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Flexural Behaviourof Reinforced Concrete Beamswith Graded FibreContent Under Monotonic and Repeated Loading

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Abstract:

This study presents an experimental program to explore the effect of the two types of load on the Flexural Behavior of Graded Hook Steel Fibre Reinforced Concrete Beams. The current work focuses on the comparison between the flexural behaviorof reinforced concrete beams with different fibre percentages 0%, 0.5%,0.75%, and 1%, different thicknesses of layers 50mm and 10mm, different numbers of layers and two types of load monotonic and repeated loads.

The experimental results showed that the steel fibreimproved the fresh and mechanical qualities of conventional concrete.According to the findings,as the percentage of fibre in concrete increased, the slump of the concrete reduced. At a fibrepercentage of 1%, however, mechanical parameters such as compressive strength, splitting strength, elastic modulus, and modulus of rupture rise by 1.3, 1.76, 1.28, and 4.11, respectively.The tested reinforced concrete beams were designed according to ACI 318M-19 to ensure flexural failure.The experimental results showed that adding hooked steel fibreimproving the structural behaviorof the reinforced concrete beams under the monotonic and repeated loads. For the monotonic load, the ultimate load for the beams with one layer, 50mm layer thickness, and steel fibrepercentages of 0.5 %, 0.75 %, and 1 % increased by 1.08, 1.11, and 1.16, respectively, and increased by 1.09, 1.1, and 1.178 for the repeated load compared with the control beams. For the monotonic load, the ultimate load for the beams with one layer, 100mm layer thickness, and steel fibrepercentages of 0.5 %, 0.75 %, and 1 % increased by 1.14, 1.2, and 1.241, respectively, and increased by 1.145, 1.2 and 1.276 for the repeated load compared with the control beams. The ultimate load for the beams with two-layer, 50mm layer thickness, and steel fibrepercentages of 0.5 % for the first layer and 0.75 % for the second layer increased by 1.16 for the monotonic load and 1.174 for the repeated load. The ultimate load for the beams with two-layer, 50mm layer thickness, and steel fibrepercentages of 0.75 % for the first layer and 1% for the second layer increased by 1.198 for the monotonic load and 1.188 for the repeated load. From the results observation, the using four layers (2 layers' top and 2 layers' bottom) with fibre percentage 0.75% and 1% has the highest effect on the behaviour of the beams specimens. The ultimate load capacity for the beam BM10 under the monotonic load was increased by 1.296 compared with the control beam, while for the beam BR10 under the repeated load with the same properties, the ultimate load increased by 1.275 compared with the control beam.In addition, observed that the adding hooked steel fibres reducing the energy dissipated of the beams specimens under the two types of the loads above and delay the first cracks due to the role of the steel fibre in improving the structural behavior of beams and carrying the internal stresses after happening the cracks in concrete.

Key words : Graded fibre, Reinforced Concrete beam, Monotonic load, Repeated load.

1. Introduction

Concrete is a structural material composed of aggregate (typically sand and gravel), which is a rough, chemically inert particle substance held together by cement and water. Concrete can be damaged by a variety of processes, including the freezing of stored water, fire, radiant heat, and the effect of repeated loads**[1].**

Several investigations on reinforced structural elements have been undertaken in the previous decade, with a focus on using of fibres to improve concrete behaviour. The strength-to-weight and stiffness-to-weight ratios of Fibre-Reinforced Composites (FRC) are frequently aimed towards improving (Lightweight stiff and sturdy constructions are desired.)**[2-4]**.

Throughout the previous decade, functional grading fibers has been used as modern technical for the manufacture of RC elements. The purpose was to estimate the performance of functionally graded RC beams that had been subjected to repeated loading. Steel fibre s were used for sample preparation.In 2008,A new type of concrete reinforcement has been created. The results of this study show that different layers of concrete reinforcement with different fiber contents enhance flexural performance in beams and slabs under monotonic stress.**[4]**.

FRC composites have been used to improve the performance of plain concrete materials as well as to repair and retrofit existing constructions**[5]**. Fibre s can be dispersed spatially (or functionally) to increase structural performance while reducing fibrecount. Functionally graded materials are those with spatially variable microstructures created by dispersion of reinforcement phase [6]. In order to increase the structural performance of a component while lowering its material cost, a functionally graded fibre-reinforced cement composite was recently produced employing the extrusion process**[7]**.

Fibreconcrete that has been functionally graded has qualities that change in response to changes in the structure's composition. It is divided into several layers and contains a variety of fibre s.Functionally graded materials are materials that have been produced specifically to grade the constituents of the material in order to define a composite with functionally and continuously changing mechanical properties inside the material. Birman looked at using different fibre-reinforced layer patterns to improve buckling resistance in composite plates and sandwich panels. Several of these concepts are applied to concrete material systems in the current studyby **[8]**.

The adoption of the functionally graded reinforced concrete steel fibrepercentages improved the behaviourof RC beams under repeated loads as compared to the entire reinforced concrete beam. The use of functionally graded RC beam has improved the behaviourof reinforced beams under repeated loads and decreased the dissipated energy.

Ghasemi Naghibdehi et al. studied the impact of cross-section reinforcement with PP fibres,steel fibres, or both types in two independent layers, both experimentally and statistically. Steel and PP fibrevolume fractions of 0.5 %, 1 %, and 2 % were used to reinforce beams in their investigation. Reinforced cross-section beams with one or two fiber types were tested under flexural loading. Steel fiber reinforcement of the entire cross-section could result in a higher load-carrying capacity than reinforcement of the cross-section with two fiber types in two distinct layers, according to the research.For the single-type reinforcement of the whole cross-section, the 2% fibre volume fraction with steel fibres offered the best flexural performance. The best performance of composite two-layer beams was also achieved with a 1% fibre volume percentage of steel fibres.**[9, 10].**

This study aims to investigate experimentally the flexural behaviourof reinforced concrete beams with graded steel fibrecontent with different thicknesses of layers under monotonic and repeated load.

2. Material

2.1. Coarse Aggregate:

In this study, Samarra coarse aggregate was used in the mix design. The coarse aggregate had a maximum size of 10mm. According to the Iraqi standard specification, Table 2 depicted the physical and chemical properties of coarse aggregate **[12]**.

Table 1

Grading Test and physical properties of course aggregate

Test Type	Result	The limitations of specification according (I.Q.S.) No.45/ 1984
	Grading Test	
Sieve size mm	Passing %	The limits of cumulative passing (%)
20	100	100
14	100	90-100
10	80.7	50-85
5	9	0-10
	Physical Test	
% of SO_3	0.03%	Not more than 0.1 %
Clay	1%	Not more than 2 %
Specific gravity	2.65	-
Absorption	0.68%	-

2.2. Cement

The specimens were cast with mass cement. Table 1 shows the chemical and physical parameters according to Iraqi standard specifications **specification No, 5/1984 [11]**.

Table 2

Chemical and physical properties of cement.

Compositions	Result	The limitations of specification according (I.Q.S.) No.5/ 1984
	Chemical properties	
CaO	66.26	---
Fe_2O_3	3.73	---
SiO_2	19.11	---
Al_2O_3	6.42	
MgO	1.45	Not more than 5 %
SO_3	2.31	Not more than 2.5 %
C_3A	2.9	Less or equal 3.5 %
C_2S	8.52	---
C_3S	61.8	---
C_4AF	7.07	---
Lime saturation factor	0.91	0.66 — 1.02
Loss on ignition	2.2	≤ 4 %
Insoluble residue	0.96	≤ 1.5 %
	physical properties	
Initial settling time	194 min.	≥ 45 min.
Final settling time	245 min.	≤10 h. (600 min.)
Fineness (cm^2/gm) by Blaine method	2600	≥ 2300
Compressive Strength at 3 days (MPa)	16	≥ 15 (MPa)
Compressive Strength at 7 days (MPa)	28	≥ 23 (MPa)

2.3 Fine Aggregate:

Easila sand was employed in the mix design in this study. According to the Iraqi standard specification, Table3depicted the physical and chemical qualities (Specification, 1984)**[12].**

Table 3

Grading Test and physical properties of fine aggregate.

Test Type	Result	The limitations of specification according (I.Q.S.) No.45/ 1984			
Grading Test					
Sieve size (mm)	Passing %	Zone1	Zone2	Zone3	Zone4
10	100	100	100	100	100
4.75	98.9	100- 90	100- 90	100- 85	100- 95
2.36	84.8	95- 60	100- 75	100- 85	100- 95
1.18	70.6	70- 30	90- 55	100- 75	100- 90
0.6	58.5	34- 15	59- 35	79- 60	100- 80
0.3	27.8	20- 5	30- 8	40- 12	50- 15
0.15	4.8	10- 0	10- 0	10- 0	15- 0
Physical Test					
% of SO_3	0.25%	≤ 0.5%			
% Passing 0.075 mm sieve	1.51%	≤ 5%			
Specific gravity	2.65	-			
Absorption	0.85%	-			
Fineness Modulus	2.6	-			

2.4 Water of Mixture:

Natural water was used for casting and curing the specimens.

