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Original Article

Effect of Specimen Size on Flexural Behavior of Doubly Reinforced Concrete Beams

Chatikam Chandra Mouli[1], G. V. Rama Rao[2]

[1,2]Department of Civil Engineering, Andhra University College of Engineering, Andhra Pradesh, India

[1]Corresponding author: chandramouli477@gmail.com

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Abstract *- Material strength is a random variable that is a statistical distribution of strengths that varies from point to point in the material. As the size of the structural element increases, the probability of encountering a fault or discontinuity in the material also increases, which leads to a reduction in the overall strength of the element. Hence, it is important to understand the relationship between specimen size and the strength of the material. The studies conducted by past researchers are mostly on the effect of beam specimen size on the shear performance of RC concrete beams. Further, very few studies were available on the effect of specimen size on load vs deflection behavior, Absorbed Strain Energy and Toughness index of doubly reinforced concrete beams. It is concluded from the study that the First crack load, Deflection at First crack load, Peak load and Fracture load, Deflection at collapse, Deflection at Peak load, Displacement ductility ratio, Strain energy absorbed up to first crack, Total Strain energy absorbed, Experimentally determined Moment of Resistance at peak load, Ultimate Moment of Resistance calculated as per IS 456 2000 and Toughness index at first crack load increase with increase in dimensions of specimen. However, the factor of safety decreases with an increase in specimen size.*

Keywords *- Specimen Size effect, Load vs deflection behavior, Peak load, Fracture load, Toughness index, Strain energy absorbed, Displacement ductility, Moment of Resistance.*

1. Introduction

Material strength is a random variable that is a statistical distribution of strengths that varies from point to point within the material. With an increase in the size of the structural member, the probability of encountering a fault or discontinuity in the material also increases, which results in the reduction of the overall strength of the element. Hence, it is important to establish the relationship between the specimen size and the strength of the material.

In the recent past, there has been increasing interest in incorporating size effects into structural design codes and standards. This led to improved design methods like the size effect method, which explicitly considers the influence of member size on the safety factor for a structural element. These methods are particularly relevant for structures made of brittle materials, such as concrete or ceramics, where size effects can significantly impact the structure's safety and reliability.

In conclusion, while classical theories of the mechanics of solids presume that material properties are independent of scale, specimen size can significantly impact the behavior of structural elements made of brittle materials.

Incorporating size effects into design codes and standards is an important step towards ensuring the safety and reliability of structures.

2. Literature Review

Many researchers have worked on the impact of specimen size on various parameters of shear and flexural members. [1] Bazˇant (1976) researched ductility, instability and the influence of specimen size on the strain-softening of concrete. [2] Bažant and Kim (1984) experimented with the effect of specimen size on the failure of longitudinally reinforced beams in shear. [3] Bažant (1984) studied the impact of rock, concrete and metal specimen size on the blunt fracture strength. [4] Bažant and Kazemi (1991) studied the effect of specimen dimensions on the diagonal shear collapse of reinforced concrete beams with no stirrups. [5] Bazˇant (1993) worked on the significance of Scaling laws on failure mechanics. [6] Shioya and Akiyama (1994) researched incorporating the effect of size on the design of reinforced concrete structural elements. [7] Walraven and Lehwalter (1994) experimentally studied the influence of specimen size on short beams loaded in shear. [8] Carpinteri and Ferro (1994) studied the size effect on the fracture properties of concrete based on its microstructure. [9]Carpinteri opined the material's failure behavior, microstructure, and specimen size on apparent mechanical properties. [10] Bazˇant and Chen (1994) researched the effect of scaling on the failure of structures. [26] Ramallo et al. (1995) experimentally studied the unintentional out-of plane actions on the size effect tests of concrete structural elements. [12] Carpinteri et al. (1995) studied the size effects on the nominal tensile strength of concrete structures. [13] Kotsovos and Pavlovic (1997) conducted a numerical experiment on the effect of specimen size on the mechanical properties of structural concrete. [14] Kuchma et al. (1997) experimentally studied the effect of the strength of concrete, reinforcement distribution in the longitudinal direction and cross-sectional dimensions and size on the shear strength of reinforced concrete beams. [15] Frosch (2000) experimentally studied the behavior of large-sized RC beams with minimum shear reinforcement. [16] Van Vliet and Van Mier (2000) conducted a comparative study on specimen size effects on sandstone and concrete [17]. Rios and Riera (2004) analysed the reinforced concrete structures, including the Size effects [27] Bažant and Yu (2005) worked on the development of design by considering the effect of structural member size on the shear strength of rectangular RC without shear reinforcement (stirrups). [19] Bažant and Yu (2005) designed the reinforced concrete beams without stirrups against the size effect on shear strength. [20] Meddah et al. (2010) studied the influence of particle size distribution and quantity of coarse aggregate per cubic meter of concrete on the strength of concrete in compression. [21] Yu and Bažant (2011) discussed the role of stirrups in minimizing the size effect on RC beams. [22] Syroka-Korol and Tejchman (2014) experimentally investigated the effect of beam dimensions on shear-deficient RC beams. [23] El-Sayed and Shuraim (2016) studied the size effect on shear resistance of deep beams of high-strength concrete. [24] Jin et al. (2016) effect of specimen size on the strength of RC cantilever beams in shear under low cyclic loading. [25] Jin et al. (2017) researched the effect of cross-sectional dimensions and transverse reinforcement on the performance of RC short square columns subjected to axial compression.

