concreting of the concrete bollards are shown in Fig. 2. Three different cross section and three volume of waste steel wire, nine specimens were produced.



Fig. 1. Waste steel tire wire sample used for tests.



Fig. 2. Appearance of the concrete bollards while casting and concrete working.

Table 1. Properties of the test specimens.

Specimen	Cross-section (mm ²)	Length (mm)	Waste steel ratio (%)
C10x10-0S	100x100	1100	0
C10x10-5S	100x100	1100	5
C10x10-10S	100x100	1100	10
C15x15-0S	150x150	1100	0
C15x15-5S	150x150	1100	5
C15x15-10S	150x150	1100	10
C20x20-0S	200x200	1100	0
C20x20-5S	200x200	1100	5
C20x20-10S	200x200	1100	10

The experimental setups of impact loading with the drop weight machine are shown in Fig. 3. The experimental setup of drop weight machine was manufactured to research the impact loading test of specimens. After the amount of load determined for the experimental study is adjusted, the load hits the determined area of the

sample by making a free fall motion on a rail. This study uses an impact load of 84 kg with the drop height of 400 mm. The accelerometers, LVDTs and load cell are also shown in Fig. 3. With the specially designed supports for the concrete bollard sample, it is ensured that the element act as cantilever for this experimental test.



Fig. 3. Set-up for the impact loading test.

3. Results and Discussion

3.1. Displacement – time graphs assessment

The displacement time graphs of the concrete bollards were acquired from the LVDTs at the right and left end sides of the specimen. The maximum deformations of the concrete bollards under impact loading were obtained 60.72 mm, 59.10 mm and 57.10 mm for 100x100 mm cross section of the specimens. Similarly, 22.83 mm, 22.30 mm and 19.80 mm for the 150x150 mm cross section specimens and 10.80 mm, 10.50 mm and 9.20 mm for the 200x200 mm cross section specimens (by respectively %0, %5 and %10 waste steel tire wire ratio). The maximum deformation of the concrete bollards under impact loading decreased by 6% to 15% depends on the waste steel tire wire content by volume. And also, the maximum deformation of the concrete bollards under impact loading increased depends on the cross section decreased. The experimentally obtained maximum deformations at the end of the concrete bollards versus steel ratio are given in Fig. 4. Maximum deformations of cross section 200x200 mm concrete bollards are very small and these are mostly elastic deformations and a

low part of it is plastic. However while the cross section of the concrete bollards under impact load decreased, deformations are ascended which mostly plastic deformations and a low part of it is elastic.

The residual deformations of the concrete bollards under impact loading were obtained 54.15 mm, 51.69 mm and 48.66 mm for 100x100 mm cross section of the specimens. Similarly, 14.11 mm, 13.27 mm and 11.80 mm for the 150x150 mm cross section specimens and 1.23 mm, 1.13 mm and 0.92 mm for the 200x200 mm cross section specimens (by respectively %0, %5 and %10 waste steel tire wire ratio). The residual deformation of the concrete bollards under impact loading decreased by 10% to 25% depends on the waste steel tire wire content by volume. And also, the residual deformation of the concrete bollards under impact loading increased depends on the cross section decreased. The experimentally obtained residual deformations at the end of the concrete bollards versus steel ratio are given in Fig. 5.

According to these results, the maximum deformation of concrete bollards decreases as the waste steel tire wire ratio increases. Thus, as their capacity increases, they have more ability of deformation. They have a greater impact load carrying capacity.

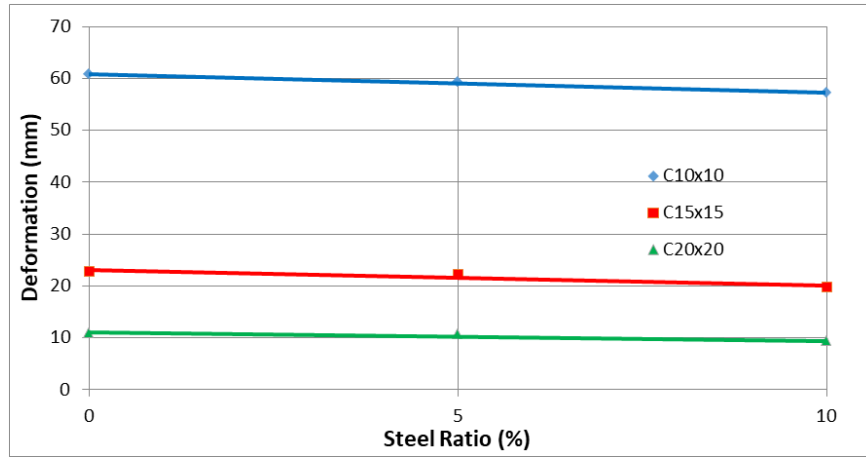


Fig. 4. Maximum deformation – steel ratio relationship obtained experimentally under impact loading.