2.5Hook Steel Fibre(HSF):

The BUNDREX firm of KOSTEEL provided hook steel fibres for this study; the hook steel fibreis shown in figure 1. For this study, the steel fibrecode was KF 65/35 CH. The qualities of hook steel fibrewere shown in Table 4.

Fig1: Hook steel fibre.

Table 4

Hook steel fibre s properties.

Code	Length mm	Diameter mm	Aspect ratio	Tensile strength MPa
KF66/35	35	0.55	64	900-2200

2.6Steel Reinforced Bars:

There are varying diameters of the steel reinforcement employed in this study. Stirrups, top bars, and bottom longitudinal bars had diameters of 6mm, 8mm, and 10mm, respectively. All steel qualities were listed in table5 according to the (ASTM A615 2009) specification (3-4).

Table 5

Steel reinforcement properties.

Size of bar (mm)	Yield stress (MPa)	Ultimate stress (MPa)	Elongation (%)
6	394	444	9%
8	331	523	16.5%
10	596	686	12.5%

3. Mix Design

The mix concrete was designed according to [13] to achieve compressive strength 35MPa. The proportions and essential features of the mix are shown in Table 6.

Table 6
Proportion of mix design.

Ingredient	**Ingredient Quantity**
Cement	395kg/m^3
Coarse aggregate	980 kg/m^3
Fine aggregate	730kg/m^3
Water	185kg/m^3

3.1Specimens Preparation

Twenty reinforced concrete beams specimens were divided into two groups A and B, each group have ten beams, with graded hook steel fibrecontent. The cross-section area of all beams was (150*200) mm, and the length was 1400mm. The layer's thickness of steel fibrewas 50mm and 100mm. The fibrepercentages were 0.5%, 0.75%, and 1%.ACI 318-19 **[13]**code was used to design the beams to fail in flexural. Figure 2 shows the reinforcement steel bars details of the beams specimens. Table 7 illustrated the details of the layers and fibrecontent for all beams.

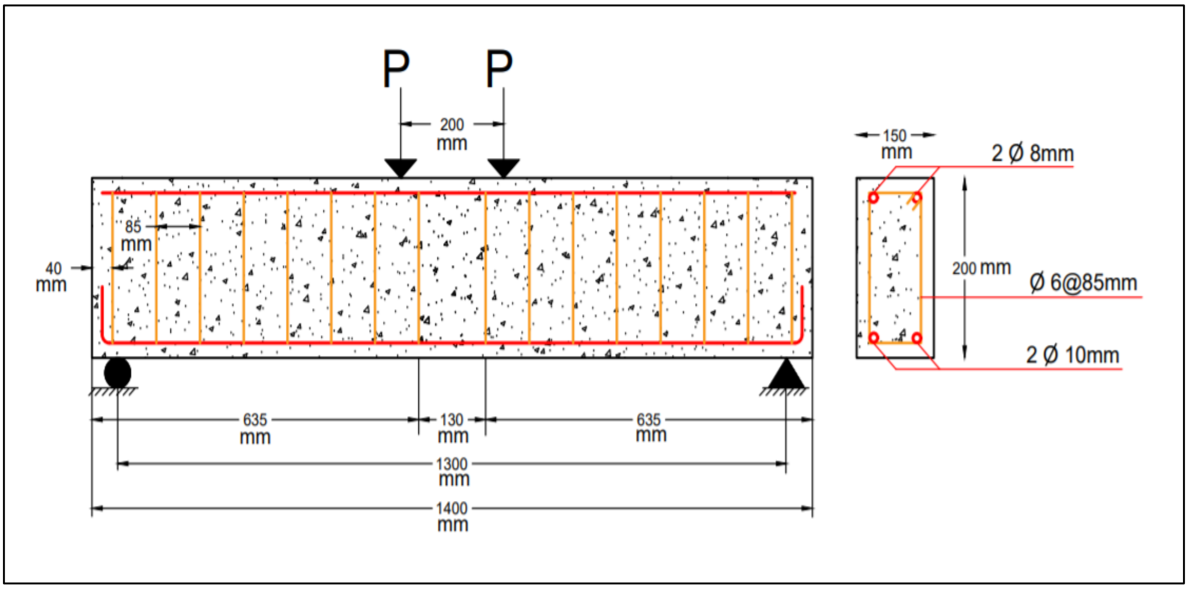


Fig2: Details of beams reinforcement

Table7. Details of the layer thickness and fibrecontent for all beams.

Group	Beam symbol	Type of Load	No. of layers	Thickness layers mm	Fibrepercentage %
A	BM1-(control)	Monotonic	N/A	N/A	N/A
	BM2	Monotonic	1	100	0.5%
	BM3	Monotonic	1	50	0.5%
	BM4	Monotonic	1	100	0.75%
	BM5	Monotonic	1	50	0.75%
	BM6	Monotonic	1	100	1%
	BM7	Monotonic	1	50	1%
	BM8	Monotonic	2	50	0.5% 0.75%
	BM9	Monotonic	2	50	0.75% 1%
	BM10	Monotonic	4	50	1% 0.75% 0.75% 1%
B	BR1-(control)	Repeated	N/A	N/A	N/A
	BR2	Repeated	1	100	0.5%
	BR3	Repeated	1	50	0.5%
	BR4	Repeated	1	100	0.75%
	BR5	Repeated	1	50	0.75%
	BR6	Repeated	1	100	1%
	BR7	Repeated	1	50	1%
	BR8	Repeated	2	50	0.5% 0.75%
	BR9	Repeated	2	50	0.75% 1%
	BR10	Repeated	4	50	1% 0.75% 0.75% 1%

When B-Beam, M-Monotonic, R-Repeated

Hooked steel fibre s were added to the beams randomly according to the specified proportions in the form of layers and with different thicknesses. Figure 3 shows the distribution of steel fibreas a layer with different fibrepercentages.

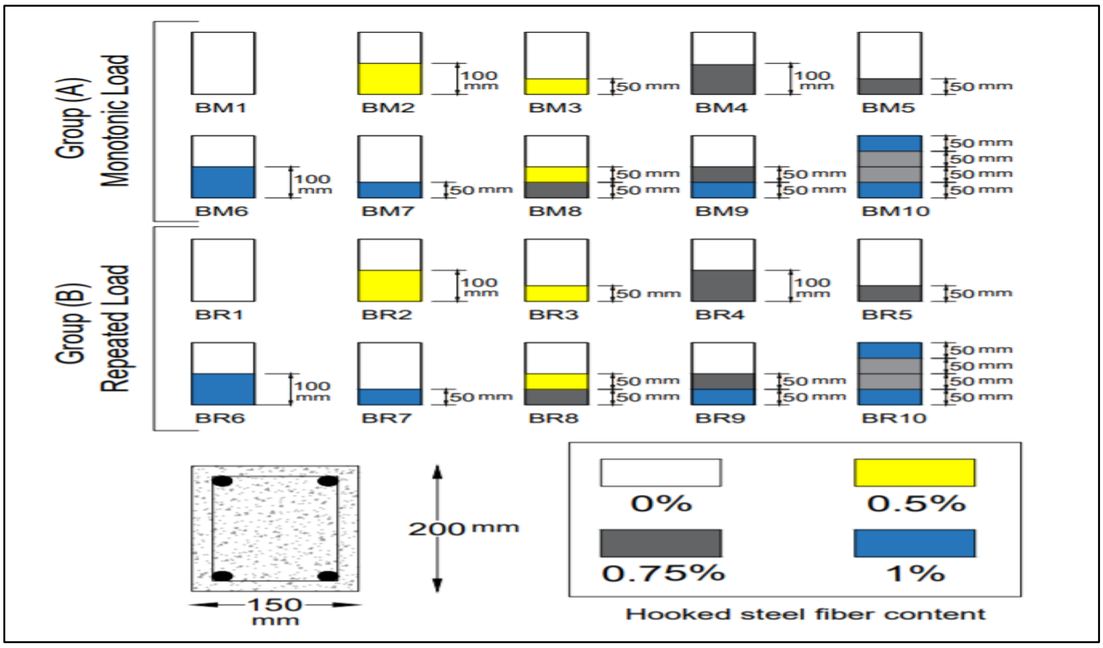


Fig3: Distribution of steel fibrelayers.

3.2 Test Setup and Instrumentation:

Beams specimen were tested under a four-point load as a simply supported beam with a clear span of 1200mm. The shear span was 635mm and the effective depth was 169mm.All beams were tested at Al-Nahrain University's Civil Engineering Department's construction laboratory using a universal testing machine with a maximum capacity of 2000 kN (see Figure 4. The hydraulic jack on the machine was built by applying 0.1 mm/sec displacements to the test segments (load increment rate of 2.5 kN/sec), and it is controlled by an electronic system made up of two components (PLC) and a controller (HMI).LVDT and dial gauge was used to determine the displacement at the mid-span of beams under the effect of monotonic and repeated load.

