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Structural Strengthening Behavior of Beams using Steel Plates

Barış Sevim

Yildiz Technical University, Department of Civil Engineering,
34220, Esenler, Istanbul, Turkey

Abstract:
This study presents the investigation of structural response of strengthened cantilever beams using steel plates. For the purpose a rectangular section is selected and full-scaled beams are three dimensionally modeled using finite element method. The dimensions of the beams such as width, height and length are selected as 25 cm, 50 cm and 300 cm, respectively. In the study, three different beam models are included to investigate the structural response of beams. First model is called as Model-1 and it considers only a traditional RC beam. Second model is called as Model-2 and it considers rectangular concrete section covered with steel plates. In model-2, thickness of the steel plate is selected as 2.5 mm. Third model is called as Model-3 and it is similar to Model-2, but the thickness of the steel plate is selected as 5 mm. Model-2 and Model-3 are used to strength the Model-1 to investigate the strengthening effects on the structural response of the traditional beam. In the study, all models and analyses are performed using ANSYS software. The rebar, concrete and steel plates are represented with LINK180, SOLID65, and SOLID185 elements, respectively. Boundary conditions are defined on started section as fixed and ended section as free. Interface between concrete and steel plates is assumed as bounded. Nonlinear pushover analyses of beam models are performed and displacements and stresses obtained from analyses are presented as graphics through beam length and contour diagrams. The results showed that strengthened beams (Model-2 and Model-3) have more capacity compared to traditional beam (Model-1).

Keywords: finite element method, nonlinear pushover analysis, structural response, traditional and strengthened beam.

1. Introduction

Beams are one of the structural elements of engineering structures such as buildings, bridges and other systems. They have a large usage area in civil engineering. They are structurally designed to against vertical loads which cause shear forces and flexural moments. They are generally used to transfer loads to columns, to provide ductility and stability on the systems. So many researches are done to investigate the beam response in the past [1-5]. With the developing of technology, new techniques are presented to increase the capacity of beams. These techniques generally include the covering of beams such as steel plates or fiber reinforced polymers (FRP).

Narmashiri et al. [6] investigated the failure and structural behavior of carbon fiber reinforced polymer (CFRP) strengthened steel I-beams. For the purpose, one non-strengthened control beam and twelve strengthened beams using different types and dimensions of CFRP strips in both experimental test and simulation modelling studies were investigated. The structural performance of the CFRP strengthened steel beams also varied according to the strengthening specifications investigated in this research.

Jankowiak [7] analyzed the RC beams strengthened by CFRP strips in the content of an experimental and numerical study. Assessment of effectiveness of strengthening at different preloading states is aimed in the study. It is explained from the study that validation of the numerical model and the verification procedure of numerical modeling based on the results of the laboratory tests have completed successfully.

Capozucca [8] studied the assessment of CFRP strengthened RC beams through some dynamic tests. He investigated the experimental vibration monitoring of strengthening according to the two aforementioned methods through dynamic tests on six RC beam models strengthened using carbon FRP. Experimental results are compared with numerical results. It is mentioned in the study that vibration monitoring is a convenient, non-destructive method for assessing strengthened beams under service loads.

Yang et al. [9] investigated flexural behavior of wood beams strengthened with hybrid fiber reinforced polymer (HFRP). For the purpose they prepared an experimental study including 12 strengthened beams and 3 control wood beams. In the study the failure modes and failure mechanisms of the FRP and HFRP strengthened beams were investigated It is concluded from the study that HFRP strengthening may significantly increase the ductility of the strengthened wood beams under the premise of increasing moment capacity greatly at a lower cost

Jasienko and Novak [10] experimentally researched about solid timber beams strengthened with steel plates. In the study, tests carried out on solid timber beams made of new wood (NW) and old wood (OW), which were subjected to bending after they were strengthened with steel plates and an epoxy adhesive. It is concluded from the study that the load-bearing capacity of the strengthened specimens increased by as much as 100% relative to that of unstrengthen reference specimens.

Tahsiri et al. [11] an experimental study presented related to RC jacketed and CFRP strengthened RC beams. In the study, three-point loadings are applied to twelve strengthened beams and three reference specimens to put the two techniques into perspective. Also, conventional analytical methods are applied for evaluation of ultimate moment, and the results are compared with the experiments.

Zand et al. [12] finite element analysis of square Concrete-filled steel tube (CFST) beam strengthened by carbon fiber-reinforced polymer (CFRP) composite material is performed. Several parameters are studied in this research, including various CFRP wrapping lengths/layers, steel tube yielding strengths, depth-to-thickness (D/t), and length-to-depth (L/D) ratios. It is highlighted from the study that better load improvement ratios were observed for the strengthened models with higher L/D and D/t ratios and for the models with lower steel yield strength when adopting the same strengthening scenario.

