Proceedings of the 9th International Conference on Civil Structural and Transportation Engineering (ICCSTE 2024)
Chestnut Conference Centre - University of Toronto, Toronto, Canada – June 13-15, 2024
Paper No. 225
DOI: 10.11159/iccste24.225

Experimental Investigation Of The Impact Performance Of Bridge Traffic Barriers Made Of Rubberized Fiber-Reinforced Concrete And Stainless Steel Bars

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Abstract – Similar to steel-reinforced concrete structures, traditional concrete bridge barriers reinforced with steel bars suffer a common problem which is the corrosion of steel reinforcement and related deteriorations which shorten their service life. The maintenance, rehabilitation, and replacement of existing bridge barriers suffering from steel corrosion are very costly. This paper proposes durable and crash-worthy rubberized fiber-reinforced concrete (RuFRC) bridge barriers incorporating synthetic macro-structural fibers made of recycled plastics and waste tyre rubber shreds and reinforced with stainless steel reinforcement bars to improve corrosion resistance. This study reports a series of tests carried out on the impact performance of the proposed crash barriers using pendulum tests replicating the vehicle impact load scenarios. The bridge barriers were made of 1% macro-synthetic fibers whereas the rubber shreds were used to replace coarse aggregate by 12%, 18%, 24% and 30%. The effects of various rubber percentages and the impact speed on the impact performance of the proposed bridge barriers are examined. It is found that increasing rubber percentages increases the displacement of the barriers, with a maximum 80% increase in the displacement observed in comparison to the control specimen when 24% rubber is used. The energy absorption capacity of the RuFRC barriers is found to be higher than the conventional control bridge barrier.

Keywords: *Rubberized concrete; fiber-reinforced concrete, bridge barriers, corrosion, impact performance.*

1. Introduction

Steel reinforcement bars are commonly used in reinforced concrete (RC) structures including traffic bridge barriers. Like all RC structures, bridge barriers suffer from reinforcement corrosion, alkali-silica reaction, cracking due to plastic and drying shrinkage of concrete and carbonization-related deterioration when exposed to a harsh environment, as shown in Figure 1. Since their first development in the 1970s, epoxy-coated reinforcement bars have been widely used to protect reinforcement bars from being corroded. However, the unsatisfactory performance of such epoxy-coated reinforcement bars due to corrosion was first reported as early as 1986 in Florida bridges in the USA and some other bridges, particularly in bridge barriers in the USA and Canada in the 1990s [1, 2]. An investigation conducted by the Ontario Ministry of Transportation (MTO) in Canada found that the reinforcement bars lost their epoxy coating after several years, leading to corrosion-related deterioration in the bridge barriers which shortened their service life [3]. Based on their finding, MTO, later on, banned the use of epoxy-coated reinforcement bars for the application of bridge barriers. Due to the geographic location, Australian infrastructure suffers a greater degree of corrosion problems.

Due to their excellent corrosion resistance, glass fiber-reinforced polymer (GFRP) bars were proposed as reinforcement bars to improve the corrosion resistance of bridge barriers [4-8]. However, the cost of high-modulus GFRP bars is significantly higher thus the construction of such a barrier is still expensive. In addition, the current bridge barrier design uses yield line analysis theories to determine the flexural capacity of barriers. Considering that GFRP bars behave elastically until failure, the barrier failure mode may shift from yield-line flexural failure to punching shear failure thus the concept of the yield line theory may not apply to barriers with GFRP bars [7].

Synthetic macro-fibers are made of carbon, acrylic, polyolefin or aramid and can be virgin and recycled polypropylene (PP), polyethylene terephthalate (PET) fibers or high-density polyethylene (HDPE). Synthetic macro-fibers decrease the width of the cracks in concrete, thus, preventing water from entering into the concrete matrix and corroding the reinforcement bars [9]. In addition, macro-fibers prevent crack tip propagation, thus, eliminating most micro-cracks. By effectively controlling and arresting cracks in concrete, macro-fibers prevent plastic and dry shrinkage of concrete and retain its integrity of the concrete. Macro-fibers also improve the post-cracking performance of concrete. Polypropylene (PP) is one of the most used plastics in our modern civilization, widely used in packaging, stationery and automotive components to name a few. Macro-fibers made of PP have higher resistance against the alkaline environment as well as have higher tensile strength and elastic modulus; however, offer ease of production and lower cost to manufacture.

