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Research Paper

# Reinforced rubberized continuous deep beams under cyclic loadings

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ABSTRACT

Continuous deep beams (CDBs) expose usually to repeated and cyclic load by loading and unloading states and the wave of an earthquake. Adding scraped tires rubber to the concrete mix (which is researcher interesting nowadays) improves its dynamic properties besides the sustainability purposes. Six CDBs were cast and tested experimentally under static and repeated loads. It can be concluded that the CDBs loss about 39% and 30.1% of their ultimate capacity after 10% volumetric replacement of sand and gravel respectively. Also, the ultimate strength of the beams decreases when compared with the static loads by 14%, 8% and 9% for conventional beam, gravel and sand replacement beams respectively. The cyclical results confirm that each load (positive and negative) make its own strut, till it's crossed together and the beams losses about 35 to 45% of their capacity due to the cycles. As a conclusion, it could be noting that the static loading results match with the strut tie method calculations.



## 1. Introduction

Environment pollution is one of the most problems that researchers working on to minimizing its effects. The world in general is going towards recycling the human waste especially the not easy biodegradable wastes such as plastics and rubber. The world produces millions of tons of scraped tires in a year (303 million tires each year in the United States) [1]. Adding rubber into the concrete mix minimizes its strength and all its mechanical properties but enhances the dynamic properties [2–7]. Concrete beams may be exposed to repeated and cyclic loads in many ways like: earthquakes and moving loads on bridges. Such members could be found at bridges, high-rise buildings, tanks pile caps, and folded plates [8–13]. Deep beams are the members in which its shear span to overall depth not accede 2 or the clear span to total depth lesser than 4 [14]. Deep beams were investigated under the effect of repeated loads [15–18], and cyclic loads [19–21]. But the behavior of continuous deep beams (CDBs) subjected to repeated and cyclic loading has not been investigated yet especially the behavior of CDBs differs from the simply supported deep beams due to many reasons. which are: (1) shear failure pattern generates below the loading section at SDB but at both CDB sides; (2) large shear and negative moment occurred at middle interior support of CDB while for SDB the maximum shear magnitude occurred at the lower bending moment point; (3) the SDB in contrast to CDB does not exposed to supporting settlement [9]; and (4) the CDB strut has a great degree of deterioration than SDB at the same parameters and specimen details [9]. So the novelty of the article is focusing on the behavior of CDBs under the repeated and cyclic load.

## 2. Literature review

Cyclic load on continuous deep beams were not investigated previously, but a single one research discussed the both ends fixed deep beam. The failure pattern of CDBs under cyclic loads differ when comparing with the monotonic static loads. The diagonal cracks orthogonally crossed together as shown in Fig. 1. This phenomenon minimizes the beam capacity by about 18% compared with the static load [21]. This is because of that, the cyclic load effects on the beam top and bottom by sequence in positive and negative series of forces, each force (positive and negative) has its own struts.

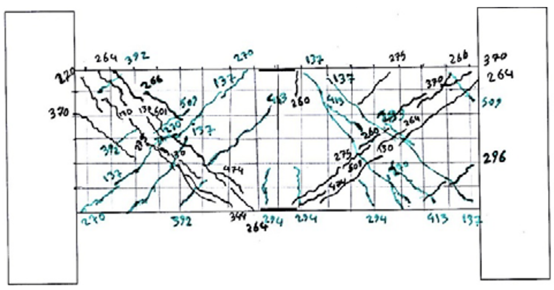

**Figure 1.** CDBs crack pattern [21].

## 3. Numerical analysis

Seven reinforced concrete deep beams were simulated with $100 \times 200 \times 1500$ *mm* dimensions in accordance to the experimental results which introduced at reference [22] as indicated in Fig. 2. The rainfall style of repeated loading Fig. 3, was applied on the casted CDBs. As well as, the same style was developed numerically to serve the cyclic reverse loading by ANSYS APDL V.15.0. Noting that, the load is applied at repeated and reverse as *Ps* equals 0.7 of the ultimate load capacity of monotonically loaded beam.

