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Numerical Investigation of GGBS Concrete Beam using Hybrid FRP and GFRP

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Abstract

In the present study, nonlinear finite element analysis of ground granulated blast furnace slag (GGBS) concrete beam using steel, hybrid FRP and GFRP bars. The major variables are types of fine aggregates and reinforcement bars. From the experimental observation, the optimum percentage of GGBS is 30% replacement of cement. The 70% of cement and 30% of GGBS is maintained for all the mix. M20 grade concrete is used. Electric strain gauges are fixed at steel and concrete to measure the strain. Totally six no of beam were modeled. Nonlinear finite element analysis is carried out by finite element software ANSYS. Finite element analysis: the load is transferred trough the bearing plate to beam. Nonlinear material properties and nonlinear stress-strain curve for concrete is incorporated. Load increment step given by Newton-Raphson method. It observed that GGBS concrete beam using Hybrid FRP reaches the ultimate strain and stress in concrete.

Keywords: GGBS, Hybrid FRP, GFR, Nonlinear, FEA

1. Introduction

Fibre reinforced polymer is used for rebar or rehabilitation of building for more than two decades. FRP has a good property like high strength and less density in order to reduce the dead weight. Reinforced bars used for a beam to increase the ductility properties. FRP is behavior in a linear elastic manner. Compare to steel, it has high strength and corrosion resistance properties than steel bars. Nowadays corrosion is a major problem in construction industry. FRP is a best alternative material for steel. Most of common fibre reinforced polymers are carbon FRP, Glass FRP and aramid FRP. Glass fibre reinforced polymer stress-strain curve is linear, up to the tension failure.

ShignaJagadish and Rona P Maria James [1] carried out finite element analysis of concrete beam using FRP bars. Authors use both CFRP and GFRP bars with various reinforcement ratio (0.5%, 1%, 1.5% and 2%). Nonlinear finite element analysis is carried out by ANSYS workbench.it concluded that ultimate load increases and deflection decreases for concrete beam using 2% of GFRP bars. Ibrahim M. Metwally [2] carried three dimensional FEA of deep beam using GFRP bars. Totally twelve deep beam without shear reinforcement with longitudinal GFRP bars. Nonlinear analysis is carried out by finite element software ABAQUS. It found that the beam is failed by shear and ultimate load and deflection of deep beam of GFRP beam is 2 to 4 times higher than CFRP bars. Maher A. Adam et al. [3] carried out experimental and analytical behavior of concrete beams reinforced with GFRP bars. The GFRP bars are main longitudinal bar with steel stirrups are used. The percentage of steel and grade of concrete are main variables. It found that GFRP bar with more than balanced reinforcement its fail by crushing of concrete less that balanced reinforcement it fail by rupture of GFRP bars. Farghaly and Benmokrane [4] investigated on Shear behavior of

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FRP-reinforced concrete deep beams without web reinforcement. It found that beam behave linearly up to the failure. Saleh HamedAlsayed [5] carried out behaviour of concrete beam using GFRP bars. It found that predicted deflection and ultimate load is 10% and 1%. HuanziWanga and AbdeldjelilBelarbi [6] carried out fibre reinforced concrete beam using FRP bars. It found that ductility index increase by 30% by adding fibre to the concrete. Nasr Z. Hassan [7] investigates strengthening of rc beam using FRP sheets. Nonlinear finite element analysis is carried out by ANSYS software. It was observed that failure of beam strength of beam is increased by FRP sheet around the opening. Fazla Rabbi Anik et al. [8] carried out the comparison of RC beam strength by CFRP and GFRP Strip. Author concluded that reinforced concrete beam using CFRP strip has higher load carrying capacity than GFRP strip. Kalpana and Subramanian [9] carried out the behaviour of rc beam using glass fibre reinforced polymer (GFRP) bars. Experimental and theoretical analysis of rc beam using steel and GFRP bars. It found that grade of concrete and percentage of GFRP bars increases the strength was increased. Ahmed SagbanSaadoon, and Hawraa Sami Malik [10] carried out the predicted load carrying capacity of rc beam using FRP bars using ANN. Artificial neural network is used to predict the ultimate load. Totally 199 beam data’s were collected with eight variables. It found that the errors in predicted vs experimental value are less than 3.6%. Smithagopinath et al. [11] investigated shear behaviour of basalt FRP beam using steel fibres. It found that the volume of steel fibres and BFRP which influence on strength. DarmansyahTjitradiet a [12] carried out finite element analysis of rc beam using ANSYS. It found that over reinforced beam fail by crushing of concrete at top.

2. Experimental Investigation

2.1 Material used

In this research, ordinary Portland cement 53 grade cement is used. M20 grade concrete design as per IS 10262-2019. The concrete mix 1:1.78:3.32:0.5 (Cement: Fine aggregate: Coarse aggregate: Water). The cement and GGBS content in concrete is 70% and 30% respectively. The fine aggregates of both river sand and fully replacement of manufacturing sand are used. The size of coarse aggregate is 20mm. The cement is replaced by GGBS content is about 30%. Slump cone value for concrete is 124 mm. The compressive strength, split tensile strength and flexural strength of GGBS concrete are 28.23 MPa, 2.83 MPa and 2.85 MPA.

2.2 Specimen details

The length of the beam is 2200 mm and 150 mm x 250 mm in cross section. Totally six number of the beam is cast using reinforced bars, hybrid FRP bars and GFRP bars. Beams are tested in simply supported condition. Beam reinforce with 2 nos of 12 mm diameter bars at bottom and 2 nos of 12 mm diameter bars at top with 8 mm stirrups with 150 mm cc spacing were provided. Two electronic strain gauge is fixed in rebars and and two fixed in concrete to measure the strain value. The strain gauge is provided in steel and FRP bars are shown in Figure 1.

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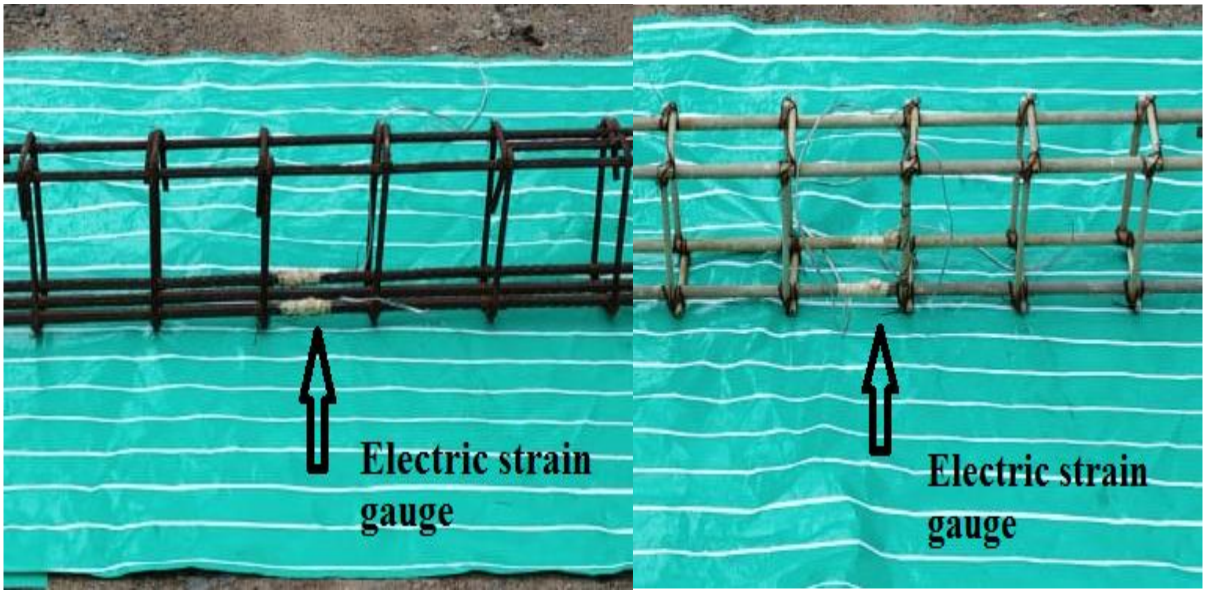