Polymeric waste such as tyre rubber is another environmental issue the world is currently facing. Around 1000 million tyres reach the end of their service life each year among which a significant amount ends up in a stockpile or landfill such as 3000 million in the EU, and 1000 million in the USA [10]. Tyre landfilling is a great ecological concern due to the toxic and soluble materials it contains. Significant research was performed to investigate the applications of waste tyre rubber in civil engineering applications as an aggregate replacement. Chipped rubber produced from the waste tyre can be used as coarse aggregates whereas crumbs rubber can be used as fine aggregates. Existing test results show that the inclusion of tyre rubber in concrete increases the energy dissipation of the concrete beams under dynamic loading [11]. Literature research also indicates that rubberized concrete has better durability than traditional concrete [12]. Rubber-based FRC bridge barriers will improve durability and will increase the energy absorption capacity of the barriers. In addition, stainless steel has superior corrosion resistance thus, together with the synthetic macro fibers can effectively provide long-term resistance to the chloride-induced corrosion problem associated with traditional reinforced concrete bridge barriers. Considering that the 0.2% proof stress of stainless steel is widely accepted as the yield strength, the specifications of the yield line theory applied in the current standardized bridge barrier design can be directly applicable to the rubber-based FRC bridge barriers made of stainless steel bars.

This paper develops durable and crash-worthy rubberized fiber-reinforced concrete (RuFRC) bridge barriers incorporating synthetic macro-structural fibers made of recycled plastics and waste tyre rubber shreds and reinforced with stainless steel reinforcement bars to improve corrosion resistance. The impact performance of proposed bridge barriers is studied using pendulum tests replicating the vehicle impact load scenarios. The bridge barriers were made of 1% macro-synthetic fibers whereas the rubber shreds are used to replace coarse aggregate by 12%, 18%, 24% and 30% of the fine aggregates by volume. The effects of various rubber percentages and the impact speed on the impact performance of the proposed bridge barriers are examined.

2. Experimental Program

2.1. Details of the specimens

A total of 5 specimens were tested to study the effects of fiber and rubber percentages on the impact performance of RuFRC bridge barriers. All the specimens except the control specimen had the same 1% fiber dose in the concrete mix design and 304/304L grade stainless steel bars having 0.2% proof strength of 674 MPa and tensile strength of 752MPa were used to reinforce the barrier walls. However, the rubber percentages varied from 12%, 18%, 24% and 30% to replace coarse aggregates. The control specimen had no fiber in the mix design and conventional deformed carbon steel bars having yield strength of 530 MPa and tensile strength of 664 MPa were used to reinforce the barrier wall. The design and layout of the reinforcement bars of the tested barriers are given in Fig, 1. It should be noted that the size and layout of the reinforcement bars used in the barrier wall were the same for the control and RuFRC bridge barriers to be consistent for comparison purposes. The deck of all barriers was cast using a regular 25MPa concrete premix. It should be noted that the slab did not include any rubber or fibers.

The concrete mix design was provided by Flexiroc Australia and was mixed in a concrete plant and delivered to the sites on the day of casting. Ordinary Portland Cement (OPC), fine sand, coarse aggregates,water-to-cement ratio and water reducer were used according to the mix design. Synthetic macro fibers made of recycled plastics called 'eMesh' having a minimum tensile strength of 350 MPa and fiber length of 47 mm were used. The rubber shreds were sourced from the waste tyres supplied by Flexiroc Australia. A vibrator was used to vibrate the samples to ensure proper compaction. The compressive strength of concrete was measured using cylindrical samples of 100mm × 200mm cast at the same time as the testing specimens. It should be noted that the slab of all barriers was cast at the same time, 7 days earlier than casting the barrier walls. The cylinders and barriers were then cured for 24 hours before removing the molds and formwork and left at normal temperature to cure for 28 days before testing. The compressive strength of concrete with rubber percentages of 0%, 12%, 18%, 24% and 30% was measured as 65, 56, 32.3, 41.2 and 27.8 MPa. It should be noted that all the mix design was targeted for a slump over 100mm. However, the delivered concrete mix batch with 24% rubber had a lower slump (40mm) than the designed resulting in higher compressive strength.