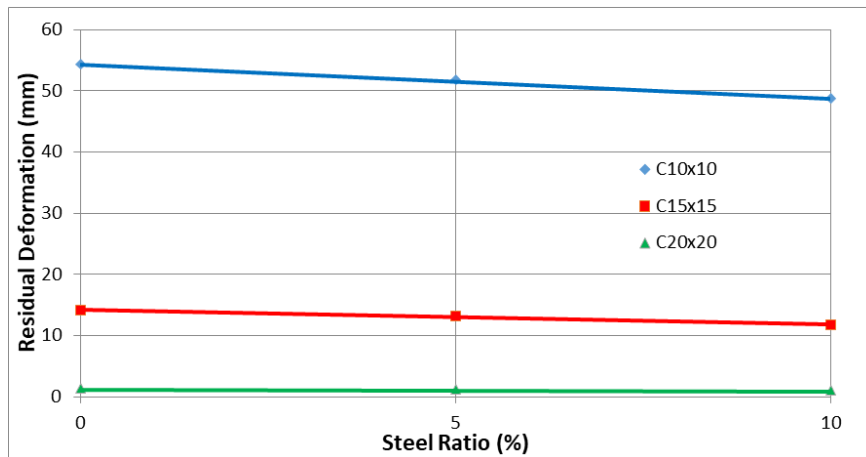


Fig. 5. Residual deformation – steel ratio relationship obtained experimentally under impact loading.

Displacement - time graphs of the concrete bollards according to waste steel tire wire ratio for all sections separately are given in Fig. 6. And also for all sections displacement versus time graphs are given below in Fig. 7.

3.2. Acceleration – time graphs assessment

The acceleration time graphs of the concrete bollards were acquired from the accelerometers at the right and left mid sides of the specimen. The maximum acceleration of the concrete bollards under impact loading were obtained 53.3, 59.6 and 64.9 g for 100x100 mm cross

section of the specimens. Similarly, 81.6, 87.0 and 93.9 g for the 150x150 mm cross section specimens and 98.5, 106.2 and 113.1 mm for the 200x200 mm cross section specimens (by respectively 0%, 5% and 10% waste steel tire wire ratio). The maximum acceleration of the concrete bollards under impact loading increased by 6% to 17% depends on the waste steel tire wire content by volume. And also, the maximum acceleration of the concrete bollards under impact loading increased depends on the cross section increased. The experimentally obtained maximum accelerations at the end of the concrete bollards versus steel ratio are given in Fig. 8.

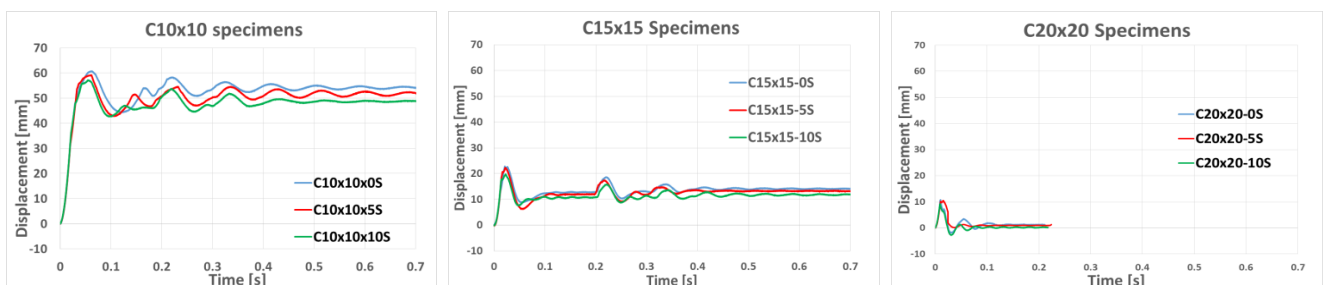


Fig. 6. Displacement – time graphs of the concrete bollards under impact loading.

