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Structural performance of 3D printing RC beams using internal and external strengthening methods

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Abstract

In this project 3D printed beams provided with internal and external strengthening methods were analyzed with the assistance of ANSYS software and its findings are compared to achieve the better version of such beams. Validation is completed and is successful. After the validation models of strengthened 3D printed concrete (3DPC) beams were produced and results are compared with reinforced concrete beams. High strength wires are utilized for internal strengthening purpose. These wires were organized in numerous patterns and are analyzed to find out the better combination. External strengthening of 3DPC beams with steel plates installed on both sides of beams are also assessed. Beams with varying plate thickness and bolt arrangement patterns are explored.

***Key Words*: 3D printed concrete beams (3DPCB), internal strengthening, external strengthening, high strength wires.**

1.Introduction

Among the additive manufacturing (AM) techniques for concrete now in use, three-dimensional concrete printing (3DCP) technology seems to have attracted the most interest due to its general technological level and demonstrated profitability. The development of 3DCP technology has led to the implementation of typical demonstration projects. 2015 saw the printing of an 11 m long, 5 m wide, and 4 m high concrete structure by the Eindhoven University of Technology. In 2016, a 3DCP office located in Dubai also started operating. China Construction Second Bureau LTD produced a two-story, 7.2 m tall office building in 2019. Instead of employing printed concrete components to create the office building, 3DCP was used on-site, in-situ. A concrete pedestrian bridge was printed by the Institute of Advanced Architecture.

However, there are numerous difficulties in using 3D printed concrete buildings in actual technical applications. With a high resistance to compression and a weak resistance to tensile and flexural pressures, concrete is a typical quasi-brittle material. AM is a good application for concrete. Its strengthening method must be carefully considered in order to improve its mechanical properties. Freshly mixed concrete is extruded from the nozzle along a predetermined path and piled on top of one another to build a building using 3DCP technology. Therefore, it is difficult to add vertical reinforcement in printed concrete walls. Additionally, printed plain concrete walls are fragile, have a low ultimate bearing capacity, and have a low level of crack resistance. However, in order to meet the requirements for buildability, the workability and compaction of 3D printed concrete must be restricted to a lower level.

Although a number of 3DPC reinforced technologies seem promising, they are still in their infancy and principally require more adaptability to automatically construct vertical and horizontal components that adhere to the necessary international building standards. The mechanical behaviour of reinforced 3DcP members should, theoretically, be the same as that of conventionally constructed ones because the addition of steel reinforcement makes up for the concrete's relatively low tensile strength and flexibility. To take the 3D printing process into account, the design concepts and models must be carefully reviewed. The shape-related mechanics, anisotropy, thin interfacial layers, potential sliding, and a weaker link between the concrete and steel are some examples of this.

When a 3D printer receives the data it needs to print, the machines start to overlay material levels in the appropriate places. This can be done using a variety of materials, the most popular of which being a blend of sand, fibre, geo polymers, and concrete. The strengthening technique used when concrete is used as a material for 3DP is crucial for enhancing its mechanical qualities. Despite the growing interest and knowledge of extrusion 3D concrete printing technologies, there is still a significant overall constraint with regard to successfully adding reinforcement in the 3DPC process. Despite the growing interest and knowledge of extrusion 3D concrete printing technologies, there is still a significant overall constraint with regard to successfully adding reinforcement in the 3DPC process. Thus 3D printing technology has many applications in the civil engineering field.

1.1 Advantages of 3D printing technology

3D printing technology ensures lower construction costs. It ensures shorter construction period. More diverse design shapes can be made and no form works are required during construction.

1.2 Objectives and scopes

The main objectives are Developing and comparing the models of conventional RCC beam and internally strengthened 3D printed concrete beams. Internal reinforcing of 3D printed concrete beams is accomplished using high strength galvanized wires. These cables are set up in various ways that can function as reinforcements. Results are obtained after ten distinct strengthened models are built, compared with traditional RCC beams, and evaluated. To study the performance of externally strengthened 3D printed concrete beams with arying bolt arrangement. Steel plates are added to both sides of 3DPC beams to strengthen their exteriors. The bolt arrangement that holds these plates together. By changing the bolt arrangement pattern, six distinct types of externally strengthened beams are examined in this chapter. A 3 mm plate thickness is used.