Concluding Remarks : From the review of studies by past researchers, it is observed that the studies were mostly focused around the influence of the dimensions of the beam on the shear performance of RC beams. Also, very few studies could be traced on the effect of beam size on load vs deflection behavior, Absorbed Strain Energy and Toughness index.

3. Objective, Scope and Methodology

3.1. Objective

To study the effect of beam dimensions on the performance of doubly reinforced concrete flexural members.

3.2. Scope

1. The study is restricted to Doubly Reinforced concrete beams of rectangular cross-sections.
2. The Toughness index, Absorbed Strain Energy and load vs deflection behavior were studied.
3. The design specifications adopted are:
   Concrete of M30 grade and steel of Fe500 grade
   Clear cover is 20 mm.
   20 mm maximum size of coarse aggregate.
   200 mm bearing length on either side of the beam support.
4. Ratio of the Span to depth ratio is considered as 6 while fixing the specimen dimensions.
5. The sizes of the three beams considered for the study are presented in Table 1.
6. The design moment of resistance is considered 1.25 × Mu, lim. for the reinforced concrete beams to ensure they are doubly reinforced. The details of the reinforcement provided for the three specimens are shown in Fig. 1.

3.3. Methodology

The methodology adopted in this research is briefly presented as follows.

1. Materials required for experimental work are procured and tested for their acceptability for use in Reinforced concrete as per relevant IS codes. All the manufactured products adopted for this work are ISI branded.
2. M30 Concrete Mix proportioning is carried out per IS: 10262 2019 provisions. Three different sizes of doubly reinforced concrete beams are designed for 1.25 × Mu, lim. and cast.
3. All the 3 specimens are tested using a computerized loading frame of 1000 kN capacity until ultimate. With the help of the Data Acquisition System, different load and deflection parameters are recorded. The patterns of cracks of the 3 RC beams after testing are shown in Fig. 2.

Table 1. Three sizes of beams adopted in this study

Size	Breadth of beams B (mm)	Depth of beams D (mm)	Clear Span of beam L (mm)
Size 1	150	150	900
Size 2	150	225	1350
Size 3	150	300	1800