a) Steel bar b) GFRP bar

c) Concrete beam

Figure 1: Electric strain gauge

2.3 Test Setup

The beam tested under simply support condition with an effective span of 2000 mm. Three liver variable differential transducer (LVDT) is placed under loading point and mid span. Test setup is shown in figure 2 Two electric strain gauge is place over the mid of concrete beam. Strain indicators are used to measure the strain for every increment of load. Electric strain gauge is shown in figure 3.

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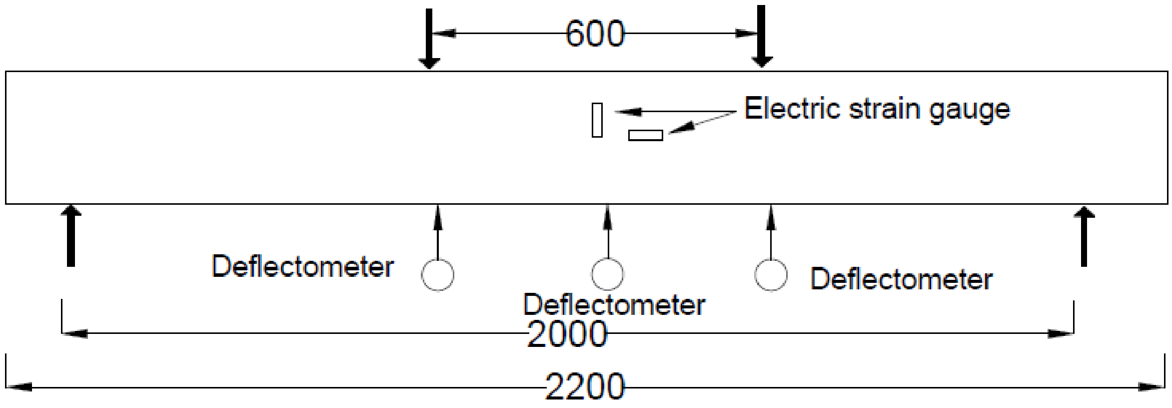

Figure 2: Test setup

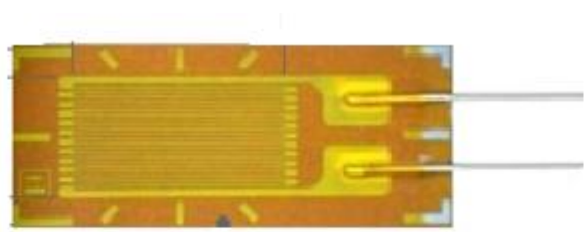

Figure 3: Electric strain gauge

Beam details are shown in table 1 and geometry details of beam shown in figure 4.

Table 1: Beam details

Beam Id	Fine aggregates	Reinforcement			Rebar
		Bottom	Top	Stirrups	
SURS B1	River sand	2 nos of 12	2 nos of 12 mm	8 mm at 150 mm cc	Steel
SUM B1	M sand	2 nos of 12	2 nos of 12 mm	8 mm at 150 mm cc	Steel
HURS B1	River sand	2 nos of 12	2 nos of 12 mm	8 mm at 150 mm cc	Hybrid FRP
HUM B1	M sand	2 nos of 12	2 nos of 12 mm	8 mm at 150 mm cc	Hybrid FRP
GURS B1	River sand	2 nos of 12	2 nos of 12 mm	8 mm at 150 mm cc	GFRP
GUM B1	M sand	2 nos of 12	2 nos of 12 mm	8 mm at 150 mm cc	GFRP

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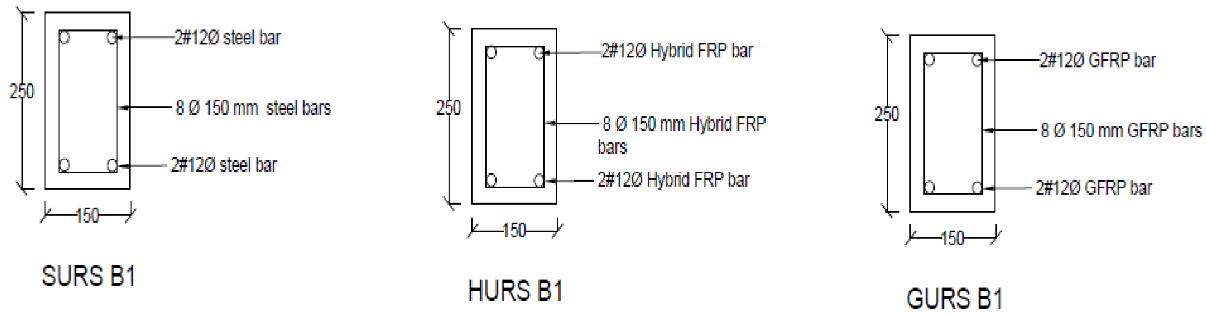

Figure 4: Geometry details

3. Nonlinear Finite Element Analysis

Nonlinear finite element analysis is carried out by finite element software ANSYS. Finite element software used to solve complex problem in civil engineering. Solid 65 are used for three-dimensional modeling of concrete. The element is capable of cracking and crushing of concrete in both tension and compression. Eight nodded element with three degrees of freedom at each node is shown in figure 5. Link180 element is used for reinforcement. Solid 185 elements are used for bearing plate. The properties of materials are shown in table 2. Stress-strain curve for concrete and steel shown in figure 5.