2. Develop and compare models of RCC and strengthened 3DPCB

The simulated beams have dimensions of 150 mm in width, 300 mm in depth, and 2 m in length. The 3DPC beams use high strength galvanized wires as reinforcement. These are constructed from two 2.5 mm diameter, 1150 N/mm2 strong twisted line wires.

We are now constructing 10 versions of 3DPC beams with various configurations of high strength wires serving as reinforcement. Results are achieved by comparing these models to a traditional RCC beam.

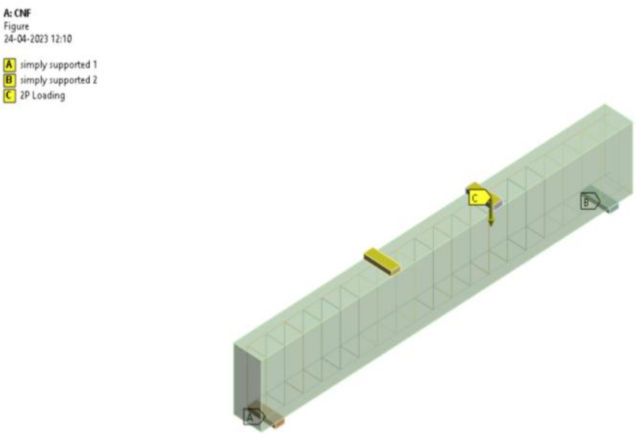

Fig 1- Boundary condition

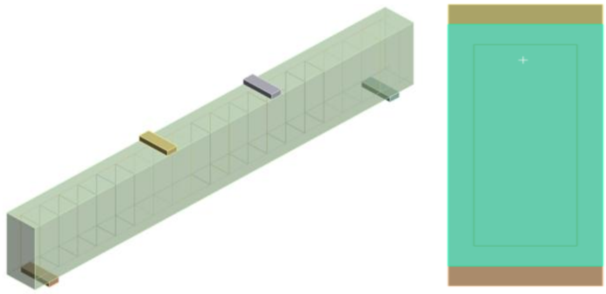

Fig 2 – Geometry of conventional beam

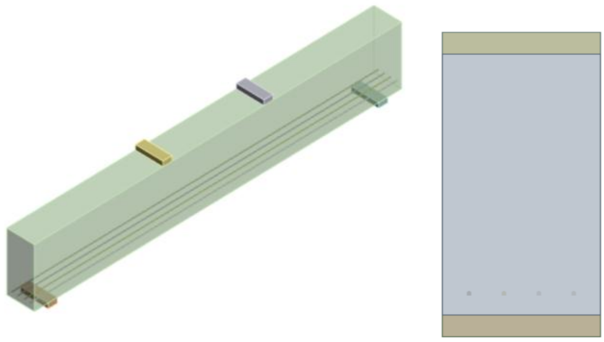

Fig 3 – Geometry of model 1 – high strength wires in one layer

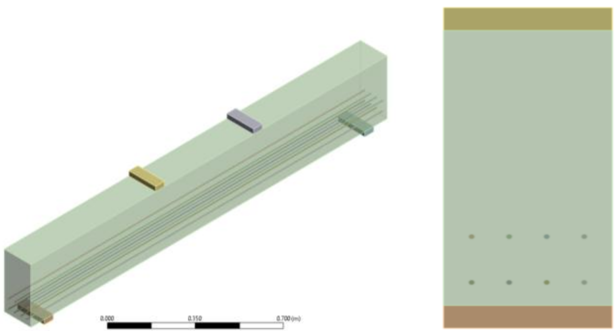