Khalifa [13] studied about the flexural performance of RC beams strengthened with near surface mounted CFRP strips. In the study, the performance and effectiveness of the near surface mounted (NSM) and externally bonded reinforcement (EBR) techniques for the flexural strengthening of RC beams are compared. In order to achieve this objective, six full-scale, RC beams were strengthened with different carbon FRP schemes and tested. It is conclude from the study that beams strengthened with NSM strips achieved higher ultimate load than those strengthened with EBR.

Fujikake et al. [14] examined the CFRP strengthened RC beams subjected to impact loading. For the purpose, four different types of CFRP strengthening schemes are applied to RC beams. It is highlighted from the study that the RC beams strengthened with CFRP are significantly improved in the resistance to impact loading.

Selvaraj and Madhavan [15], investigated the failure modes and structural performance of CFRP strengthened steel beams. They tested the externally bonded CFRP strengthened steel C channel beams. In the study surface and closed strengthening methods are considered. Also, the effectiveness of CFRP strengthening under environmental exposure is also studied by conducting the durability test with artificial rain. İt is highlighted from the study that CFRP strengthening technique can significantly improve the flexural moment capacity compared to the unstrengthen specimen by converting the lateral torsional buckling (LTB) mode of failure to failure due to yielding.

Tanarslan et al. [16] determined the flexural strengthening of RC beams using Ultra-high performance fiber-reinforced concrete (UHPFRC) laminates. In the study, real-sized laminates were tested to define the bare properties of full-scaled laminate and then flexural deficient RC beams were strengthened with 30 mm thick UHPFRC laminates using two different bonding methods: gluing with epoxy and mechanical anchoring. It is concluded from the study that UHPFRC laminate usage, especially in the case of anchorage, is an effective technique to improve the load carrying capacity of RC beams.

In addition to these studies some specific investigations are done related to strengthening of beams. In these studies, different type of beams such as concrete, timber, wood, steel or composite are experimentally and numerically examined [17-21].

The literature review showed that, more studies required to understand structural response of beams epically strengthened with new materials such as steel plates and FRP. So this study is prepared to investigate the structural response of strengthened beams using steel plates. For the aim, three different beam models considering with and without steel plates are three dimensionally constituted in ANSY software. Then nonlinear analyses are performed and the effectiveness of strengthening are examined comparing displacements and stress results for all models. In the content of the study, firstly importance of subject is highlighted and literature review is presented in introduction part. Then finite element models are descripted considering, geometrical dimensions, material properties, boundary conditions and other assumptions in numerical example part. This part also considers nonlinear pushover analyses of models and results obtained from the analyses which are shared with graphics and counter diagrams. Lastly, conclusions obtained from the study are presented.

2. Numerical Example

2.1 Description of Beams and Finite Element Models

This study presents the investigation of structural response of strengthened cantilever beams using steel plates. For the purpose a rectangular section is selected and full-scaled beams are three dimensionally modeled using finite element method. The dimensions of the beams such as width, height and length are selected as 25 cm, 50 cm and 300 cm, respectively (Fig. 1).

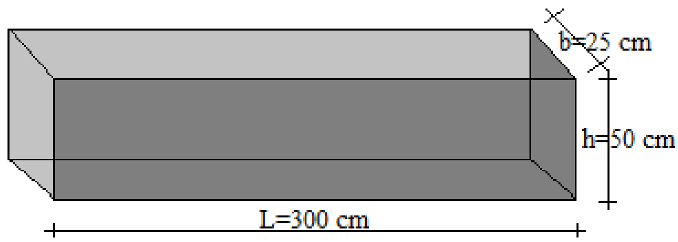

Fig. 1: Geometrical dimensions of the beam

Three different beam models are included in the study as Model-1, Model-2 and Model-3 to investigate the structural response of beams. Definition of the models are summarized below:

- **Model-1:** Model-1 considers a traditional RC beam including longitudinal and tie reinforced bars. Diameters of the bars are selected as 14 mm and 8 mm for longitudinal and tie bars, respectively.
- **Model-2:** Model-2 considers a strengthened beam including concrete covered with steel plates. In Model-2, thickness of the steel plates is assumed as 2.5 mm.
- **Model-3:** Model-3 considers a strengthened beam including concrete covered with steel plates. In Model-3, thickness of the steel plates is assumed as 5 mm.