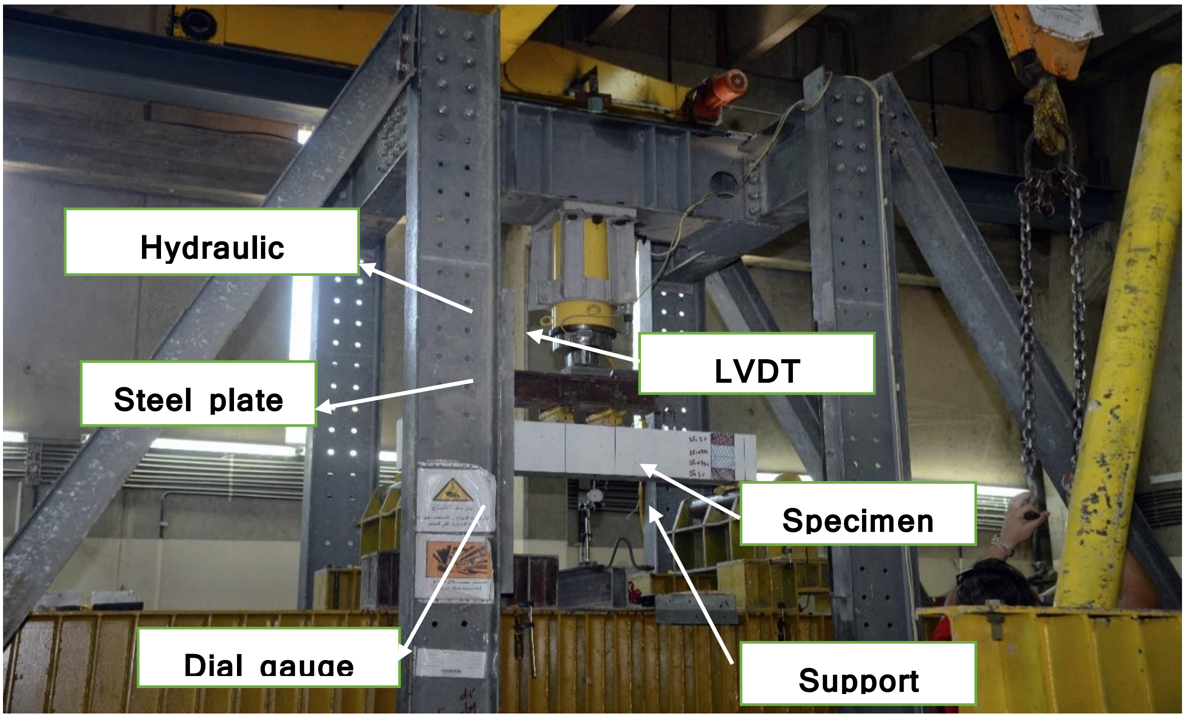


Fig4:Test setup.

4. Results and discussion

The findings of experimental work for this study were discussed, compared, and analyzed according to the load capacity and deflection value at the mid-span of beams. The analysis and discussion are justifiable for the difference of layers' thickness, different fibrepercentage and two types of load applied.

4.1 Fresh and Hardened Properties

The effect of using hook steel fibres on fresh and mechanical properties of concrete are summarized in table 8 below. The specimens of cylinder were tested for each fibre percentage and take the average. The compressive strength was tested according to the specification(ASTM C39/C39M-05)**[14]**. The splitting tensile strength was tested according to the specification (ASTM C496-04)**[15]**. The Elastic modulus was tested according to the specification (ASTM C469-02(104))**[16]**. The modulus of rupture was tested according to the specification (ASTM C78-02)**[17]**.

Table 8

Mechanical properties of fresh and hardened concrete.

Fibre s %	Compressive Strength (MPa)	Splitting tensile Strength (MPa)	Elastic modulus (GPa)	Modulus of rupture (MPa)
0	34	3.09	25.67	3.1
0.5	37.8	4.1	30	5.4
0.75	39.4	4.73	31.12	6.1
1	44	5.45	32.80	6.5

The results indicated that the hook steel fibrehas a good role in improving the mechanical properties of the concrete. The slump of concrete decreases with the fibrevolume increase due to the increaseof internal friction between fibre s and aggregate.On the other hand, the compressive strength, splitting strength, elastic modulus and modulus of rupture were increased with the fibrepercentage increase due to the steel fibrerole in restricting the concrete and reducing the extension of cracks by connecting the two opposite sides of it.Also, the steel fibrewill carry the stresses after the cracks happen. The maximum increase in the compressive strength, splitting strength, elastic modulus and modulus of rupture were 22.7%, 43.3%, 34.2%, and 52.3%, respectively at the fibrepercentage of 1%.

4.2 Results of Beams Specimens Under Monotonic and Repeated Loading

All beams were tested under the two-point loads as a simply supported beam. The monotonic load was with a constant rate of 2.5 KN/sec until the failure. while the repeated loaded history according to was federal emergency management Agency (FEMA) of low cyclic load[18], the first stage of low cycle fatigue applies ten cycles of deformation amplitude, i.e. $\Delta1 = 0.1\Delta u$, followed by three further cycles of amplitude 1.2 times the first stage, i.e. $\Delta2 = 1.2\Delta1$. In each of the subsequent stages, the deformation amplitude is increased by 0.2 (i.e.$\Delta3 = 1.2\Delta2$, $\Delta4 = 1.2\Delta3$, $\Delta5 = 1.2\Delta4$, $\Delta6 = 1.2\Delta5$, $\Delta7 = 1.2\Delta6$...etc.) while subjecting the specimen to three cycles until complete damage, as shown in figure 5.

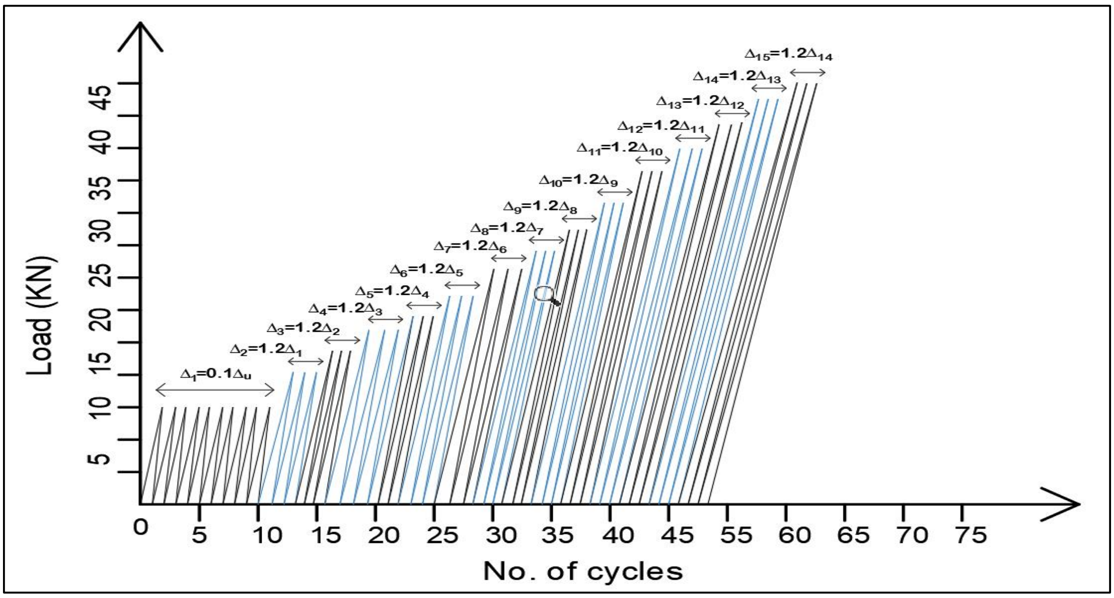


Fig 5: History of repeated load

The results of the beams under the monotonic load showed that in general the ultimate load increase with adding the hooked steel fibre, on the other hand, the deflection of beams decreased with adding hooked steel fibre. The explanation for this behaviourwas due to the role of steel fibrein restricting the cracks of concrete and carrying the stresses instead of the concrete.

Also, the ultimate load for the beams under the repeated increased, but the increase was less than the increase in monotonic load due to the effect of the repeated load. It leads to the weakening of concrete due to the increase in the internal cracks of the concrete. Figures6, 7, 8, 9, 10, 11, 12, 13, 14, and 15 were illustrated the results of the specimens beamsB1, B2, B3, B4, B5, B6, B7, B8, B9, and B10 under the monotonic and repeated loads.

