Diyala Journal of Engineering Sciences Vol (17) No 1, 2024: 75-83

Diyala Journal of Engineering Sciences

Journal homepage: https://djes.info/index.php/djes

ISSN: 1999-8716 (Print); 2616-6909 (Online)

Finite Element Investigation of the Ultimate Capacity of FRP Strengthening Soffit Curved Girders

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ARTICLE INFO

Article history:
Received December 30, 2022
Revised March 1, 2023
Accepted March 10, 2023
Available online March 6, 2024

Keywords:
Curved-soffit girders
Strengthening
FE numerical simulation
Curvature
Analysis FRP
RC girder

ABSTRACT

In recent decades, fiber reinforced polymer (FRP) has been increasingly used to reinforce curved reinforced concrete girders. The main objective of this research is to study the effect of curvature on the performance of curved reinforced concrete (RC) girders reinforced with fiber reinforced polymers (FRP). Five models with a length of 6 m and different degrees of curvature (1,2,3,4,5) mm/m were used, each with dimensions similar to the models used in cross-sectional area and effective extension similar to those of the source model. The modeling was in Ansys software and the girders were simulated to obtain the load deflection with respect to the mid span, failure load and failure pattern, in order to understand the effect of variable curvature on the performance of this type of structural element, it was applied under one central load from the middle of the girder length until failure. It was observed that the curvature pitch of 5 mm/m reduced the load-bearing capacity of the c RC curved girders by 7.33%.

1. Introduction

Curved reinforced concrete (RC) girders are used in many different types of construction, and it is said that they are more productive than straight girders. Modern architects prefer curved structural elements to the straight structural elements that were used in the past. Because of this, there is a growing trend in modern building projects to use more curved structural elements [1].

Curved bridges evolved from the concept of curved bridges that had been in use for centuries. The basic principle of curved bridges is that the load is transferred along the curvature to the abutments instead of being pushed down. There have been a lot of studies done on the causes of failure of FRP-reinforced RC roof beams [2,3] . Examples of curved girder bridges include the Clearwater Memorial Bridge, Florida, USA, the recently deteriorated West Seattle Bridge, Washington, USA, and the Swan Street Bridge, Melbourne, Australia. Several numerical studies have been published in the literature confirming the behavior of many types of curved concrete bridges reinforced with polymer panels under different types of loads and supports [4].

Analytical studies proposed finite element models for the analysis of flat and curved girders, which are designed to give improved analyzes and knowledge of the behavior of different girders [5].

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DOI: 10.24237/djes.2024.17107

Al-Ghrery et al. [6] modeled five CFRP reinforced concrete girders and analyzed by nonlinear finite element method. The results showed that the curvature of 20 mm per meter reduces the efficiency of FRP reinforcement by 17.8% Also, the beams suffer from decoherence due to CFRP from the high stress concentration generated from the tensile stress resulting from the existing curvature. The failure form in this case is the visible cracks. The highest stress with the highest displacement was taken in experimental tests accurately using nonlinear finite element models.

Eshwar et al. [7] studied the CFRP reinforcement of existing concrete bridges that have inward curvature. He used six girders each 6 m in length and each with different bending ranges, were tested under a three-point static loading test. One of the beams with internal bending has been fixed with GFRP anchor bolts to prevent the expected premature peeling. Significant increases in flexural capacity ranging from 27% to 82%.

Sarode and Vesmawala [8] analyzed the various models for curved box girders by making use of the LUSAS FEA program for various parameters including span lengths, radii, and loadings, and addressed the flexural and torsional behavior, stability, and mid-span deflections of the curved box girders of various parameters.

Majeed [9] compared using ANSYS software, nonlinear finite element models of U-jacket iron-reinforced rectangular reinforced concrete beams with experimental data for unreinforced beams. The results show that the load deflection and the maximum load had improved significantly in the reinforced girders. Reference beam predictions match experimental findings. The number of wire mesh layers has an effect on the strength of studied beams that have been strengthened with ferrocement jackets. Following the process of reinforcing the beam using U-jacket sheets made of carbon fiber reinforced polymer (CFRB), the expected results are compared to those obtained by reinforcing comparable beams with ferrocement jackets. The U-shaped carbon fiber polymer jackets provided a 37.44 percent increase in the ultimate beam loading.