Model- 2 and Model-3 are used to see effectiveness of strengthening response of beams. The sections of the models are illustrated in Fig.2.

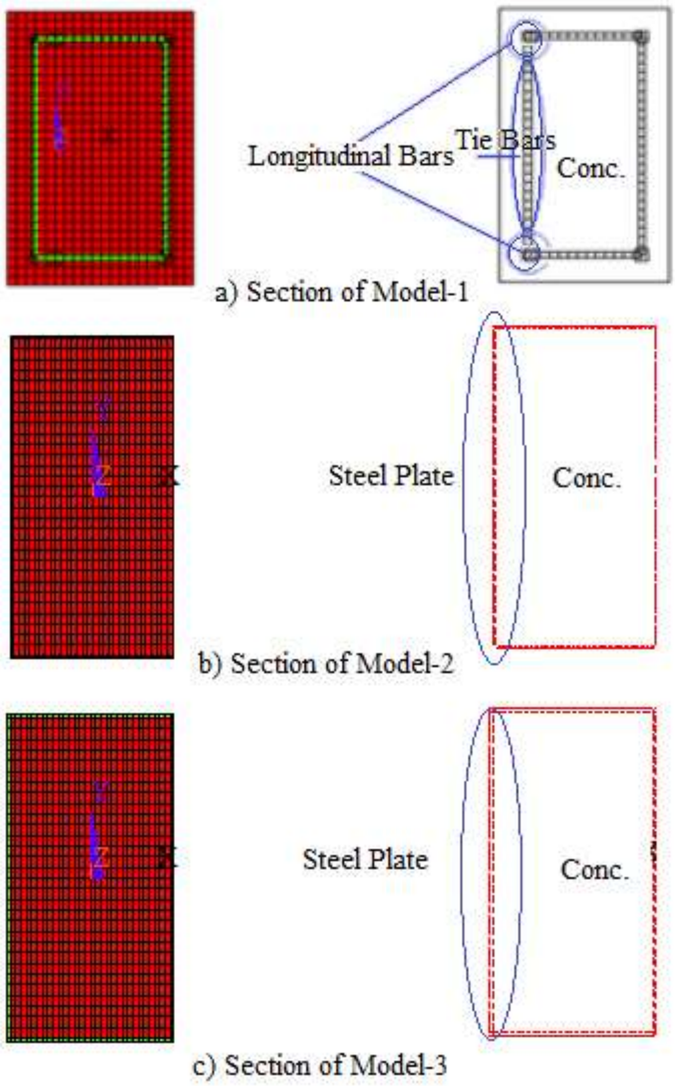

Fig.2: The sections of the beam models

3D finite element models of the beams are constituted using ANSYS software [22]. In the models, concrete is represented by SOLID65 elements, reinforcement bar is represented by LINK180 elements, and steel plates are represented by SOLID185 elements. SOLID65 has 8 nodes considering three translational degrees of freedom on each node. The element is capable of crushing in compression and cracking in tension. LINK180 is generally used to model reinforcement bars. It is a uni-axial tension-compression element including 2 nodes and three translational degrees of freedom on each node. It also has plasticity and large deflection capabilities. SOLID185 can be used to represent steel plates. It has same numbers of nodes and degrees of freedom with SOLID185. The element has nonlinear properties such as plasticity, stresses stiffening, and large deflection and strain capabilities.

In this study, nonlinear pushover analyses are performed for each model. So finite element models consider geometrical nonlinearity, also materials used in the models has nonlinear properties. Table 1 includes the material properties used in the finite element models. In the study, multi-linear elastic behavior for concrete and bilinear kinematic hardening behavior for reinforced bars and steel plates are assumed in nonlinear modeling and analysis. In multi-linear elastic behavior, unloading occurs along the same path as loading. In bilinear kinematic hardening behavior, it is assumed the total stress range is equal to twice the yield stress. In addition to these, boundary conditions are defined on started section as fixed and ended section as free. Interface between concrete and steel plates is assumed as bounded.

Table 1. Materials properties of the beams

Material Properties	All Beams		
	Concrete	Bar	Steel Plate
Weight per unit volume (kg/m^3)	2400	7850	7850
Elasticity Modulus (N/m^2)	3E10	2.1E1 1	2.1E11
Poisson Ratio	0.2	0.3	0.3
Yield Strength (MPa)	30	420	235
Tangent Modulus (MPa)	-	21	21
Yield Strain	0.001		
Ultimate Strain	0.003	Automatically calculated by ANSYS	

According to geometrical and material properties and boundary conditions, 3D finite element models of the beams are given in Fig. 3.

