



# Experimental and Numerical Analysis of Flexural Behavior of Layered Polyethylene (PET) Fibers RC Beams

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## ABSTRACT

Nonlinear numerical analysis of nine reinforced concrete beams with dimensions (150 x 200 x 1200) width, height and length, respectively, was carried out through the finite element theory using the ANSYS software (version 15) to know the effect of different properties of layers in the one beam on the flexural behavior of reinforced concrete beams. The beams are consisting from two layers for the one cross-section. three beams are similar properties layers and the other six are with different properties layers. The beams differ among them depending on the percentage of Polyethylene terephthalate (PET) fibers added, the location of the fibrous concrete layer as well as the thickness of the layer. PET fibers were added in proportions (0%,0.5%, and 1%) from volume of the one layer, with dimension (50 x 4 x 0.3) mm length, width, and thickness respectively. All beams are reinforced with steel reinforcement (6 mm diameter at the top, 10 mm diameter for reinforcement against shear and 12 mm diameter in the tension area). The mechanical properties of each type of mixture have been studied. It was found that the different properties of the layers significantly affected the flexural behavior of reinforced concrete beams. Also the results of the numerical modeling were very close to the laboratory results obtained from the practical study, where the largest difference between the two studies was 8% and 11% for the load and deflection respectively at the ultimate point.

## 1. Introduction

The finite elements is numerical method widely used to find approximate solve many complex engineering problems (Ghernouti et al., 2015). Numerical analysis of reinforced concrete has been used a lot in the past years due to the long time, the great efforts that must be made in the practical study and the difficulty of providing some materials during the period of conducting the study (Lawrance KL, 2002). (Elmezaini & Ashour, 2016) conducted a numerical study of the reinforced concrete beams with different layers that contain steel fibers using the ANSYS software. The results of the theoretical study showed a very good convergence with the results of the practical study. Also, the difference of the layers showed results better than the similar layers, where they achieved an increase in the ultimate load and the ultimate deflection. The convergence of the results of the theoretical study with the results of the laboratory assures researchers of the possibility of using numerical modelling methods in the investigation about a study, without need the time, effort and cost that are used in the practical study.

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## 2. Materials of experimental study

The materials were used in the production of all concrete mixtures in the laboratory are shown in Figure 1 of a-e:



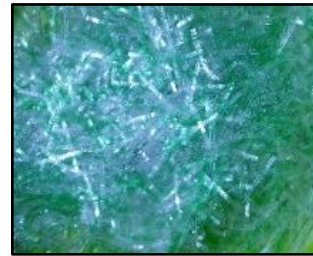
a) Portland cement ( $395 \text{ Kg/m}^3$ ), and the water cement ratio (0.46)



b) Fine aggregate ( $730 \text{ Kg/m}^3$ ) with maximum size 4.75 mm and specific gravity 2.54



c) Coarse aggregate ( $980 \text{ Kg/m}^3$ ) with maximum size 10 mm, and specific gravity 2.6



e) PET fibers



d) Steel reinforcement

Figure 1 Materials of experimental study

## 3. Beams of experimental study

Nine beams were studied in this paper (B-R) representing the reference beam and it's no contain PET fibers, (B-0.5), (B-1) containing 0.5% and 1% PET fibers, respectively, of the volume of the full beam's layers. The beams with different characteristic layers are (LB-0.5-Q), (LB-0.5-H), (LB-0.5-T), (LB-1-Q), (LB-1-H), and (LB-1-T) where, the symbol (LB) represents the different layer, and (0.5, 1) represents the percentage of fibers in the layer. The symbols (Q, H and T) represent the ratio of the height fibrous concrete layer to the height of the beam. The Q is One fourth of the height of the beam and it is located at the bottom, the H is half the height of the beam and it's located at the bottom too, while the T is half the height of the beam and it's located on the top. Figure 2 explain the nine beams of this study. Experimental testing results explained in the Table 1. Appendix A explains the details of the dimensions of the beams and reinforcement them and how the load was applied during the examination.

Table 1- Flexural results of layered beams

Beams symbols	B-R	B-0.5	B-1	LB-0.5-Q	LB-0.5-H	LB-0.5-T	LB-1-Q	LB-1-H	LB-1-T
$P_u$ (kN)	104	114	95	110	123	124	114	125	113
$\Delta_u$ (mm)	5.38	5.55	5.5	5.34	9.75	8.67	6.97	8.2	6.15

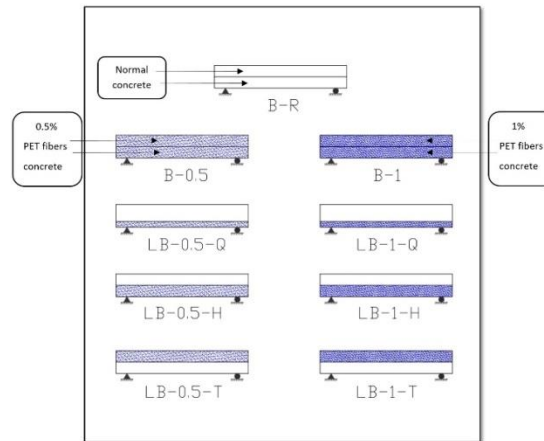


Figure 2 Beams study.

#### 4. Numerical study

All beams were studied in the laboratory will be theoretically studied by the numerical analysis program (ANSYS software). The numerical study carries out through several steps:

- Choosing the element type.
- Define the real constant such as (cross section area and others) for elements.
- Define properties of materials such as (compressive stress, splitting tensile stress, modulus of elasticity, and Poisson’s ratio).
- Creating elements geometry.
- Meshing process through which ANSYS program transform the materials into elements.
- Selecting merge nodes.
- Applying loads (loads and the supports).
- Solution

#### 5. Modeling of materials

The process of representing the components of the study samples in reality within an ANSYS program is called modelling. These compounds are (concrete, steel reinforcement, plastic fibers, and steel plates for supports and load-bearing points).

##### 5.1. Modeling of concrete

The element (SOLID65) is appropriate to represent concrete because it simulates the behavior of concrete by cracks and crushes which occur in the tension and compression regions, respectively. It has eight nodes; each node has three degrees of freedom in the (x, y, and z) directions (ANSYS Version 2015) such as Figure 3.

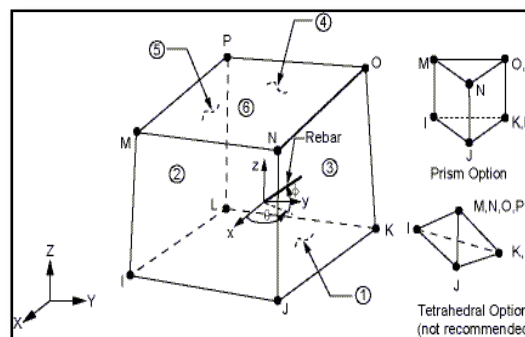


Figure 3 SOLID 65 geometry (ANSYS Version 2015).

### 5.2. Modeling of steel reinforcement

The LINK180 was used to model all steel reinforcement (compression rebar, rebar of bending, and rebar of shear). It has two nodes, each node has three degree of freedom in (x, y, and z) directions (ANSYS Version 2015), Figure 4 explain it's geometry.

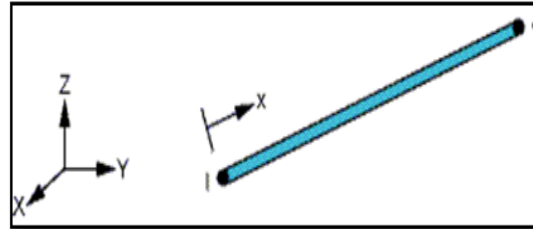


Figure 4 LINK180 geometry (ANSYS Version 2015).

### 5.3. Modeling of Waste plastic fibers

The existence of the plastic fibers inside concrete is similar to existence the aggregate whose location and direction are difficult to determine, so they cannot be modeled or represented by a specific element, this is consistent with a previous study prepared by (Hang J. & Yong-quan Li, 2012). Since the addition of plastic fibers to concrete caused a change in its mechanical properties, the behavior of concrete will differ with the existence of fibers from its behavior without the fibers. Accordingly, the plastic fibers will be modeled implicitly through concrete with properties that differ from the properties of ordinary concrete, i.e. (SOLID65) with the characteristics of a concrete that contains plastic fibers and this is agree by (Majeed, H.Q., 2012), and (Hafedh et al., 2020).

### 5.4. Modeling of steel plate for support and applied load

Plates for support and load are represent by element (SOLID185) because it has, many properties such as (plasticity, high elasticity, stress stiffening, large deflection, and large strain capabilities). It has Eight nodes, three degrees of freedom for each node in (x, y, and z) directions (ANSYS Version 2015). Figure 5 show it's geometry.