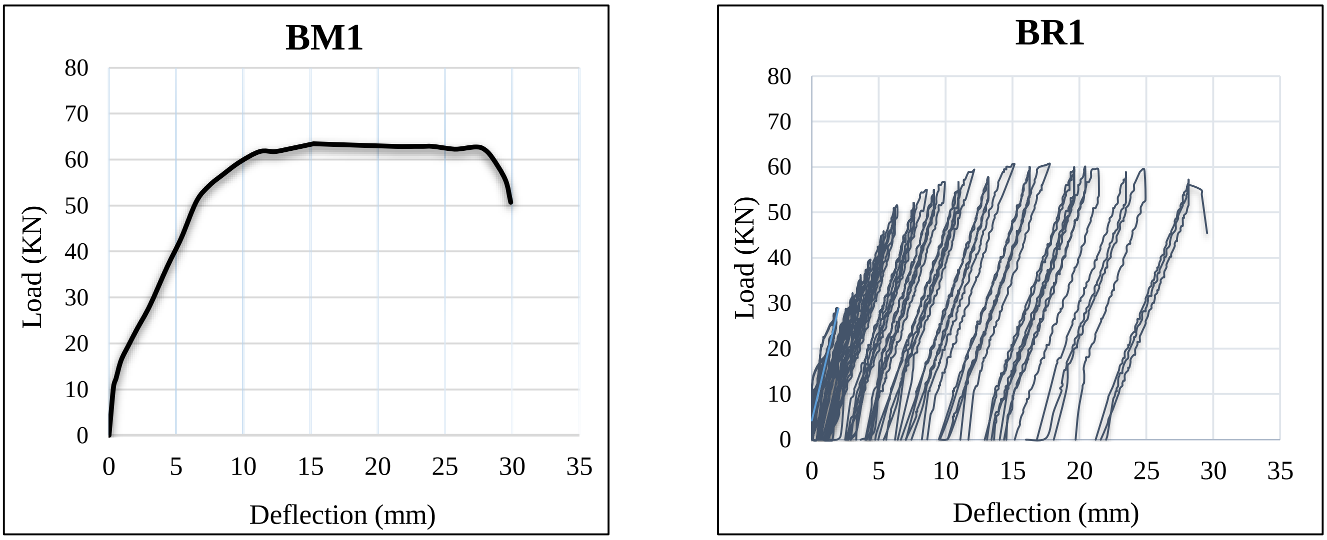


Fig 6: load deflection curve of beam specimen (B1)

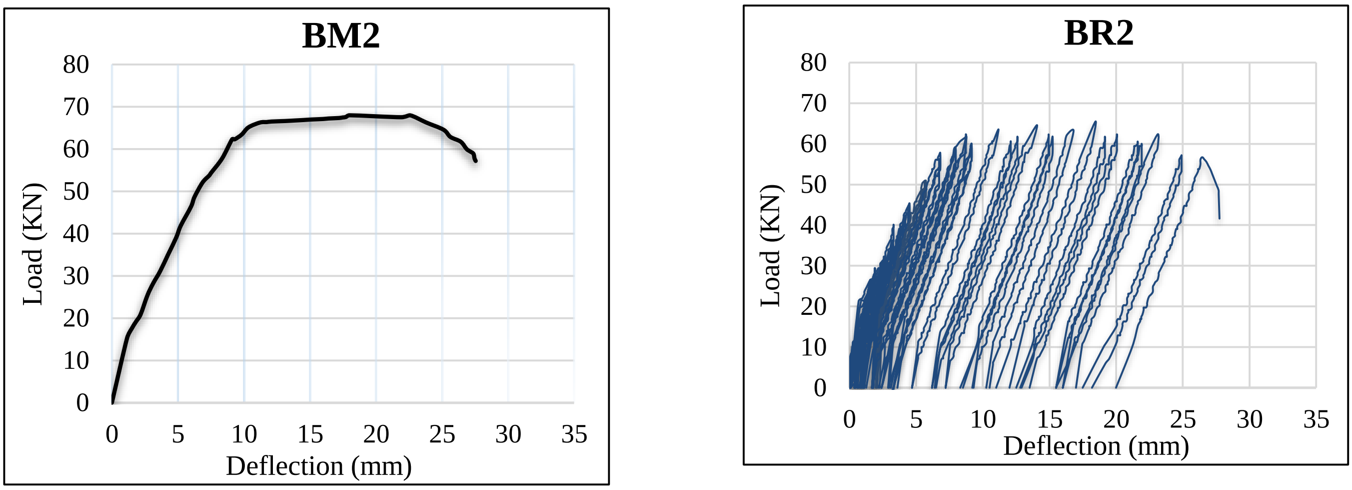


Fig 7: load deflection curve of beam specimen (B2)

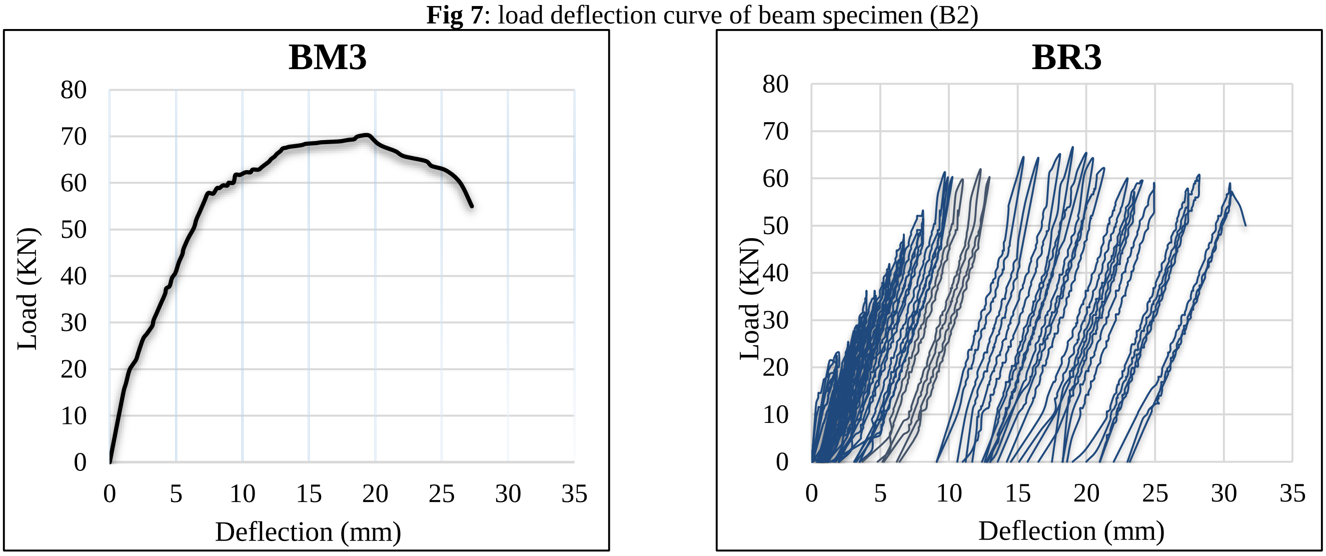


Fig 8: load deflection curve of beam specimen (B3)

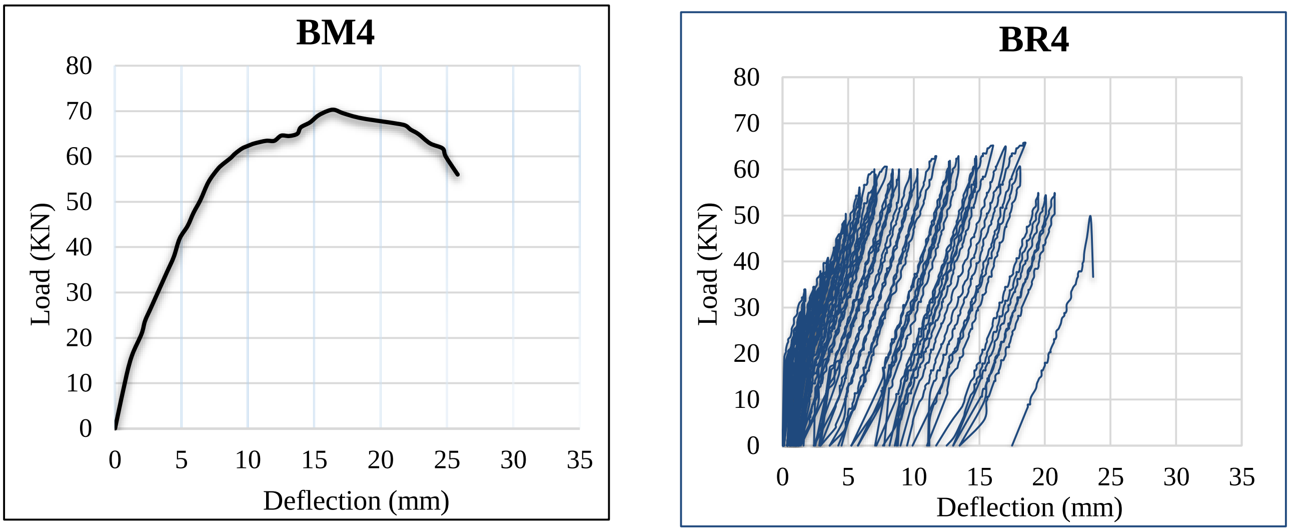


Fig 9: load deflection curve of beam specimen (B4)