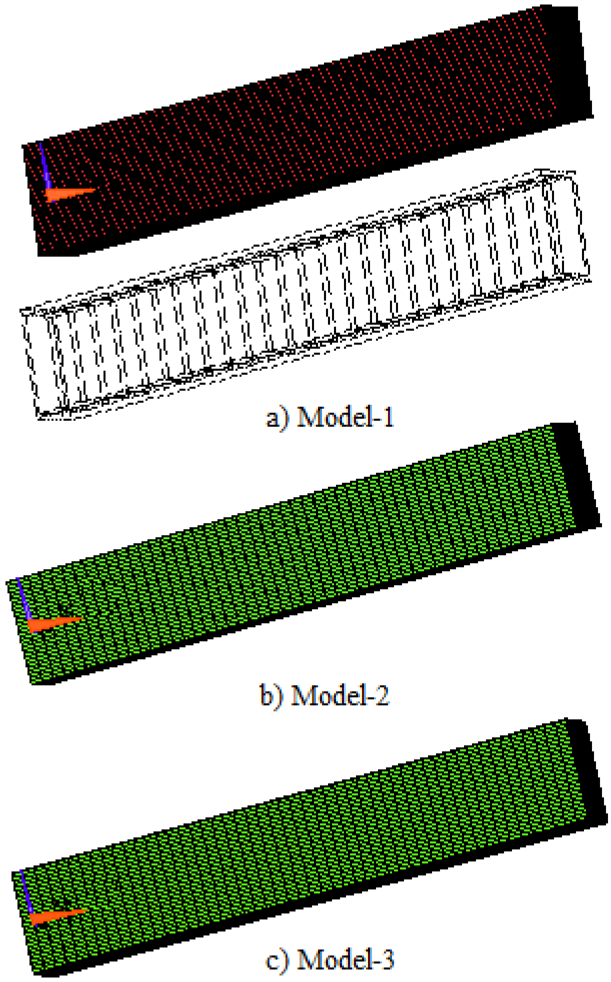

Fig. 3: Finite element models of the beams

2.2 Finite Element Analyses of Beams Models

In the study, nonlinear pushover analyses of the beams are performed using ANSYS software [22]. In nonlinear analyses, the size step is chosen as 0.005. The beams are statically loaded on the ended section nodes in vertical direction (through height direction) until the failure of materials. Schematic loading and sections on the beam used to present and compare result are shown in Fig. 4. In Fig. 4, A-A and B-B are the top and bottom section lines on the beam respectively. P is the static load applied to nodes on beam ended section

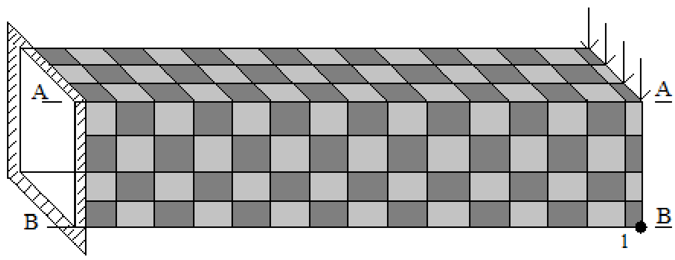

Fig. 4: Schematic loading and sections on the beam

Vertical displacements contour diagrams are illustrated in Fig. 5 a-c, respectively for Model-1, Model-2, and Model-3. As is seen Fig. 5, displacements have an increasing trend through beam from started section to ended section which is expected. In addition, maximum displacement are occurred on Model-1 which is only RC beam. The value of maximum displacement is about 9 cm for Model-1. This shows that the relative displacement ratio is nearly 0.03 which can be assumed as much for the beams. But the maximum displacements occurred on Model- 2 and Model-3 are nearly two and four times lower compared to Model-1 results. This shows that strengthened beams has least twice displacement capacity compare to traditional beam.