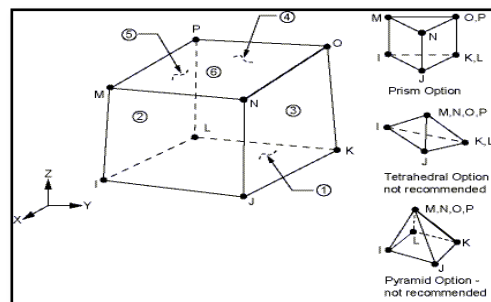
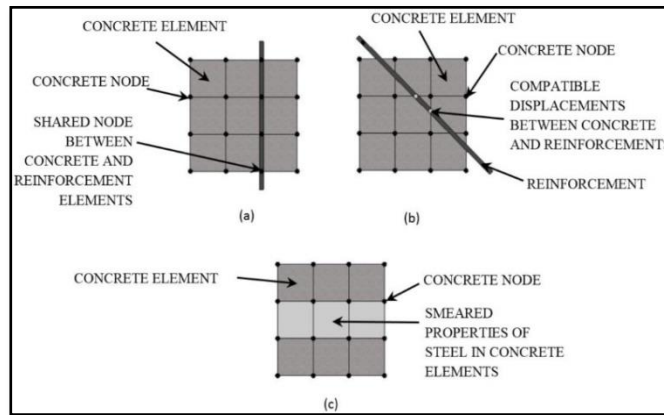


Figure 5 SOLID185 geometry (ANSYS Version 2015).

## 6. Mechanism of RC beams modeling

There are three techniques for modeling reinforced concrete which are (discrete modeling, embedded modeling, and smeared modeling) according to the Tavarez model (Tavárez, F.A., 2001) such as Figure 6. In this paper, the discrete technique will be used for modeling all beams because the concrete and the steel reinforcement are divided so that their elements meet the same node, this makes this method more used.



(a) discrete; (b) embedded; and (c) smeared  
**Figure 6 Reinforcement concrete modeling techniques (Tavárez, F.A., 2001).**

### 7. Real constant

Real constants for all elements chosen were illustrate in the Table 2.

**Table 2- Real constants for selected elements**

Material	Element type	Real Constant set	Constants			
			Material Number	Volume Ratio	Orientatio Angle	Orientation Angle
Concrete 0% PET	Solid65	65	0	0	0	0
Concrete 0.5% PET	Solid65	66	0	0	0	0
Concrete 1% PET	Solid65	67	0	0	0	0
			Area ( $mm^2$ )			
Steel Ø6 mm	Link180	6	28.26			
Steel Ø10 mm	Link180	10	78.5			
Steel Ø12 mm	Link180	12	113			
Steel support	Solid185					

### 8. Material properties

Material properties are shown in the Table 3 and Table 4 . Three materials used in this modeling were (concrete **SOLID65**, steel reinforcement **LINK180**, and steel plates for support and loading **SOLID185**). To define the element (**SOLID65**), several information must be available regarding the three stages that it passes through. This information is the elastic modulus and the Poisson ratio for the linear stage, the values of the stress-strain curve for the nonlinear stage, while the definition of concrete failure is by the model Willam and Warnke, (Willam, K.J. & Warnke, 1975), Which consist of four parameters are (open and closed cracks coefficients (shear transfer coefficients), splitting tensile strength, and compressive strength). Several researchers (Elmezaini N., & M. Ashour, 2016), (Majeed, H.Q., 2012), and (Chen, M., &C. Pei, 2017) have entered a value of (-1) for the compressive strength of the concrete to avoid stop loading in ANSYS because its considers cracking a failure in some cases

**Table 3- Material properties of concrete**

Element type	Real Constant set	Material properties							Multi-linear	
		Linear isotropic		Concrete					Strain	Stress
		EX (GPa)	PRXY	ShrCf-Op	ShrCf-CI	UnTensSt	UnCompSt			
Solid65	65	28.8	0.19	0.5	1	3.3	-1	0.00005	1.44	
								0.0003	8.64	
								0.00054	15	
								0.00086	20.2	
								0.00135	26	
								0.00203	31	
								0.0028	33	
Solid65	66	30.4	0.2	0.5	1	3.5	-1	0.00005	1.52	
								0.00027	8.2	
								0.00053	16	
								0.00068	20	
								0.0014	29.5	
								0.0024	34	
								0.0031	35	
Solid65	67	27.5	0.2	0.5	1	3.3	-1	0.00005	1.37	
								0.00035	9.62	
								0.00095	19.7	
								0.0016	26	
								0.002	29	
								0.00245	30.5	
								0.0027	31	

**Table 4- Material properties of steel reinforcement and steel plates**

Element type	Real constant set	Material properties			
		Linear isotropic		Bilinear isotropic	
		EX(Gpa)	PRXY	Yield Stress (MPa)	Tangent Modulus
LINK180	6	200	0.3	240	_____
LINK180	10	200	0.3	648	_____
LINK180	12	200	0.3	558	_____
SOLID185	_____	2000	0.3	5000	_____

## 9. Loads application

The load transfer on the beam was carried out through the nodes located along the thickness of the beam, so that the sum of the loads of the nodes is equal to the total load applied to the beam in the (Y) direction, with progressively increasing in the loading steps according to Newton-Raphson method. Maximum number of iterations permitted is (50) of each load step. In order to simulate the simply supported beam, the displacements on the left side were restricted in the (X, Y, and Z) directions, while on the right side only in the (Y) direction such as Figure 7. Steel reinforcement of beams is shown in Figure 8.

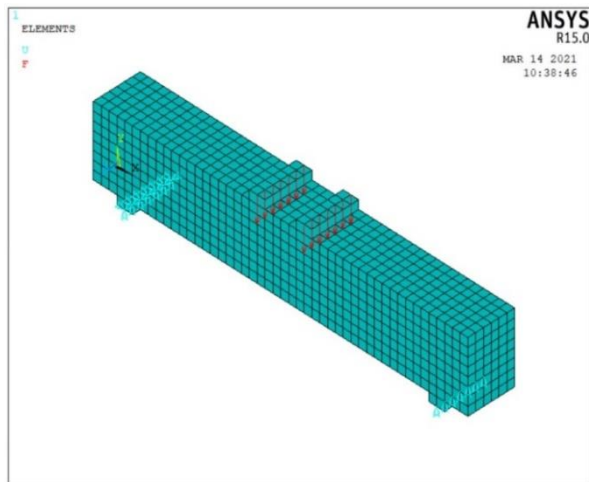


Figure 7 applying load and supports.

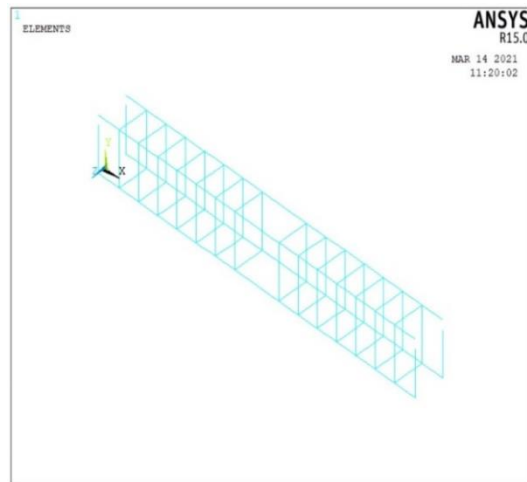


Figure 8 steel reinforcement of beams.

## 10. Results and discussions

### 9.1. Load-deflection relationship

Table 5 shows the results of the numerical modeling of beams and their comparison with the laboratory results. The data of the two studies were recorded for the point located in the middle of the beam at the bottom. There is a very great convergence between practical and theoretical results, this indicates the possibility of conducting a specific study in reality with the help of numerical analysis programs.

Table 5- Comparison of the numerical and experimental results

Beam symbol	Modeling results		Experimental results		Modeling / Experimental	
	$P_u$ (kN)	$\Delta_u$ (mm)	$P_u$ (kN)	$\Delta_u$ (mm)	$P_u$	$\Delta_u$
B-R	99.02	5.72	104	5.38	0.95	1.06
B-0.5	105.5	5.95	114	5.55	0.92	1.07
B-1	98.64	5.58	95	5.5	1.03	1.01
LB-0.5-Q	109.14	5.51	110	5.34	0.99	1.03
LB-0.5-H	121.26	9.56	123	9.75	0.98	0.98
LB-0.5-T	120.53	8.13	124	8.67	0.97	0.93
LB-1-Q	107.63	7.1	114	6.97	0.94	1.01
LB-1-H	116.36	8.8	125	8.2	0.93	1.07
LB-1-T	118.22	6.83	113	6.15	1.04	1.11

The Figures 9 to 17 show that beams in theoretical study was more stiff than in actual study, especially in the linear stage and before the yielding stage, this agree with previous studies prepared by (Majeed, H.Q., 2012), and (Mustafa A. A., 2018), The reason for this is that in the ANSYS program, there is no sliding between concrete and steel reinforcement (perfect bonding), unlike actually present in reality (lab study), (Majeed H.Q., 2012) mentioned this in his study.