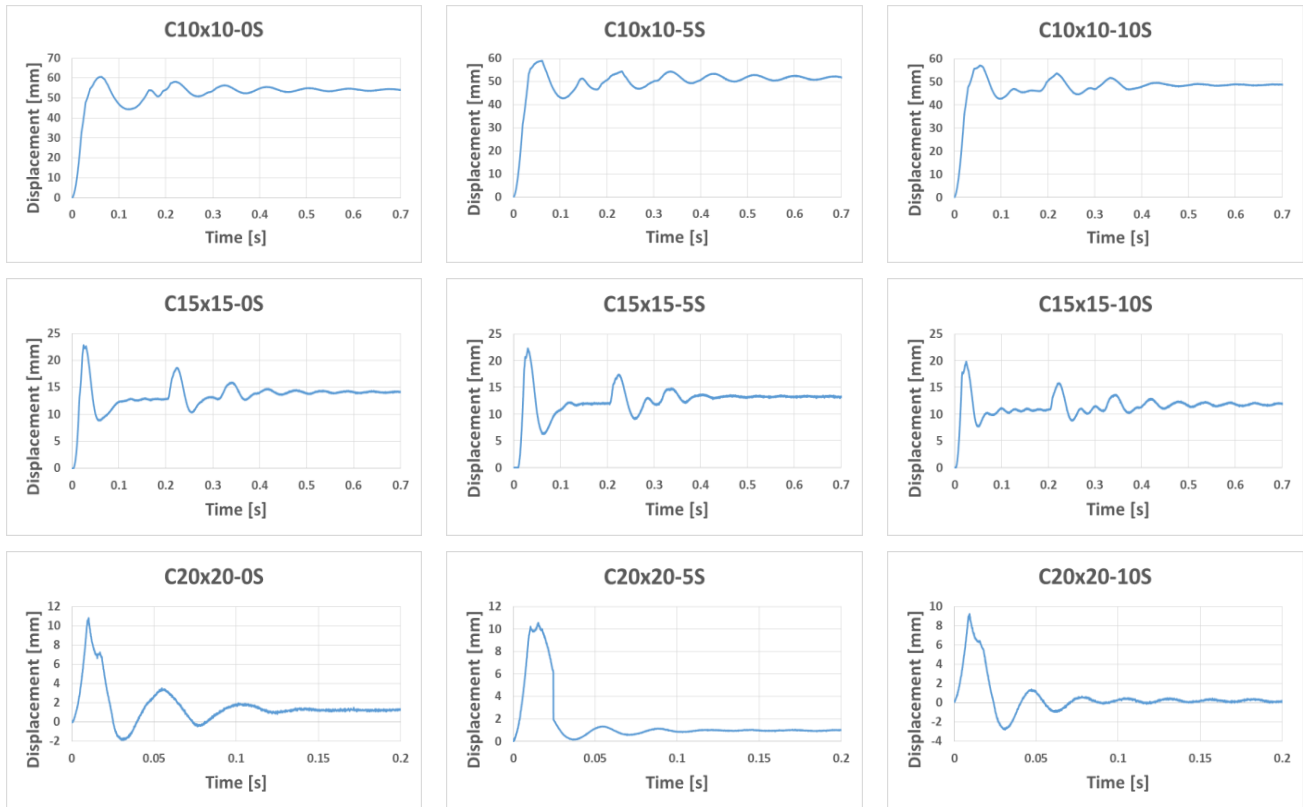


Fig. 7. Displacement – time graphs for all of the concrete bollards under impact loading.