Ibrahim and Mahmood [10] used the finite element method by ANSYS to analyze the modeling of reinforced concrete beams externally reinforced with fiber-reinforced polymer (FRP) sheets. The concrete was modeled using a stained-crushing technique, while the FRP composites were modeled using three-dimensional layered components. The accuracy of finite element models is evaluated by comparison with experimental results. The finite element analysis's load skew curves match well with the experiments' in the linear range, albeit the finite element findings are a little more stable overall. The most significant variation in total loads across all scenarios is 7.8 percent.

Al-Ahmed and Al-Jburi [11] studied the behavior of deep beams of CFRP reinforced concrete. Seven RC deep beams of identical length and steel reinforcement were put through their paces in the lab, split into two groups according to stiffening techniques. The center-to-center distance (orthogonal spacing) between the strips was the independent variable for each set (100 mm, 125 mm and 150 mm). Experimental results show that among two reinforcing systems for deep beams utilizing FRP strips, the U-coiled vertical scheme is somewhat better than the inclined scheme, but requires more CFRP strips. The percentages increase in first cracking and ultimate loads were (50.0%, 46.0% and 20.5%) and (14.6%, 13.3% and 12.2%) respectively for beams strengthened with vertical U-wrapped scheme. While these percentages were changed to (36.5%, 18.0% and 12.5%) and (12.5%, 10.4% and 8.6%) for beams strengthened with inclined scheme.

The main objective of this research is to study the effect of bending on the performance of curved reinforced concrete (RC) beams reinforced with fiber reinforced polymers (FRP).

2. parametric study

2.1 specimen of RC girders

Typical FE model for curved and soffit RC girders is shown in Figure 1.

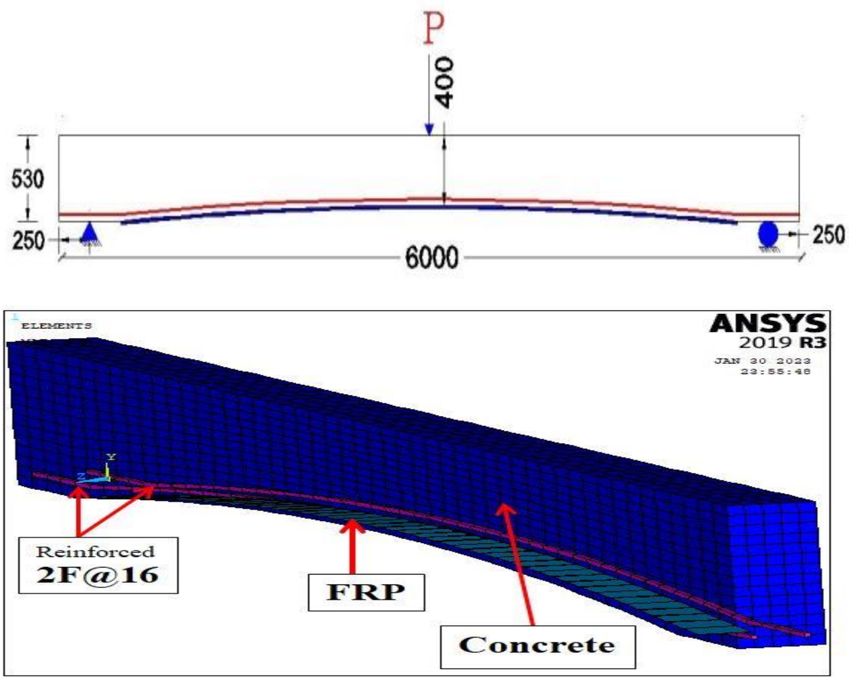


Figure 1. The typical curve girder

2.2 Material details

In this investigation, it is assumed that the concrete is both initially isotropic and homogeneous. Furthermore, the stress-strain relation is derived from Desayi and Krishnan's [12] work as are shown in Figure 2.