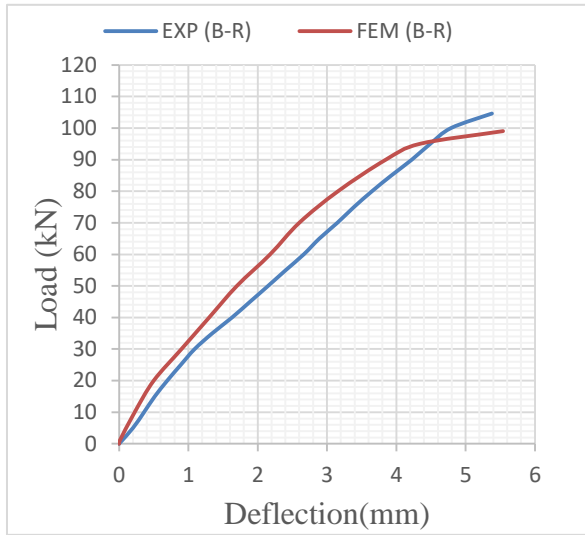


Figure 9 Load-deflection relationship of beam (B-R).

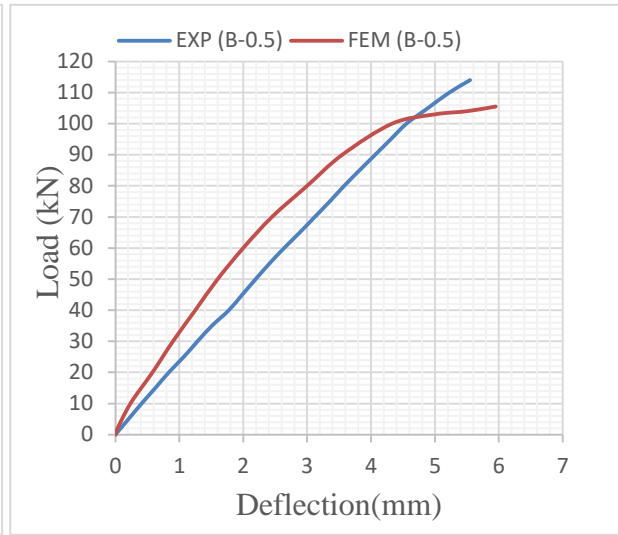


Figure 10 Load-deflection relationship of beam (B-R).

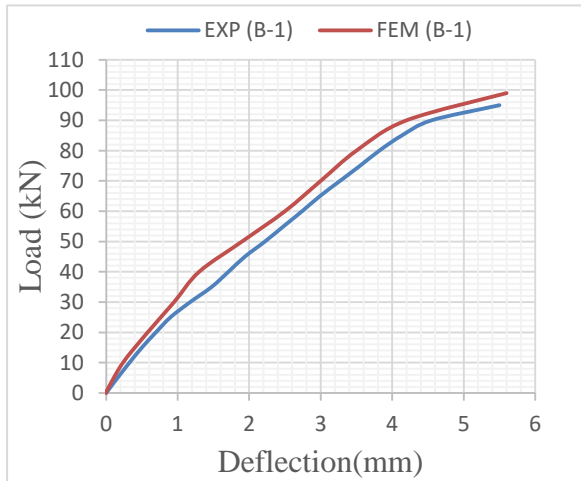


Figure 11 Load-deflection relationship of beam (B-1).

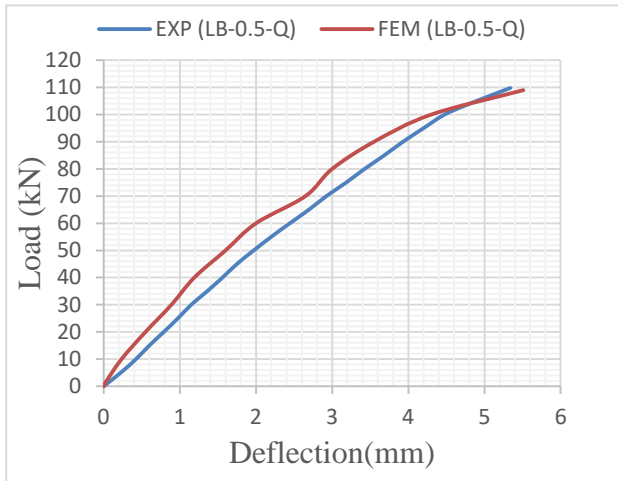


Figure 12 Load-deflection relationship of beam (LB-0.5-Q).

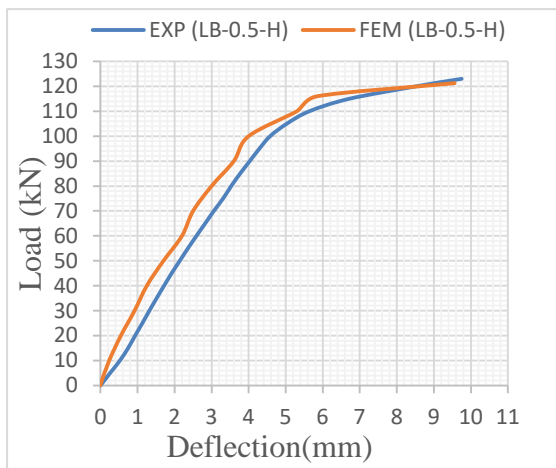


Figure 13 Load-deflection relationship of beam (LB-0.5-H).

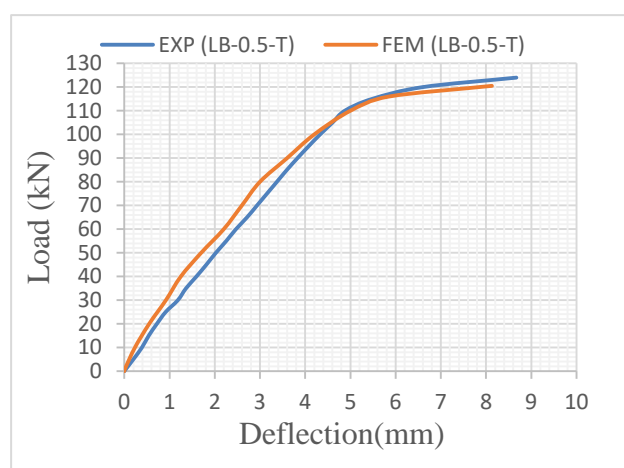
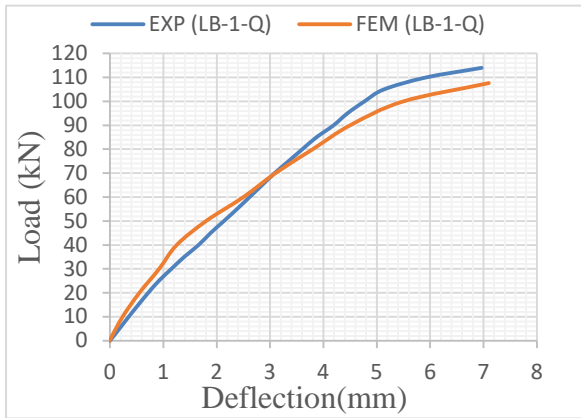
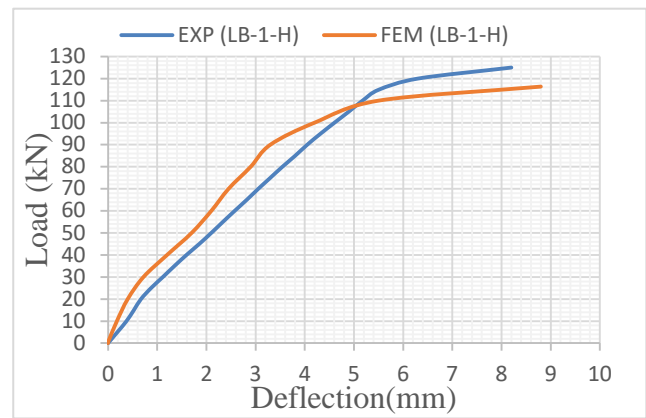


Figure 14 Load-deflection relationship of beam (LB-0.5-T).