Fig 4 – Geometry of model 2 – high strength wires in two layers

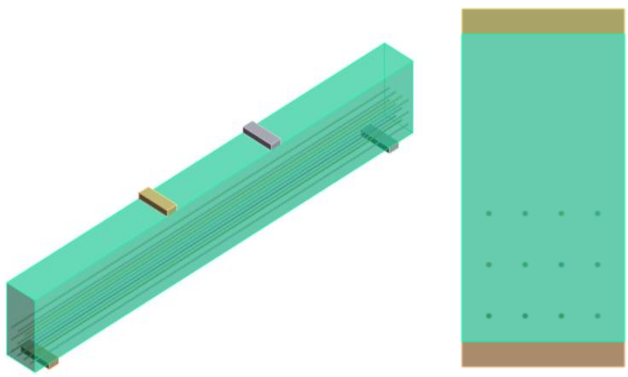

Fig 5 – Geometry of model 3 – high strength wires in 3 layers

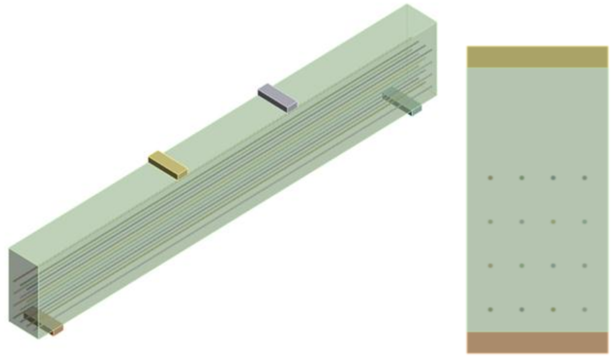

Fig 6 – Geometry of model 4 – high strength wires in 4 layer**s**

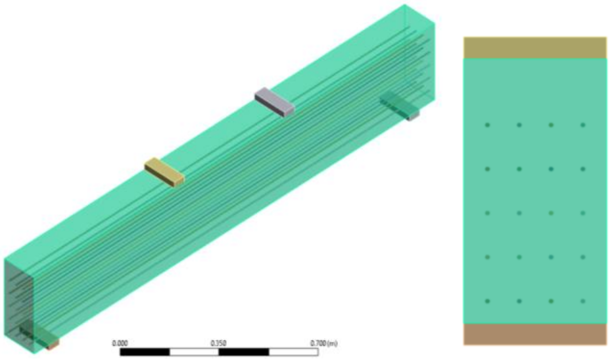

Fig 7 – Geometry of model 5 – high strength wires in 5 layers

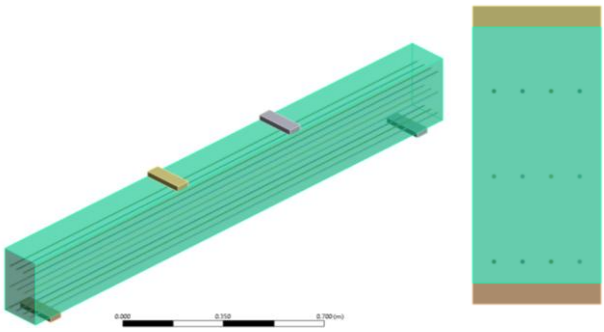

Fig 8 – Geometry of model 6 – high strength wires in alternate layers

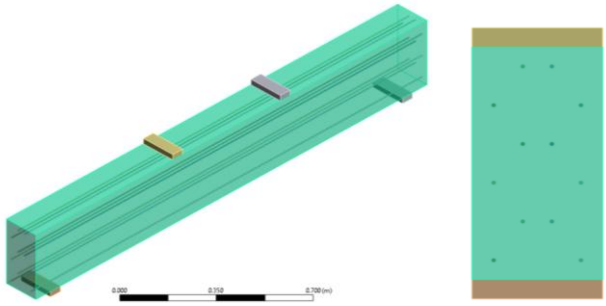

Fig 9 – Geometry of model 7 – high strength wires in zig – zag pattern

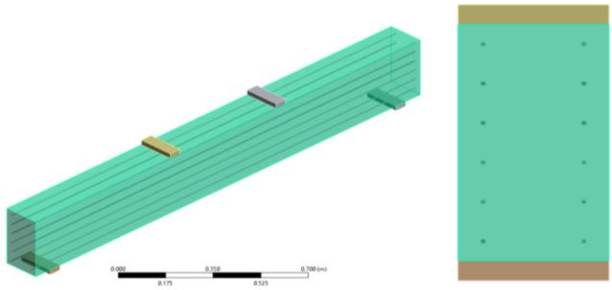

Fig 10 – Geometry of model 8 – high strength wires in column pattern at ends

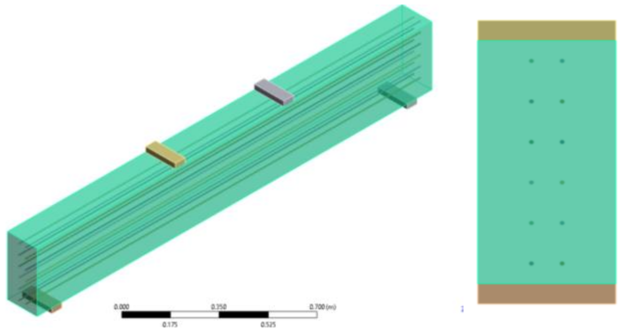

Fig 11 – Geometry of model 9 – high strength wires in column wise pattern – away from ends