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**Nomenclature:**

| | | | |
|---|---|---|---|
| $C$ | Conventional concrete continuous deep beam | $C.G30$ | 30% gravel versus chips replacement continuous deep beam |
| $C.S10$ | 10% sand versus crumb replacement continuous deep beam | $Fcu$ | Cube compressive strength ($MPa$) |
| $C.S20$ | 20% sand versus crumb replacement continuous deep beam | $fc$ | Cylinder compressive strength ($MPa$) |
| $C.S30$ | 30% sand versus crumb replacement continuous deep beam | $Ft$ | Tensile strength ($MPa$) |
| $C.G10$ | 10% gravel versus chips replacement continuous deep beam | $MOR$ | Modulus of Rupture ($MPa$) |
| $C.G20$ | 20% gravel versus chips replacement continuous deep beam | $RF$ | Reference model |

After verifying the model with the experimental results, the ANSYS program was adopted to apply reverse load on the beam then investigating the modifying concrete properties from conventional mix into rubberized concrete beams. 10%, 20% and 30% of coarse rubber were replaced volumetrically by gravel in three different mixes and the same percentages were also replaced by sand versus crumb rubber to be totally seven concrete mixes with one conventional. The properties of concrete mixes after replacement were investigating at previous research [23] and summarized in Table 1, Considering Fig. 4 for sample symbols. Figure 5 shows the simulated specimen.

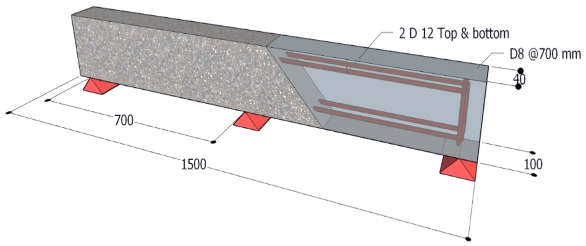



**Figure 2.** Beam details.

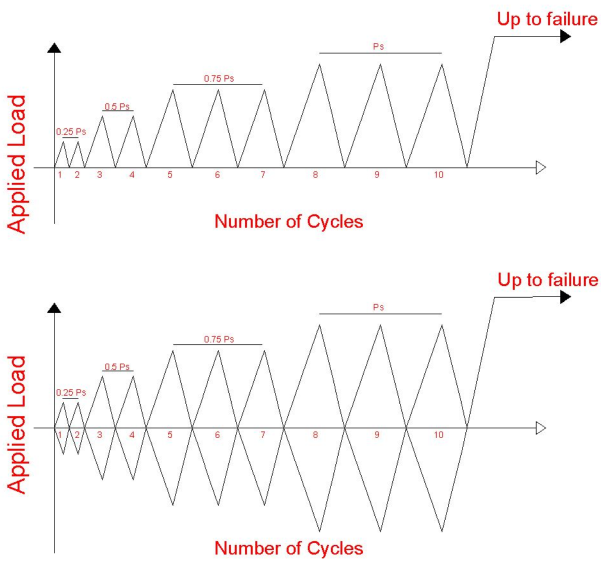



**Figure 3.** Simulated reverse cyclic load using ANSYS APDL.

### 3.1 Finite element setup

Concrete material simulated with element called Solid 65 which is an eight-node isotropic brick element (hexahedral brick element). Each node contained three usual degrees of freedom [24]. It is suitable for concrete because it provides the characteristics of concrete like plastic deformation, creep and crash of concrete besides the capability of cracking in the 3 directions. Steel reinforcement modeled by link 180, which is two nodded line element capable to undergo yielding stress which is a necessary property for the imbedded steel. Loading plate and supports were simulated as SOLID 185. Several trial models of different mesh sizes were investigated to found the most suitable mesh of such model and it found to be ($20 \times 10 \times 5$ $mm$) per x, y and z axes as explained in Table 2. Half beam was simulated and the remaining part was indicated as symmetrical portion. Supports were selected as all DOF fixed and the loading distributed on beam using a steel bearing plates. The inputs data matches with the experimental testing properties which mentioned in Table 1 and Makki, O. et al. [23].