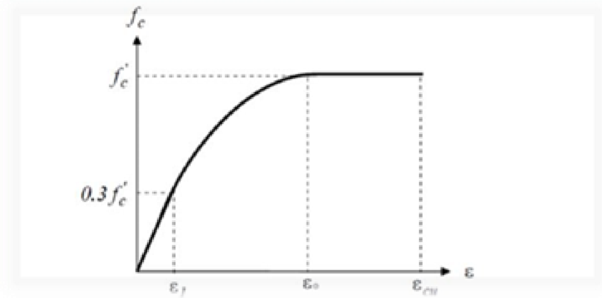


Figure 2. A typical stress-strain curve for concrete

Steel is easy to work with because its mechanical properties are very good. It seems likely that the relationship between strain and stress in tension and compression is the same. Figure 3 shows a typical uniaxial stress-strain curve for a steel specimen loaded in a tension. This study looks at the second case, in which the strain hardening modulus (Et) is (0.03 Es). This value is chosen so that problems with iterative convergence don't happen.

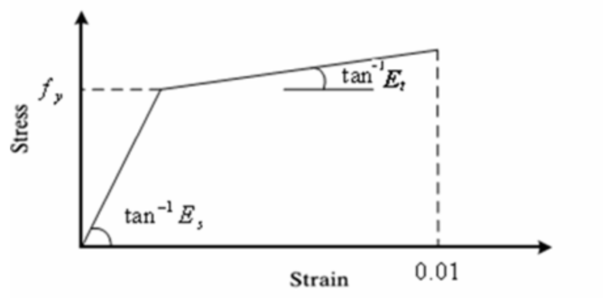


Figure 3. Alternative Bilinear Stress-Strain Relationship

There are two main parts to FRP materials.

The reinforcement is the first component, and it is encased in the matrix, which is a continuous polymer [13]. The FRP composites are treated as orthotropic elastic materials in the finite element model; consequently, their properties differ in both directions [14,15].

Due to the unidirectional nature of the FRP material, Young's modulus in the lateral direction and shear modulus are assumed to be zero in this study [16]. Contributions to the lateral and shear stiffness of the FRP plate can also be assumed to be negligible because the sheet is only loaded in the longitudinal direction [17,18]. The value of 0.3 has been chosen for the Poisson's ratio, and the behavior of the linearly elastic stress-strain relationship is shown in Figure 4, which is thought of for FRP strips that have no plastic behavior before breaking, is an option [19].

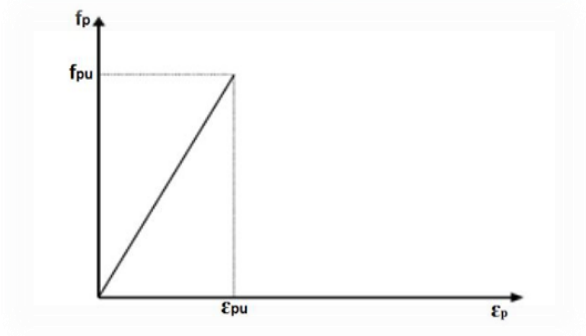


Figure 4. Idealized stress-strain relationship for CFRP

To simulate the flexural load at the center - Span, a concrete girder with dimensions (6000 *530 *200 mm) reinforced with a FRP strips of length (5000 mm) and width (100 mm) is used in this research. These dimensions and measurements have been utilized in investigations by other researchers [20]. This research made use of a standard ANSYS 2019 finite element analysis.

Concrete, reinforced concrete, and FRP strips are represented by the SOLID65, link180, and SHELL181 components, respectively. The 8-node SOLID65 brick element is a 3-D solid modeling element. This element may fracture in tension, crush in compression, and represent non-linear material characteristics, and it is combined with the LINK 180[21]. Other researchers have used these sizes and dimensions in testing.