In the naming of the specimens, CB refers to crash barrier followed by the number which represents the number of fiber doses used (0 for control, 1% for others). The last number in the naming of the specimens refers to the percentage of rubber shreds used to replace the coarse aggregate.

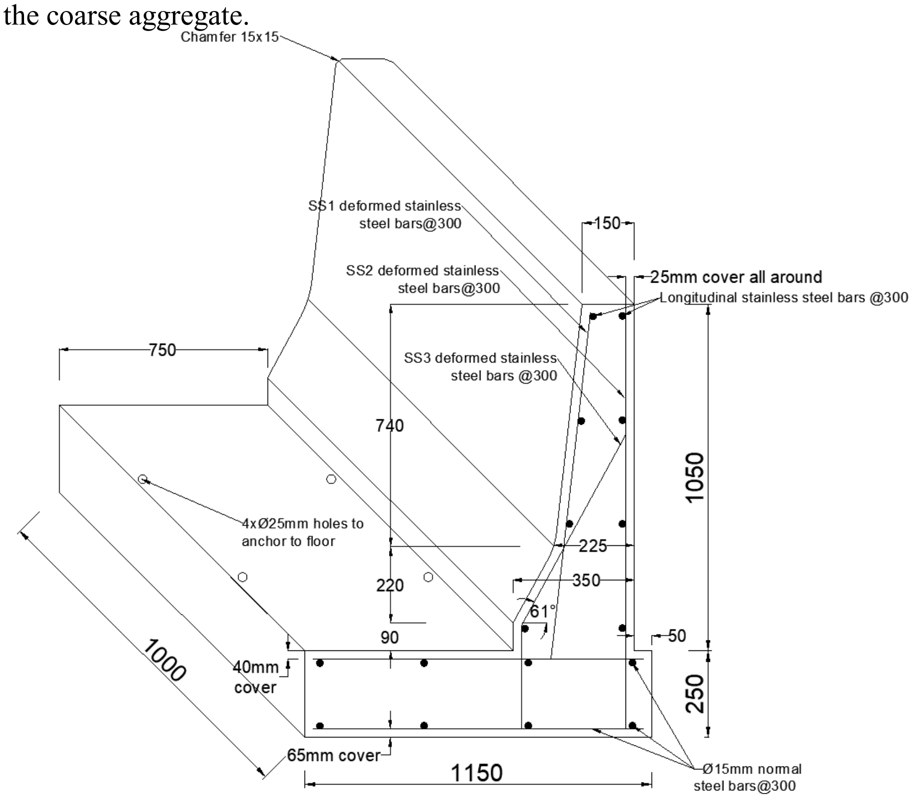


Fig 1. Layout of steel reinforcements in tested bridge barriers.

2.2. Test setup

The impact performance of the proposed crash barriers was examined using pendulum tests replicating the vehicle impact load scenarios. The barrier was fixed to the strong floor through the barrier's slab using two RHS sections as shown in Fig. 2. The pendulum impact rig has a 550 kg impactor. The barriers were subjected to two consecutive impact forces of a 20^{o} (first impact) and 30^{o} release angle (second impact). The design velocity of the impacts was measured using high-speed camera processing. Table 1 shows the measured velocity of the impacts for different barriers. A 500 mm long 100×4 SHS was attached to the pendulum lever arm to distribute the impact load. A 500kN load cell was used to record the impact forces. Two LVDTs were placed behind the barrier wall to measure the displacement (see Fig. 2b) due to the impact at the height of the strike (1000mm from the ground) and at the top edge of the barrier wall (1160 mm from the ground). A high-speed camera (Photron FASTCAM) was used with a frequency rate of 10,000 frames per second to recordthe impact and deformation. Two tracking points were used along the side of the barrier to track the displacement at the heights of the LVDTs.

Table 1: Measured velocities at impact.