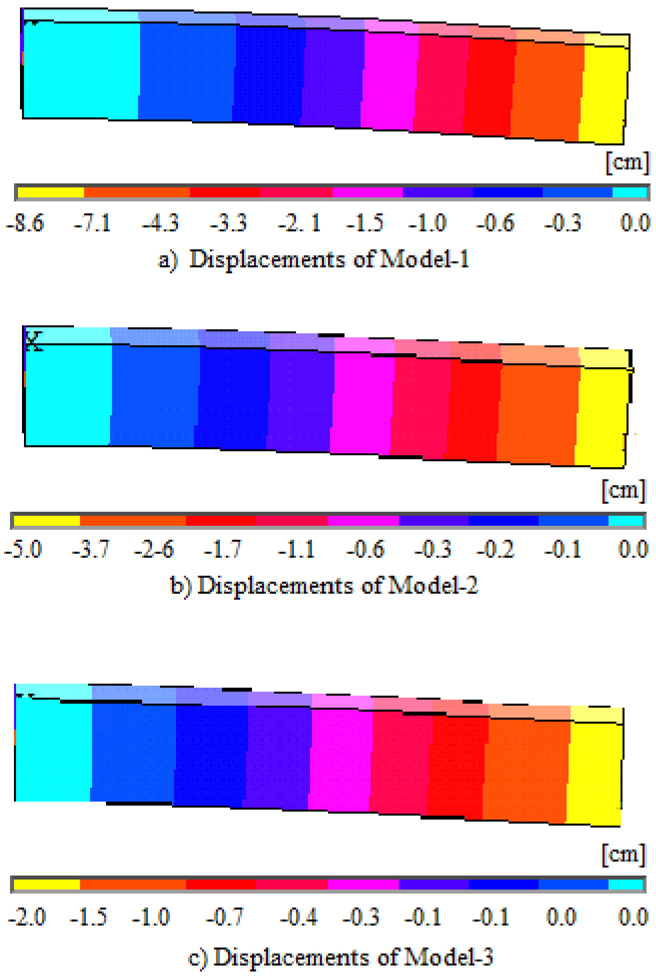

Fig. 5: Vertical displacements contour diagrams

The changing of vertical displacements along to beam length (B-B section, see Fig. 4) for Model-1, Model-2 and Model-3 is respectively presented in Figs. 6-8. As seen in Figs. 6-8, the displacements are exponentially increased through the end of the beam. Also, minimum displacements are occurred on Model-3, when maximum displacements are occurred in Model-1.

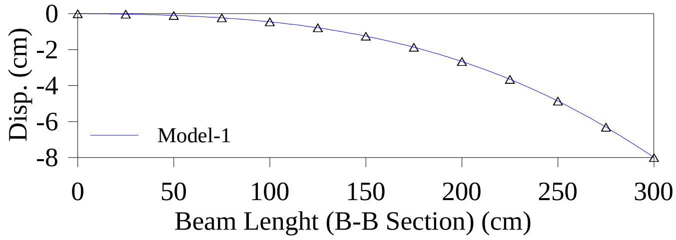

Fig. 6: Vertical displacements on the beam for Model-1

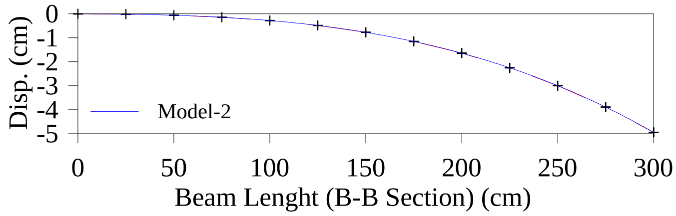

Fig. 7: Vertical displacements on the beam for Model-2

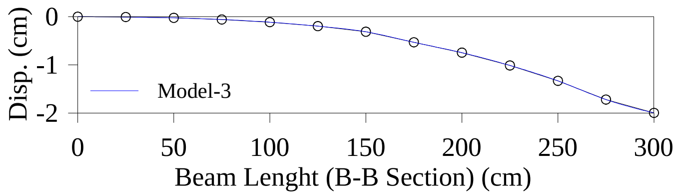

Fig. 8: Vertical displacements on the beam for Model-3

The force-displacement curves on 1 point (See Fig.4) of the beams are respectively plotted in Figs. 9-11 for Model-1, Model-2 and Model-3. It is stated from Figs. 9-11 that maximum displacement on 1 point is obtained from nonlinear pushover analysis of Model-2 and Model-3 at about 1500 kN vertical load. However, Model-1 is started to fail after 80 kN vertical load. The results show that strengthened models (Mdel-2, and Model-3) have more ductility and rigidity compared to traditional model (Model-1). The result also show that when the force increased on strengthened models, displacements are not as much as increased compared to traditional model.

Maximum principal stresses (tensile stress) contour diagrams obtained from nonlinear analyses are illustrated in Fig. 12 a-c, respectively for Model-1, Model-2, and Model-3. As is seen Fig. 12, maximum principal stresses are occurred on the top region and near fixed support for each model. Contrary of this response, the minimum stresses are occurred under the beams and near the fixed support. As results of Fig. 12, 8 MPa, 17 MPa, and 23 MPa tensile stresses are occurred on Model-1, Model-2, and Model-3, respectively. When considered capacity of strengthened models with steel plates, it can be stated that Model-2 and Model-3 have better behavior than Model-1.

