STUDY ON NEAR SURFACE MOUNTED REINFORCEMENT FOR STRENGTHENING DEEP BEAM WITH LONGITUDINAL DUCT

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Abstract: *Beams are the important part of structures. They are the primary load carrying member of any concrete structures. Deep beams are having large depth to thickness ratio and are used for heavy load carrying structures. These beams are mainly used in bridges, multistorey building, transfer girders and shear walls. These beams utilize some amount of space as well and is very difficult to provide space for many services like electrical, drainage and other services. In-order to accommodate these services effective alteration are provided within the structures without losing their strength properties, i.e. by providing ducts of different shape and size and also at different locations of beams. Due to introduction of these alterations there are some losses of effective area in the structures which may affect the strength properties. In-order to retain the strength properties strengthening methods is adopted. There are many strengthening methods to adopt. Near surface mounted method (NSM) is a strengthening method in which a shallow groove is provided on the concrete surface, in required direction, for accommodating a strengthening material such as steel, carbon fibre reinforcement, which is fixed by any adhesive material.*

Keywords: (NSM) Near surface method

1. INTRODUCTION

1.1 GENERAL

Beams and columns are inevitable part of a concrete structure. They are the primary load carrying members and give support for the entire structure. While using the beams with large spans, it perhaps will fail due to flexure. We can use post tensioned beams, composite beams, plate girders and deep beams instead of long spans beams. Deep beams are becoming popular and are progressively used in modern constructions; and have useful applications in a variety of structures. Beams with large depths in comparison with span are called deep beams. Opening in the deep beams are provided for the accessibility to allow for services including electric and mechanical. The beam strength and stiffness reduces due to this openings and it will leads to excessive cracking and deflection.

1.2. DUCT PROVIDED DEEP BEAM

In modern buildings the duct openings in beams are provided and it is very necessary to accommodate the service pipes and service ducts. Sometimes the duct openings are used for aesthetical purpose also. Beam depth is one of the factors to decide the floor to floor height and overall height of the building. Retaining the load carrying capacity of the beam without increasing the depth is a major problem for the Structural Engineer. If service ducts are provided at the bottom of the beam, then the floor to floor height increases and the overall height of the building also increases. The load carrying capacity and stiffness of the beam reduces due to these ducts provided in the beam. Despite the fact that the presence of openings reduces beam strength and stiffness, as well as causing excessive cracking and deflection. Researchers choose self-consolidating concrete (SCC) for deep beam casting. The purpose of the opening determines the type of opening. As a result, many shapes are used; the most prevalent types of openings are rectangular and circular in shape, with varying sizes and locations.

1.2.1 LONGITUDINAL OPENING IN DEEP BEAM

Beams with longitudinal apertures are RC beams with openings parallel to the longitudinal axis. Longitudinal openings of many forms are employed, including circular, rectangular, diamond, triangular, trapezoidal, and even irregular shapes. The corners of the rectangular longitudinal hole are sometimes rounded off, with the goal of lowering stress concentration at sharp corners and thereby improving the beam's cracking behavior in service

1.3 NEAR SURFACE MOUNTED METHOD

There are several methods available to provide shear and flexural strengthening, they are by adding external stirrups, jacketing, bonding external plates using epoxy or bolts and bonding external FRP laminates. After the research of fiber polymer, newer class of FRP strengthening techniques have been used: externally bonding technique (EBR) and near surface mounting reinforcement (NSMR).

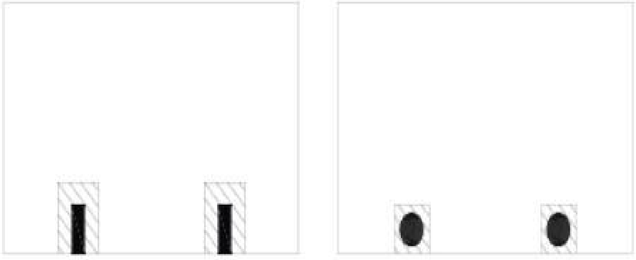

Figure 1.1 near surface mounted FRP, rectangular shapes and rods
(Source: Parth D Shahand (2015))

Near surface mounting technique has many advantages. NSMR resists end peeling significantly better than bonded laminates, has superior corrosion resistance, can mobilize a higher percentage of tensile strength, has better anchorage capacity, and requires no preparation work other than grooving.

1.4 ANSYS SIMULATION

The analysis of the project is done by developing a finite element model of duct provided deep beam in ANSYS 19.2 WORKBENCH and compare the results with standard experimental project papers. ANSYS simulation gives engineers the ability to explore and predict how products will work - or won’t work - in the real world. It’s like being able to see the future, enabling engineers to innovate as never before. This simulation superpower also speeds time-to-market, lowers manufacturing costs, improves quality and decreases risk. Based on the fundamental principles of modelling, physics, mathematics and computer science, simulation gives engineers the power to see how their designs will behave in millions of real-world scenarios, while reducing or even eliminating the need for costly physical testing.

2. SPECIMEN MODELLING

By comparing the standard results by Ahmed Ismail el-kassas et al (2020), finite element models of deep beam with longitudinal duct are made with same size and same material properties. Same way various finite element models strengthened by NSM methods are made by comparing the standard results of the experimental projects by Hayder Mirdan Abdzaid et al (2019).