Table 2: Material properties

Details	Description	Value
Concrete	Grade of concrete	M20
	Compressive strength of concrete	28.23 MPa
	Young's modulus	26566 MPa
	Poisson's ratio	0.2
Steel bar	Young's modulus	2 x 10^5MPa
	Poisson's ratio	0.3
	Yield stress	550 Mpa
	Ultimate stress	625 Mpa
Hybrid FRP	Ultimate stress	1679 Mpa
	Young's modulus	1.35 x 10^5MPa
GFRP	Ultimate stress	525 Mpa
	Young's modulus	0.46 x 10^5MPa
Bearing plate	Young's modulus	2 x 10^5MPa
	Poisson's ratio	0.3
	Yield stress	250 Mpa

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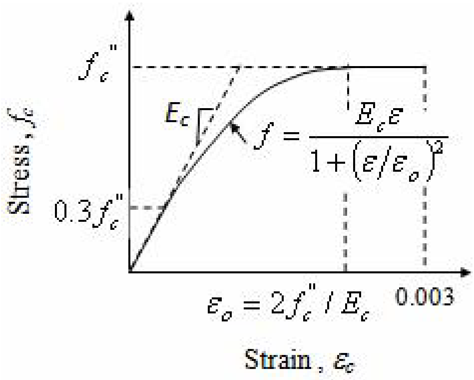
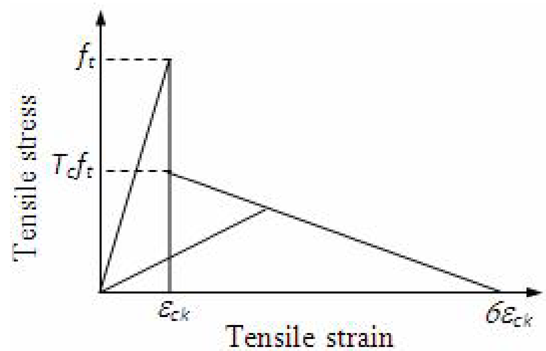
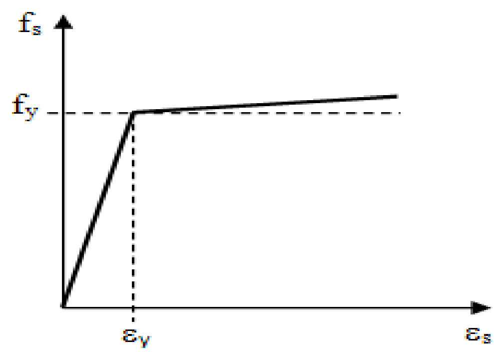


a) Concrete in compression



b) Concrete in tension

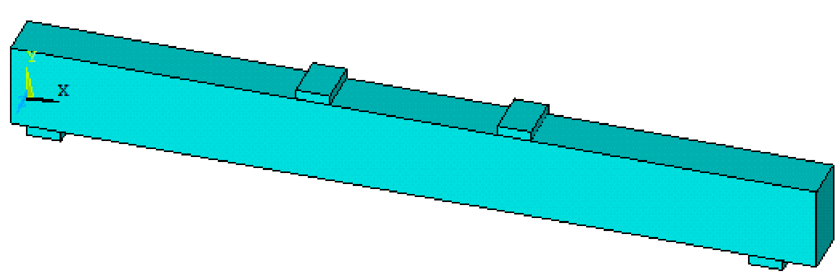


c) Steel

Figure 5: Stress-strain curve for concrete and steel

3.1 Beam SURS B1

The GGBS based concrete beam using steel bar. Finite element analysis of the beam is shown in figure 6. It found that maximum strain in concrete and steel occur at the bottom of the beam is 0.00339 and 0.002498 respectively. The beam reaches the ultimate stress strain values. Concrete reaches the maximum compressive stress at bottom is 24.11 MPa and steel reaches the maximum compressive stress at bottom is 499.53 MPa.



a) Beam model

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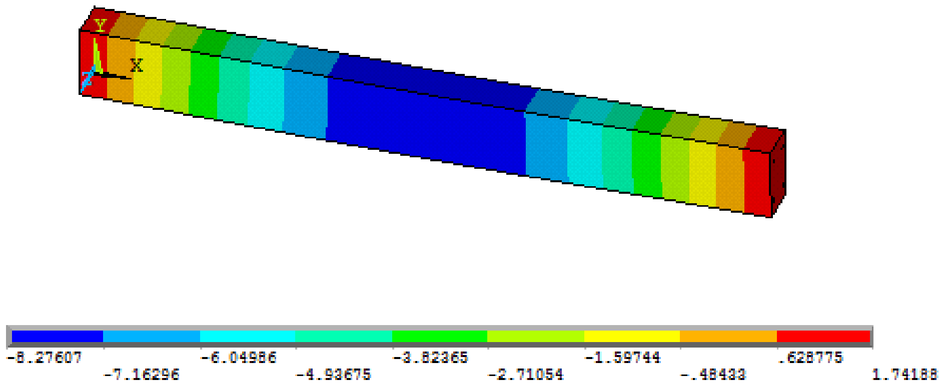
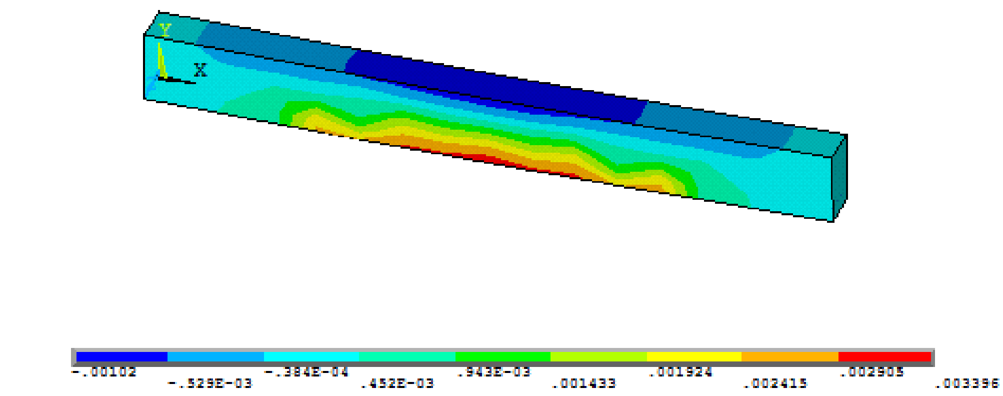
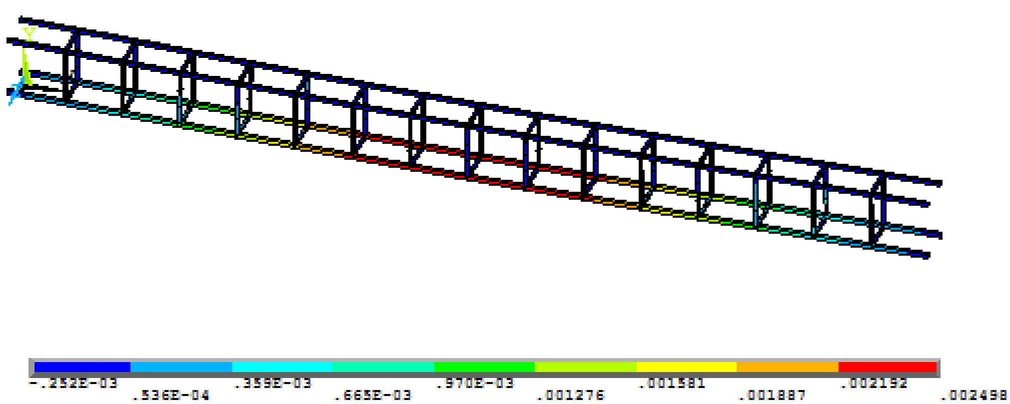