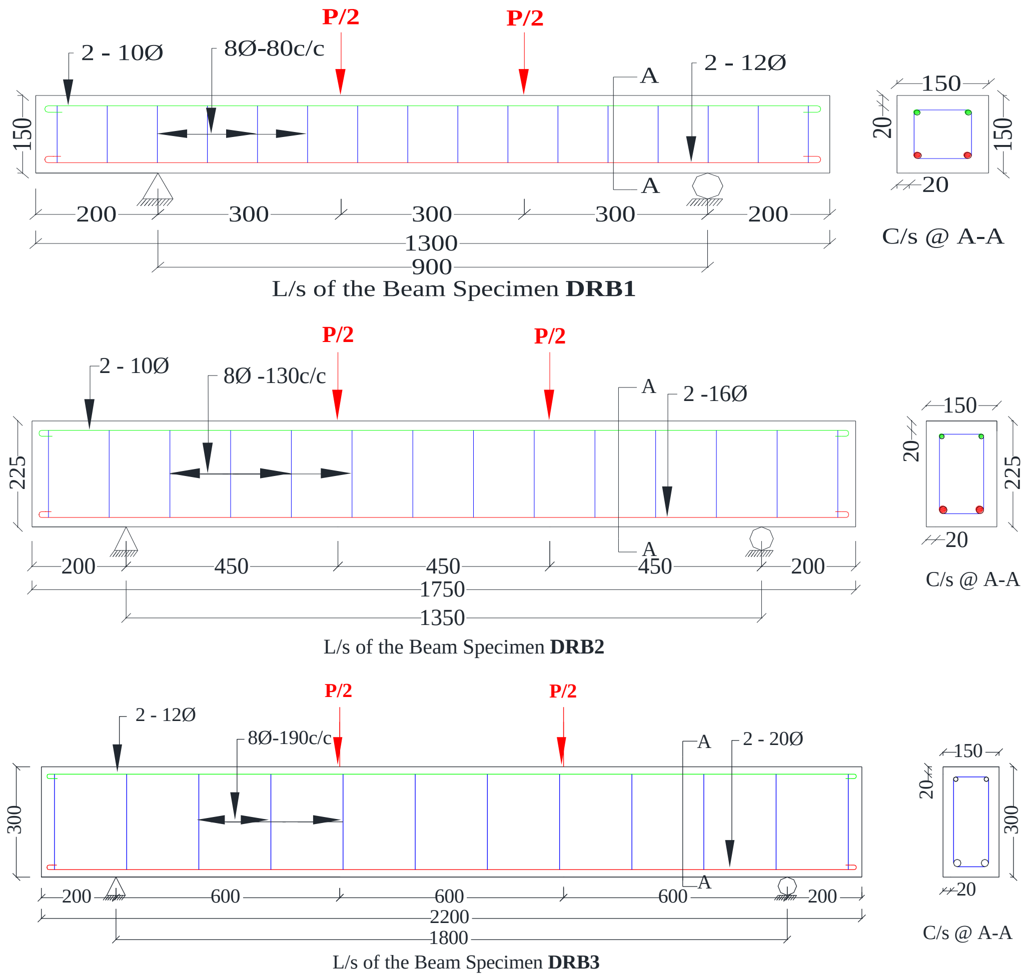

Fig. 1 Reinforcement details of the three specimens

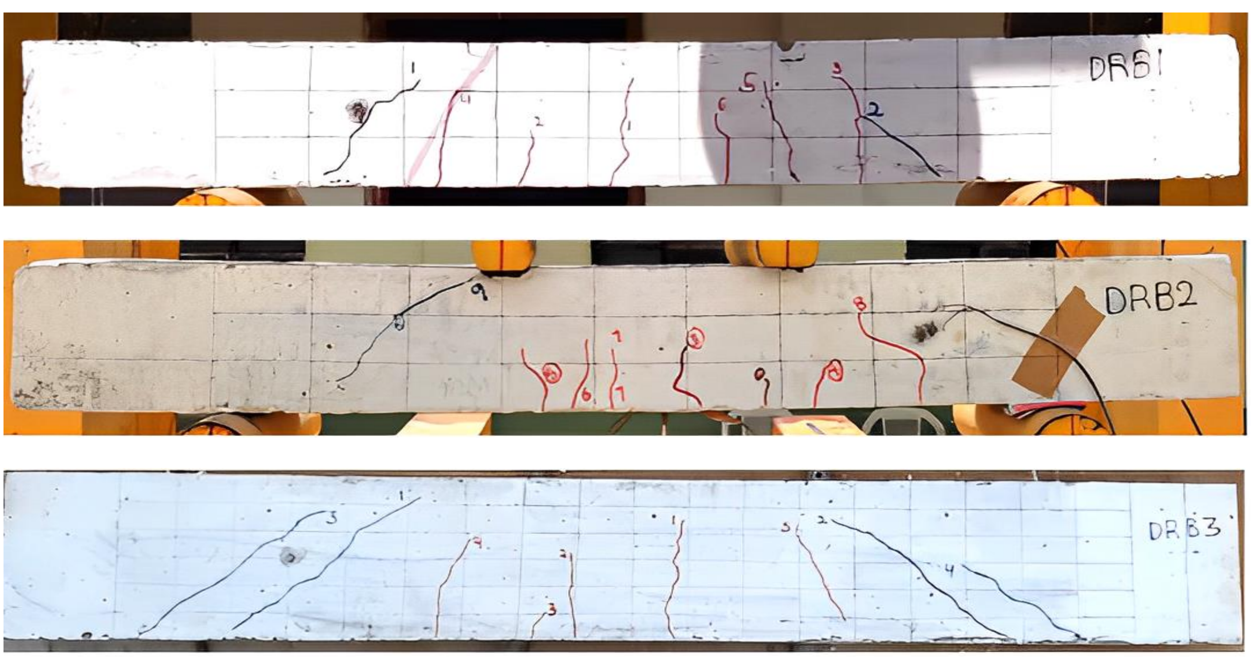

Fig. 2 Crack patterns of the three beams after testing

4. Results and Discussions

4.1. Load vs Deflection Behavior

The load vs deflection curve for all 3 Doubly reinforced concrete beams cast and tested are shown in Fig. 3. From Fig. 3, it is observed that the load up to which the load vs deflection curves is linear increases with size. Table 2 presents the Load vs. Deflection parameters for DRB1, DRB2 and DRB3.