Table 2.1 HSSCC mix design by Ahmed Ismail el-kassas

Cement (kg/m3)	550
Silica fume (kg/m3)	27.5
Coarse aggregate (kg/m3)	762
Fine aggregate (kg/m3)	762
Water (Liter/m3)	184.5
Super plasticizer (Liter/m3)	6.93
Slump of concrete dia (Cm)	65
Time of slump (sec)	4.2
Characteristic cube strength (Mpa)	73.6

TABLE 2.2 Mechanical properties of steel reinforcement by Ahmed Ismail el-kassas et al., (2020)

Steel Type	Yield strength (kg/m2)	Tensile strength (kg/m2)	Elongation %
Mild steel	2950	3900	22.2
High tensile steel	3680	5310	13.2

TABLE 2.3 SPECIMEN DETAILS

SPECIMEN	SIZE OF BEAM (mm)	DUCT SHAPE (mm)	DUCT SIZE (mm)	POSITION
D75S	1100 X 150 X 300	Square	75	Tension
D50S	1100 X 150 X 300	Square	50	Tension
D75C	1100 X 150 X 300	Circular	75	Tension
D50C	1100 X 150 X 300	Circular	50	Tension

2.1 REINFORCEMENT DETAILS

Two numbers of 12 mm diameter HYSD bars are provided at compression side of the beam at distance of 98 mm. Eight number of 12 mm diameter of HYSD bars are provided at tension side of beam at a distance of 260 mm from top surface of beam. Two numbers of 8mm MS steel bars are provided as side reinforcement at a distance of 160 mm from top surface. Six numbers of 8 mm diameter bars are provided as stirrups. Duct are provided at 160 mm from top surface of tension side and 20 mm cover provided.

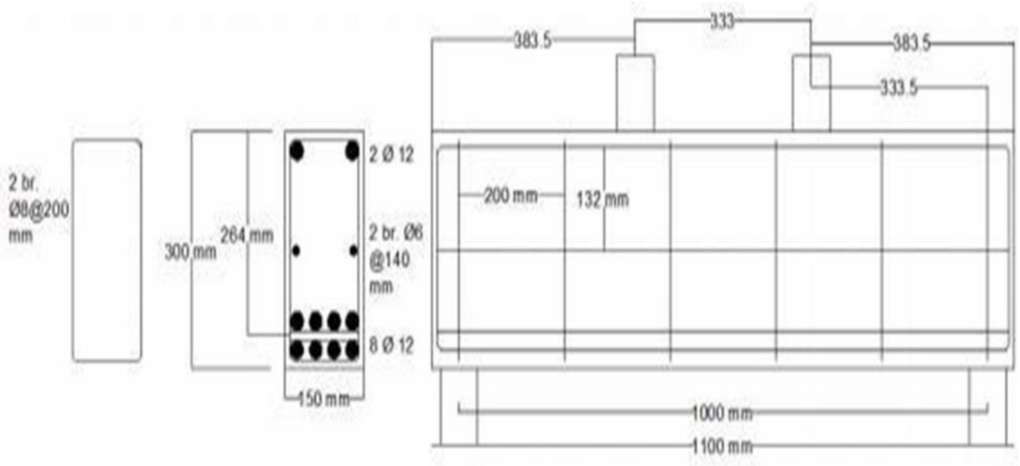

Fig 2.1 Reinforcement details of deep beam by Ahmed Ismail el-kasses et al., (2020)

2.2 MODELLING

The geometric model for the duct provided deep beam was modeled in ANSYS 19.2 WORKBENCH and the cross-section of the beam is 300 X 150 mm of length 1100mm and duct of size 75 and 50 mm of square and circular shapes are provided on tension zone corresponding to the experimental model tested by Ahmed Ismail el-kasses et al., (2020). Figure 3.2 a, b, and c shows the model.