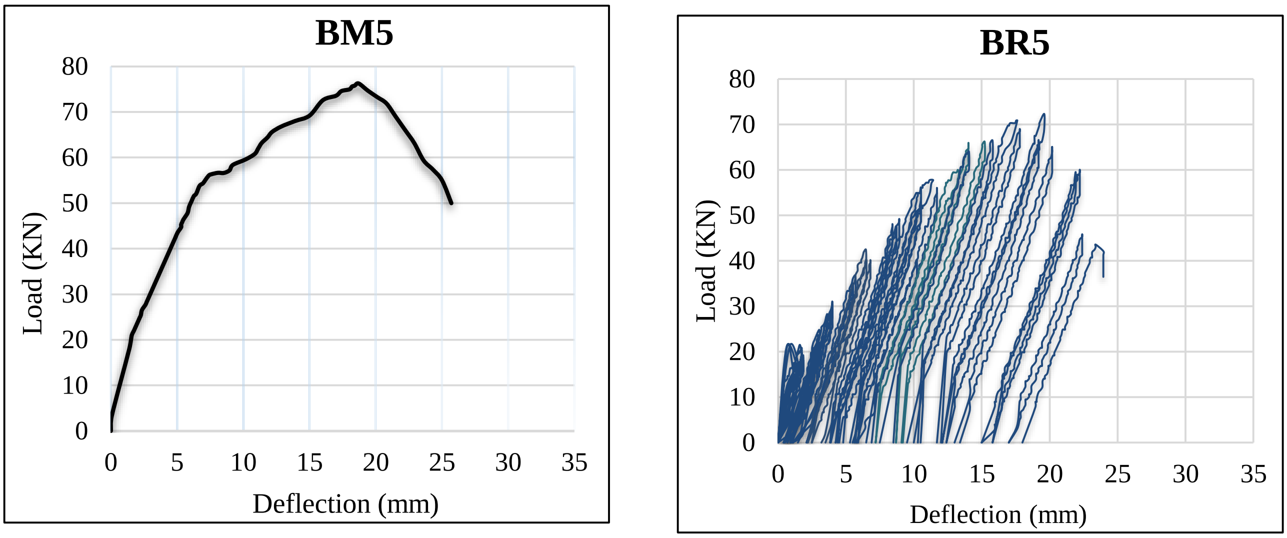


Fig 10: load deflection curve of beam specimen (B5)

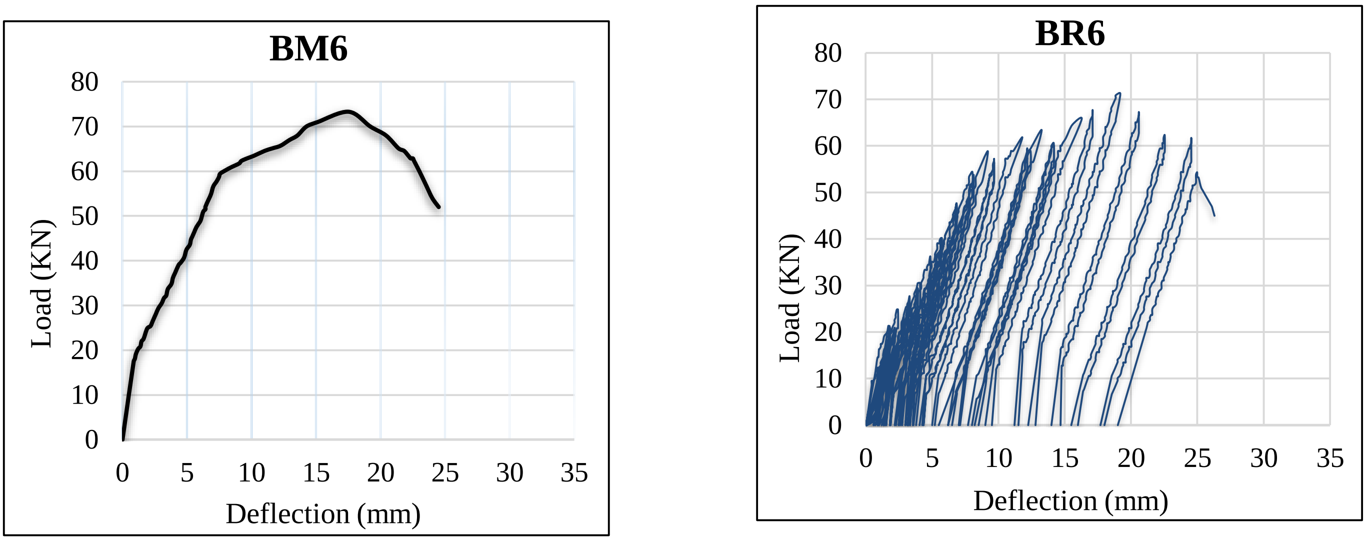


Fig 11: load deflection curve of beam specimen (B6)

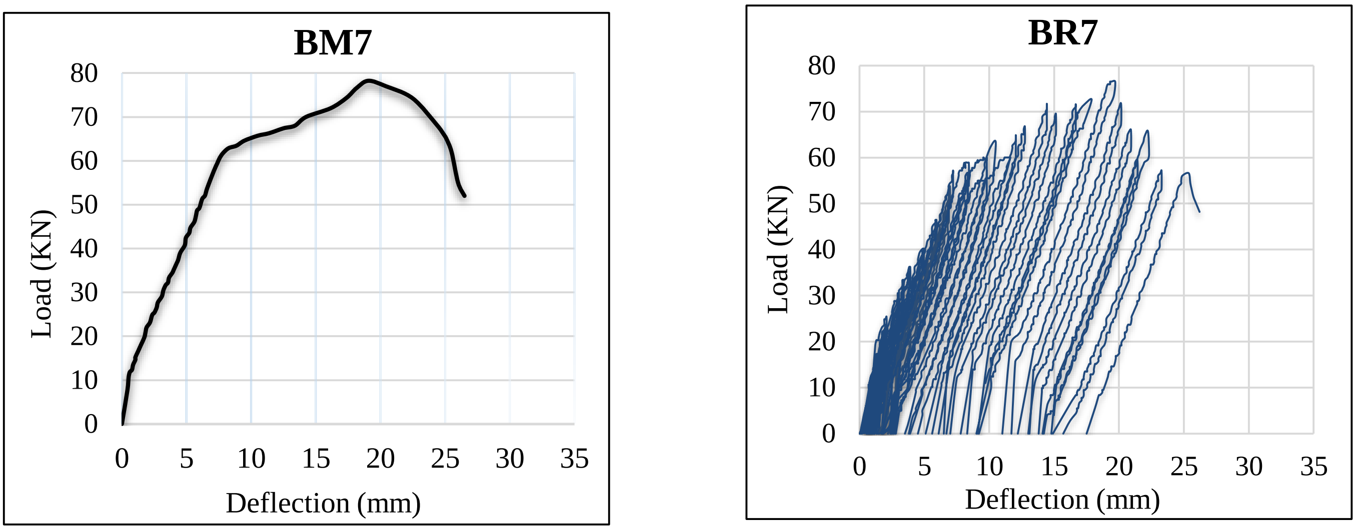


Fig 12: load deflection curve of beam specimen (B7)

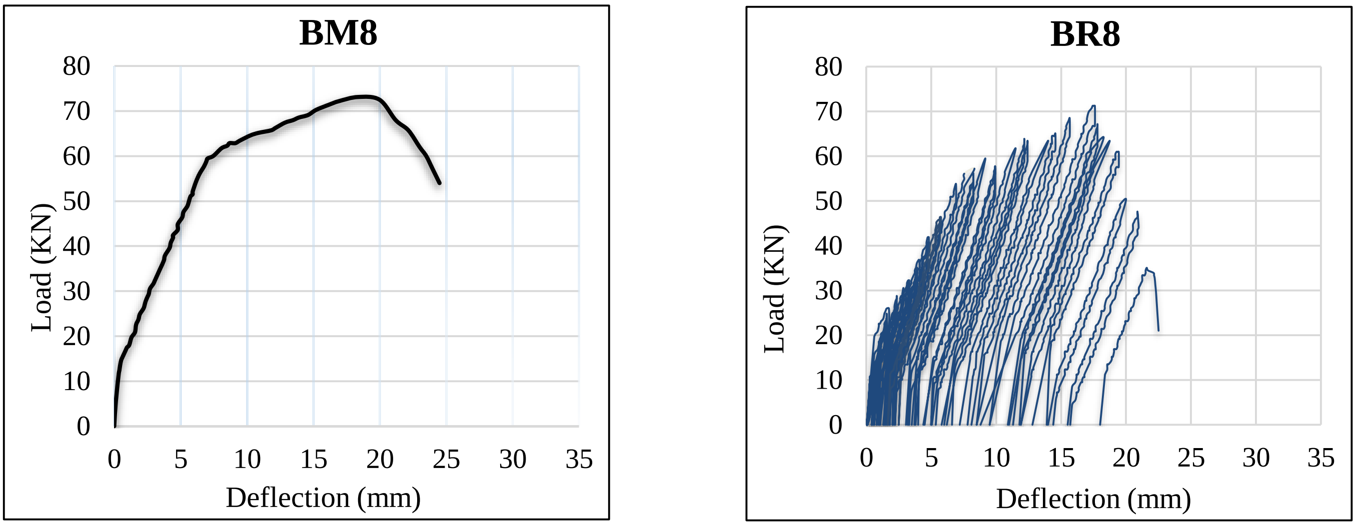


Fig 13: load deflection curve of beam specimen (B8)