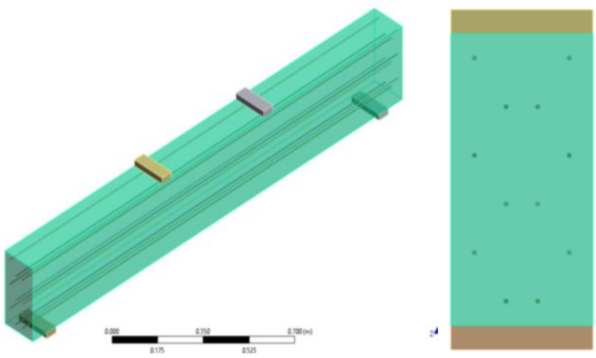

Fig 12 - Geometry of model 10 – high strength wires in zig zag way (reversed)

2.1 Analysis

In ANSYS software, nonlinear static structural analysis is performed. Studies are done on deformation and load carrying capacity. The following figures display the deformation diagrams.

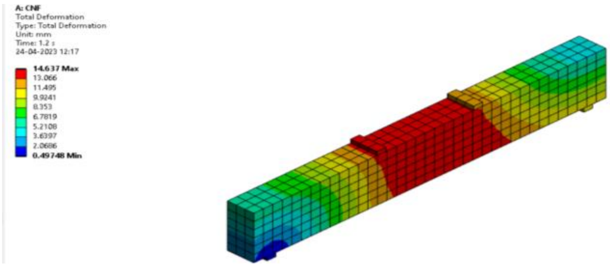

Fig 13 - Deformation of conventional beam

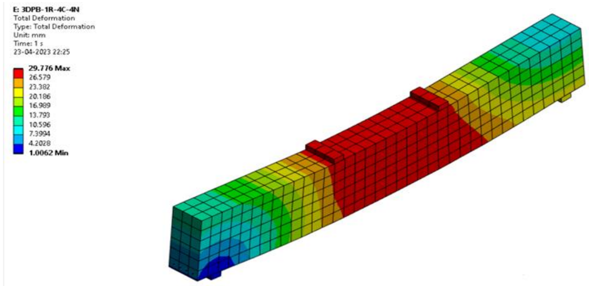

Fig 14 - deformation of model 1

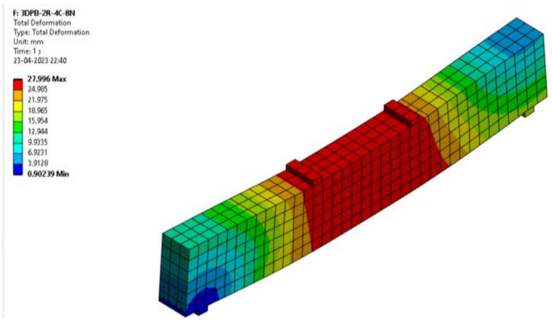

Fig 15 - Deformation of model 2

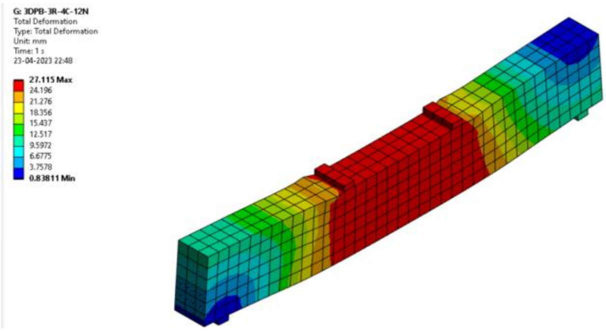

Fig 16 - Deformation of model 3

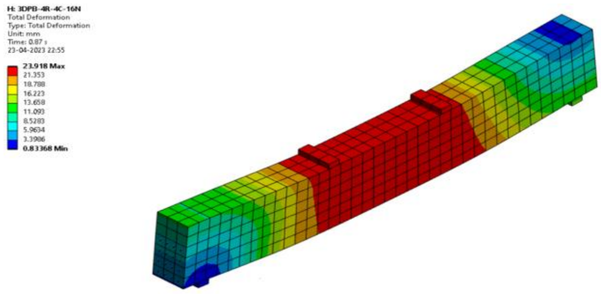

Fig 17 - Deformation of model 4