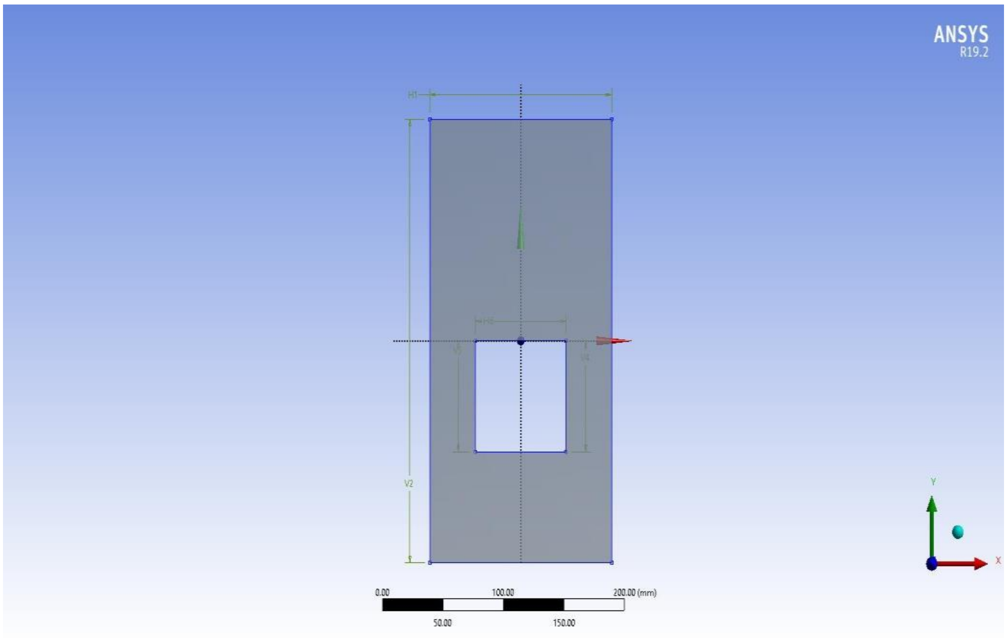

Fig 2.2 Front view of the model

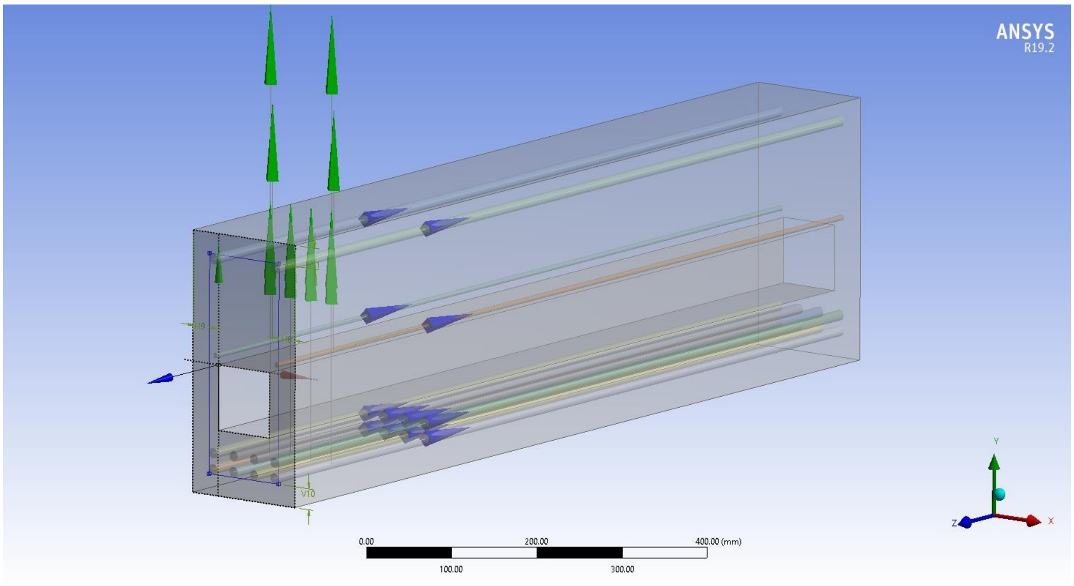

Figure 2.3 Reinforced deep beam model

2.3 LOADING CONDITIONS

As per journal by Ahmed Ismail el-kasses et al., (2020) deep beams are subjected to four point loading arrangement. Load are applied from the top surface given in the figure 3.4. 1000 KN load applied through a high strength steel plate of size 100 x 150 x 20 mm which are placed at a distance of 550 mm from one end the beam. Load was imposed on the model by means of displacement i.e., load was gradually by increasing the displacement of the top surface of the beam and a remote point coinciding with the centroid of the deep beam, along y direction and keeping the displacement in other two direction zero. A slow rate loading is allowed. The maximum strain applied was 0.5%. The rate of movement of the support is kept at 0.5mm/s.

Meshing is an integral part of finite element simulation process. It influences the accuracy, convergence and speed of the solution. Meshing technologies in ANSYS provide the flexibility to produce meshes that range in complexity from pure hex to highly detailed hybrid meshes. Meshing is applied for concrete and steel reinforcement and size of meshing is 10 mm

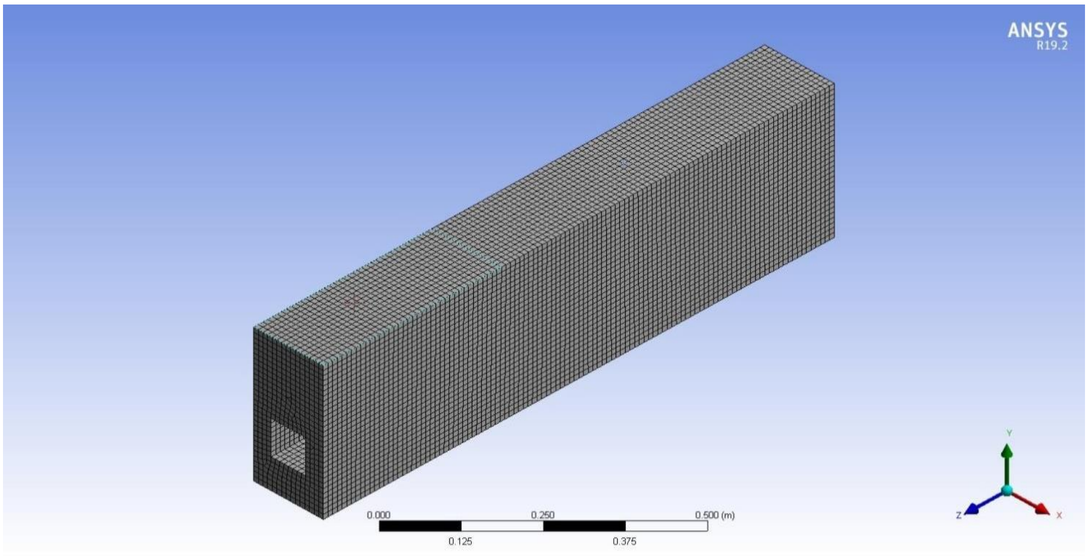

Figure 2.4 mesh of 10mm provided

Simple supported end conditions with loading is made in the finite element model with using the remote displacement option. The ultimate load carrying capacity and the deflection of duct provided deep beam is obtained from the finite element model generated in ANSYS and the result is compared to the experimental result from Ahmed Ismail el-kassas et al., (2020)