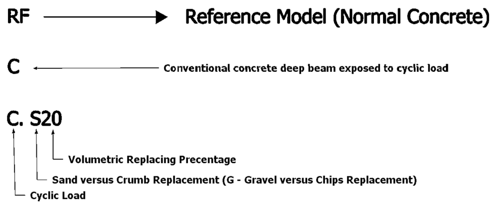



**Figure 4.** Samples code definitions.

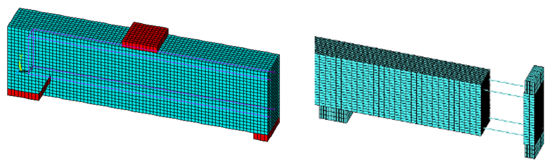


**Figure 5.** The Concrete, Supports and bearing plate meshing and Steel rebars.

## 4. Results and discussions

### 4.1 Trial meshing results

The best suitable size is ($10 \times 10 \times 20$ $mm$) after many trial models (as shown in Table 2).

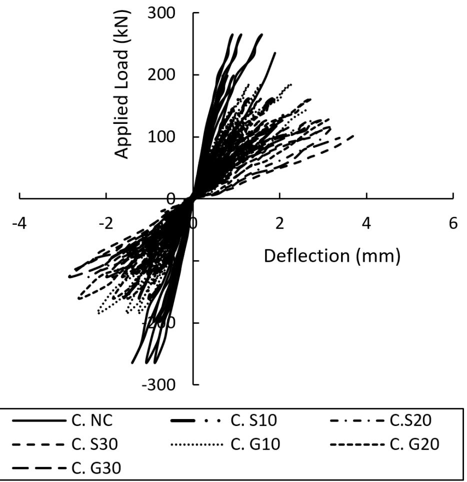
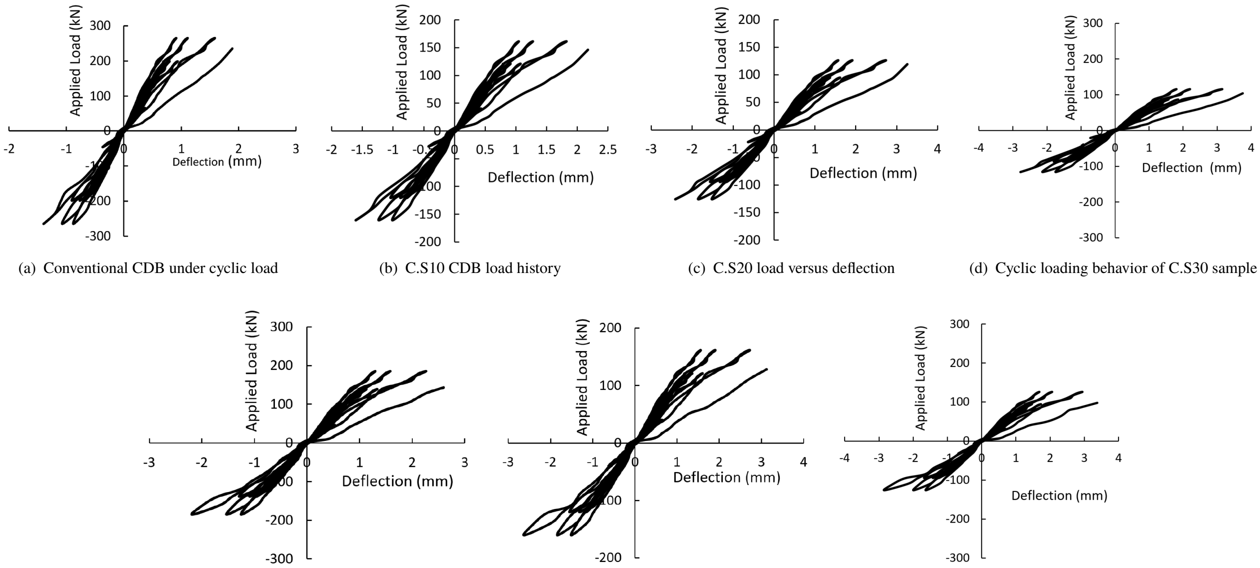