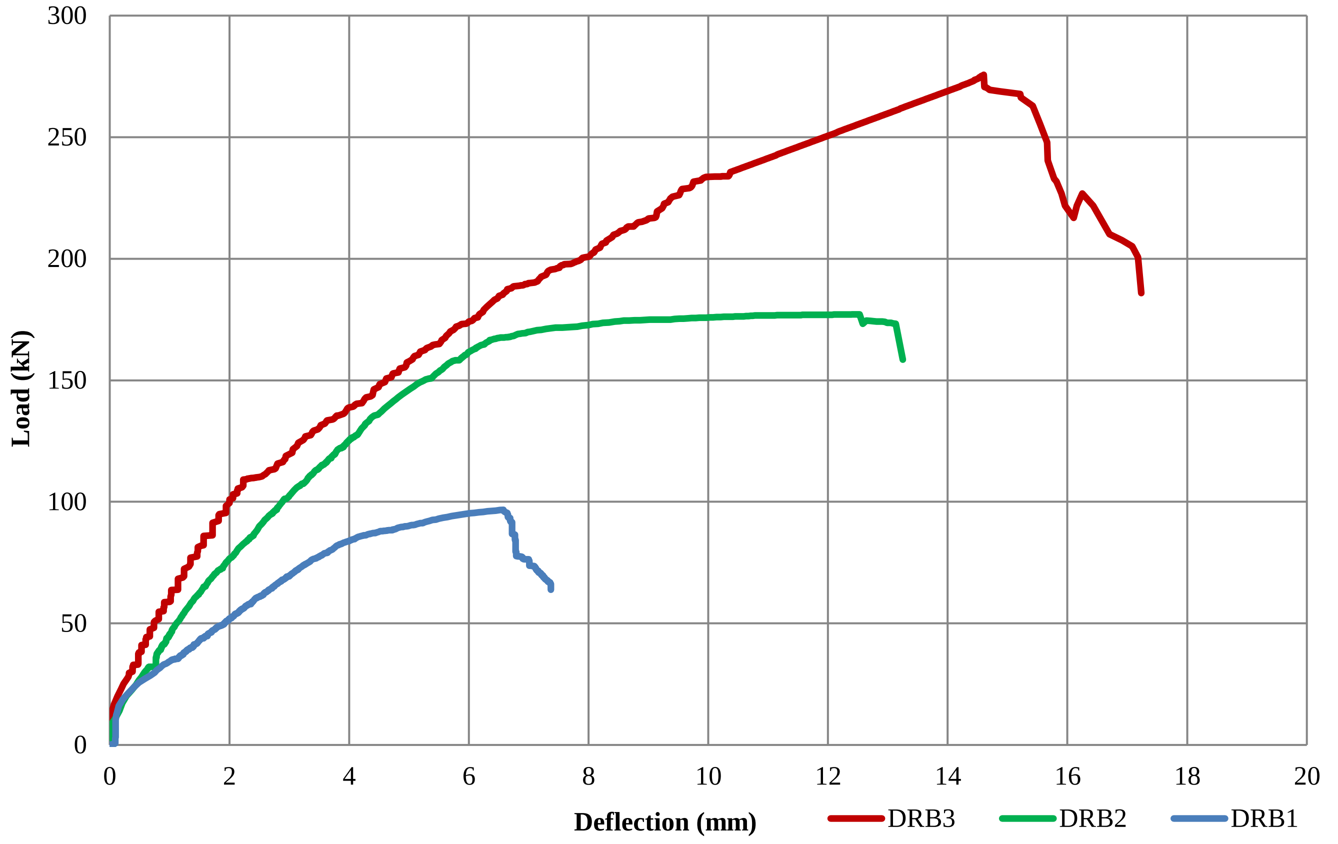

Fig. 3 Load Vs. Deflection curves for DRB1, DRB2 and DRB3.

Table 2. Load vs. Deflection parameters for DRB1, DRB2 and DRB3

Specimen	1st Crack Load (kN)	1st Crack def. (mm)	Peak Load (kN)	Def. @ Peak Load (mm)	Fracture Load (kN)	Deflection @ Fracture Load (mm)	Displacement ductility
DRB1	51.20	1.98	96.70	6.58	63.80	7.37	3.32
DRB2	77.00	2.03	177.00	12.39	158.50	13.25	6.10
DRB3	109.50	2.30	275.65	14.60	185.83	17.23	6.35