2.4 VALIDATION OF DUCT PROVIDED DEEP BEAM

The ultimate load carrying capacity and the deflection of duct provided deep beam is obtained from the finite element model generated in ANSYS and the result is compared to the experimental result from Ahmed Ismail el-kassas et al., (2020). Four specimens are validated. Load on beam applied at the rate of 5KN/m using remote force from the workbench tool. Validation results of four models are shown in Table 2.4.

Specimen	**Pexp (kN)**	**Pansys (kN)**	**% error**
D75S	355.87	350.62	1.48
D50S	429.93	445.37	3.47
D75C	376.7	391.83	3.86
D50C	436.32	396.92	9.16

On performing finite element analysis on the developed models under loading conditions similar failure patterns were observed as in experimental setup.

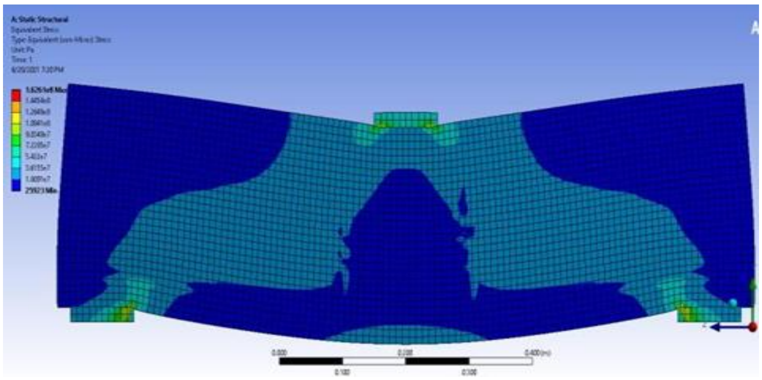

Fig 2.5 Failure pattern from analysis

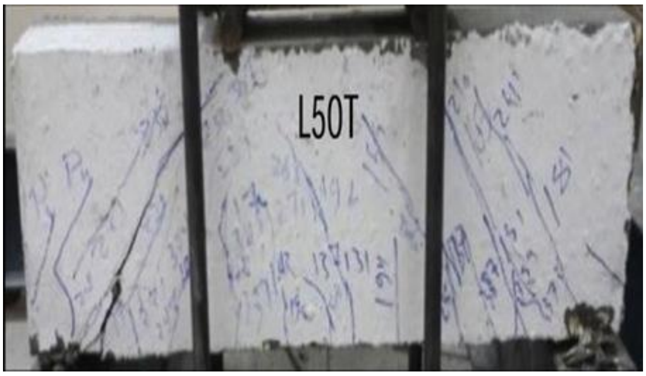

Fig 2.6 Experiment failure pattern

(Source: Ahmed Ismail el-kassas et al., (2020))

Both beams experience similar failure pattern and the ultimate loading carrying capacity values are almost same. Values obtained from analysis are compared with the experimental values for four models and are shown in figure.2.7 a & b