**Figure 6.** Load versus deflection curves for all specimens under cyclic loadings.

The CDBs forms upward and downward struts crossed at the neutral axis (N.A.) which formed a point of high stress intensity due to the negative and positive cracks. The presence of rubber plays a significant effect on the cyclically loaded beam's deflection. The three samples of repeated load were simulated to the cyclic load and then the percentage of rubber was increased for both sand and gravel replacement to be 20% and 30%. The properties of such percentages were experimented, and detailed in reference [23] and inserted in the numerical model properties. In another word, the total mix




(a) Conventional CDB under cyclic load (b) C.S10 CDB load history (c) C.S20 load versus deflection (d) Cyclic loading behavior of C.S30 sample

(e) Cyclic loading history of C.G10 specimen (f) Applied cyclic loading on C.G20 sample (g) C.G30 Applied cyclic loading

**Figure 7.** The Cycling loading verses the defection of tested samples.

in cyclic load were seven. One conventional mix, three mixes of sand versus crumb replacement by 10%,20%, and 30%, and gravel-chips replacement by percentages 10%, 20%, and 30% as shown in Table 1.

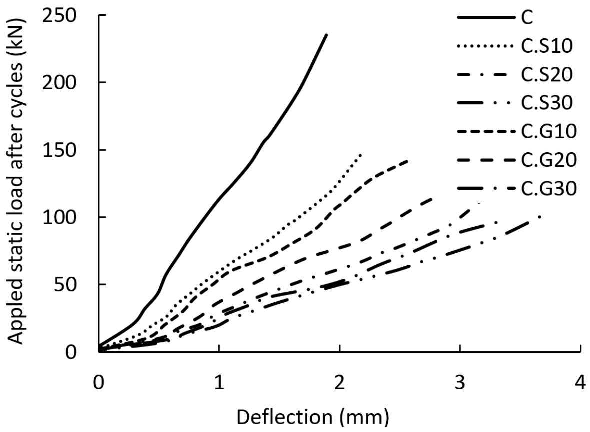



**Figure 8.** Final static loading.

## 4.2 Cyclic load

The same loading process of repeated rainfall style has been depended to simulate the reverse cyclic wave numerically. All modelling data involves the static and repeated samples were successfully worked on the reverse cyclic loading. The same behavior of failure observed for all specimens modelling results.

**Table 1.** Concrete mixes' properties

| No. | Slump (*cm*) | Fcu (*MPa*) | fc (*MPa*) | F't (*MPa*) | MOR (*MPa*) | Ultrasonic (*m/s*) | Impact resistance |
|---|---|---|---|---|---|---|---|
| RF | 10 | 53.06 | 43.20 | 10.9 | 4.0 | 5191 | 0162.8 |
| S10 | 9 | 34.35 | 26.60 | 7.88 | 3.6 | 4928 | 0346.0 |
| S20 | 8 | 25.97 | 19.00 | 6.42 | 3.4 | 4304 | 0712.3 |
| S30 | 6 | 22.74 | 18.11 | 5.21 | 2.7 | 4224 | 1241.5 |
| G10 | 6 | 37.92 | 30.50 | 8.28 | 3.2 | 4444 | 0488.4 |
| G20 | 4 | 34.30 | 27.80 | 6.68 | 3.1 | 4201 | 0773.4 |
| G30 | 3 | 27.48 | 22.00 | 5.85 | 2.2 | 4172 | 2361.0 |