For this study, a typical finite element model was developed in ANSYS 2019. The SOLID65, link180, and SHELL181 components are used to simulate concrete, reinforcement, and a carbon fiber reinforced polymer plate, respectively. Three-dimensional components, such as the 8-node SOLID65 brick element, may be used to depict solids. This element may simulate non-linear material properties such as cracking under tension and crushing under compression.

The SHELL181 is a 3D element with membrane (in-plane) stiffness but without bending (out-of-plane) stiffness. It is suitable for shell constructions when member bending is secondary. It is regarded as a contact element between the concrete and the FRP strips, and the behavior of the elastic stress-strain relationship is assumed to be linear, as with epoxy. The epoxy substance to establish complete integrity between the two materials, a nominal thickness of epoxy (1.5 mm) is suggested along the FRP strips. Table 1 demonstrate several kinds of FRP strips elements and material properties.

Table 1: Material properties of model

No. of material	Material	Element type
1	Concrete	SOLID65
2	reinforced	Link180
3	CFRP	SHELL181

2. 3 Meshing of models

When using SOLID65, link180, or SHELL81 elements, it is advised that you use a rectangular mesh. Since this was the goal, the mesh was constrained to produce only square and rectangular components. As a result of the convergence analysis, the optimal mesh size was chosen. By comparing the generated findings to the already existing test results, the least amount of inaccuracy was found. The initial mesh size was rather large and was progressively fine-tuned over time. In the end, a 125x40x40 mm element is used [22].

2.4 Geometry of models

Five models of girders with different degree of curvatures were taken in this part, and the degrees of curvatures are (DC1, DC2, DC3, DC4, and DC5) mm/m according to ACI. Figure 5(a-b-c-d-g) show the geometry and loading of the proposed models. The dimensions of the sample for all curved girders were 6000*530*200 mm and compressive strength and yield strength is stable as Table (2). The curved girders are subjected to a concentrated point load, one in the center. The curved girder ends are simply supported (pin and roller). Table 3 The symbolization of degree of curvature of curved girders.