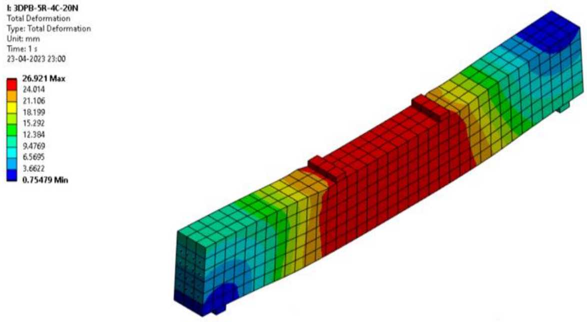

Fig 18 - Deformation of model 5

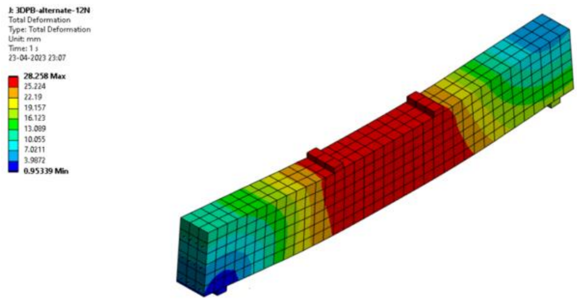

Fig 19 - Deformation of model 6

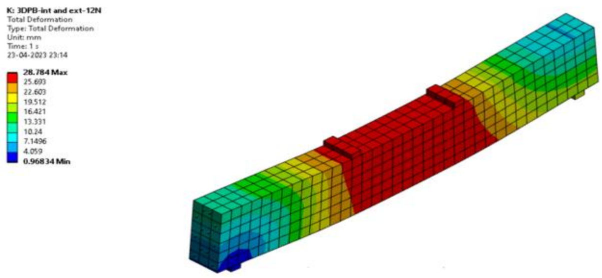

Fig 20 - Deformation of model 7

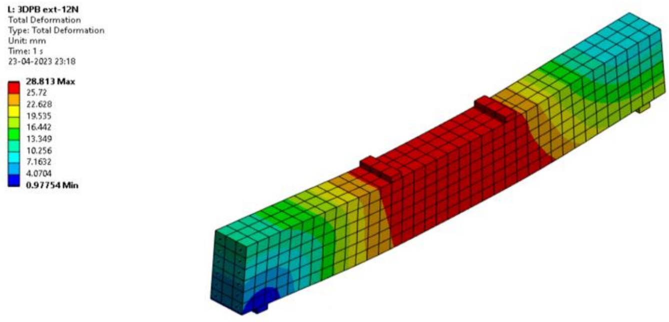

Fig 21 - Deformation of model 8

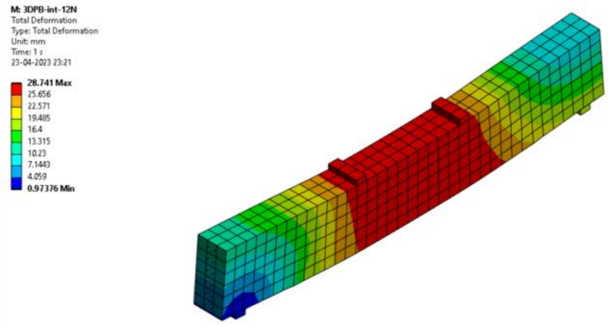

Fig 22 - Deformation of model 9

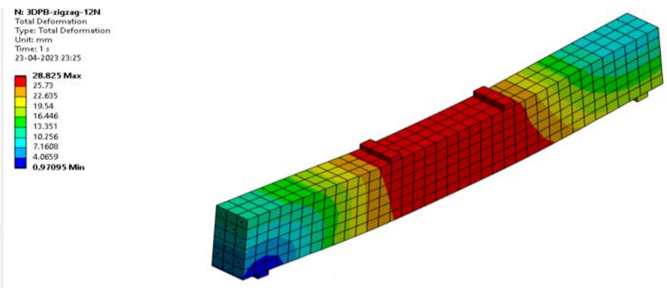

Fig 23 - Deformation of model 10

2.2 Result and discussion

The result obtained from the analysis of internally strengthened 3DPC beams are compared with conventional beam. For that load deformation curve is taken for each model. The graphical representation of load and deflection of beams are shown.