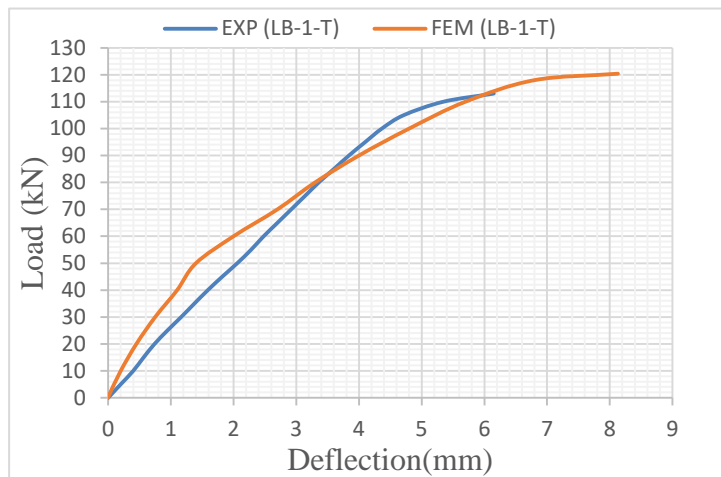




**Figure 15 Load-deflection relationship of beam (LB-1-Q).**



**Figure 16 Load-deflection relationship of beam (LB-1-H).**



**Figure 17 Load-deflection relationship of beam (LB-1-T).**

The slight variation in bending behavior between numerical and in experimental study may be due to deficiencies in characterization of numerical materials, constituent models, and numerical instability in modeling of cracks (Elmezaini and Ashour, 2016). The Figures 18 to 26 explain the ANSYS program results of the load and deflection at the ultimate stage for all beams, which also shows that the ultimate load in the theoretical study is less than in the practical study of most beams, this like to a previous study (Elmezaini N., & M. Ashour, 2016), and (Majeed, H.Q., 2012), in contrast to the deflection that was higher in the theoretical study.

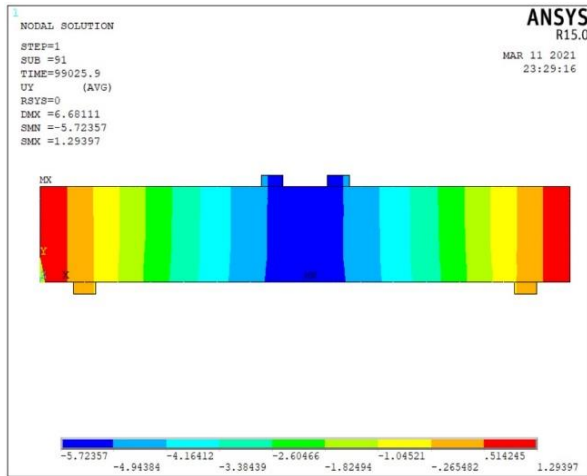


Figure 18 Ultimate stage of beam (B-R).

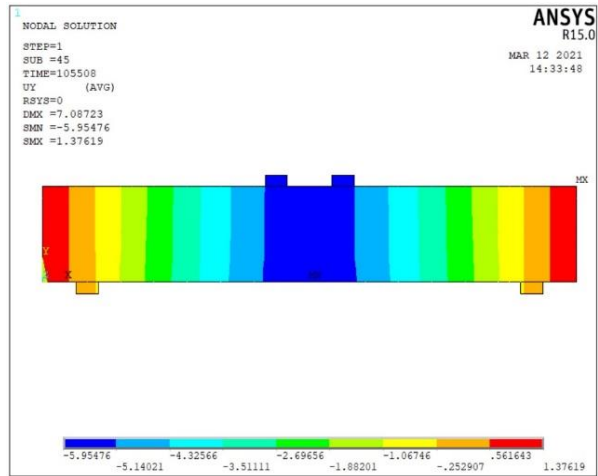


Figure 19 Ultimate stage of beam (B-0.5).

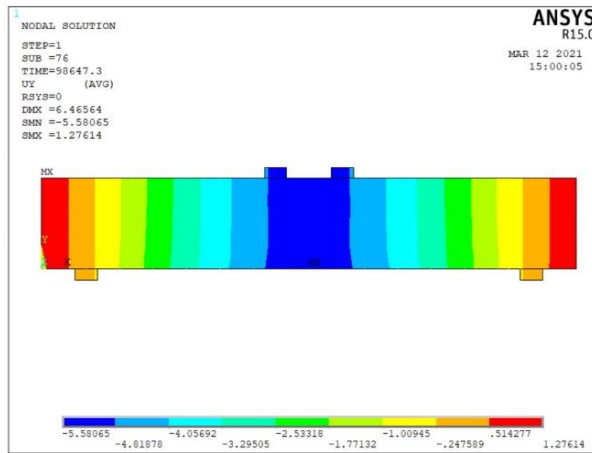


Figure 20 Ultimate stage of beam (B-1).

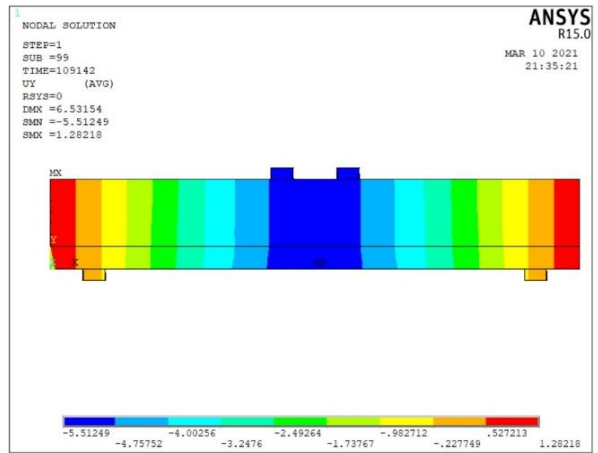


Figure 21 Ultimate stage of beam (LB-0.5-Q).

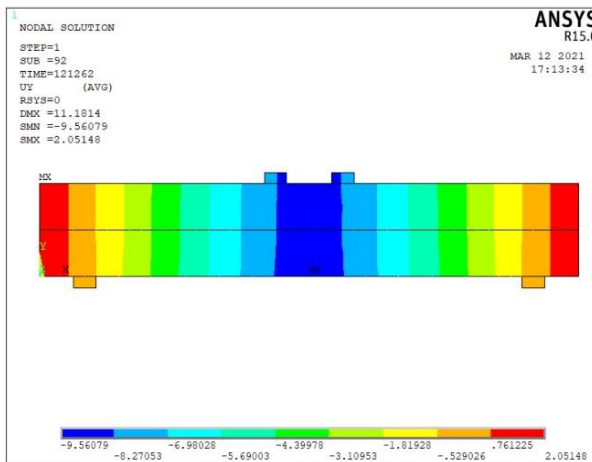


Figure 22 Ultimate stage of beam (LB-0.5-H).

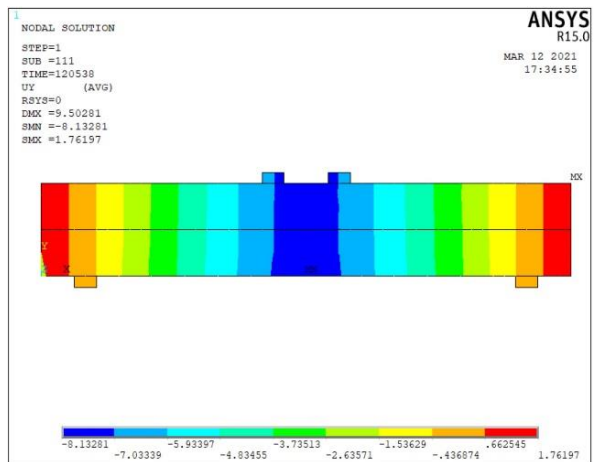


Figure 23 Ultimate stage of beam (LB-0.5-T).

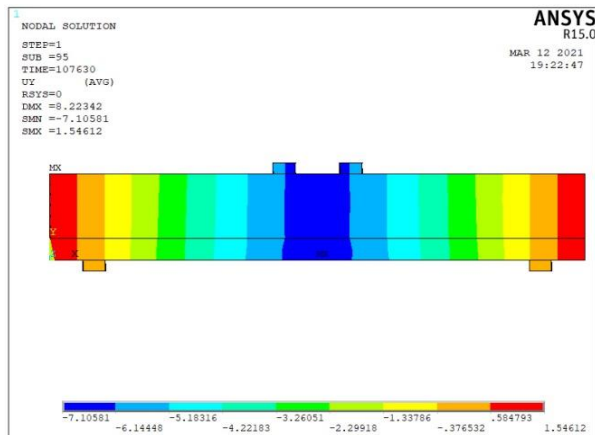


Figure 24 Ultimate stage of beam (LB-1-Q).

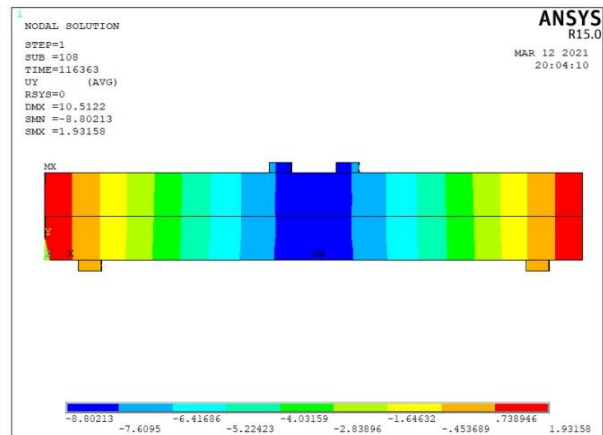


Figure 25 Ultimate stage of beam (LB-1-H).