b) Deflection



c) Strain in concrete



d) Strain in steel

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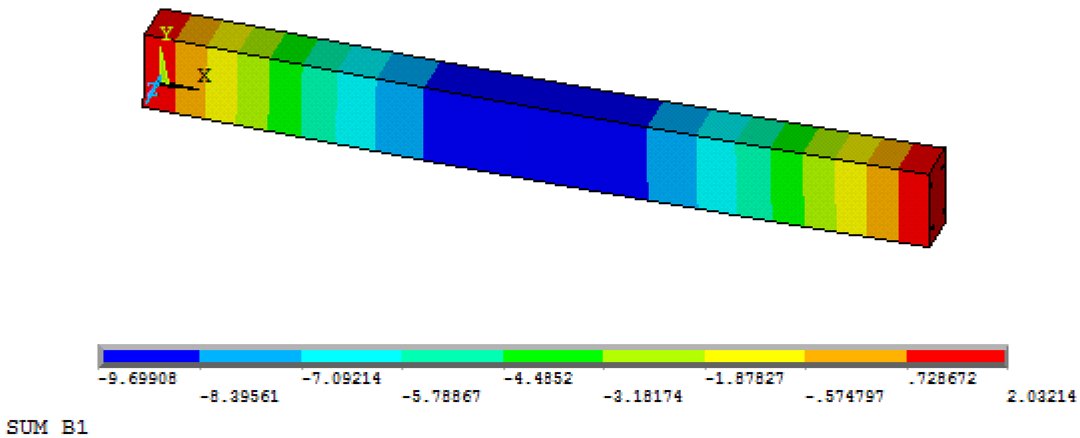
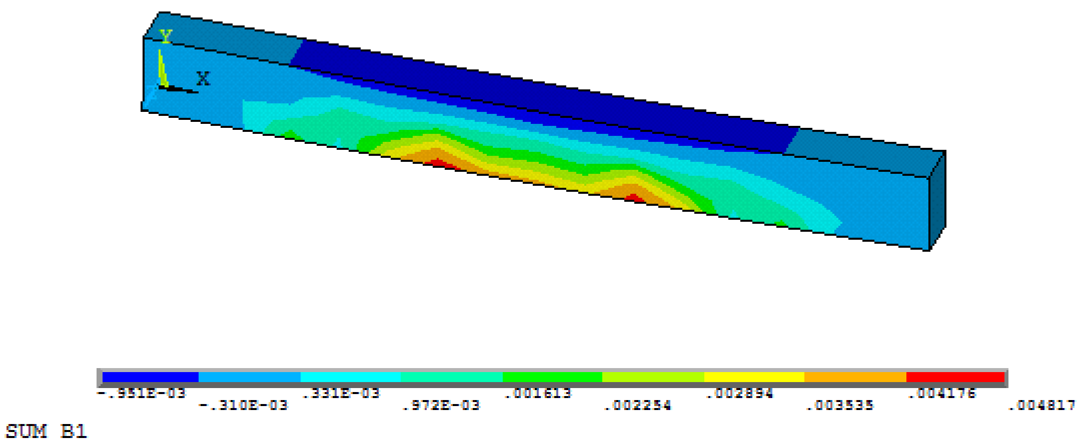
Figure 6: Beam SURS B1

3.2 Beam SUM B1

The GGBS based concrete beam using steel bar. Finite element analysis of the beam is show in figure 7. It found that maximum strain in concrete and steel occur at the bottom of the beam is 0.004817 and 0.00275 respectively. The beam reaches the ultimate stress strain values. Concrete reaches the maximum compressive stress at bottom is 24.626 MPa and steel reaches the maximum compressive stress at bottom is 550.018 MPa.



a) Deflection



b) Strain in concrete

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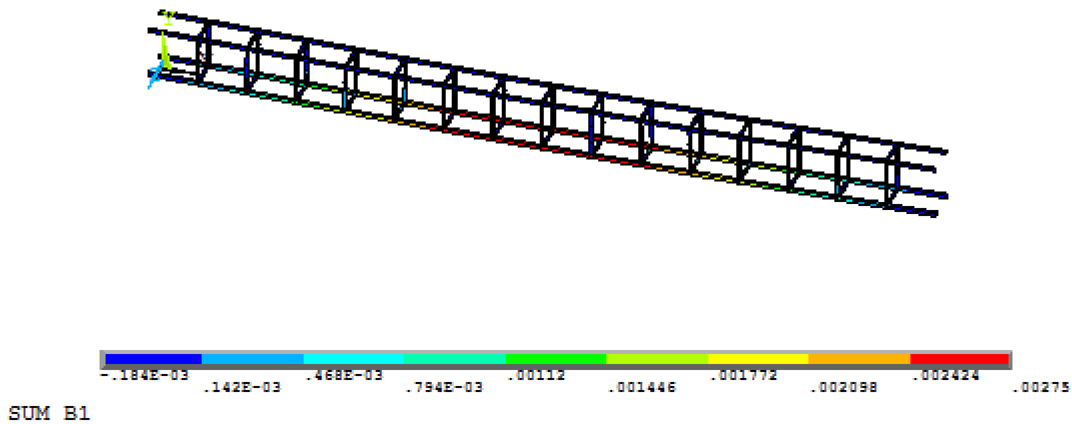
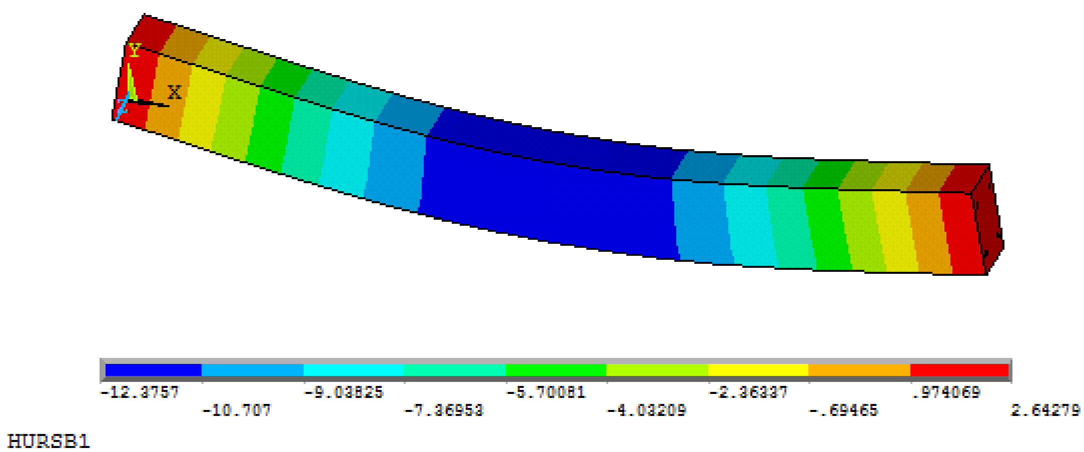


c) Strain in steel

Figure 7: Beam SUM B1

3.3 Beam HURS B1

The GGBS based concrete beam using hybrid FRP bar. Finite element analysis of the beam is show in figure 8. It found that maximum strain in concrete and steel occur at the bottom of the beam is 0.00833 and 0.00394 respectively. The beam reaches the ultimate stress strain values. Concrete reaches the maximum compressive stress at bottom is 25.232 MPa and steel reaches the maximum compressive stress at bottom is 532.12 MPa.