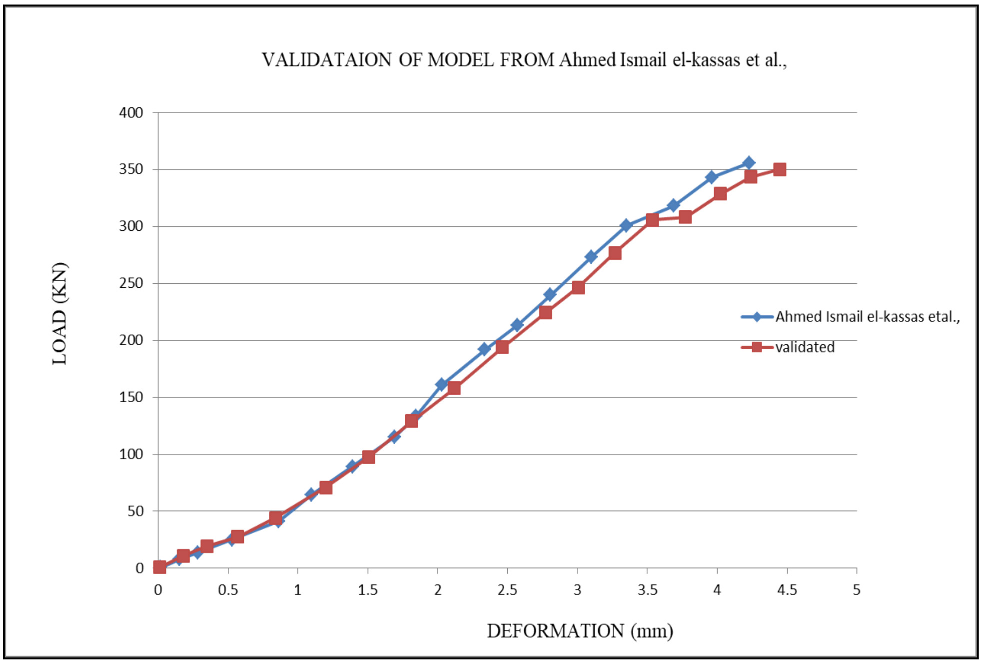

Fig 2.7 a. Validations of D75S

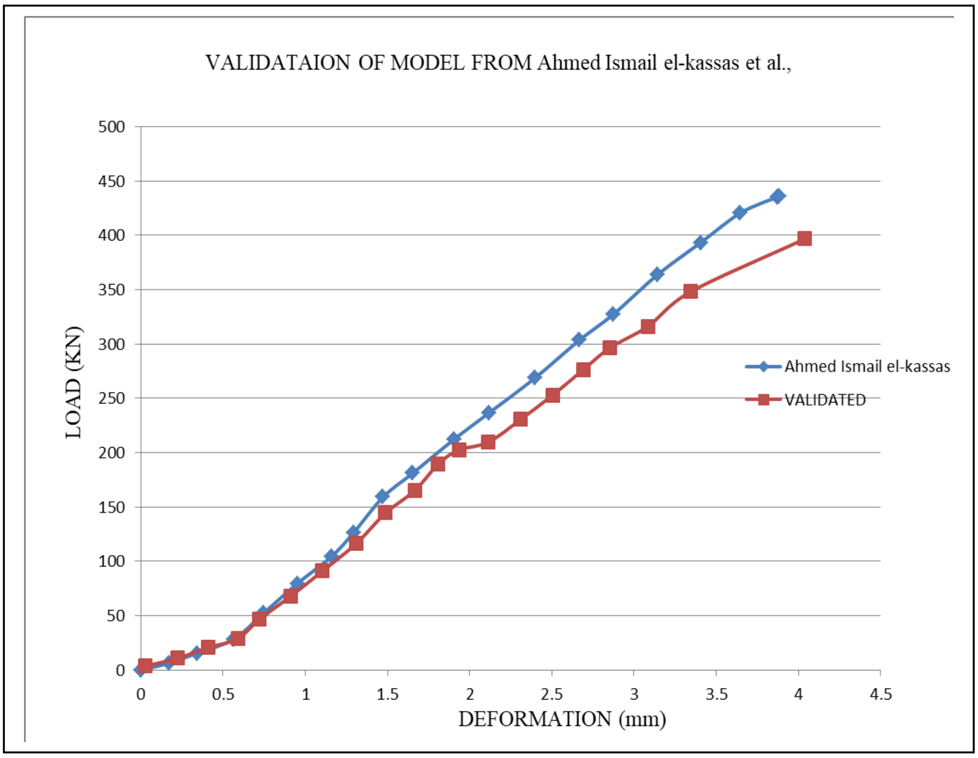

Fig 2.7 b Validation of D50C

Similarly, the duct provided deep beams strengthened by NSM method are analyzed by making a finite element model using ANSIS and compare the results with the experimental results by Hayder Mirdan Abdzaid et al., (2019.

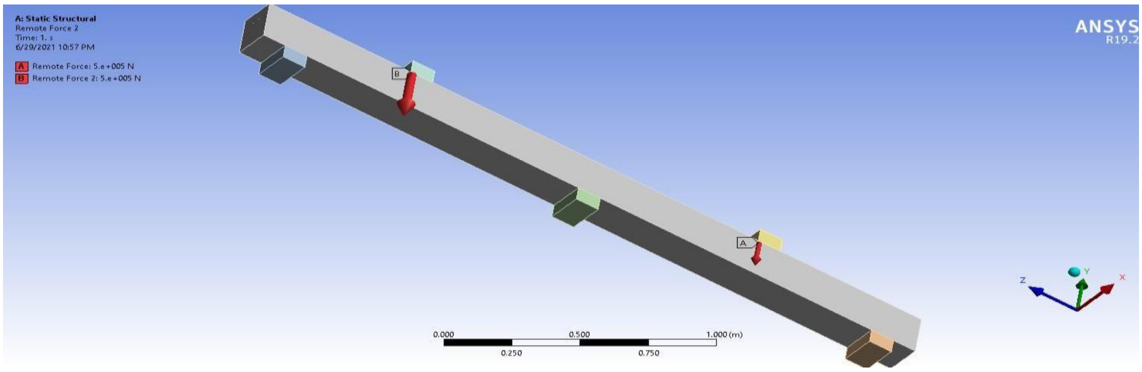

Figure 2.8 Support and loading conditions

The ultimate load carrying capacity and the deflection of beam strengthened by NSM method was obtained from the finite element model generated in ANSYS and the result was compared to the experimental result from Hayder Mirdan Abdzaid et al., (2019).

3.PARAMETRIC STUDY

The parametric study of duct provided deep beam conducted in ANSYS WORKBENCH 19.2. Using the validated finite element model, a comprehensive parametric investigation was conducted to study the effect of variation on parameters like duct shape, duct size, duct position, and different types for bars used for strengthening the duct provided deep beam.