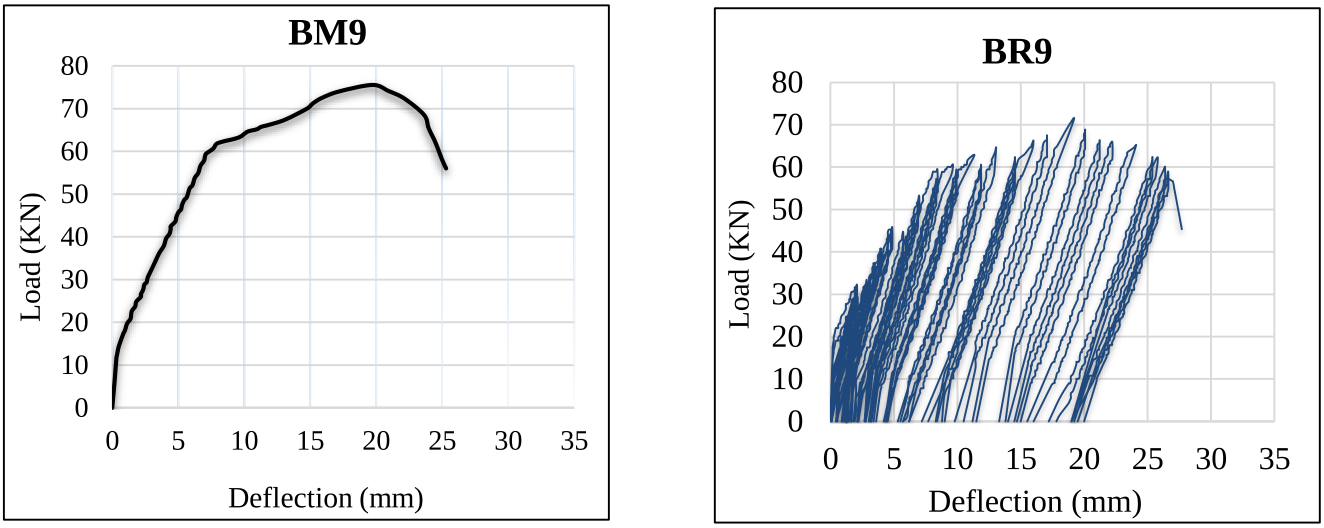


Fig 14: load deflection curve of beam specimen (B9)

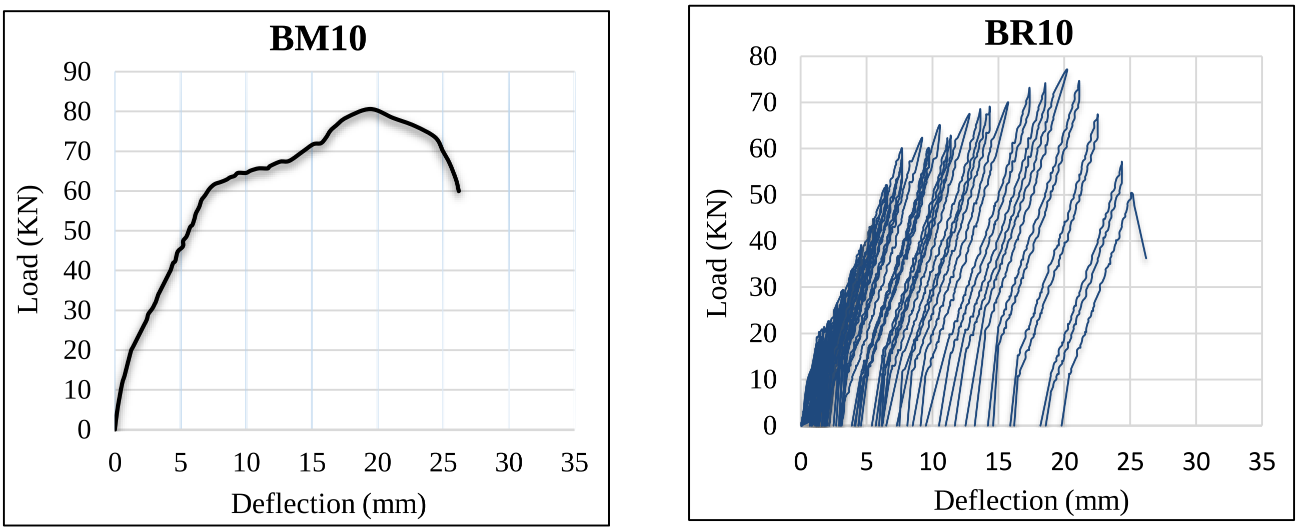


Fig 15: load deflection curve of beam specimen (B10)

According to the load-deflection relationship, adding steel fibrewith different layer thicknesses and fibrepercentages increased the monotonic and repeated loads of the beams with varying values depending on layer thickness and fibrecontent. Table 9 summarized the results.

Table 9
Load and deflection results of beams specimens.

Beam symbol	Ultimate Load (KN)	Deflection. At ultimate load (mm)	Load at first crack P_{cr} (KN)	Deflection. At first crack (mm)
BM1 (control)	63	15.02	22	1.82
BM2	72.14	18.27	25.6	3.02
BM3	68.25	17.87	23.4	2.52
BM4	76.01	18.65	25.5	2.95
BM5	70.28	17.85	24.8	2.74
BM6	78.24	19.06	26.4	3.2
BM7	73.32	17.52	25	2.84
BM8	73.12	18.36	25.8	3.05
BM9	75.52	18.72	26	3.1
BM10	81.65	19.54	28	3.2
BR1 (control)	60	17.75	21	1.99
BR2	68.7	18.92	24.5	3.21
BR3	65.57	18.66	22.5	2.61
BR4	72.4	19.6	24.8	3.04
BR5	66.14	18.25	23.4	2.84
BR6	76.57	19.9	25.8	3.4
BR7	70.7	19.27	24.2	2.99
BR8	70.44	18.93	25	3.2
BR9	71.28	19.18	26	3.3
BR10	76.51	20.17	27	3.5

The results showed that the ultimate load was affected by adding the hooked steel fibres to the RC beams as layers, the maximum increase in ultimate load was 22.88% and 21.5% for the monotonic and repeated loads, respectively.

In addition, the results showed that the first cracks were affected by adding the hooked steel fibres to the RC beams as layers, the load of the first cracks was increased by 27.2% for the monotonic load at the beam (BM10) and increased by 22.2%% for repeated load at the beam (BR10).

The upward curve does not follow the same path as the descending curve when loaded and unloaded, and the difference between the two curves is due to the amount of energy dissipated or lost during the loading and unloading operation (and it can be observed in figures above). The energy is wasted or lost by increasing the proportion of fibre s because the fibre s from multiple cracks as a result of their presence inside the concrete, which leads to the dispersal of a greater amount of energy. From the above results, we can note the following:

1. The ultimate load for the same layer thickness increased with the fibrepercentage increased as shown in Figures 16a and b.

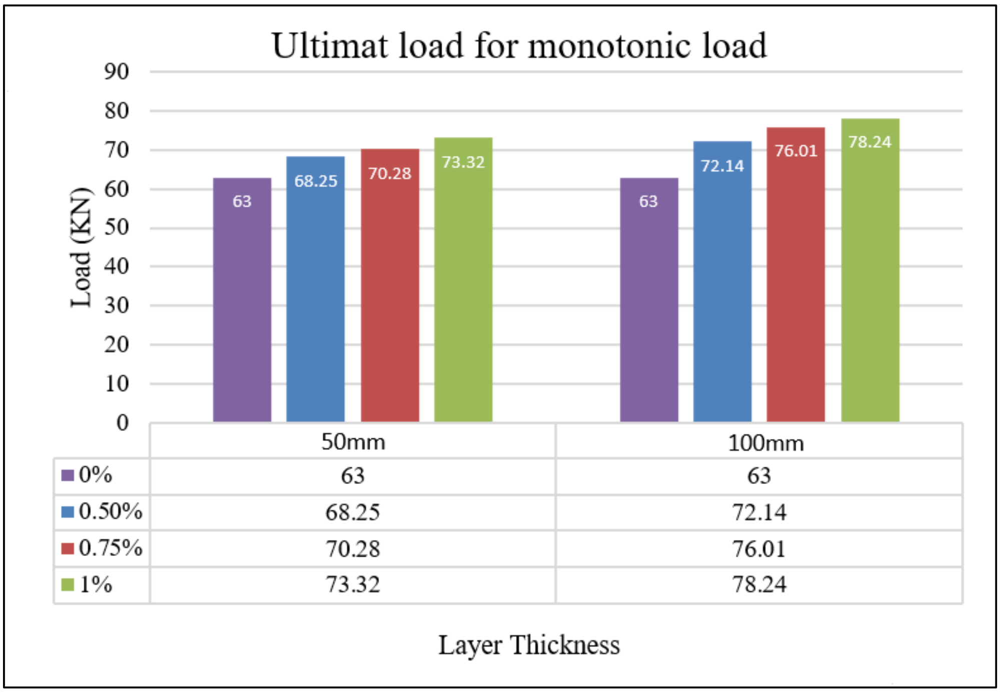


Fig 16a: Ultimate load for monotonic load with different fibre s content and layers thickness.