The changing of maximum principal stresses along to beam length (A-A section, see Fig. 4) for Model-1, Model-2 and Model-3 is respectively presented in Figs. 13-15. As seen in Figs. 13-15, the maximum principal stresses are exponentially increased from the end to start of the beam.

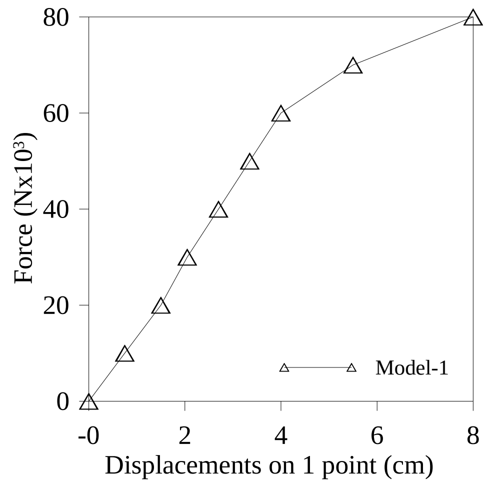

Fig. 9: Force- displacement curve for Model-1

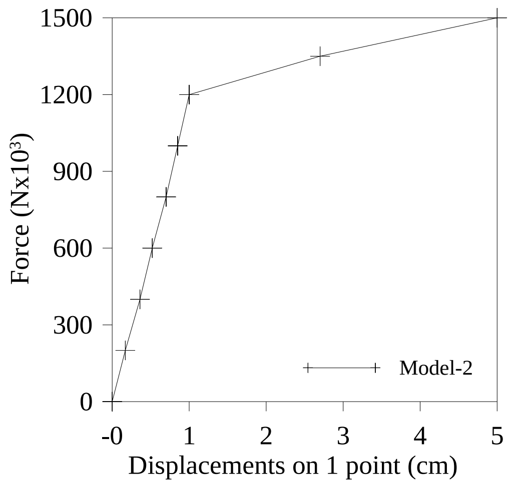

Fig. 10: Force- displacement curve for Model-2

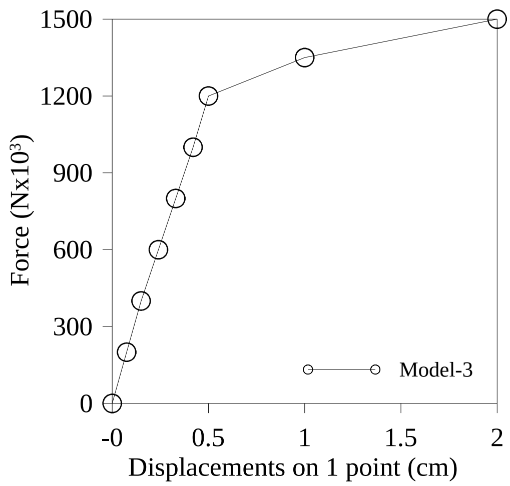

Fig. 11: Force- displacement curve for Model-3

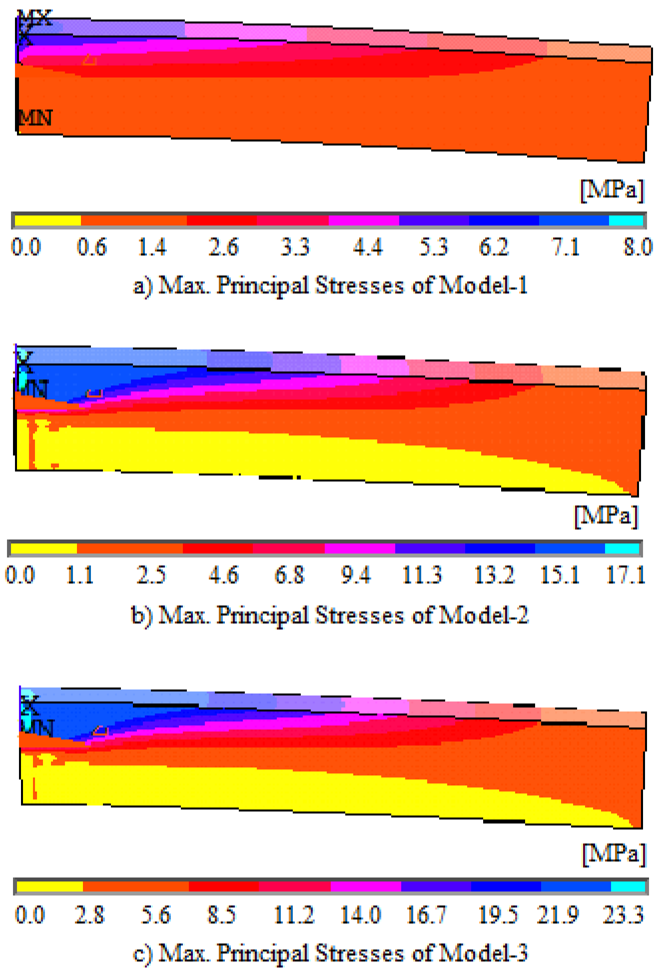

Fig. 12: Maximum principal stresses contour diagrams

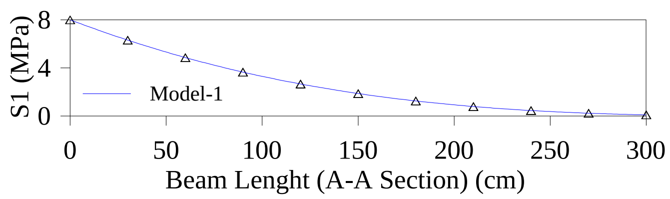

Fig. 13: Maximum principal stresses on the beam for Model-1

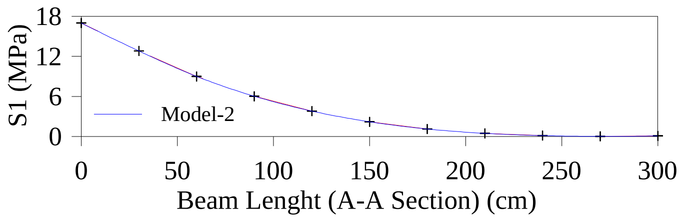

Fig. 14: Maximum principal stresses on the beam for Model-2

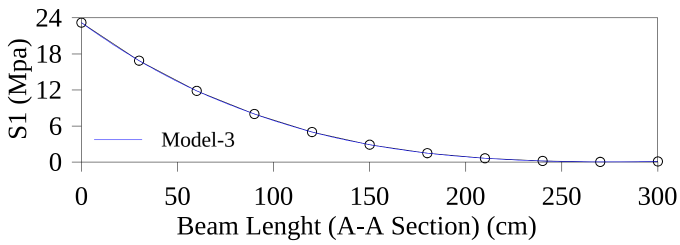

Fig. 15: Maximum principal stresses on the beam for Model-3

3. Conclusions

This study investigates the structural response of strengthened cantilever beams using steel plates. For the purpose, a rectangular concrete beam section is selected. In the study, three cantilever beam models (one of them is traditional RC beam, Model-1; the others are strengthened covering the concrete beam with steel plates, Model-2, and Model-3) are considered and full-scaled finite element models are nonlinearly performed. According to the study fallowing conclusions are obtained:

- ✓ The maximum displacements occurred on Model- 2 and Model-3 are nearly two and four times lower compared to Model-1 results. This shows that strengthened beams has least twice displacement capacity compare to traditional beam.
- ✓ The maximum displacement on 1 point is obtained from nonlinear pushover analysis of Model-2 and Model-3 at about 1500 kN vertical load. However, Model-1 is started to fail after 80 kN vertical load. The results show that strengthened models (Mdel-2, and Model-3) have more ductility and rigidity compared to traditional model (Model-1).
- ✓ The maximum principal stresses are occurred on the top region and near fixed support for each model. Contrary of this response, the minimum stresses are occurred under the beams and near the fixed support. When considered capacity of strengthened models with steel plates, it can be stated that Model-2 and Model-3 have better behavior than Model-1.
- ✓ The both of displacements and stresses results are showed that strengthened beam models have more capacity than unstrengthened model. Also, the thickness of steel plates has an importance on the displacement and stresses results compared the Model-2 and Model-2, which are the strengthened beam models.

References

1. Z.R. Lu, J.K. Liu, M. Huang, W.H. Xu, "Identification of Local Damages in Coupled Beam Systems from Measured Dynamic Responses", Journal of Sound and Vibration, 326(1-2), pp. 177-189, 2009.

A. Chatterjee, "Structural Damage Assessment in A Cantilever Beam with a Breathing Crack using Higher Order Frequency Response Functions", Journal of Sound and Vibration, 329(16), pp. 3325-3334 (2010).