In this parametric study, 20 models developed in ANSYS 19.2 and dimensions of these models were obtained from Ahmed Ismail el-kassas et al., (2020). In order to study the effect of shape in deep beam, circular and square shape ducts were provided. To study the effect of size, four different sizes of duct were taken viz.80, 70, 55 and 45mm. To study the effect of position of duct in deep beam, location of duct was provided in tension and compression side. NSM method is adopted for strengthening. In this study two different diameter reinforcement bars viz. 8 and 10 mm were used for strengthening

Table 3.1 Specimen details

SPECIMENS	DIAMETER OF NSM BARS USED	SHAPE OF DUCT PROVIDED	SIZE OF DUCT USED
1100 X 150 X 300	8 mm	SQUARE	80 & 70 mm
			55 & 45 mm
		CIRCULAR	80 & 70 mm
			55 & 45 mm
	10 mm	SQUARE	80 & 70 mm
			55 & 45 mm
		CIRCULAR	80 & 70 mm
			55 & 45 mm

Table 3.2 Properties of steel used

STEEL TYPE	**YEILD STRENGTH (Mpa)**	**TENSILE STRENGTH (Mpa)**	**YOUNG'S MODULUS (Mpa)**	**POISSON'S RATIO**
Mild steel	295	399	210000	0.3
HYSD steel	368	531	210000	0.3

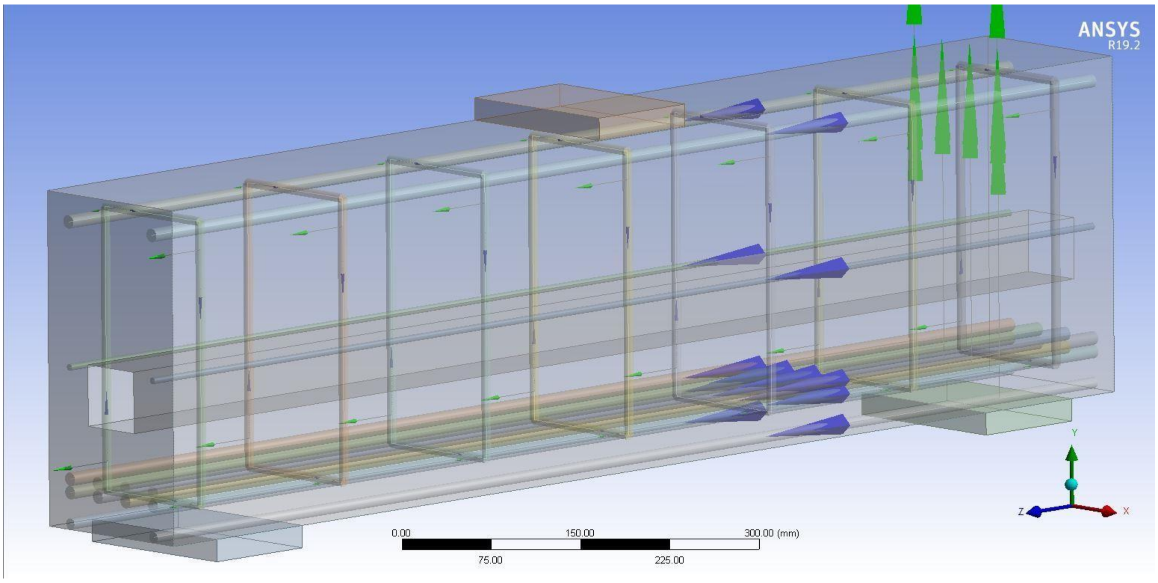

Fig 3.1 Model of duct in deep beam strengthened with NSM bar

Deep beams were designed as single element. Two number of 12 mm bars were provided in the compression side and four numbers of high strength bars of 12mm diameter on tension side. NSM bars were provided at a distance of 1.5 times diameter of NSM bar used. Loading on beam was applied gradually at the rate of 5 kN/min through high strength plate and simply supported condition was applied by two high strength plate placed bottom of the beam.

The study was conducted using 16 specimens with ducts of different size and shape; and with NSM bars of 8 mm and 10 mm for strengthening with duct on tension side Results obtained from analysis of specimens(16 nos) with duct on tension side are shown in tables 3.3 a -3.3 d

Table 3.3 a. 80 mm square duct with 10 mm NSM bar

Deflection(mm)	Load (kN)
0	0
0.474	67.346
0.947	134.69
1.42	202.04
1.89	269.38
2.37	336.73
2.84	404.08
3.32	471.42
3.79	538.77
4.26	606.11
4.74	611.35
5.21	678.35
5.51	720.65
6.08	808.78
6.63	875.97
7.42	740.81
7.81	673.87
8.15	605.32

Table 3.3 b. 80 mm square duct with 8 mm NSM bar

Deflection (mm)	Load (kN)
0	0
0.434	26.616
0.868	53.232
1.3	79.847
1.74	106.46
2.17	133.08
2.6	159.69
3.04	186.31
3.47	212.93
3.91	239.54
4.34	266.16
4.77	292.77
5.21	319.39
5.64	328.36
6.21	372.62
6.51	399.24
6.94	415.28
7.38	394.25
7.81	369.58
8.25	345.67