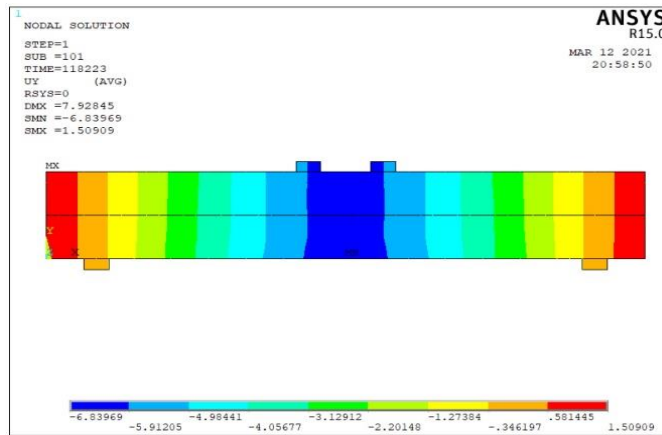


Figure 26 Ultimate stage of beam (LB-1-T).

## 9.2. Crack pattern

In each loading step, ANSYS software records data related to the value of the apply load, among these data the cracking pattern, Figures 27 to 35 show the cracking pattern of the beams at the last loading step (ultimate load), the red color represents the first crack, the green color represents the second crack, and the blue color represents the third crack (ANSYS Version 2015).

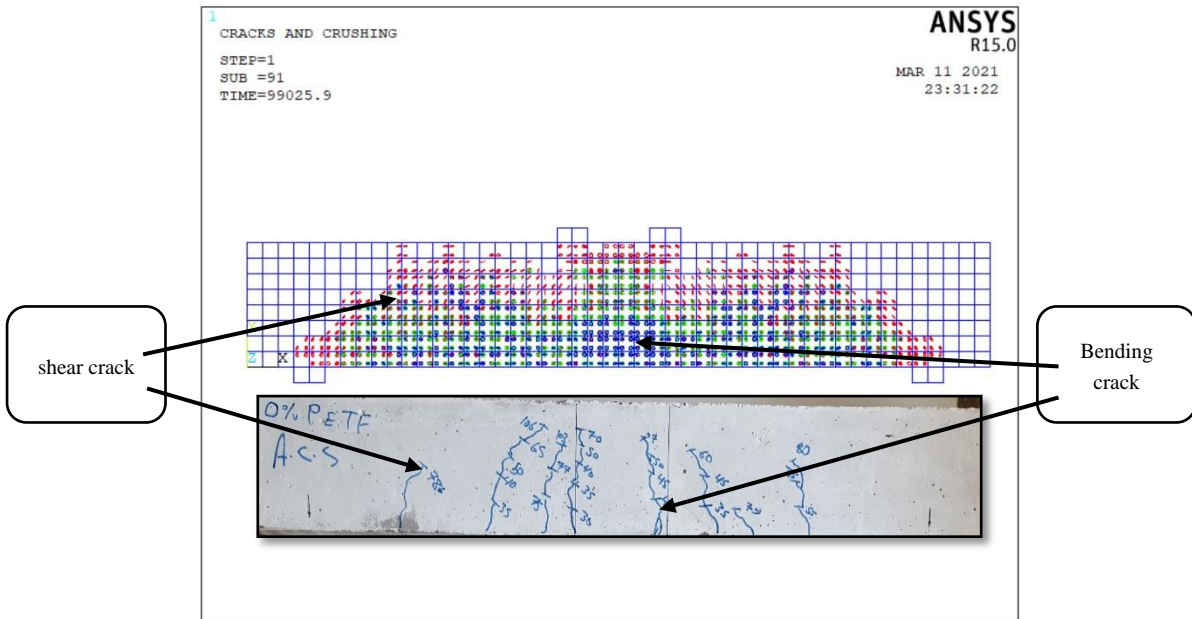


Figure 27 Crack pattern of (B-R).

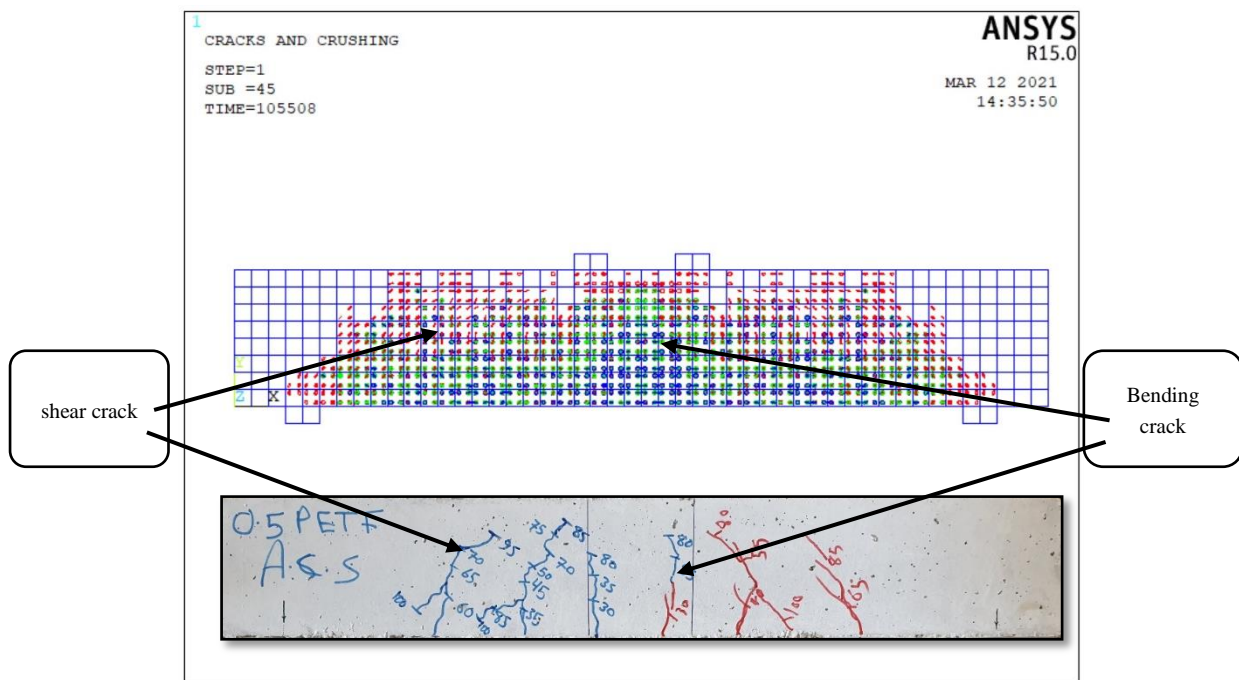


Figure 28 Crack pattern of (B-0.5).

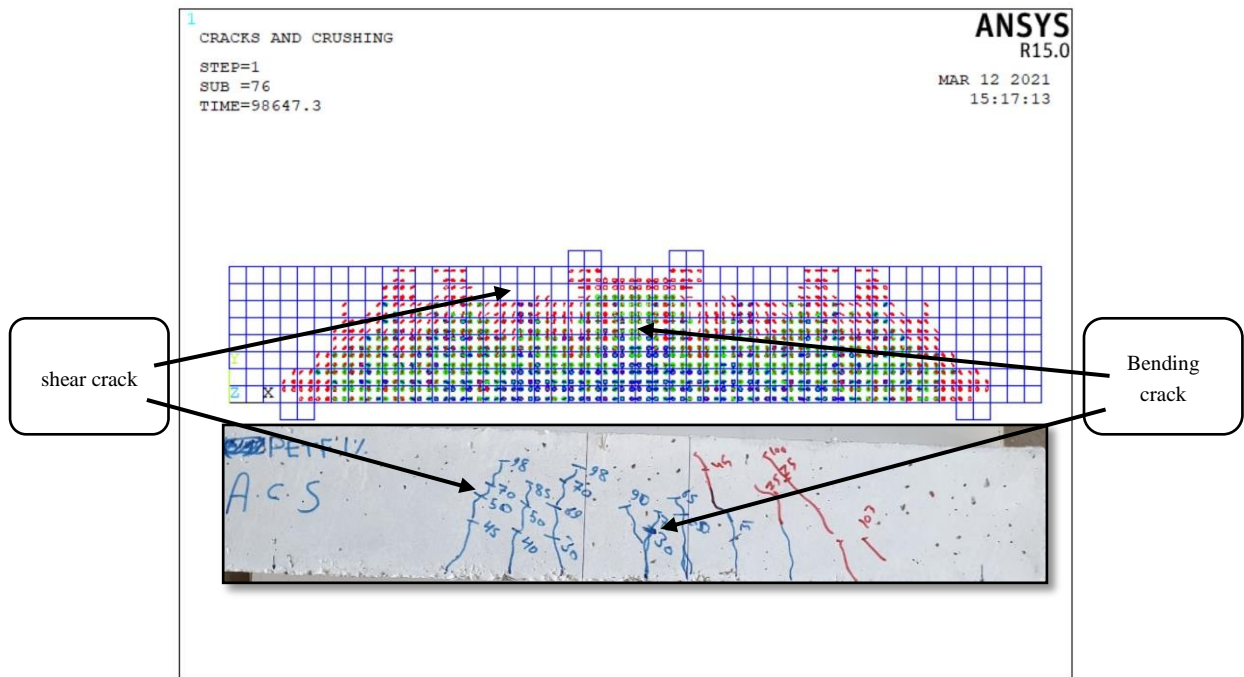


Figure 29 Crack pattern of (B-1).