**Table 2.** Convergence study for R.G10 beam (Repeated load. Gravel replacement 10%).

| Meshing size | Experimental | | Simulation | |
|---|---|---|---|---|
| | Load (kN) | Def. (mm) | Load (kN) | Def. (mm) |
| $20 \times 20 \times 20$ | 266 | 1.63 | 232.7 | 0.88 |
| $15 \times 15 \times 15$ | 266 | 1.63 | 245.5 | 1.2 |
| $10 \times 10 \times 10$ | 266 | 1.63 | 263.9 | 1.6 |
| $10 \times 10 \times 10$ | 266 | 1.63 | 263.9 | 1.6 |

**Table 3.** Decrement percentages of beams capacity.

| Sample | Static test (*KN*) | Static after cycles (*KN*) | Dropping strength (%) |
|---|---|---|---|
| ST.0 | 378 | 235 | 37.83 |
| ST.S10 | 230 | 146 | 36.52 |
| ST.G10 | 264 | 143 | 45.83 |

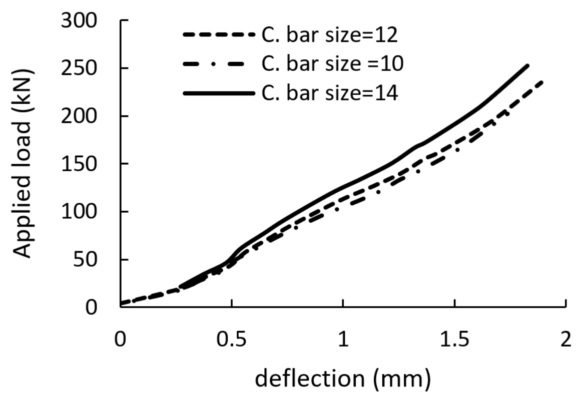



**Figure 9.** Conventional cyclically loaded beam with different steel reinforcement sizes.

The ultimate load capacity of each sample was effected by the concrete compressive strength in the first degree, and secondly be the amount of cracks in the beam (increasing rubber leads to higher micro cracks inside the concrete mix, and that is because of leaking bond between cement paste and the rubber

particles). Figure 6 and Fig. 7 listed the behavior of conventional and rubberized CDBs under reverse cyclic loading for the final stage of loading. The slope of curves decreases gradually after each percentage of rubber replacement, due to the changing of concrete mix behavior from brittle to ductile. It can be also noting that, the replacement method (sand or gravel) has no essential significant effect, because C.S10 and C.G10 data almost approached, as well as the same curves data. It's clear to notice that from Table 3, the CDBs losses between 34 to 45% of its capacity after the ten rainfall cycles. It is a logical result and matched with a decreasing occurs as discussed by Aarabzadeh, A. et al. [21].
The amount of deflection increases gradually by rising the amount of rubber in the mix, which is due to that, adding rubber into the mix create micro cracks caused by the large difference in elastic modulus between rubber and the aggregate. These cracks will merge and lengthened during loading and the matter get more worse if the load was cyclic, where the cyclic load generates more cracks and effect in the first degree on the cracks creeping.