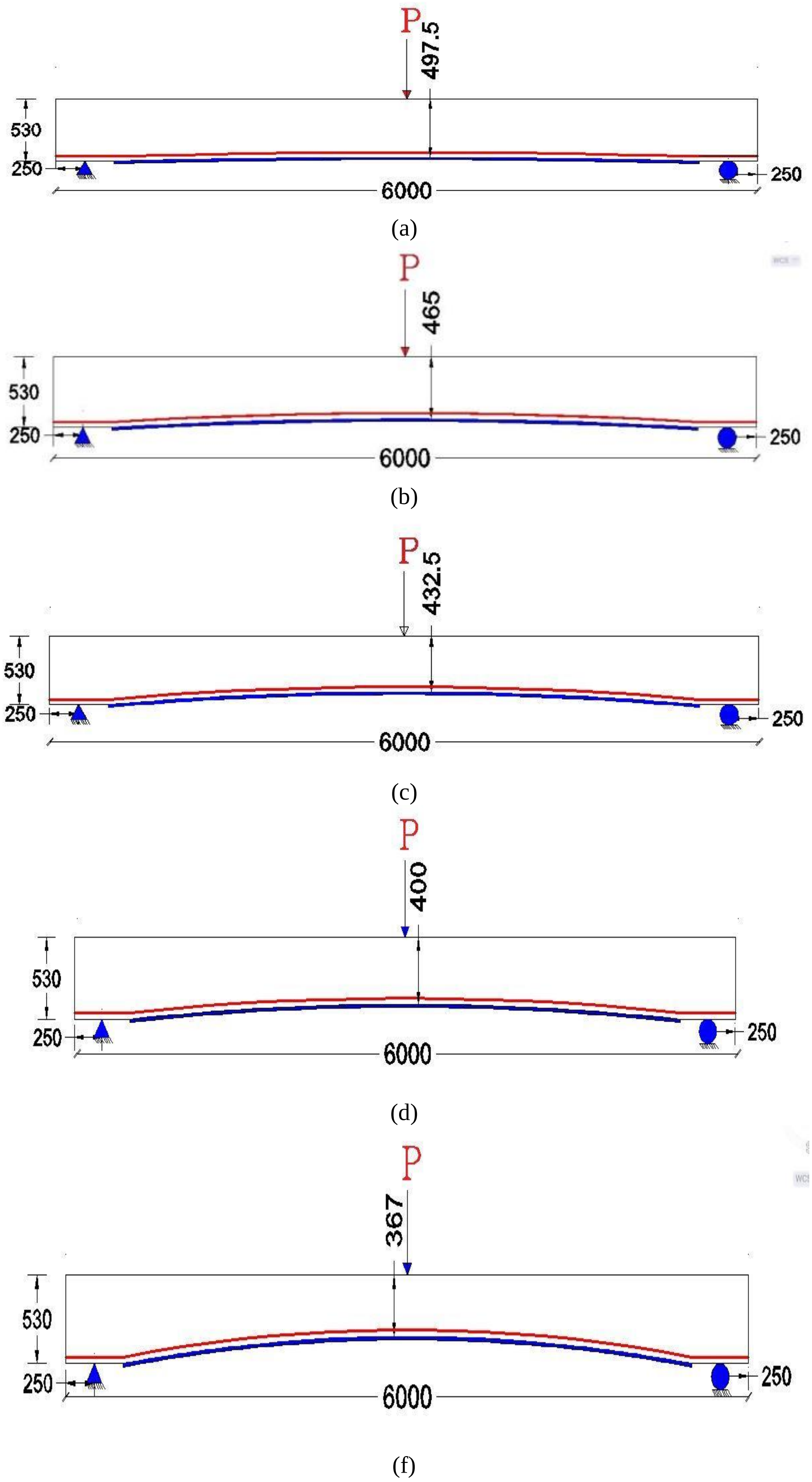


Figure 5. (a,b,c,d,f) Geometry, support and loading for the proposed curved girder

Table 2: The properties of models of degree of curvature

No. of models	f′c (Mpa)	Fy (Mpa)	Type of FRP
All models	35.8	414	Pre-cured

Table 3: The symbolization of degree of curvature of curved girders

Models	Total Length (mm)	Length of curve (mm)	Total Height (mm)	Height girder of mid (mm)	Height curve of mid (mm)	Degree of curve mm/m
DC1	6000	5000	530	497.5	32.5	1
DC2	6000	5000	530	465	65	2
DC3	6000	5000	530	432.5	97.5	3
DC4	6000	5000	530	400	130	4
DC5	6000	5000	530	367	163	5

3 Results and discussion

The analytical results for different models of curvatures are represented in Table 4 ultimate capacity load of the curved girders. Figure 6 describes the results for different degrees of curvature. It was found that the curvature of 5 mm/m model girder had more failure and tearing than the rest of the FRP girders that crack started from the concrete surface of the middle layer and spread to the support in both girders. As the forces in curvature failed at about (55.6,60,68.5,76,85.3) kN, respectively. That less curvature reduces displacement and requires more force.