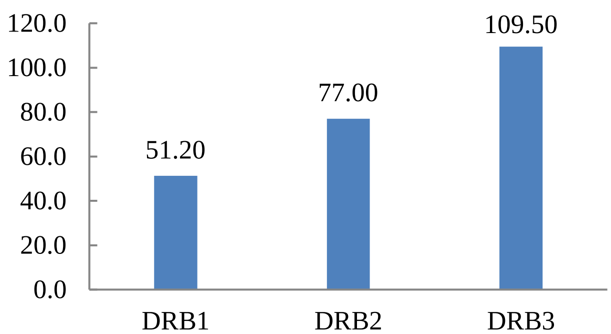

Fig. 4 Load at 1st crack w.r.t size

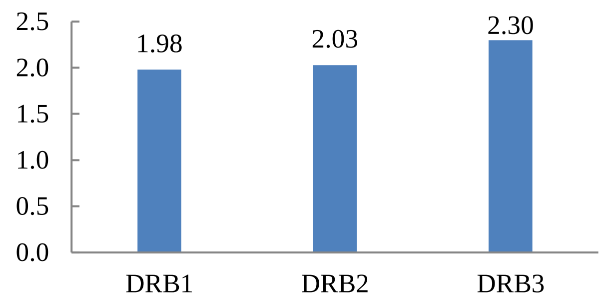

Fig. 5 Deflection at 1st crack w.r.t size

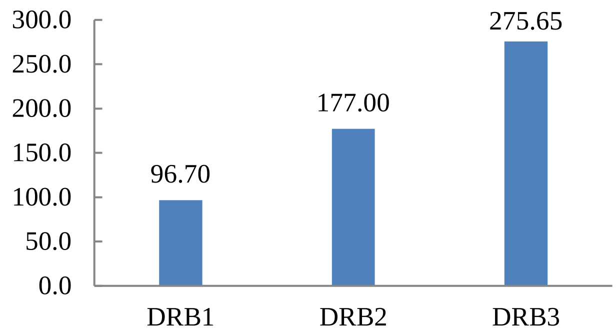

Fig. 6 Peak load w.r.t size

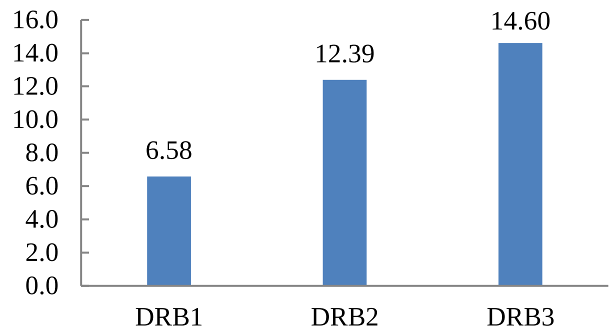

Fig. 7 Deflection at Peak load w.r.t size

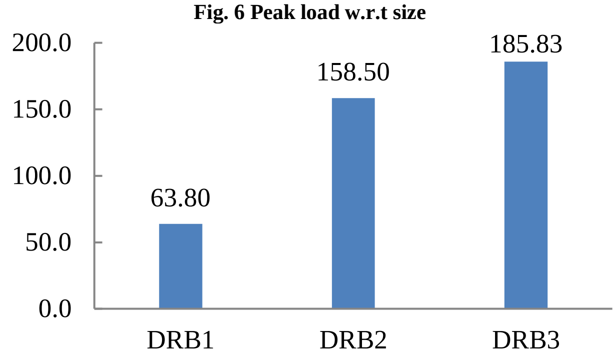

Fig. 8 Fracture load w.r.t size

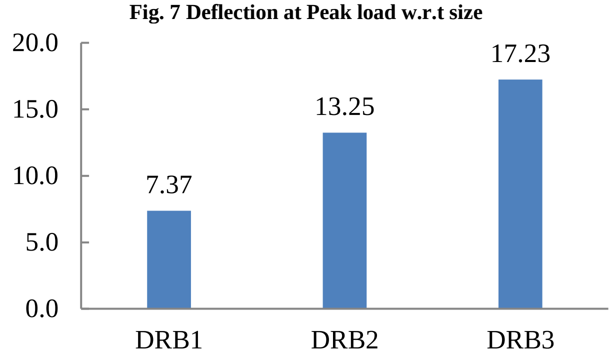

Fig. 9 Deflection at Fracture w.r.t size

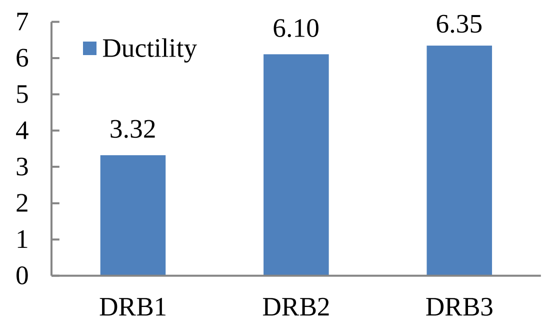

Fig. 10 Displacement ductility ratio

From Fig. 4, and Fig. 5, it is observed that the 1st crack load and deflection increases with increase in size. The 1st crack load for DRB2 and DRB3 increased respectively by 50.39% and 113.87% with respect to that of DRB1. Also, the deflection at 1st crack load for DRB2 and DRB3 increased respectively by 2.53% and 16.16% with respect to DRB1.

From Fig.6, and Fig.7, it is found that Peak load and deflection increase with an increase in member size. The Peak load for DRB2 and DRB3 increases respectively by 83.04% and 185.06% with respect to DRB1. Also, the deflection at Peak load for DRB2 and DRB3 increased respectively by 88.30% and 121.88% with respect to DRB1.

From Fig. 8, and Fig. 9, it is observed that the Fracture load and deflection at fracture increase with an increase in member size. The ultimate load for DRB2 and DRB3 increased respectively by 148.43% and 191.27% with respect to that of DRB1. However, the deflection at Peak load for DRB2 and DRB3 increases respectively by 79.78% and 133.79% with respect to DRB1.