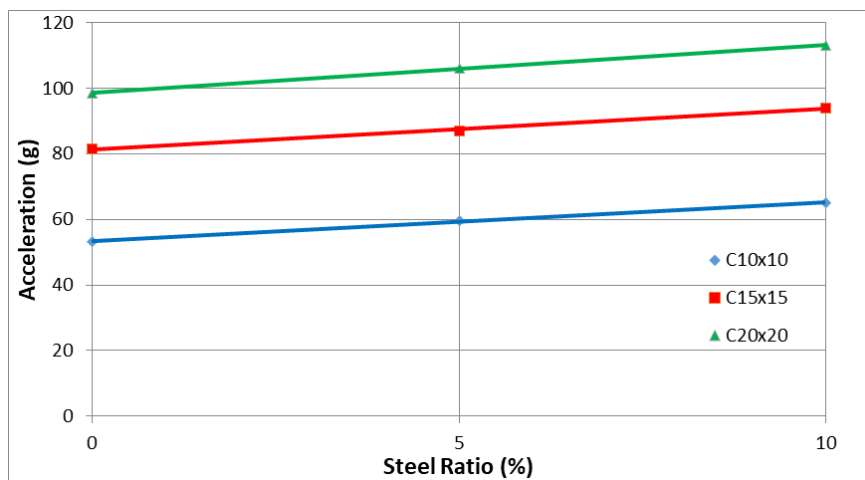


Fig. 8. Maximum average acceleration – steel ratio relationship obtained experimentally under impact loading.

Acceleration versus time graphs of the concrete bollards for all sections are given in Fig. 9.

3.3. Impact load – time graphs assessment

The impact load versus time graphs of the concrete bollards were acquired from the load cell on the top side of the specimen end. The impact load of the concrete bollards all exhibits a similar pattern with an initial peak point. Similarly, the initial peak is considerably bigger than subsequent peaks. The experimentally obtained impact load versus time graphs on the top side of the con-

crete bollards end are given in Fig. 10.

3.4. Deformation

The impact failures and the crack progressives of the 100x100 mm cross section specimens (by respectively 0%, 5% and 10% waste steel tire wire ratio) are given in Fig. 11. Whole crack initiation region is the support region of the concrete bollards. The crack size decrease with the waste steel tire wire ratio increase. It can be explained with the formation of crack bridges with the help of the steel wires and they slow down the crack.