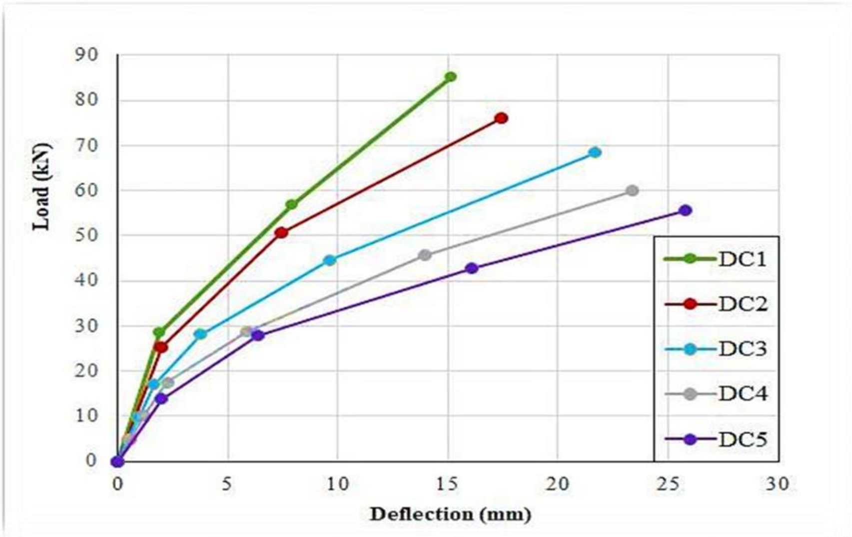


Figure 6. Load-displacement curves for the curved girders

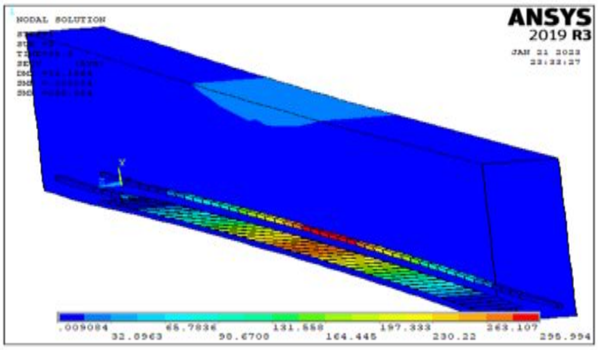
Table 4: Ultimate capacity of the curved girders

Model	load (kN)	displacement(mm)	Change with Pu %
1mm/m	85.3	15.151	42.167
2mm/m	76	17.384	26.67
3mm/m	68.5	21.7	14.167
4mm/m	60	23.377	0
5mm/m	55.6	25.755	-7.33

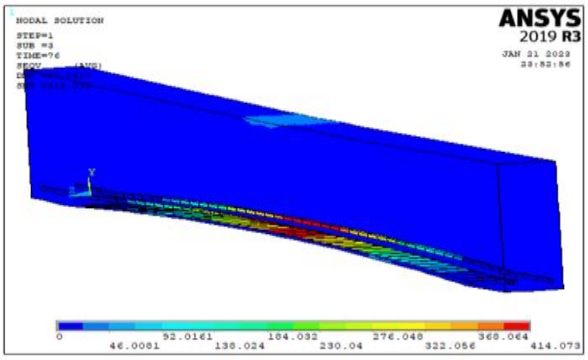
Under flexural load, girders are now subjected to nonlinear static analysis. In nonlinear finite element analysis, the entire load applied to a finite element model is divided into load stages. The strains, displacements, and stresses at the connecting nodes of these components were determined after loading. The effect of curvature on girders was studied in this work using five models. curved girders have the same cross-sectional area in all variants. The load and deflection curves for the models are shown in the Figure 6.

Maximum ultimate load is (85.3, 76, 68.5, 60, 55.6) KN, respectively. Degree of curvature

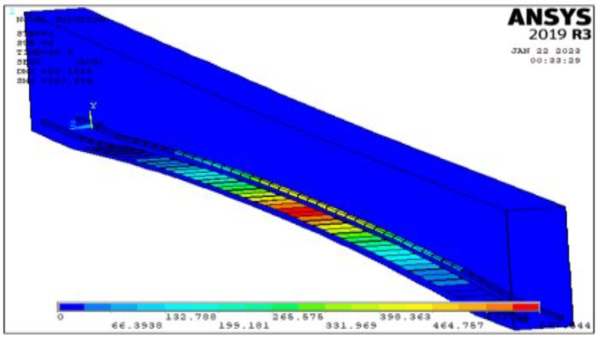
5mm/m showed lower behavior and lower load capacity than the other girders. The less the curvature, the greater the force and the less the displacement. As seen in Figure 6. The degree of curvature 1mm/m can carry a greater load than others, for the reason that the higher the degree of curvature, the less the effective depth, and thus the less the moment load, it fails with less weight, i.e. (decrease in the concrete area). The effect of curvature can be seen easily in the results of the degree of curvature of 5mm/m, because the moment that becomes a curve is higher, meaning that the rigidity is less, and the deflection increases according to the following formula ($D=5WL^4/384EI$). As shown in Figure (7) the deflection of 5mm/m deflection is more than the deflection of others under the same load, which indicates that 5mm/m deflection is softer than others. The mod failure in five models in this part was flexural failure and was found that the failure occurred with concrete in the first model DC1, but the remaining four models failed the entire model, i.e. the failure of concrete with reinforced with a value of (296, 414.07, 597.6, 570.7 and 536.4) Mpa, respectively.