a) Deflection

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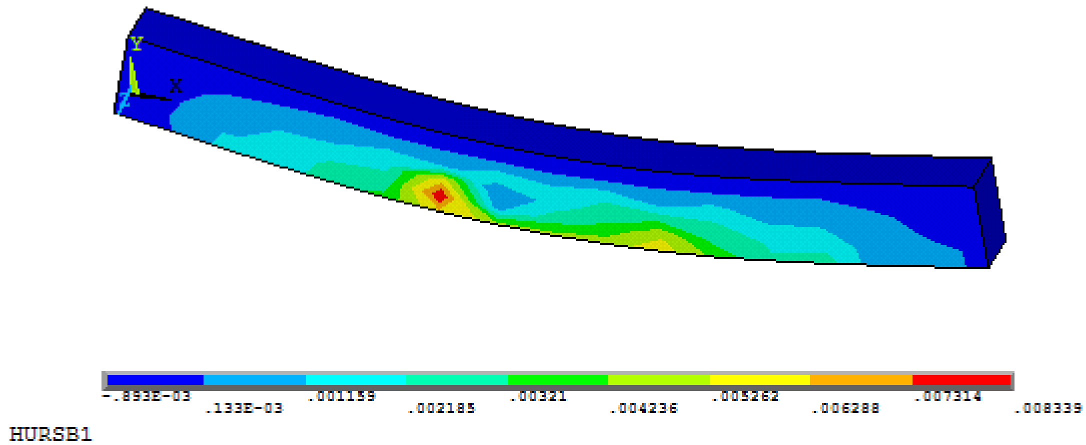
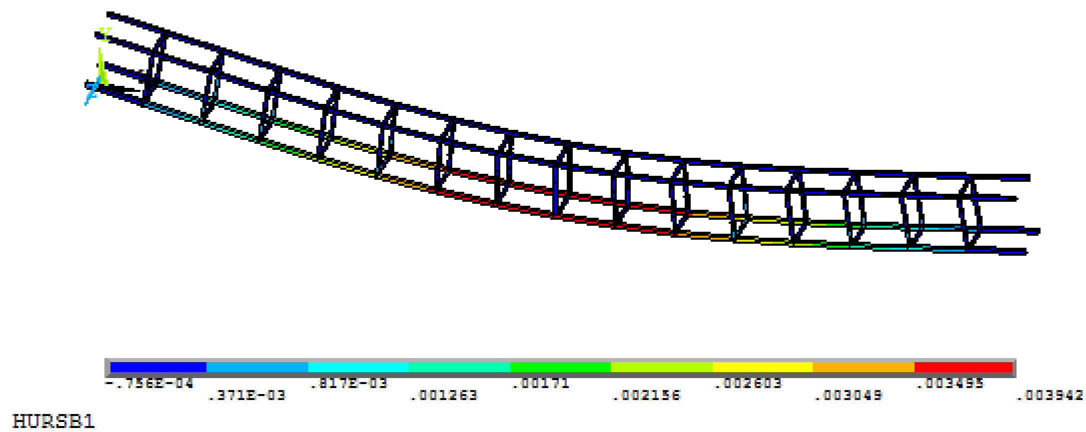


b) Strain in concrete



c) Strain in steel

Figure 8: Beam HURS B1

3.4 Beam HUM B1

The GGBS based concrete beam using hybrid FRP bar. Finite element analysis of the beam is show in figure 9. It found that maximum strain in concrete and steel occur at the bottom of the beam is 0.0075 and 0.00423 respectively. The beam reaches the ultimate stress strain values. Concrete reaches the maximum compressive stress at bottom is 26.71 MPa and steel reaches the maximum compressive stress at bottom is 571.53 MPa.

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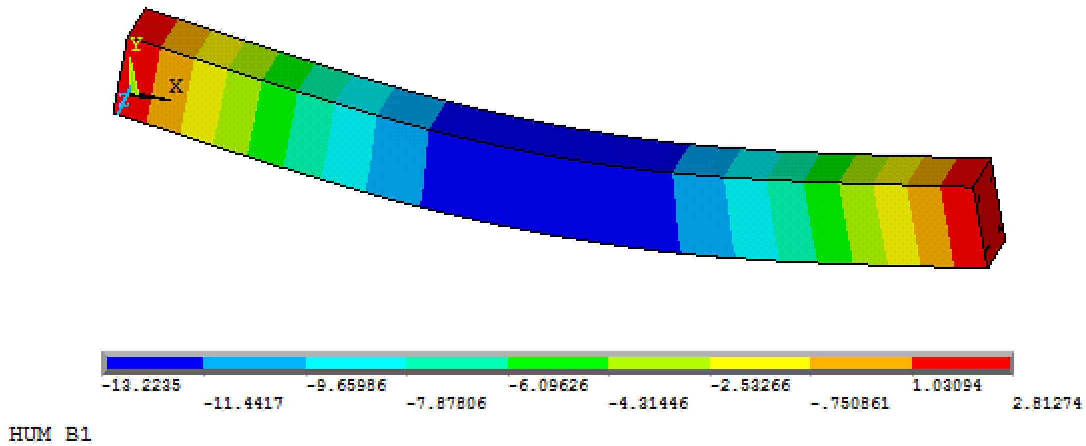
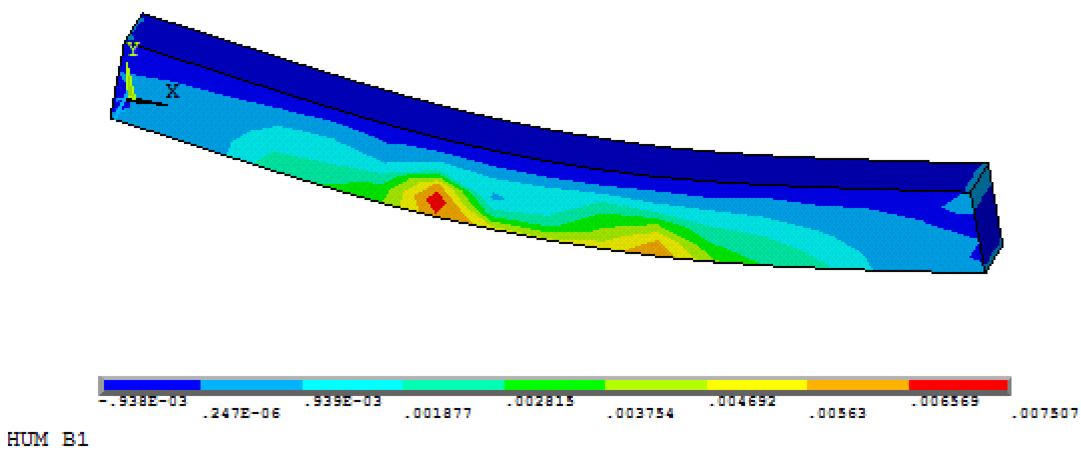
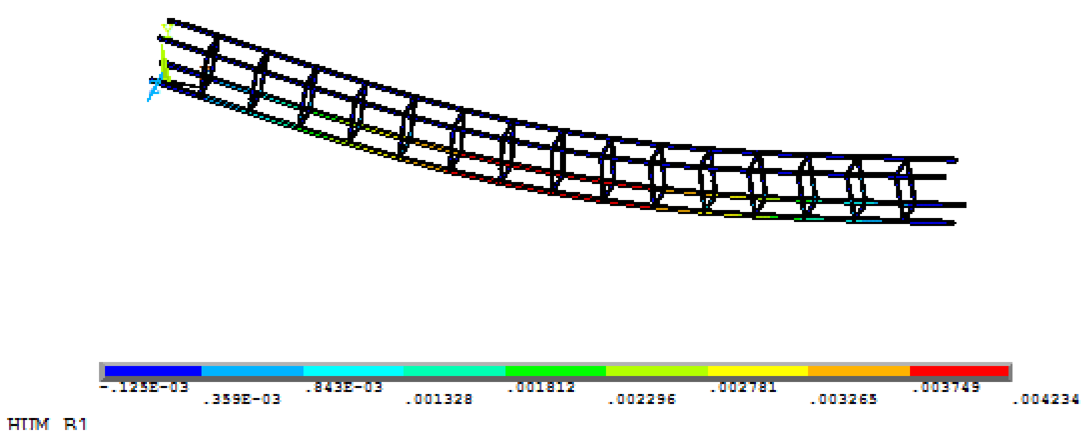