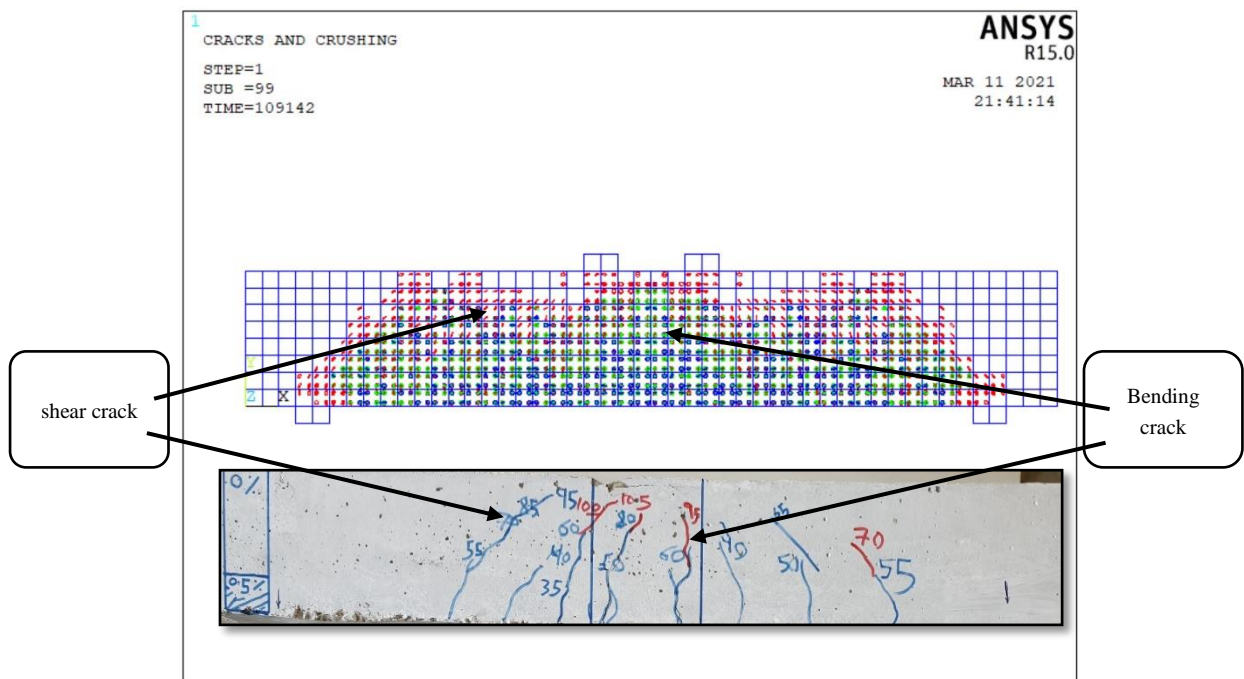


Figure 30 Crack pattern of (LB-0.5-Q).

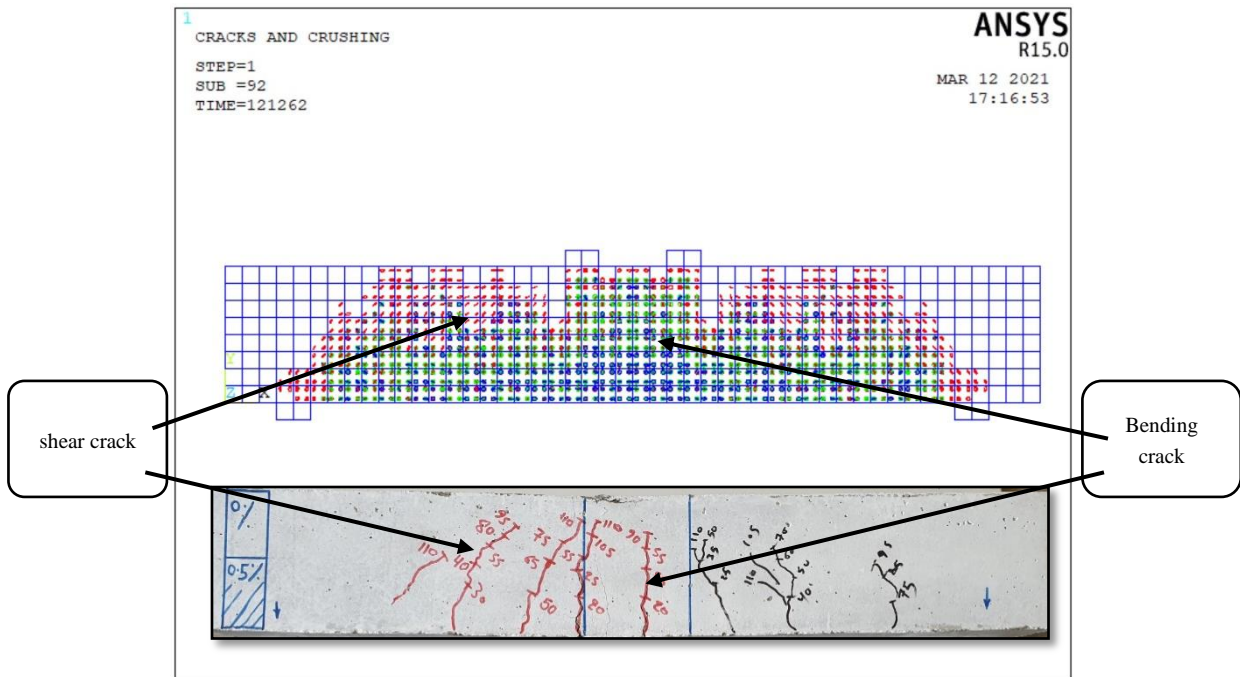


Figure 31 Crack pattern of (LB-0.5-H).

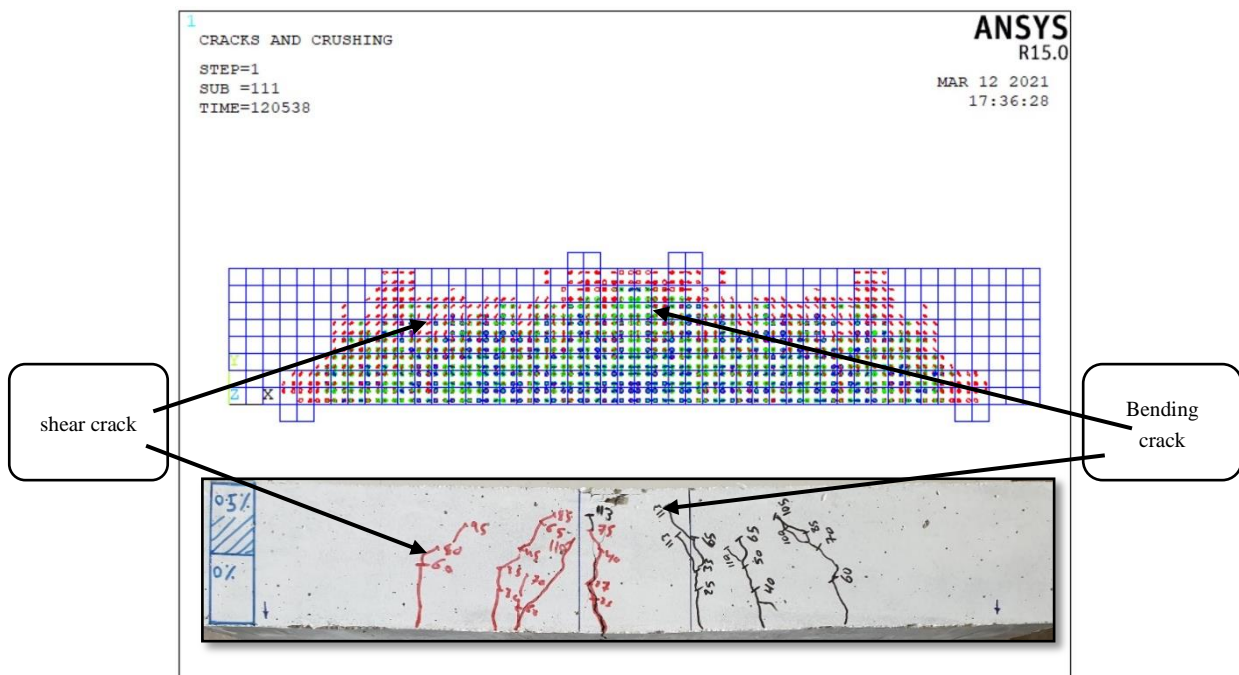


Figure 32 Crack pattern of (LB-0.5-T).