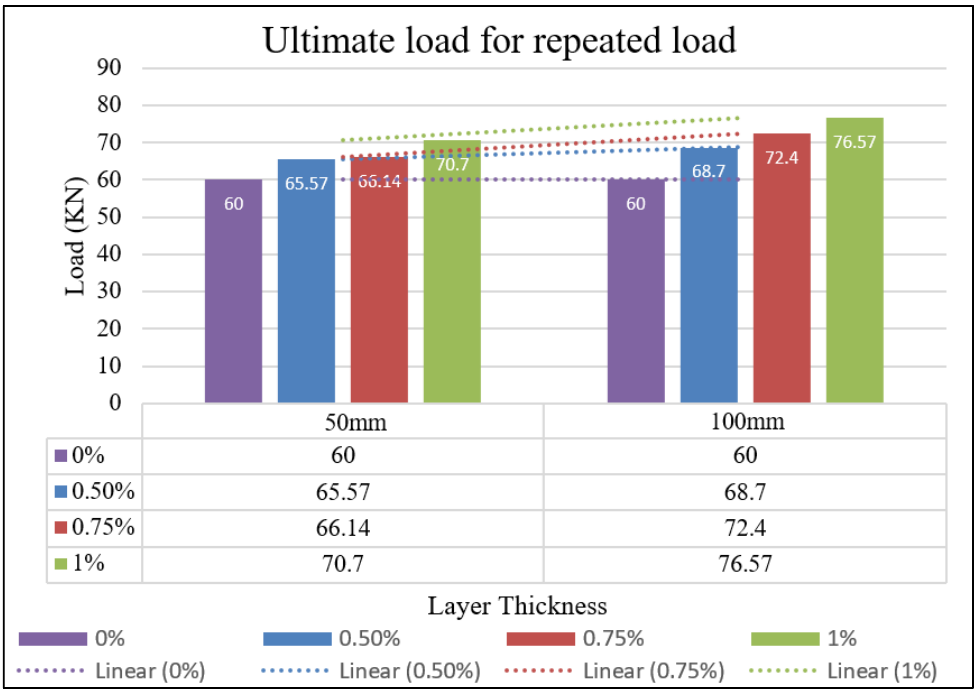


Fig 16b:Ultimate loads for monotonic load with different fibre s content and layers thickness.

2. Because of the crushing that occurs in the model as a result of repeated loading cycles, the stiffness decreases as the number of loading cycles increases.

3. Increasing the ductility by increasing the percentage of fibre s, as it works to increase the resulting deflection, especially in the final stages of fading.

Also, as shown in Figure 17, the ultimate load value for the beam specimens under repeated loads was less than the ultimate load value under monotonic loads.

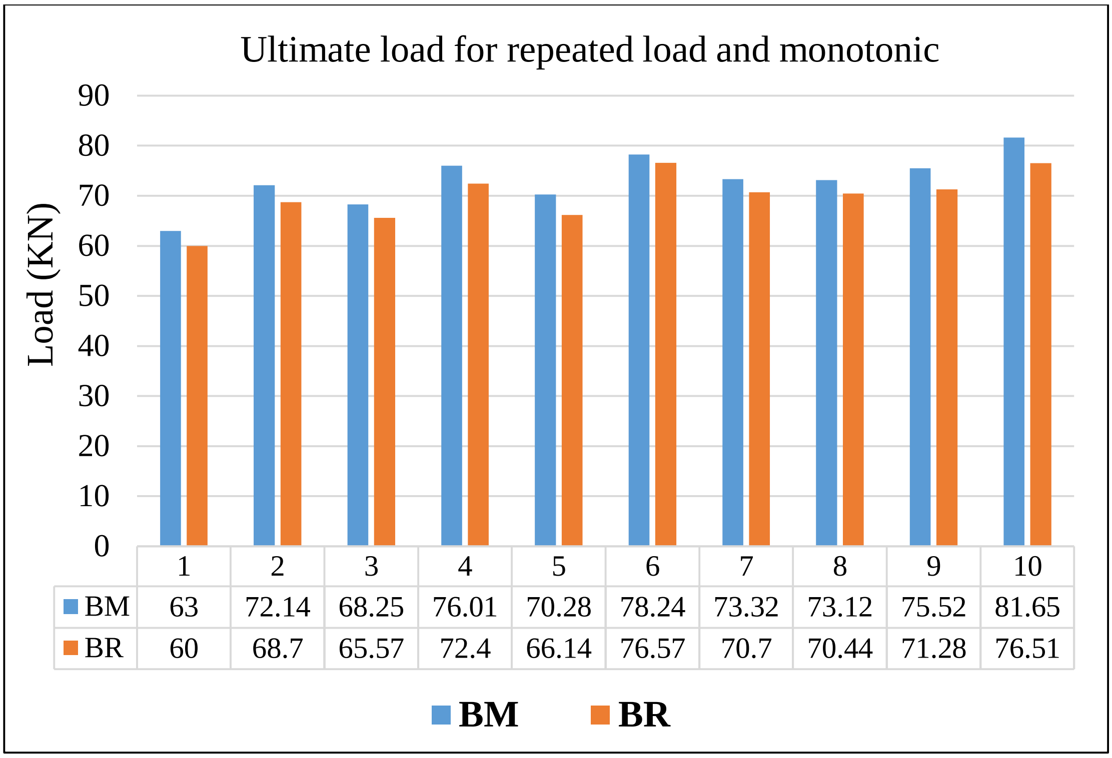


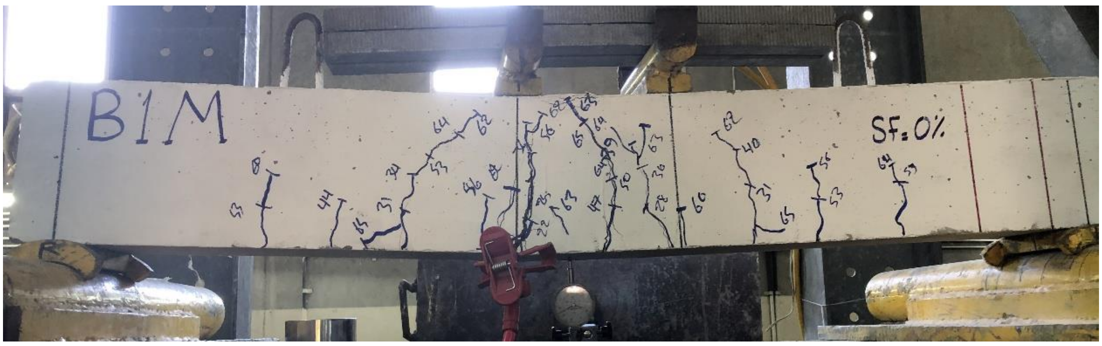
Fig 17: deference between the monotonic and repeated load for the same beams specimens.

The results showed that using layers of steel fibres in reinforced concrete beams (functionally graded reinforced concrete beams) instead of entirely reinforced cross-section beams with steel fibres as a structural element has a great potential for use under monotonic and repeated stresses. According to the results acquired for each cycle, using the functionally graded reinforced approach with steel fibres permitted the achievement of the highest normalized absorbed energy.

4.3. Failure Mode and Cracks Pattern for Specimens Beams Under Monotonic and Repeated Loads

Under monotonic and repeated loads, Figures18, 19, 20, 21, 22, 23, 24, 25, 26, and 27 were illustrated the mode failure of all specimen beams. The initial location and shape of the critical fracture—that is, the crack that causes the beam to collapse—was thoroughly examined, as was its relevance to the failure mode.The experimental results are examined using an extension of the bridging crack model. The model can examine the evolution of flexural-shear fractures while determining the failure mechanism within a unified framework (flexural, shear, or compression).The amount of hooked steel fibre in an RC beam affects the crack pattern and mechanical behaviour significantly.

The hooked steel fibreratio will define the first position and shape of the cracks in the element. The cracks will grow closer to the spot where the load is applied, and one of them, known as the critical crack, will cause the element to fail. The cracking process and the failure mode are intrinsically related, according to this statement. On the other side, the steel fibrereaction reduces the spread of flexural cracks. The cracks for the same beam qualities under different load types, such as monotonic and repetitive loads, were more than the cracks for the same beam qualities under repeated load, according to the findings.



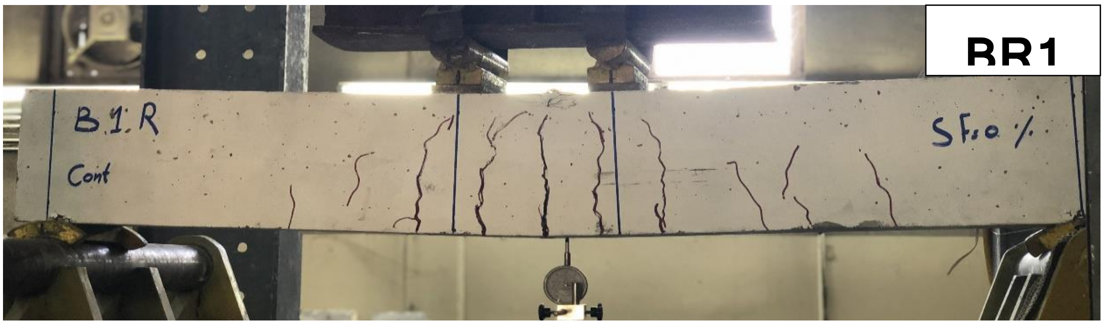


Fig 18: Failure mode of the beam specimens (B1) under the monotonic and repeated loads.