a) Deflection



b) Strain in concrete



c) Strain in steel

Figure 9: Beam HUM B1

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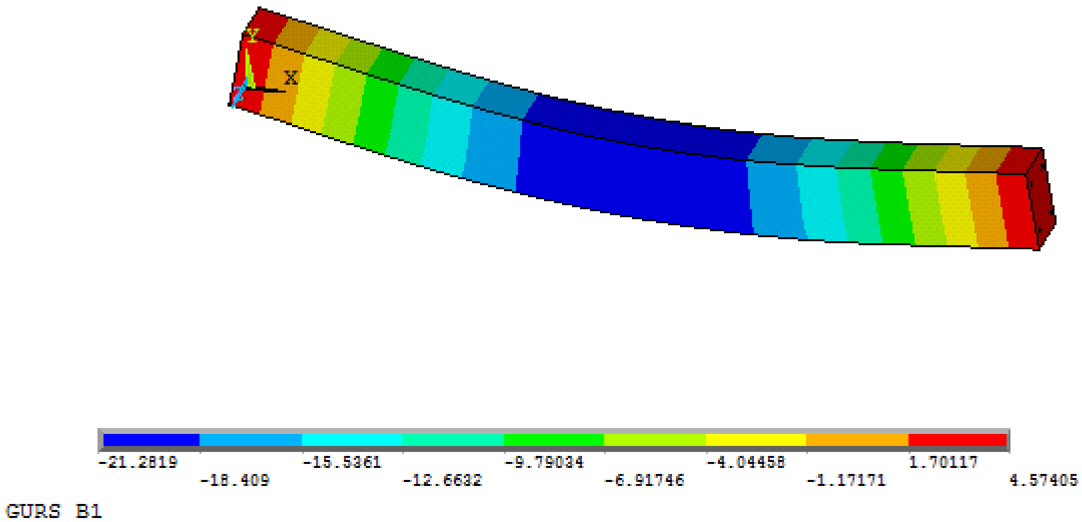
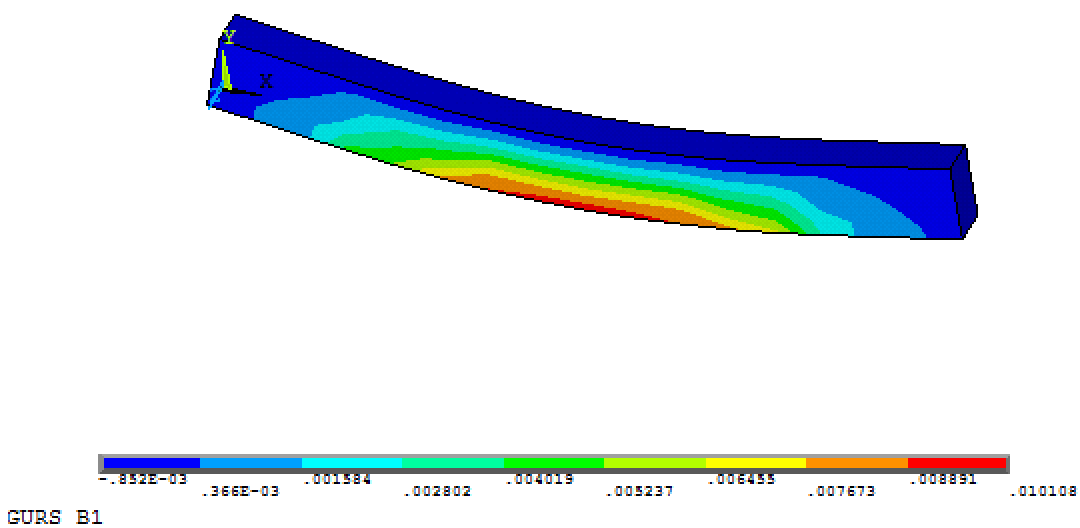
3.5 Beam GURS B1

The GGBS based concrete beam using GFRP bar. Finite element analysis of the beam is shown in figure 10. It found that maximum strain in concrete and steel occur at the bottom of the beam is 0.0101 and 0.00799 respectively. The beam reaches the ultimate stress strain values. Concrete reaches the maximum compressive stress at bottom is 23.88 MPa and steel reaches the maximum compressive stress at bottom is 367.8 MPa.