Specimen	Measured Velocity (m/s)	
	First Impact (20^{o})	Second Impact (30^{o})
CB-00-00	1.84	2.62
CB-01-12	1.54	2.51
CB-01-18	1.79	2.46

CB-01-24	1.62	2.33
CB-01-30	2.05	2.91

(a) Front (b) Back

Fig. 2: Test setup of the RuFRC bridge barriers under impact loading.

3. Test results and discussions

The impulse of each impact test as well as the energy absorption of the tested barriers were determined as the area under the force-time curves recorded during the test. Table 2 summarizes the peak impact force, impulse, peak displacement and residual displacement of each test recorded during the test. It can be observed that the energy absorption capacity of the rubberized barriers was higher than the control barrier. The increase of the energy absorption for barriers with rubber percentage was calculated as high as 147% for the first impact load and 294% for the second impact load when compared with the control barrier.

Table 2: Summary of test results.

Specimen	Release Angle (°)	Impulse (kN-ms)	Peak Impact Load (kN)	Maximum Displacement (mm)	Residual Displacement (mm)	Energy Absorption (J)
CB-00-00	20	1485.91	181.08	8.28	1.88	102
	30	2055.73	311.67	12.79	2.71	186
CB-01-12	20	1732.33	185.19	10.73	-0.95	120
	30	2882.24	300.43	18.20	5.20	404
CB-01-18	20	2074.19	196.64	12.02	4.94	252
	30	3208.99	330.15	19.29	10.40	533

CB-01-24	20	2843.51	228.84	11.36	3.25	250
	30	4364.53	354.78	23.07	11.41	732
CB-01-30	20	1567.89	175.70	10.51	2.93	117
	30	2048.51	285.44	17.38	6.13	219

There was no damage on the barriers' walls observed during the test under different impact loads (see Fig. 3b). This is due to the distribution of the load through a 500mm long 100×4 SHS, as this prevented the formation of localized cracking at the point of impact. However, cracks on the slabs were observed for CB-01-18 and CB-01-24. This can be due to the formation of cold joints, as the slab and barrier wall were cast at separate times. In addition, all samples showed damage in the wall-slab interface with all samples displaying a crack width of approximately 1.5mm due to the formation of cold joints as can be observed in Fig. 4.

Figure 5 shows the impact forces of the tested barriers under different impact loading. It can be seen that the impact force profile of all the barriers was very similar where an impact force peak was followed by a force plateau. It can be seen that CB-01-24 exhibited the highest peak values (228.84kN and 354.78kN respectively). This is likely due to the stiffer nature of the concrete mix used to cast this barrier.

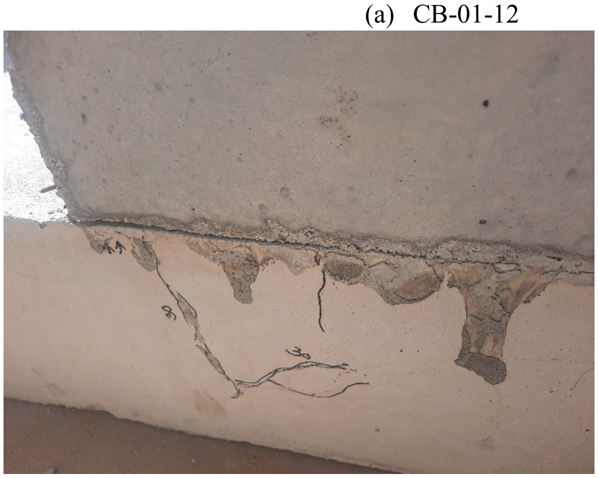
The displacement responses of the tested barriers under different impact loading are shown in Figs. 6 and 7. As expected, the displacement was higher for the top location compared to the actual impact location. Furthermore, the displacements were higher for the 2nd impact due to the increased accumulative impact energy. It can be seen that all the RuFRC barriers exhibited higher displacement under different impact loading when compared with the control barrier. It was observed that for the 1st impact, all RuFRC barriers exhibited a very close displacement response. However, CB-01-24 exhibited higher displacement for the 2nd impact load. The rate of the increase of the displacement of CB-01-24 was 80% compared to the control barrier. Overall, it is found that the RuFRC barriers can be more flexible than the traditional concrete barriers under impact loading.