Table 3.3 c 70 mm circular duct with 10 mm NSM bar

Deflection (mm)	Load (kN)
0	0
0.436	46.77
0.873	93.54
1.31	140.31
1.75	187.08
2.18	233.85
2.62	280.62
3.02	327.39
3.49	374.16
3.93	420.93
4.36	422.35
5.1	514.47
5.38	561.24
5.67	608.01
6.11	654.78
6.55	608.01
6.98	561.24
7.42	515.63
7.85	468.95

Table 3.3 d. 70 mm circular duct with 8 mm NSM bar

Deflection (mm)	Load (kN)
0	0
0.529	48.703
1.06	94.406
1.59	146.11
2.11	194.81
2.64	243.51
3.17	292.22
3.7	340.92
4.23	389.62
4.72	438.33
5.29	440.25
6.01	535.73
6.34	584.43
6.87	633.14
7.4	583.64
7.93	536.32
8.46	488.32
8.99	430.265

3.1 DUCT PROVIDED IN COMPRESSION ZONE

To study the effect of position of duct, duct was also provided in compression zone of the beam. Specimen used for analysis was 1100 x 150 x 300 mm deep beam and square duct was provided at a distance of 50 mm from top surface of the beam. For analysis duct size of 80 mm and 45 mm size were taken and also these beams were strengthened by NSM bars of 10 mm and 8 mm. Al the other material properties like, tangent modulus of elasticity, Poisson's ratio and frictional coefficient between contacts surfaces were kept unchanged.

Four specimens were developed for analysis; remote loading condition was applied on the top of the beam surface and using displacement probe the deflection of beam was obtained. Results are given in the table.

Table 3.4 a. 80 mm square duct with 8 mm NSM bar

Deflection (mm)	Load (kN)
0	0
0.40252	20.112
0.80505	40.224
1.2076	60.336
1.6101	80.447
2.0126	100.56
2.4151	120.67
2.8177	140.78
3.2202	160.89
3.6227	181.01
4.0252	201.12
4.7778	221.23
5.1803	241.34
5.5828	261.45
5.9853	281.57
6.3879	301.68
6.7904	321.79
7.1929	341.9
7.5954	320.54
7.998	301.2

Table 3.4 b. 80 mm square duct with 10 mm NSM bar

Deflection (mm)	Load (kN)
0	0
0.48224	70.401
0.96448	140.8
1.4467	211.2
1.929	281.6
2.4112	282.65
3.1435	422.41
3.6257	492.81
4.1079	563.21
4.59	633.35
5.2924	704.01
5.7747	635.23
6.2569	565.32
6.7391	491.35

4. DISCUSSION

The parametric study was conducted on a total of 20 samples. The influences of the following parameters are considered.

- shape of duct
- size of duct
- position of duct
- NSM bar diameter used for strengthening

4.1 EFFECT OF DUCT PARAMETERS.

Numerical study was conducted on 16 specimens with different size of duct. The influence of size of duct in deep beam strengthened by NSM bar to ultimate load carrying capacity are graphically represented in figure 4.1 & 4.2