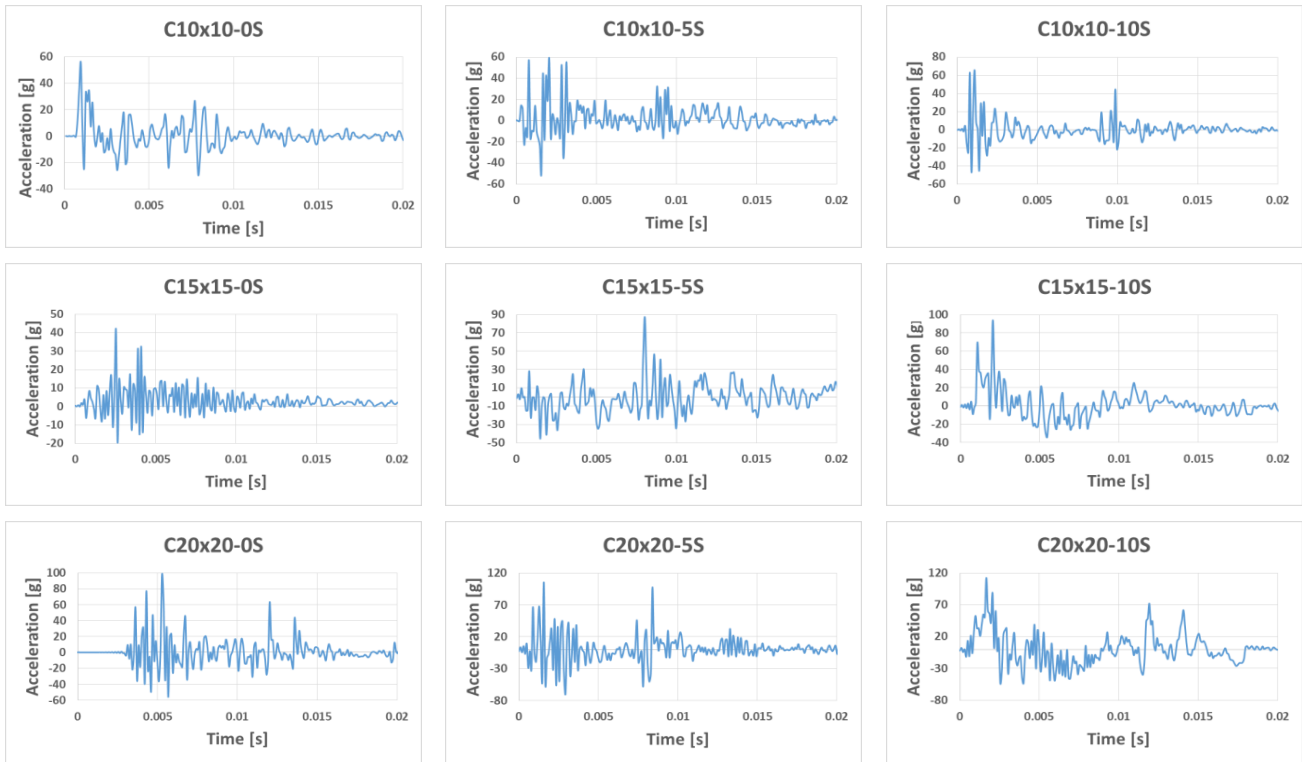


Fig. 9. Acceleration – time graphs for all of the concrete bollards under impact loading.

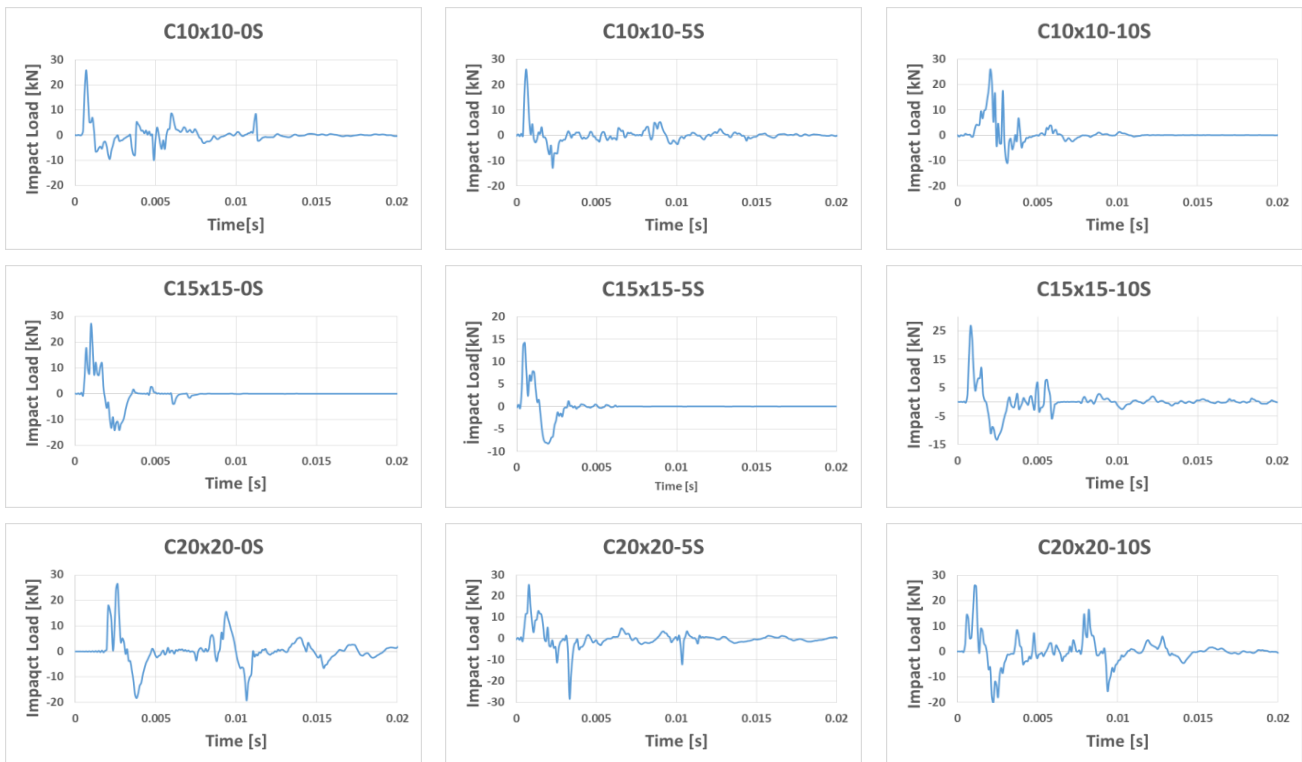


Fig. 10. Impact load – time graphs for all of the concrete bollards under-impact loading.