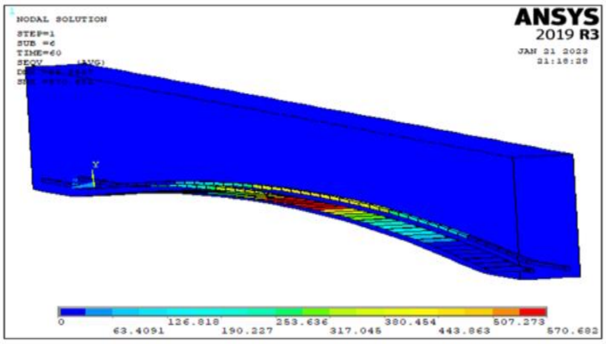
a)DC1



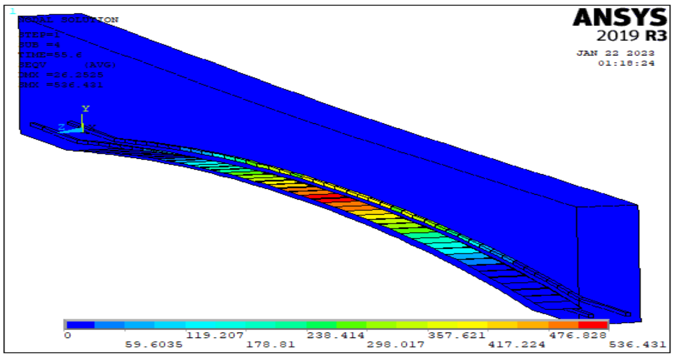
b)DC2



c) DC3



d)DC4



f) DC5

Figure 7. (a,b,c,d,f) Variation in stress at failure curved girders at(DC1,DC2,DC3,DC4 and DC5)

4. Conclusions

In this paper, the following conclusions can be drawn:

1. It was noted that the value of the degree of curvature 5mm/m cannot be exceeded, which is the boundary for reinforced concrete girders with FRP. (The value of the degree of curvature cannot exceed 5 mm / m in this type of concrete structure because its bearing capacity is less and its susceptibility to failure is greater than the other of the degrees of curvature chosen by observing the results of the analysis, which appeared to be less by 7.33%).
2. For different values of degree of curvature that are taken as, the ultimate load is increased by42.167% when curvature is 1mm/m on reference girder.
3. The displacement of the curved girder 5mm/m greater than 1mm/m to failure give notice, when the curvature is more, the strength of the form increases.
4. Due to the increased force of the curved girder, the 5mm/m model is less than 1mm thinner, so the 5mm/m model is less flexible.
5. The cracks spread in the 5mm/m curvature girder are more than 1mm/m, which indicates that the failure of the 1mm/m with the same applied force is faster.

References

[1] Al-Ghrery, K. G. (2022). Behaviour of Curved Soffit Reinforced Concrete Girders Strengthened with Carbon Fibre-Reinforced Polymer (Doctoral dissertation, SWINBURNEUNIVERSITY OF TECHNOLOGY).

[2] Rahimi, H. and Hutchinson, A. (2001), "Concrete beams strengthened with externally bonded FRP plates", Journal of Composites for Construction, vol. 5, no. 1, pp. 44-56.

[3] Pham, H. and Al-Mahaidi, R. (2004), "Experimental investigation into flexural retrofitting of reinforced concrete bridge beams using FRP composites", Composite Structures, vol. 66, no. 1, pp. 617-625.