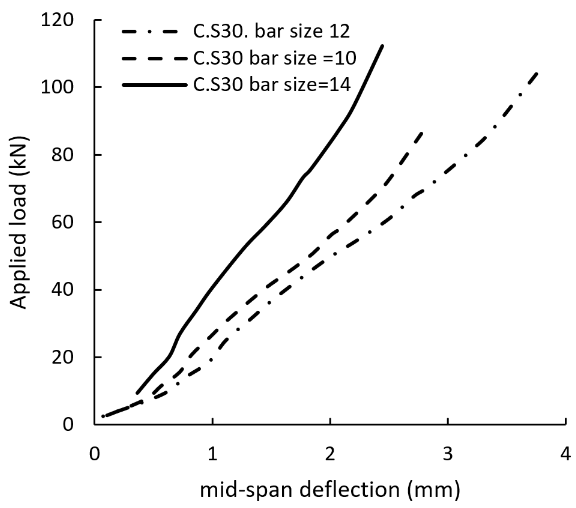



**Figure** 10**.** Fine aggregates rubberized concrete beams under cyclic load for different reinforcement amounts.

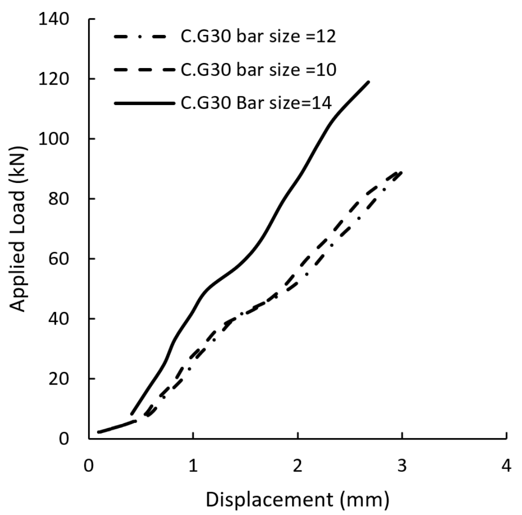



**Figure** 11**.** Final stage of loading the cyclic load on chips rubberized concrete beam.

### 4.3 Mathematical model

Mathematical equations for the final loading stage were computed in accordance to the deflection versus load curves. It could be concluded from Table 4 that, a polynomial from the second degree was enough to present the failure curves for all models with a reality factor equals 99% for all models.

**Table** 4**.** Mathematical model equations.

| Specimen | Equation | Reliability |
|---|---|---|
| C | $y = 16.9230x^2 + 90.050x + 0.4784$ | 0.9962 |
| C.S10 | $y = 08.7448x^2 + 46.031x + 0.6779$ | 0.9956 |
| C.S20 | $y = 03.7124x^2 + 22.322x + 1.1395$ | 0.9934 |
| C.S30 | $y = 02.0292x^2 + 19.373x + 0.3914$ | 0.9958 |
| C.G10 | $y = 04.7969x^2 + 44.514x - 0.9272$ | 0.9916 |
| C.G20 | $y = 02.3526x^2 + 34.710x - 1.5458$ | 0.9924 |
| C.G30 | $y = 01.8825x^2 + 23.696x - 0.8002$ | 0.9925 |

### 4.4 Parametric study - influence of steel rebars size

To investigate the effect of increasing rebars diameter, the specimens C, C.S30 and C.G30 were selected to view the behavior. Two rebars sizes were chosen besides the reference size (12 *mm*), which are 10 and 14 *mm*. Analysis results were illustrated at Figs. 8 up to Figs. 11, from which could be noted that, increasing the steel bars size leads to increase the overall ultimate load due to giving me tensile strength to the beam which will on the other side deceases the bending thus the deflection of beam. The behavior of beam during failure as well as the stiffness of models does not change and seems the same for all analysis.

## 5. Conclusions

After ensuring the accuracy of numerical model and depending on the experimental results, the outline of the concluded are:

- The CDBs behave continuously form strut cracks and fail by shear as usual.
- Adding rubber decreases its ultimate load due to strength dropping but rises the deflection due to the beam flexibility.
- Deflection at each loading stage of repeated or even cyclic load increases due to remaining residual cracks and the increment forms in a polynomial from the fifth degree.
- Ultimate load capacity of R.G10 larger than R.S10 due to the higher compressive strength. While deflection values for sand replacing beam were slightly larger than the R.G10 due the higher flexural capacity of S.R.10.
- Each load makes its own strut, till it's crossed together.
- Increasing steel bars size leads to increase the ultimate load of the specimen and minimizes the beam displacement.
- The final stage of cyclic load generally takes a shape of a polynomial of the second degree for even conventional and rubberized concrete beams, with a reliability equals 99%.

### Authors' contribution

All authors contributed equally to the preparation of this article.

### Declaration of competing interest

The authors declare no conflicts of interest.

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This study didn't receive any specific funds.

### Data availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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