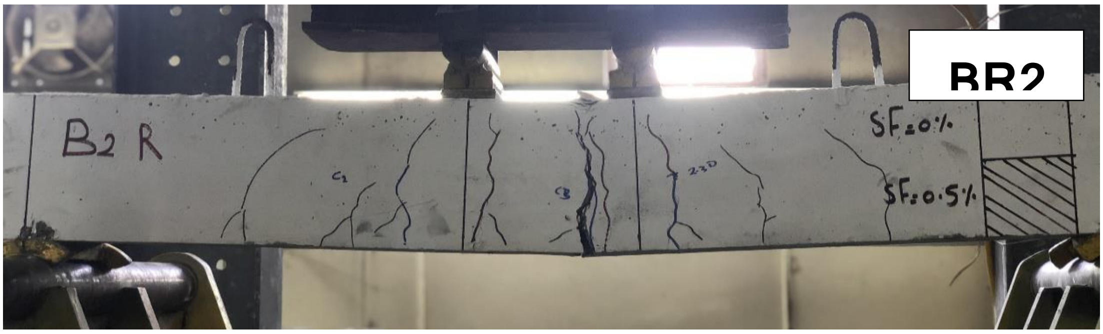


Fig 19: Failure mode of the beam specimens (B2) under the monotonic and

Figure 18: Failure mode of the beam specimens (B1) under the monotonic and repeated loads.

Fig 20: Failure mode of the beam specimens (B3) under the monotonic and

Fig21: Failure mode of the beam specimens (B4) under the monotonic and repeated loads.

Figure 21: Failure mode of the beam specimens (B4) under the monotonic and repeated loads.

Fig 22: Failure mode of the beam specimens (B5) under the monotonic and repeated loads.

Fig 23: Failure mode of the beam specimens (B6) under the monotonic and repeated loads.

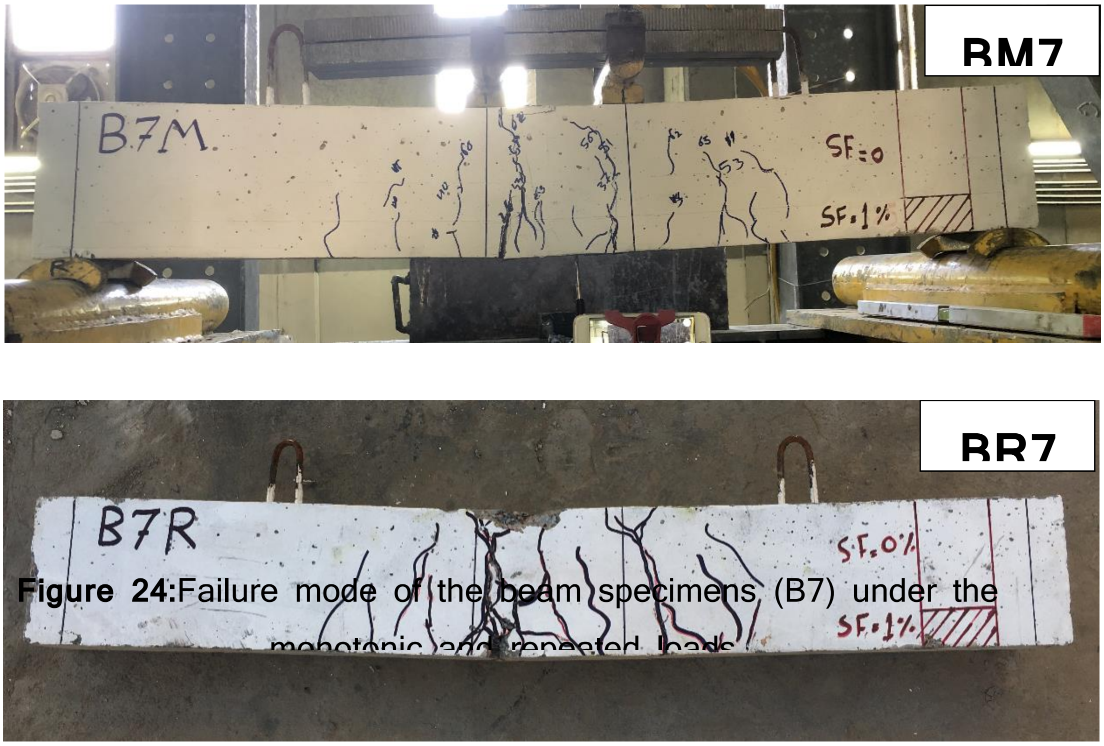


Figure 24: Failure mode of the beam specimens (B7) under the monotonic and repeated loads.

Fig24: Failure mode of the beam specimens (B7) under the monotonic and repeated loads.

Fig 25: Failure mode of the beam specimens (B8) under the monotonic and

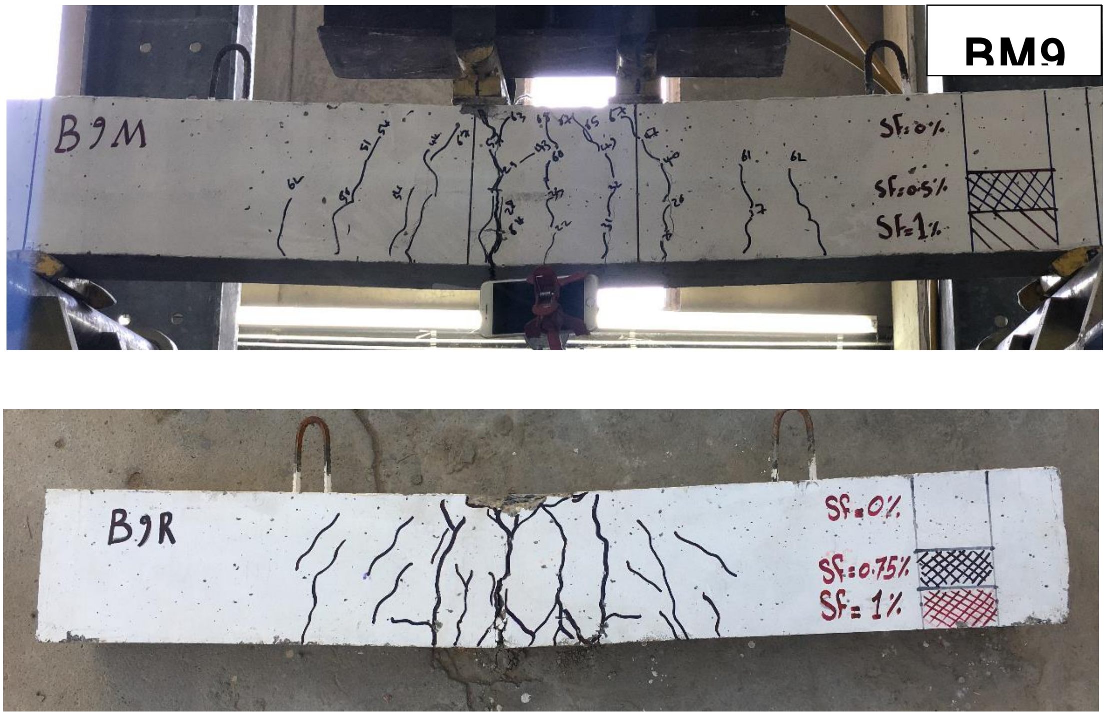


Fig 26: Failure mode of the beam specimens (B9) under the monotonic and repeated loads.

Fig 27: Failure mode of the beam specimens (B10) under the monotonic and repeated loads.

5. Conclusion

Previous research has suggested that functionally graded reinforced concretes have a lot of potentials. The behaviourof functionally graded reinforced concretes under monotonic and repeated loads was validated using these findings. At this point, our research looked into the performance of functionally graded reinforced concrete beams under monotonic and repeated loads. The following outcomes were obtained in this regard:

1) The best performance was achieved at the reinforced concrete beam B_{10} with fourlayers. The load of the specimen beam BM10 was increased by 22.88% for the monotonic load. On the other hand, the load of the specimen beam BR10 load increased by 21.50% for the repeated load.
2) The functionally graded reinforced concretes reduced the energy dissipated for beams under the repeated load due to reducing the internal crack of beams.
3) Because the hooked steel fibre s were involved in confining the concrete and inhibiting crack extension and expansion, therefore the hooked steel fibrewas carried the interior stress due to the load applied. The highest increase in deflection was at BM10 by 23.13% for the monotonic load.while the highest increase in deflection was at BR10 by 12% for the repeated load. on the other hand, the deflection of all beams specimens under the repeated load was more than the deflection of specimens beams under the monotonic load
4) Previous findings on the influences of fibrecontent, fibretype, and reinforced concrete layer placements on the functionally graded reinforced concrete responses [4, 19, 20] were confirmed in this investigation.
5) For two beams at the same layer thickness and fibrepercentage, the ultimate load for the beams under the repeated was less than the ultimate load for beams under the monotonic load due to the effect of repeated load In weakening and crushing concrete as a result of internal cracks.
6) In comparison to the reinforced cross-section, the application of the functionally graded approach to reinforce concrete raises the dissipated energy because of the applied cyclic stress, according to the obtained data. As a result, using this technology to reinforce concrete elements with steel fibres can improve the structural elements' capacity in seismic applications.

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