[4] Gao, B., Leung, C. and Kim, J. (2005), "Prediction of concrete cover separation failure for RC beams strengthened with CFRP strips", Engineering Structures, vol. 27, no. 2, pp. 177-189.

[5] Wu, Z. and Niu, H. (2007), "Prediction of crack-induced debonding failure in r/c structures flexurally strengthened with externally bonded frp composites", Doboku Gakkai Ronbunshuu E, vol. 63, no. 4, pp. 620-639.

[6] Al-Ghrery, K., Kalfat, R., Oukaili, N., Al-Mosawe, A., & Al-Mahaidi, R. (2019). Finite element modelling of curved soffit reinforced concrete beams strengthened with fibre reinforced polymer. In Bridge Engineering Institute Conference (BEI-2019), Bridge Engineering Institute.

[7] Eshwar, N., Ibell, T., & Nanni, A. (2003). CFRP strengthening of concrete bridges with curved soffits. In Proceedings of The 10th International Conference and Exhibition-Structural Faults and Repair Conference 2003, Held London, July 2003-Cd Rom.

[8] Sarode, A. B., & Vesmawala, G. R. (2014). Parametric study of horizontally curved box girders for torsional behavior and stability. International Refereed Journal of Engineering and Science (IRJES), 3(2), 50-55.

[9] A Majeed, S. (2013). Finite Element Analysis of Strengthened Reinforced Concrete Beams. Al-Rafidain Engineering Journal (AREJ), 21(1), 134-145.

[10] Ibrahim, A. M., & Mahmood, M. S. (2009). Finite element modeling of reinforced concrete beams strengthened with FRP laminates. European Journal of Scientific Research, 30(4), 526-541.

[11] Al-Ahmed, A. H. A., & Al-Jburi, M. H. M. (2016). Behavior of reinforced concrete deep beams strengthened with carbon fiber reinforced polymer strips. Journal of Engineering, 22(8), 37-53.

[12] Qusay Wahhab Ahmed, " Behavior of Composite Steel-Concrete Beams

[13] Yao, J. and Teng, J. (2007), "Plate end debonding in FRP-plated RC beams—I: Experiments", Engineering Structures, vol. 29, no. 10, pp. 2457-2471.

[14] Alfano, G., De Cicco, F. and Prota, A. (2012), "Intermediate debonding failure of RC beams retrofitted in flexure with FRP: Experimental results versus prediction of codes of practice", Journal of Composites for Construction, vol. 16, no. 2, pp. 185-195.

[15] Fu, B., Chen, G. and Teng, J. (2017), "Mitigation of intermediate crack debonding in FRP-plated RC beams using FRP U-jackets", Composite Structures, vol. 176, pp. 883-897.

[16] A. Kaw, Ed., "Mechanical of Composite Materials", CRC Press LLC, Boca Raton, Florida, USA,1997.

[17] Seracino (ed), "FRP Composites in Civil Engineering – CICE 2004", Taylor & Francis Group,London, pp. 556, 2004.

[18] Aiello, M., Galati, N. and Tegola, A., (2001) "Bond analysis of curved structural concrete elements strengthened using FRP materials", FRPRCS-5: Fibre-reinforced plastics for reinforced concrete structures Vol. 1, pp. 399-408.

[19] D. Porter., A, Denton., S, Nanni., A and Tim, I. (2003), "Effectiveness of FRP plate strengthening on curved soffits", FRPRC-6.

[20] Eshwar, N., Ibell, T. and Nanni, A. (2005), "Effectiveness of CFRP strengthening on curved soffit RC beams", Advances in Structural Engineering, vol. 8, no. 1, pp. 55-68.

[21] Mohammadi, T., Wan, B., Harries, K. and Sweriduk, M. (2017), "Bond Behavior of FRP–Concrete in Presence of Intermediate Crack Debonding Failure", Journal of Composites for Construction, vol. 21, no. 5, p. 04017018.

[22] ACI Committee 209, (1992), “Guide for Modelling and Calculating Shrinkage and Creep in Hardened Concrete”,American Concrete Institute, Detroit.