a) Deflection



b) Strain in concrete

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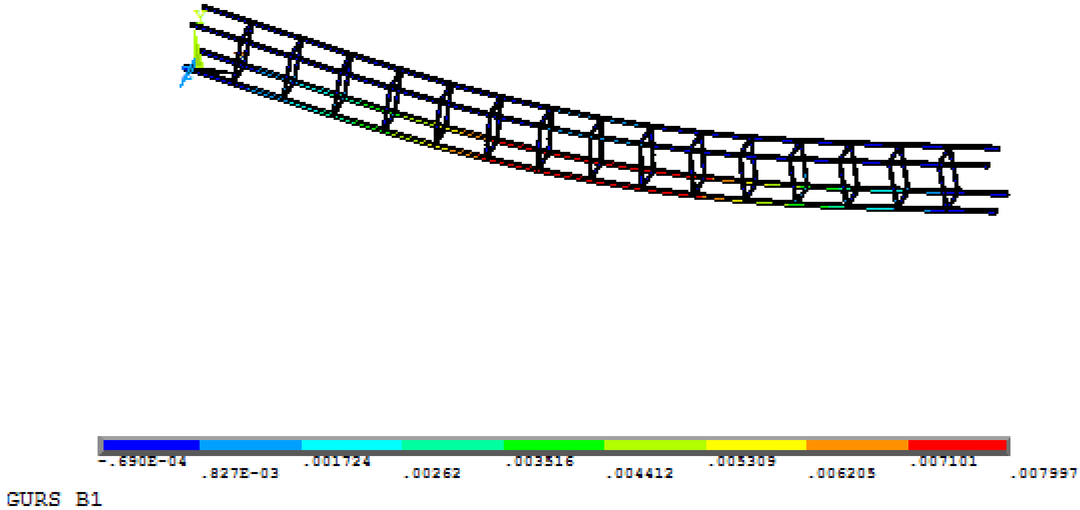
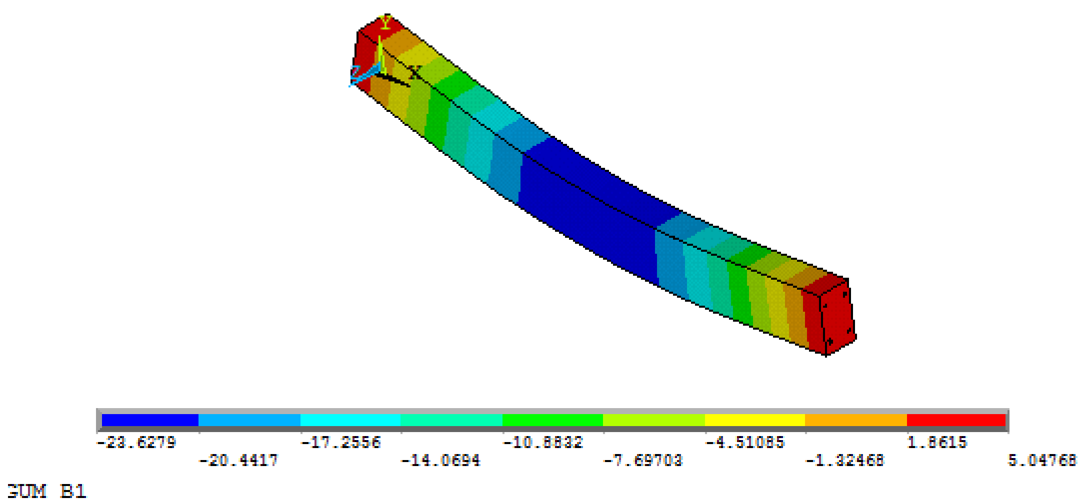


c) Strain in steel

Figure 10: Beam GURS B1

3.6 Beam GUM B1

The GGBS based concrete beam using GFRP bar. Finite element analysis of the beam is shown in figure 11. It found that maximum strain in concrete and steel occur at the bottom of the beam is 0.0125and 0.0088 respectively. The beam reaches the ultimate stress strain values. Concrete reaches the maximum compressive stress at bottom is 26.63 MPa and steel reaches the maximum compressive stress at bottom is 408.43 MPa.



a) Deflection

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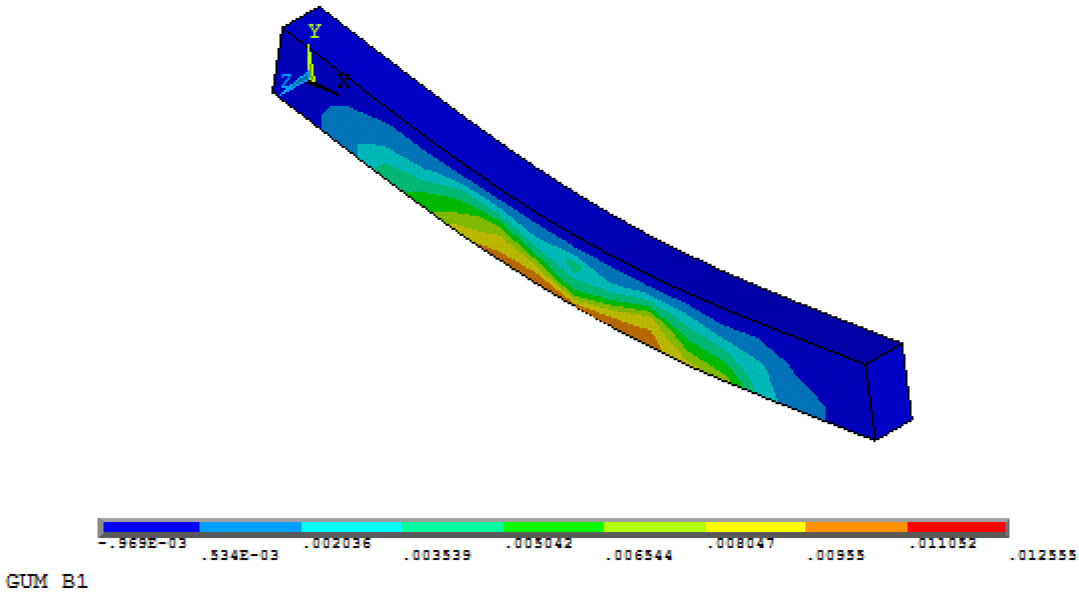
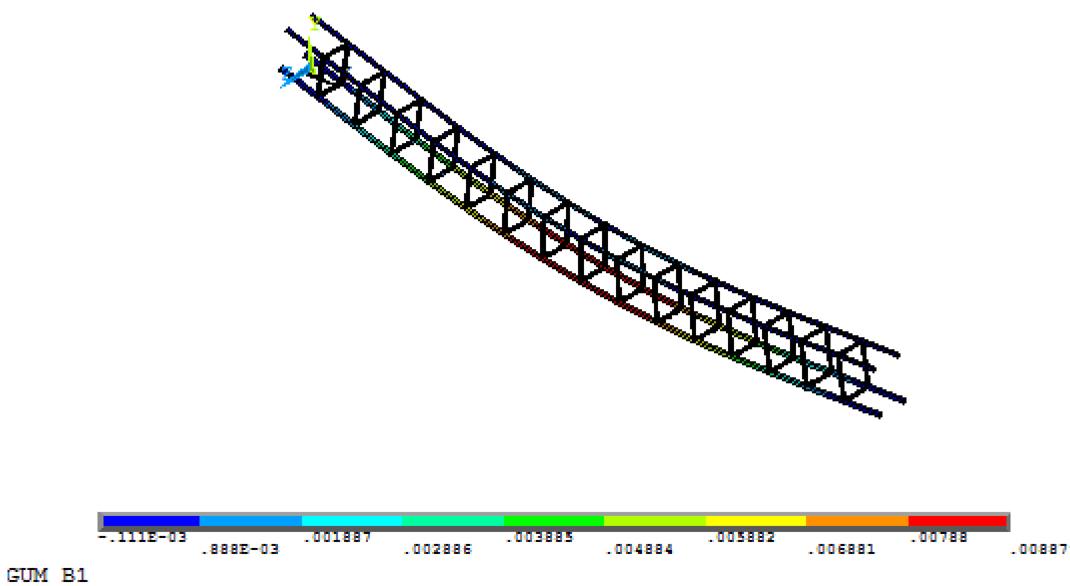


b) Strain in concrete



c) Strain in steel

Figure 11: Beam GUM B1

3.7 Load vs deflection behaviour

Load vs deflection behaviour of all the beams is shown in figure 12. From load-deflection curve we found that experimental load and deflection are higher than the finite element results. Finite element analysis is shows that the GGBS beams