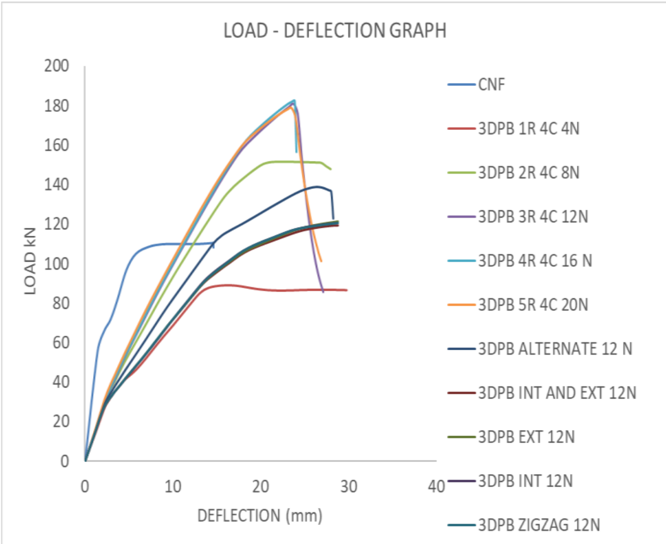

Chart -1: comparison graph

Table - 1: comparison table

MODEL	DEFLECTION (mm)	LOAD (kN)	PERCENTAGE INCREASE IN LOAD CAPACITY
CNF	10.17	110.21	1
3DPB 1R 4C 4N	17.15	89.015	-23.81059372
3DPB 2R 4C 8N	26.941	151.05	27.03740483
3DPB 3R 4C 12N	23.742	181.02	39.11722462
3DPB 4R 4C 16 N	23.918	182.25	39.52812071
3DPB 5R 4C 20N	23.535	178.91	38.39919513
3DPB alternate 12N	27.242	138.03	20.15503876
3DPB INT AND EXT 12N	28.784	119.46	7.743177633
3DPB EXT 12 N	28.813	121.21	9.075158815
3DPB INT 12 N	28.741	120.39	8.455851815
3DPB ZIGZAG 12 N	28.825	120.5	8.539419087

The fourth model's 3DPB has a larger load carrying capacity than a typical beam. It's possible that 3DPB -4R -4C -16N performs better than standard beam. Thus, Model 4 with four rows of strengthening wires is selected.

3. Performance of externally strengthened 3DPC beams with varying bolt arrangement

The various bolt arrangement patterns holding the steel plates are analyzed in this chapter to find the best configuration. External strengthening of 3DPC beams are done by providing steel plates on both sides of beam. These plates are held together by bolt type arrangement. In this chapter 6 different models of externally strengthened beams are analyzed by varying the bolt arrangement pattern. Plate thickness of 3 mm is chosen