2. A.N. Kallias, M.I. Rafiq, "Finite Element Investigation of the Structural Response of Corroded RC Beams", Engineering Structures, 32(9), pp. 2984-2994, 2010.
3. S. Sreenath, U. Saravanan, V. Kalyanaraman, "Beam and Shell Element Model for Advanced Analysis of Steel Structural Members", Journal of Constructional Steel Research, 67(12), pp. 1789-1796, 2011.
4. H. Zhao, Y. Yuan, Z. Ye, "Simplified Nonlinear Simulation of Steel–Concrete Composite Beams", Journal of Constructional Steel Research, 71, pp. 83-91, 2012.
5. K. Narmashiri, N.H.R. Sulong, M.Z. Jumaat, "Failure Analysis and Structural Behaviour of CFRP Strengthened Steel I-Beams", Construction and Building Materials, 30, pp.1-9, 2012.
6. Jankowiak, "Analysis of RC Beams Strengthened by CFRP Strips-Experimental and FEA Study", Archives of Civil and Mechanical Engineering, 12, pp. 376–388, 2012.
7. R. Capozucca, "Assessment of CFRP Strengthened RC Beams through Dynamic Tests", Composites: Part B, 46, pp. 69-80, 2013.
8. Y.L. Yang, J.W. Liu, G.J. Xiong, "Flexural Behavior of Wood Beams Strengthened with HFRP", Construction and Building Materials, 43, pp. 118-124, 2013.
9. J. Jasienko, T.P. Nowak, "Solid Timber Beams Strengthened with Steel Plates – Experimental Studies", Construction and Building Materials, 63, pp. 81-88, 2014.
10. H. Tahsiri, O. Sedehi, A. Khaloo, E.M. Raisi, "Experimental Study of RC Jacketed and CFRP Strengthened RC Beams", Construction and Building Materials, 95, pp. 476-485, 2015.

11. A.W. Zand, W.H.W. Badaruzzaman, A.A. Mutalib, A.H. Qahtan, "Finite Element Analysis of Square CFST Beam Strengthened by CFRP Composite Material", Thin-Walled Structures, 96, pp. 348-358, 2015.
12. A.M. Khalifa, "Flexural Performance of RC Beams Strengthened with Near Surface Mounted CFRP Strips", Alexandria Engineering Journal, 55, pp. 1497-1505, 2016.
13. K. Fujikake, S. Soeum, T. Matsui, "CFRP Strengthened RC Beams Subjected to Impact Loading", 6th International Workshop on Performance, Protection & Strengthening of Structures under Extreme Loading, PROTECT2017, 11-12 December 2017, China.
14. S. Selvaraj, M. Madhavan, "CFRP Strengthened Steel Beams: Improvement in Failure Modes and Performance Analysis", Structures, 12, pp. 120-131, 2017.
15. H.M. Tanarslan, N. Alver, R. Jahangiri, Ç. Yalçınkaya, H. Yazıcı, "Flexural Strengthening Of RC Beams using UHPFRC Laminates: Bonding Techniques and Rebar Addition", Construction and Building Materials, 155, pp. 45-55, 2017.
16. K. Xiang, G.H. Wang, "Calculation of Flexural Strengthening of Fire-Damaged Reinforced Concrete Beams with CFRP Sheets", Procedia Engineering, 52, 446-452, 2013.
17. M. Khelifa, A. Celzard, "Numerical Analysis of Flexural Strengthening of Timber Beams Reinforced with CFRP Strips", Composite Structures, 111, pp. 393-400, 2014
18. G. Spadea, F. Bencardino, F. Sorrenti, R.N. Swamy, "Structural Effectiveness of FRP Materials in Strengthening RC Beams", Engineering Structures, 99, pp. 631-641, 2015.
19. G.M. Chen, Z. Zhang, Y.L. Li, X.Q. Li, C.Y. Zhou, T-Section RC Beams Shear-Strengthened with Anchored CFRP U-Strips", Composite Structures, 144, pp. 57-79, 2016.
20. M. Subhani, A. Globa, R. Al-Ameri, J. Moloney, "Flexural Strengthening of LVL Beam using CFRP", Construction and Building Materials, 150, pp. 480-489, 2017.
21. ANSYS, Swanson Analysis System, USA, 2017.

Author Profile

Barış Sevim He was born in Trabzon in 1982 in Turkey. He completed his high school education in Istanbul Üsküdar Haydarpaşa in 2000. Then he had got a bachelor degree from Karadeniz Technical University, Department of Civil Engineering in 2004. Lastly, he finished his Phd Thesis in the same university in 2010. Now, he is an academician in Yildiz Technical University, Department of Civil Engineering. He studies about the earthquake responses of engineering structures and operational and experimental modal analyses. He is married and has got a child.