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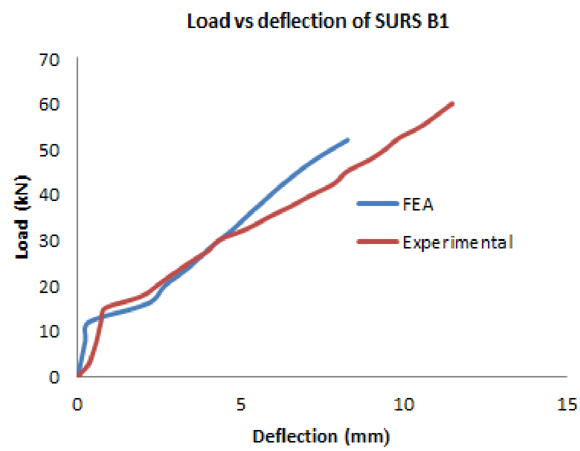
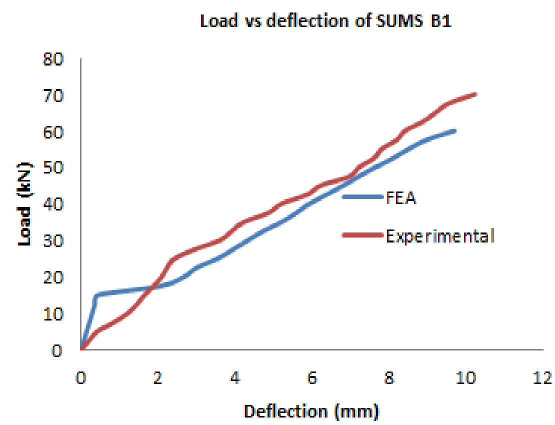
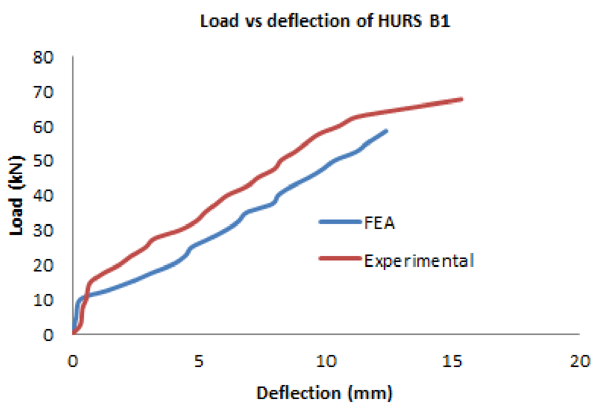
are behave linearly up to the elastic limit. It gives better agreement with experimental values. The experimental vs numerical values are given in table 3.



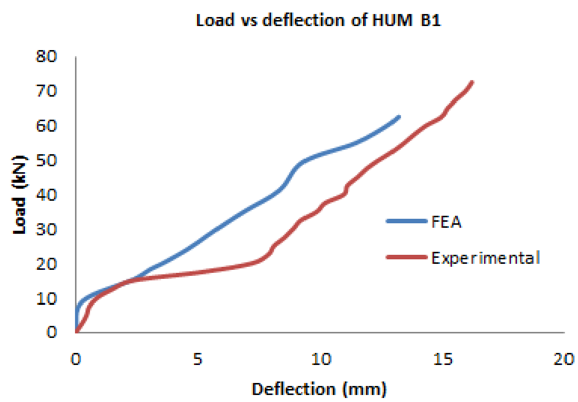
Load vs deflection of SURS B1



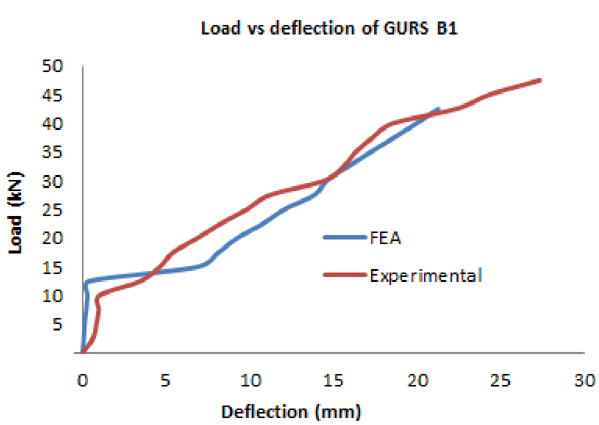
Load vs deflection of SUM B1



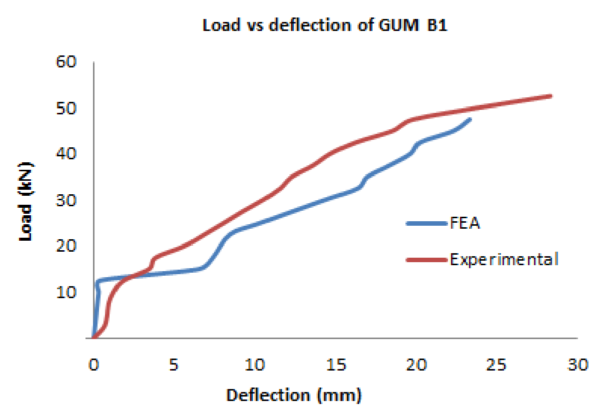
Load vs deflection of HURS B1



Load vs deflection of HUM B1



Load vs deflection of GURS B1



Load vs deflection of GUM B1

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Figure 11: Experimental and numerical load vs deflection

Table 3: Experimental vs numerical results

Numerical					Experimental			
ID	Load (kN)	Deflection (mm)	Strain		Load (kN)	Deflection (mm)	Strain	
			Concrete	Steel			Concrete	Steel
SUM B1	60	9.699	0.00482	0.00275	70	10.214	0.00520	0.00320
SURS B1	52	8.276	0.00337	0.00250	60	11.24	0.00365	0.00315
HUM B1	62.58	13.223	0.00750	0.00423	72.5	16.234	0.00785	0.00452
HURS B1	58.4	12.377	0.00833	0.00394	67.5	15.34	0.00912	0.00462
GUM B1	47.5	23.334	0.01250	0.00880	52.5	28.34	0.01850	0.00920
GURS B1	42.5	21.281	0.01010	0.00799	47.5	27.34	0.01420	0.00825

4. Conclusion

Nonlinear finite element is carried out for six full scale GGBS concrete beam using steel, hybrid FRP and GFRP bars. The GGBS concrete beam is cast using both manufacturing sand and river sand. It found that GGBS concrete beam using manufacturing sand has higher strength than concrete beam using river sand. Finite element analysis of GGBS concrete beam using steel bars shows the closer experimental results. Strain in concrete of SUM B1 is 42% higher than the SURS B1. SURS B1 ultimate stress in concrete and steel is lower than SUM B1. The GGBS concrete beam using hybrid FRP bar is higher than the GGBS concrete beam using GFRP bar. Compare to the entire beam, HUM B1 beam reaches the maximum stress in concrete and steel. It observed that compare to GGBS concrete beam using hybrid FRP and GFRP bar, hybrid FRP bars have higher strength and lesser deflection. GGBS concrete beam using hybrid FRP bars shows higher strain value compare to all other specimens. The difference between numerical observation and experimental results is not exceeding 15%. Finite element results are better agreement with experimental values.

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