(a) crack on deck (b) impact region on the barrier wall

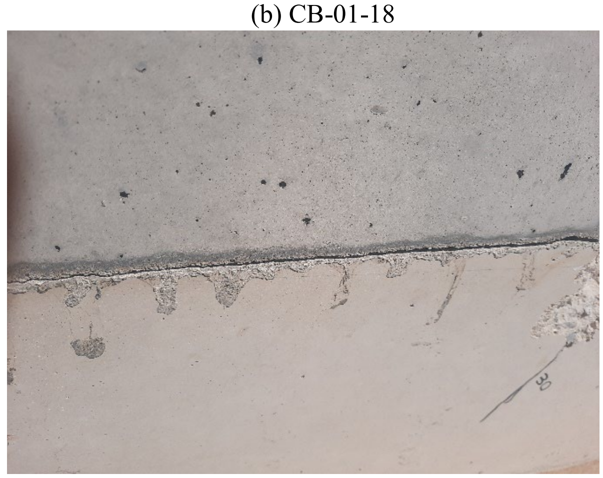
Fig. 3. Failure models of control bridge barrier.

(a) CB-01-12

(b) CB-01-18

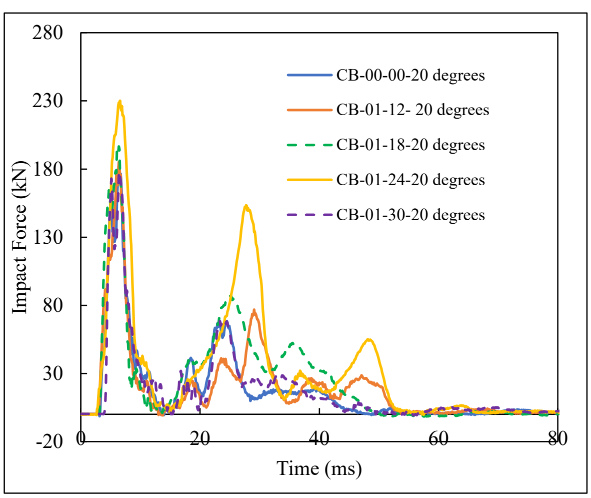


(c) CB-01-24

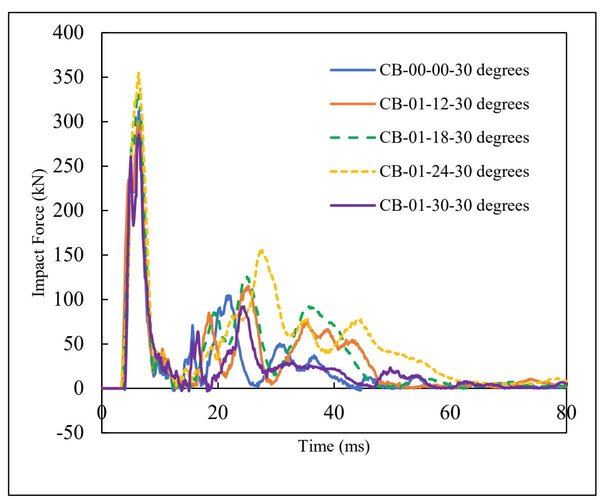


(d) CB-01-30

Fig. 4. Failure models of RuFRC bridge barriers

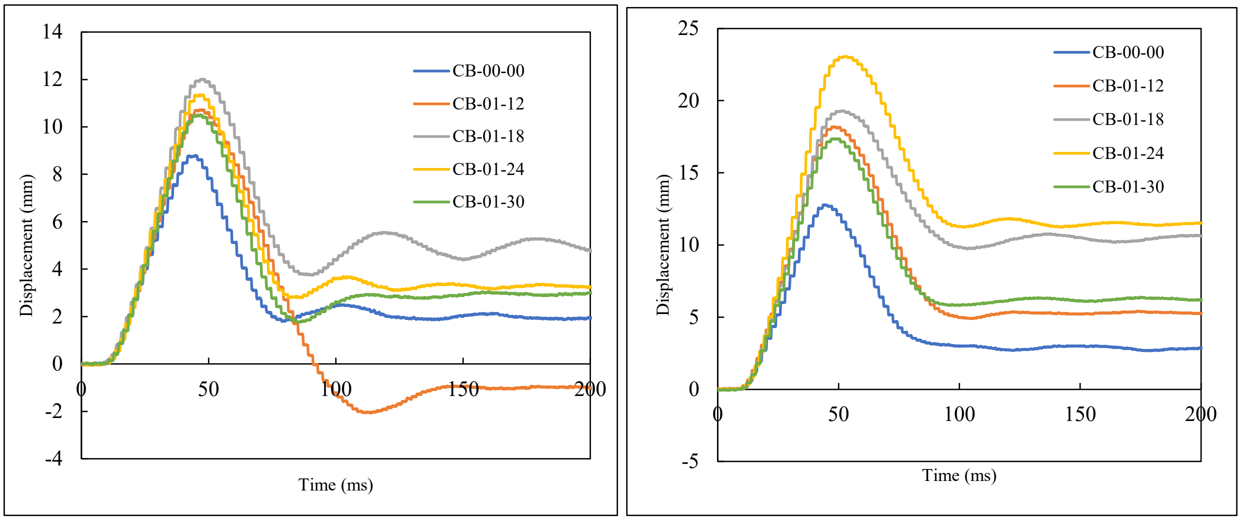


(a) first impact



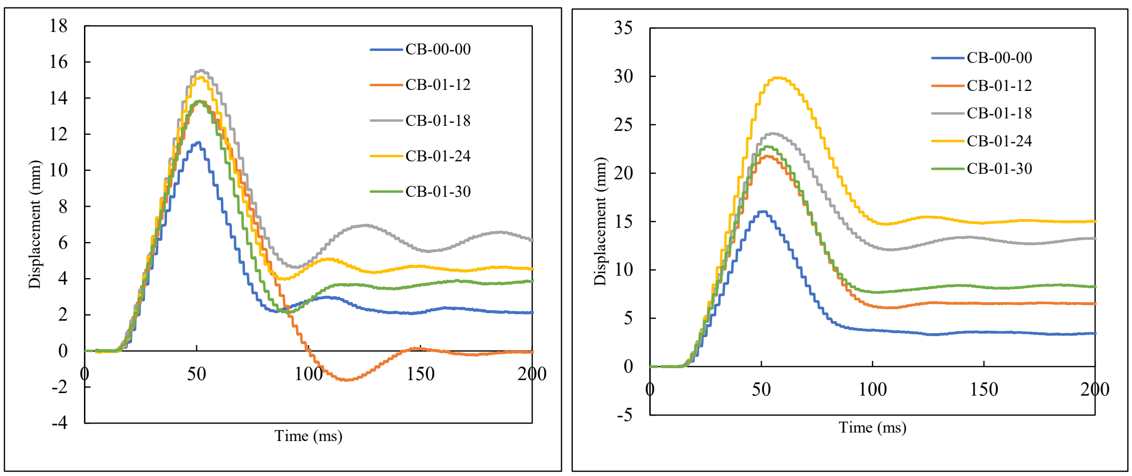
(b) second impact

Figure 5: Impact force time histories of the bridge barriers under different impact loadings.



(a) first impact (b) second impact

Figure 6: Displacement time history at height of impact under different impact loadings.



(a) first impact (b) second impact

Figure 7: Displacement time history at the top location under different impact loadings.

4. Conclusions

This paper presents experimental work carried out on RuFRC bridge barriers reinforced with stainless steel bars subjected to pendulum tests. The test parameter includes the various rubber percentages (0 to 30%) and the consecutive impact forces of a 20º (first impact) and 30º release angle (second impact) on the impact performance of RuFRC barriers. It was found that RuFRC barriers exhibited greater energy absorption capacity and displacement responses compared to the control barrier. There was no damage on the barriers' walls observed during the test under different impact loads; however, cracks on the slabs were observed for CB-01-18 and CB-01-24. The CB-01-24 barrier exhibited higher impact force and displacement response even higher than the CB-01-30 barrier which had 30% rubber. However, the compressive strength of the CB-01-24 barrier was higher than CB-01-30.

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