From the Fig.10, Displacement ductility is observed to increase with an increase in size. The displacement ductility for DRB2 and DRB3 increases respectively by 83.66% and 91.01% with respect to that of DRB1.

Concluding Remarks : The 1st crack Load and Deflection, Peak load and Fracture load increase with increased flexural member size.

The Deflection at Fracture load and Peak load and Displacement ductility ratio also increase with an increased size of the specimen.

4.2. Absorbed Strain Energy and Toughness index

The magnitude and percentage increase in various parameters like Strain energy up to 1st crack load, Total strain energy, and Toughness index @ 1st crack load for all three doubly reinforced concrete beam specimens are presented in Table 3.Table 3 considers the safety factor as the ratio of the Moment of Resistance obtained experimentally to that of the Moment of Resistance calculated as per IS 456 2000.

Table. 3 Strain energy up to 1st crack load, total strain energy, toughness index at 1st crack load for the three beams

Specimen	Strain Energy up to 1st crack	Total Strain Energy	Mu., Cal. (kNm)	Mu. Exp. @ Peak load (kNm)	Toughness index @ 1st crack	FS
DRB1	65.04	501.96	9.37	14.51	7.72	1.55
DRB2	91.01	1864.83	27.61	39.83	20.49	1.44
DRB3	152.15	3285.19	60.85	82.70	21.59	1.36