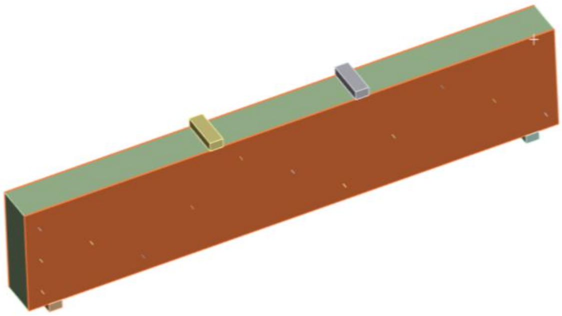

Fig 24 – pattern 1

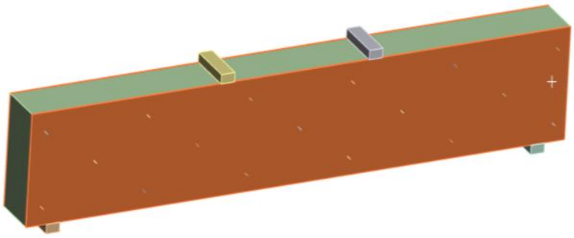

Fig 25 - pattern 2

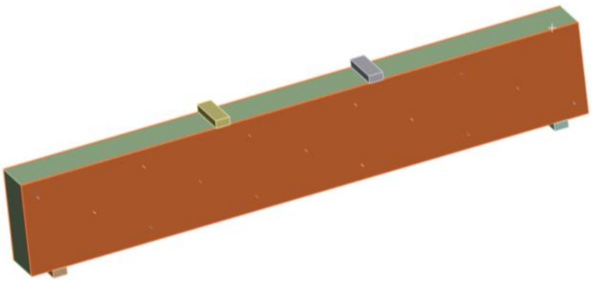

Fig 26 – pattern 3

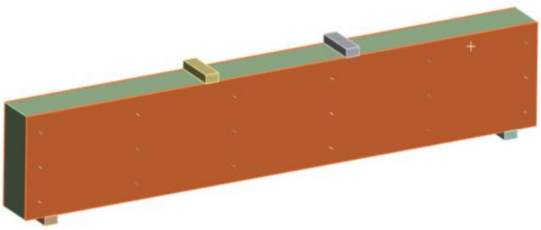

Fig 27 – pattern 4

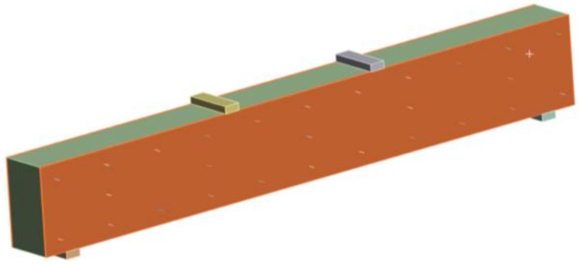

Fig 28 – pattern 5

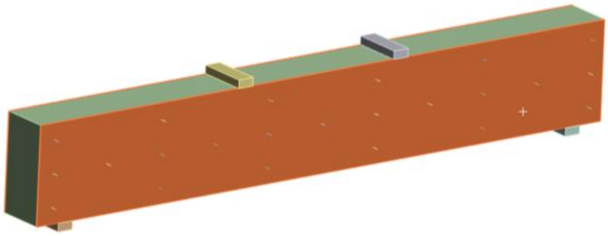

Fig 29 – pattern 6

3.1 Analysis

Software called ANSYS is used to perform structural analysis. Beam deformation and load carrying capability are determined.