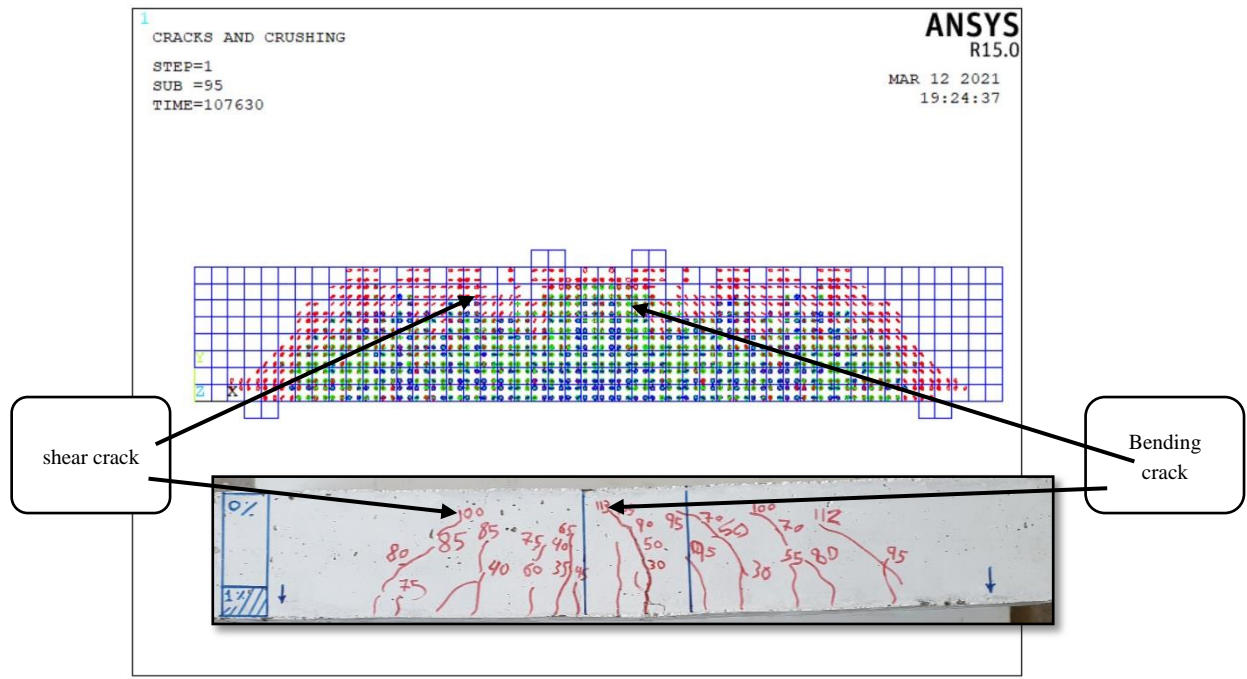


Figure 33 Crack pattern of (LB-1-Q).

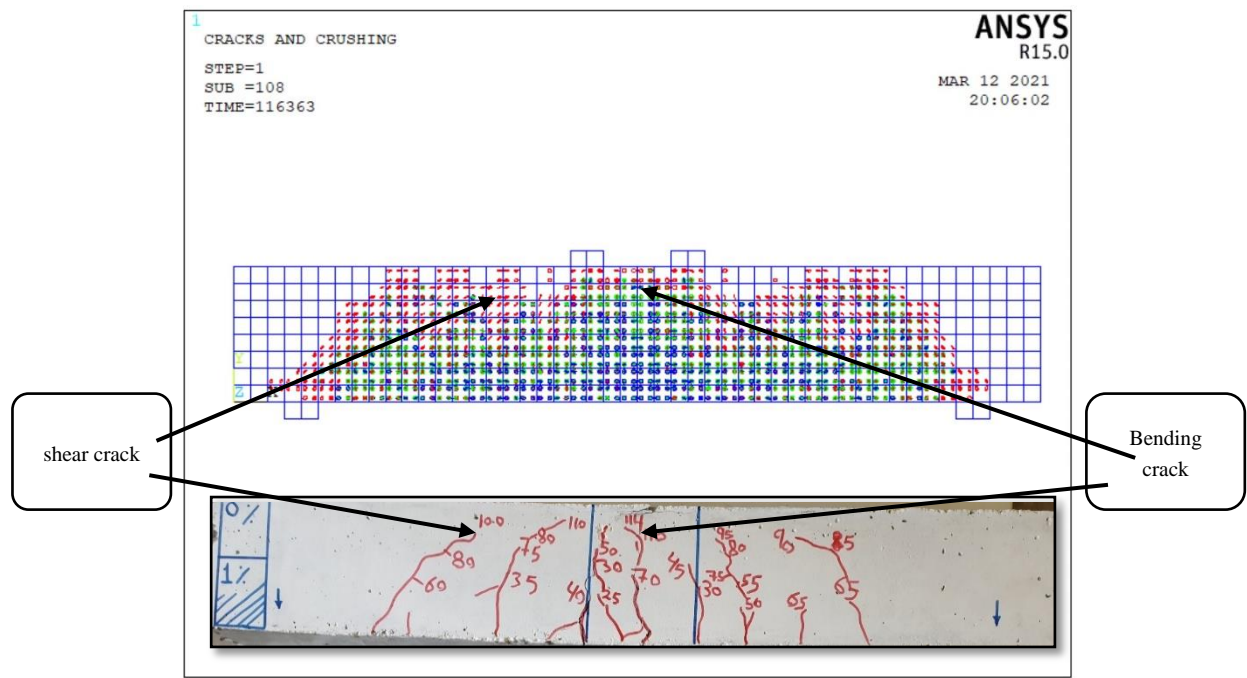


Figure 34 Crack pattern of (LB-1-H).

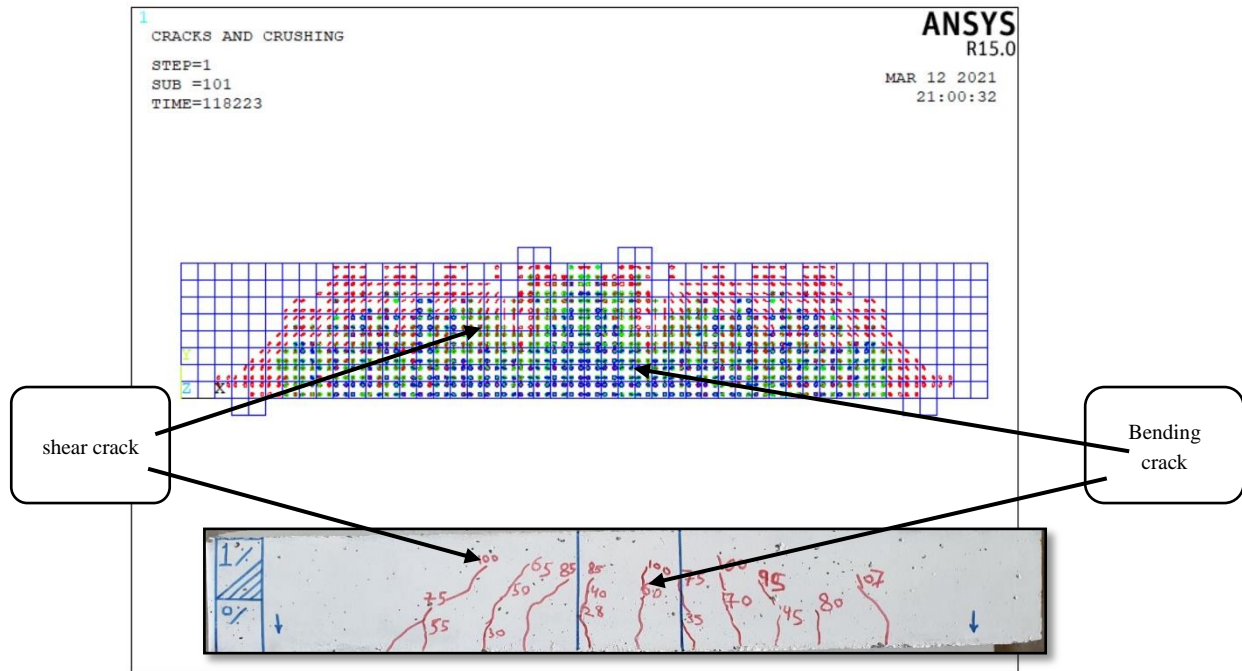


Figure 35 Crack pattern of (LB-1-T).