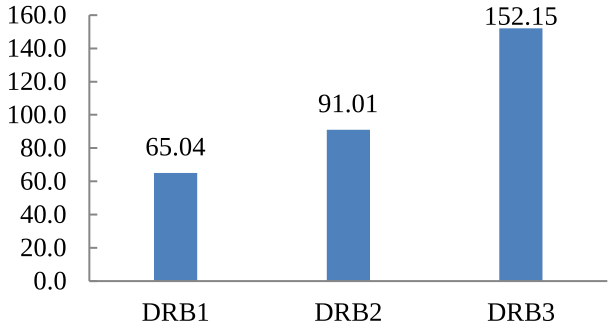

Fig. 11 Strain energy absorbed up to 1st crack w.r.t size

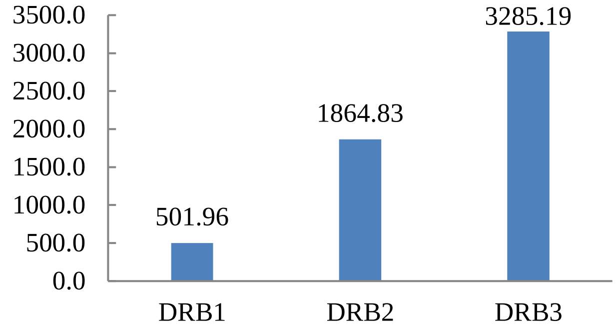

Fig. 12 Total Strain energy absorbed w.r.t size

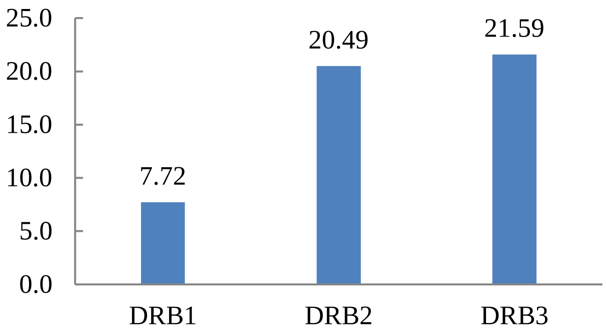

Fig. 13 Toughness index @ 1st crack load

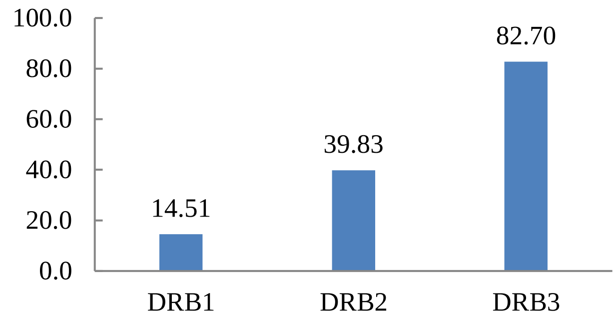

Fig. 14 Experimentally determined Moment of Resistance at peak load

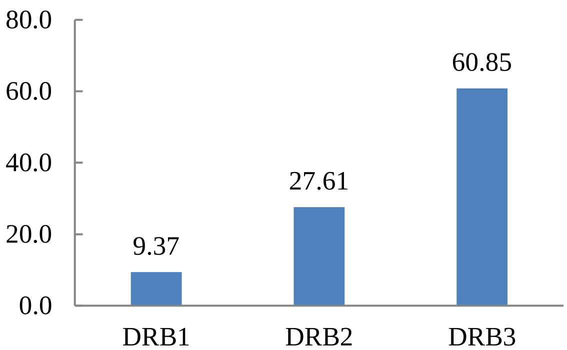

Fig. 15 Ultimate Moment of Resistance calculated as per IS 456 2000

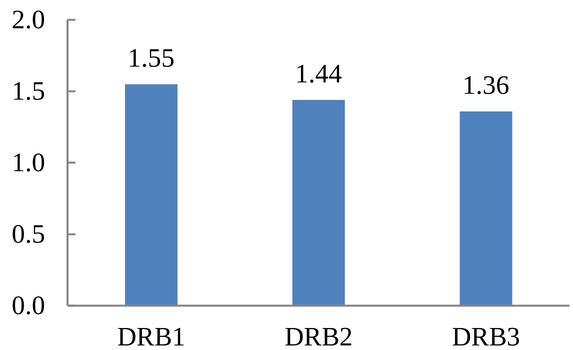

Fig. 16 Factor of safety

From Fig.11, and Fig.12, it is observed that the strain energy absorbed up to 1st crack load decreases with an increase in size. The strain energy absorbed up to 1st crack load for DRB2 and DRB3 increased respectively by 39.93% and 133.93% with respect to DRB1. Also, the total strain energy absorbed by DRB2 and DRB3 increased respectively by 271.51% and 554.47% with respect to that of DRB1.

From Fig.13, it is observed that the toughness index increases with an increase in size. The toughness index up to 1st crack load for DRB2 and DRB3 increased respectively by 165.50% and 179.77% with respect to DRB1.

From Fig.14, and Fig.15, it is observed that the experimentally determined Moment of Resistance at peak load and Ultimate Moment of Resistance calculated as per IS

456 2000 Increase with an increase in size. The Experimentally determined Moment of Resistance at peak load for DRB2 and DRB3 increases respectively by 174.56% and 470.11% with respect to DRB1.

The Ultimate Moment of Resistance calculated as per IS 456 2000 for DRB2 and DRB3 increases respectively by 194.66% and 549.41% with respect to DRB1.

However, the factor of safety decreases with increase in size. From Fig.16, The Factor of safety for DRB2 and DRB3 decreased respectively by 6.82% and 12.21% with respect to DRB1.

Concluding Remarks: Strain energy absorbed up to 1st crack, Total Strain energy absorbed, Experimentally determined Moment of Resistance at peak load, Ultimate Moment of Resistance calculated as per IS 456 2000, Toughness index at 1st crack load increase with increase in specimen size. However, the factor of safety decrease with an increase in specimen size.

5. Conclusion

The following conclusions are drawn from the study conducted within the scope of this research.

1. The 1st crack load and Deflection at first crack load, Peak load and deflection at Peak load, Fracture load and Deflection at Fracture load, Displacement ductility ratio, Strain energy absorbed up to 1st crack, Total Strain energy absorbed, Experimentally determined Moment of Resistance at peak load, Ultimate Moment of Resistance calculated as per IS 456-2000, Toughness index at 1st crack load increase with increase in size of specimen.
2. The safety factor decreases with an increase in the dimensions of the flexural member.

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