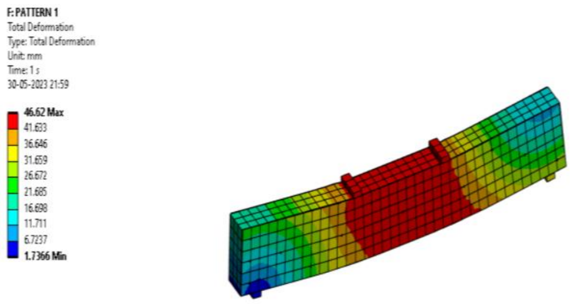

Fig 30 – deformation diagram of pattern 1

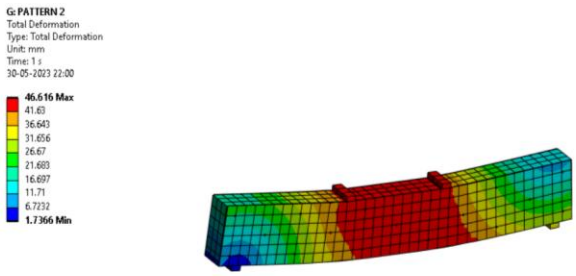

Fig 31 – deformation diagram of pattern 2

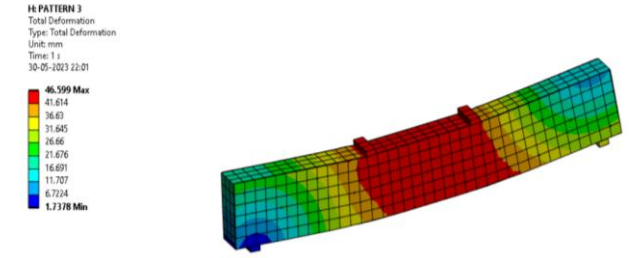

Fig 32 – deformation diagram of pattern 3

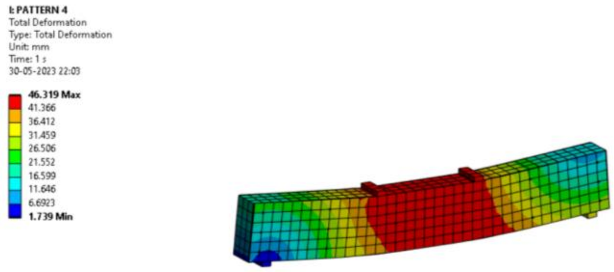

Fig 33 – deformation diagram of pattern 4

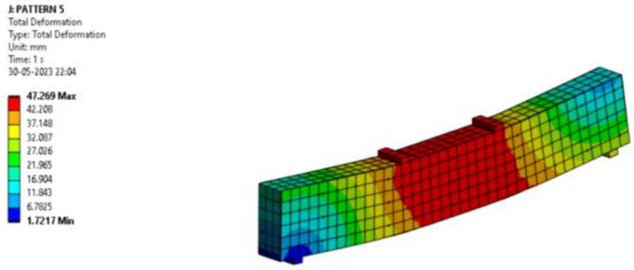

Fig 34 – deformation diagram of pattern 5

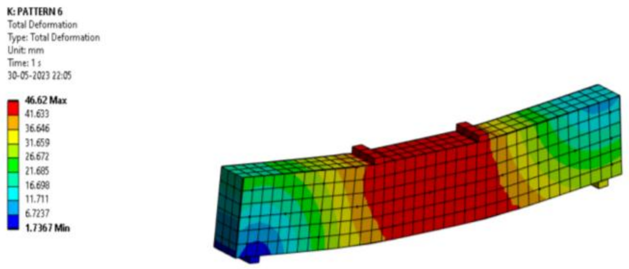

Fig 35 – deformation diagram of pattern 6

3.2 Result and discussion

By adding steel plates on both sides of the beam, 3DPC beams are externally strengthened. These plates are connected by a bolt arrangement. The bolt arrangement pattern is changed to assess six alternative models of externally strengthened beams in this chapter. 3 mm thick plates are selected

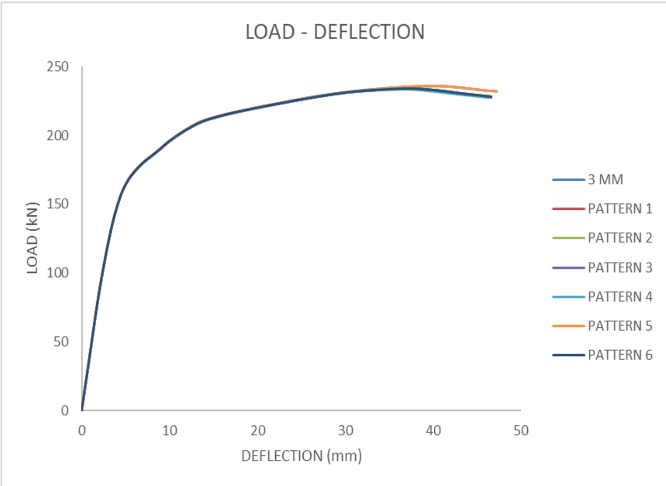

Chart -2: comparison graph

Table – 2: comparison table

	Deflection (mm)	Load (kN)	% increase in load
3 mm	40.558	235.97	1
pattern 1	37.337	234.28	0.716
pattern 2	37.335	234.28	0.716
pattern 3	37.337	234.42	0.6568
pattern 4	36.231	236.58	1.012
pattern 5	33.725	233.9	0.877
pattern 6	37.338	234.27	0.720

Steel plates are added to both sides of 3DPC beams to strengthen their exteriors. The bolt arrangement that holds these plates together. By changing the bolt arrangement pattern, six distinct types of externally strengthened beams are examined in this chapter. A 3 mm plate thickness is used. The load-deflection graph of the six different bolt arrangement patterns is examined, and pattern 4 is selected.

4. CONCLUSIONS

High strength galvanized wires are used for internal strengthening. By comparing 10 distinct strengthened models to a standard beam model, the % improvement in load carrying capacity was determined. The fourth model's 3DPB has a larger weight carrying capacity than a typical beam. It's possible that 3DPB -4R -4C -16N performs better than standard beam. Thus, Model 4 with four rows of strengthening wires is selected. Steel plates are added to both sides of 3DPC beams to strengthen their exteriors. The bolt arrangement that holds these plates together. By changing the plate thickness, four distinct types of externally strengthened beams are examined. The available plate thicknesses are 3mm, 2.5mm, 2mm, and 1.5mm. Plate thickness is determined to be 3 mm after evaluation of the load deflection curves. By changing the bolt arrangement pattern, six distinct types of externally strengthened beams are examined. A 3 mm plate thickness is used. The load-deflection graph of the six different bolt arrangement patterns is examined, and pattern 4 is selected. Thus, 16 number of bolt type arrangements will hold 3 mm plates for external beam strengthening purposes on either side of the beam.

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