The impact failures and the crack progressives of the 200x200 mm cross section specimens (by respectively 0%, 5% and 10% waste steel tire wire ratio) are given in Fig. 12. Crack initiation region is the support region of the concrete bollards as the same with other cross section specimens. The crack size decrease with the waste

steel tire wire ratio increase. It can be explained with the formation of crack bridges with the help of the steel wires and they slow down the crack.

Experimentally obtained results such as maximum deformation, residual deformation, maximum impact load and maximum average acceleration are given in Table 2.



Fig. 11. Failure of the C100x100 concrete bollards under impact loading.

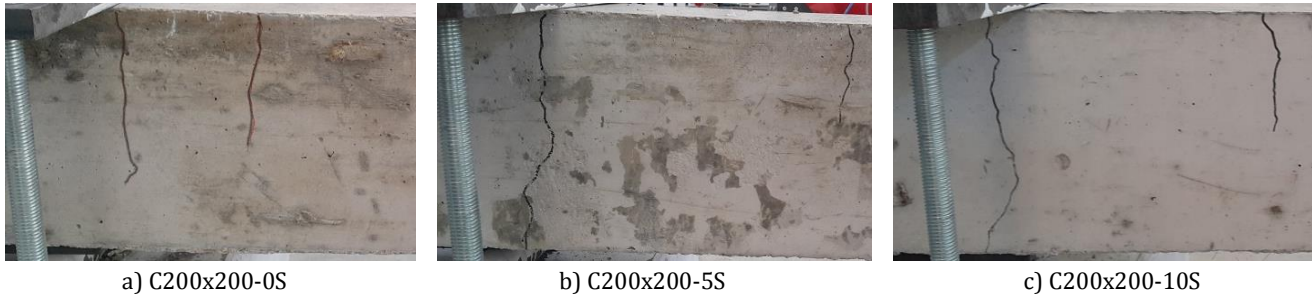


Fig. 12. Failure of the C200x200 concrete bollards under impact loading.

Table 2. Experimentally obtained test results.

Specimen	Maximum deformation (mm)	Residual deformation (mm)	Maximum impact load (kN)	Maximum average acceleration (m/sn^2)
C10x10x110R-%0S	60.72	54.15	25.86	53.3
C10x10x110R-%5S	59.10	51.69	25.92	59.6
C10x10x110R-%10S	57.10	48.66	26.02	64.9
C15x15x110R-%0S	22.83	14.11	26.79	81.6
C15x15x110R-%5S	22.30	13.27	14.16	87.0
C15x15x110R-%10S	19.80	11.80	26.68	93.9
C20x20x110R-%0S	10.80	1.23	26.45	98.5
C20x20x110R-%5S	10.50	1.13	26.40	106.2
C20x20x110R-%10S	9.20	0.92	26.01	113.1

4. Conclusions

The conclusions of this experimental study that investigated effect of waste steel tire wired concrete on the mechanical behavior under impact loading are summarized below.

- Specifications of the waste steel tire wires may not be equal such as thickness and length of wires. Steel wires recovered from waste tires also have some shredded rubber particulars in content. One more process may be useful to ensure the homogeneous and standardization of the steel wires recovered from waste tires.
- The maximum deformation of concrete bollards decreases as the waste steel tire wire ratio increases. Thus, as their capacity increases, they have more ability of deformation. They have a greater impact load carrying capacity.

- As the added volume of the steel wires recovered from waste tires increases, the workability decreases.
- Promising results are obtained by adding steel wires recycled from waste tires to concrete bollards, in terms of impact resistance,
- In terms of sustainability and a cleaner nature for posterity, recycling should be increased in our lives.

The experimental test aimed to research the effect of waste steel tire wired concrete on the mechanical behavior under impact loading as a possible environmentally friendly and sustainable solution. It can be said that the results provide the potential usage of waste steel tire wire manufacturing friendly to nature concrete bollards. Utilization of waste steel tire wire contributes to the sustainability of the concrete bollards. And also it is possible to enhance the productivity with more research. The effect of waste steel tire wire alignment during placing can be considered for further investigation. The more waste

steel tire wire ratio can be studied for better applicability and acceptability of this material. Since concrete bollards can be exposed to aggressive environmental conditions, their durability should also be considered in future studies. It also needs to be investigated under dynamic and static loading conditions. Generally, the usage of waste steel tire wire in concrete could be an innovative method in the construction industry.

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Conflict of Interest

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