### 11. Benefits of layered RC beam by modeling

Table 6 contains the results of differentiation of the theoretical study among beams, which indicate the preference of beams with different properties layers over beams of similar properties layers, achieving the beam (LB-0.5-H) the highest increase load and deflection at the point of failure, this is consistent with the results of the practical study.

Table 6- Comparison the results of layered beams

Beam symbol	Modeling results		Increase (%)	
	$P_u$ (kN)	$\Delta_u$ (mm)	$P_u$	$\Delta_u$
B-R	99.02	5.72	_____	_____
B-0.5	105.5	5.95	6.5	4
B-1	98.64	5.58	-0.38	-2.4
LB-0.5-Q	109.14	5.51	10	-3.6
LB-0.5-H	121.26	9.56	22.4	67
LB-0.5-T	120.53	8.13	21.7	42
LB-1-Q	107.63	7.1	8.6	24
LB-1-H	116.36	8.8	17.5	53
LB-1-T	118.22	6.83	19.4	19.4

The beam (LB-0.5-H) consists of half the beam (B-R), half the beam (B-0.5), as well as the beam (LB-0.5-T), The beam (LB-1-H) consists of half the beam (B-R), half the beam (B-1). The Figures 36 to 38 shows the relationship between these beams, and the achievement of beams (LB-0.5-H, LB-0.5-T, and LB-1-H) advantage



in flexural behavior over beams (B-R, B-0.5, and B-1) formed from similar properties layers and contain more fibers.

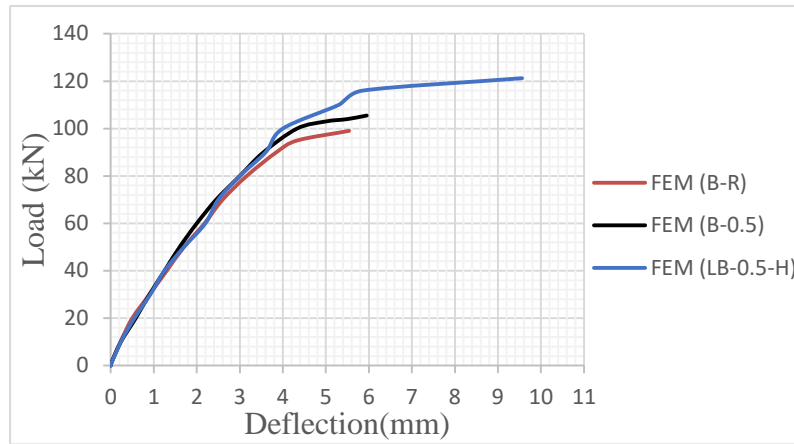


Figure 36 Comparison between beam(LB-0.5-H) and beams (B-R, B-0.5).

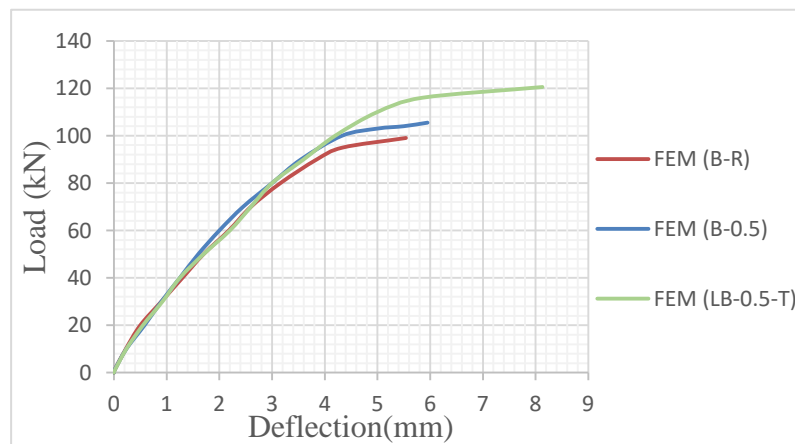


Figure 37 Comparison between beam(LB-0.5-T) and beams (B-R, B-0.5).

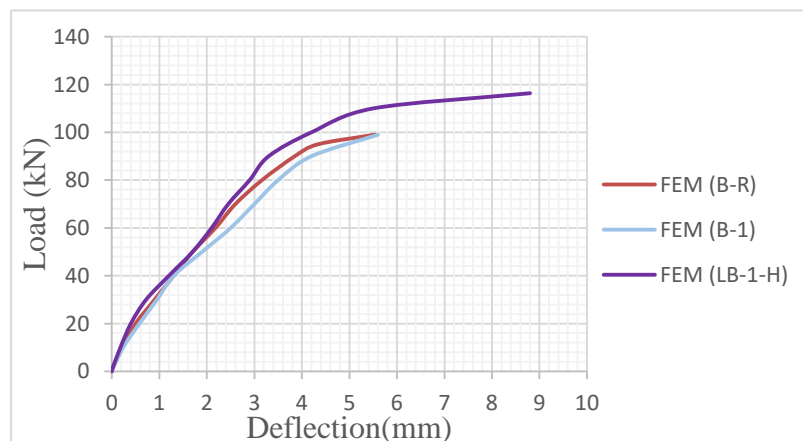


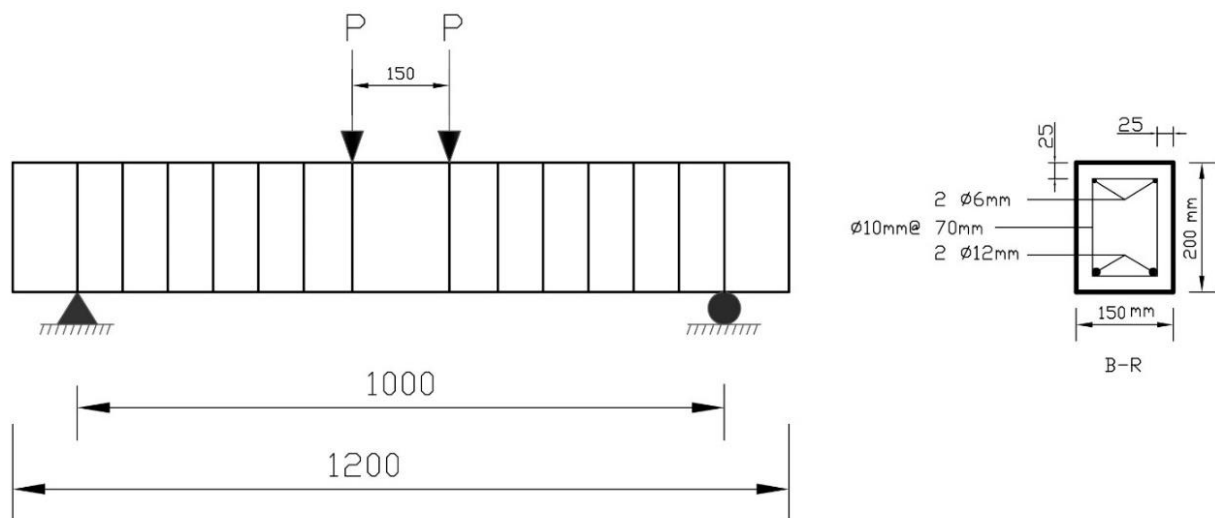
Figure 38 Comparison between beam(LB-1-H) and beams (B-R, B-1).

## 12. Conclusions

- 1- The theoretical study achieved very close results with the results of the practical study of all beams.
- 2- Adding the plastic fibers to the two layers with a ratio of (0.5%) achieved an increase in the ultimate load and ultimate deflection of (6.5%, and 4%), respectively compared to the reference beam (B-R).
- 3- All different properties layered beams achieved an increase in the ultimate load and ultimate deflection compared to the reference beam, except for the beam (LB-0.5-Q), which achieved a decrease in the ultimate deflection by (3.6%).
- 4- The beam (LB-0.5-H) achieved the highest increase in the ultimate load and ultimate deflection around (22.4%, and 67%) respectively compared to the control beam, so it can be considered the optimal beam.
- 5- The beam (B-1) achieved the worst results compared to all beams as well as the reference beam and this was also identical to the results of the laboratory study.
- 6- Increasing the thickness of the fibrous concrete layer at the bottom led to an increase of (11%, and 73.5%) for the beam (LB-0.5-H) compared to the beam (LB-0.5-Q) and by (8%, and 24%) for the beam (LB-1-H) compared to the beam (LB-1-Q) for the ultimate load and the ultimate deflection, respectively.

## Appendix A:

Details of, the dimensions of the beams, reinforcement them and applied load.



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