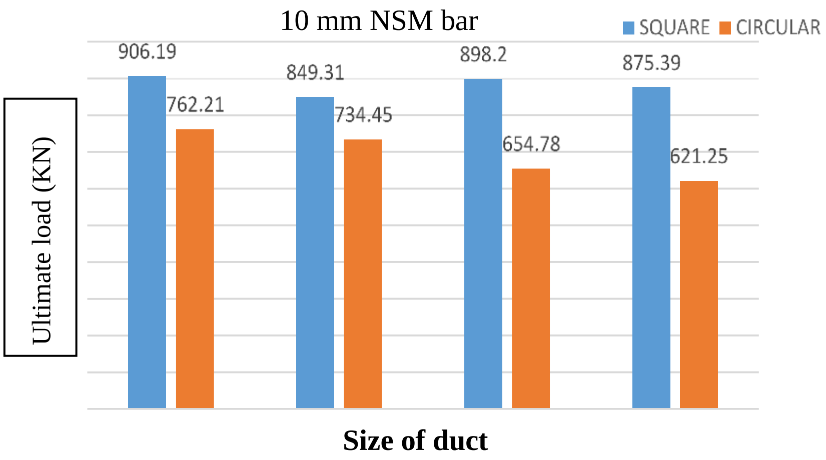

Fig 4.1 Ultimate load v/s size of duct for 10mm bar

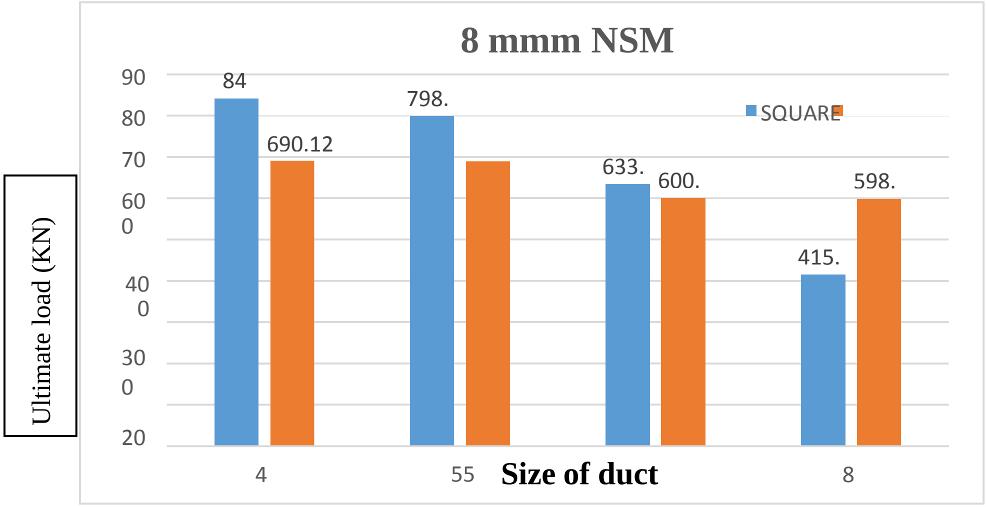

Fig 4.2 Ultimate load v/s size of duct for 8mm NSM

In the case of square duct, when area of duct increased by 216% (45 to 80 mm side), ultimate load decreased by 46% for 8mm NSM and by 3% for 10mm NSM which means that higher diameter bar for strengthening is very effective in square ducts. For beams with circular ducts, when area of duct increased by 216% (45 to 80 mm dia), ultimate load decreased by 13% for 8mm NSM and by 18.5% for 10mm NSM which means that higher diameter bar for strengthening is not effective in circular ducts.

Similarly, Effect of size of duct in stiffness and Effect of positions of duct on ultimate load are analysed and chart prepared accordingly. Absorbed energy also analysed with both 8mm bar and 10mm bar. The increase in absorbed energy indicates increase in ductile behavior. In the case of deap beams with ducts strengthened by NSM, the absobed energy depends on the size and shape of duct; and also on the diameter of NSM bars.

4.2 FAILURE OF BEAM

From analysis all beam are subjected to shear failure as shown in the figure 4.8. Shear stress is maximum at support and loading region. When load was applied gradually to the top of beam shear stress was developed in the support region and propagated at 450 to the load applied.

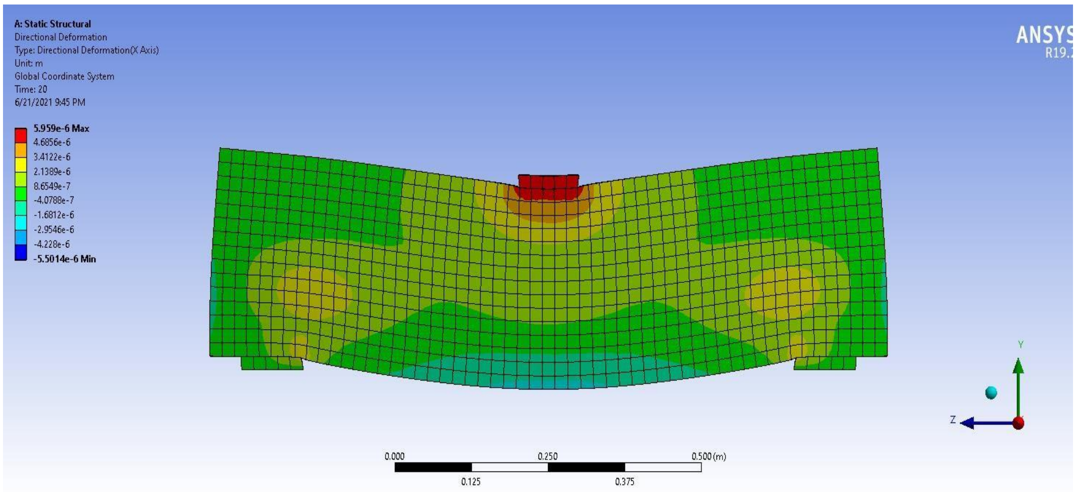

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Fig 4.3 Shear failure of deep beam

CONCLUSIONS

In this study, a finite element model for duct provided deep beam strengthened by NSM method was developed using ANSYS WORKBENCH 19.2. Bilinear isotropic hardening property of the material was considered. Using the developed model, an extensive parametric study was conducted by varying the shape, size and position of duct; and diameter of strengthening bars. In total twenty samples were studied numerically by varying the mentioned parameters. The major observations found from the study are as follows:

- Increasing the size of opening causes reduction in load carrying capacity; for square ducts, the reduction can be minimized to around 3% for about 200% increase in area of duct by NSM with 10 mm bars.
- 10 mm NSM bars have more load carrying capacity than 8 mm for both square and circular duct
- NSM with 10 mm bars is more effective in deep beams with square ducts compared to that with circular ducts.
- NSM with 8 mm bars becomes less effective in beams with square ducts compared to that with circular ducts particularly as the duct area becomes larger.
- When 10 mm NSM bars were used beams with square duct showed about 45 % increase in stiffness compared to beams with circular duct
- Size of NSM bars had negligible effect on the stiffness of beams with circular ducts.

- Position of duct on compression side is less effective compared to that on tension side particularly as the size of duct becomes large owing to more stress concentration due to proximity to externally applied loads, leading to early failure.
- Duct size reduces the ductility of deep beam

- 10 mm NSM bars shows more ductility than 8 mm

- As the size of duct increases there is less reduction in absorbed energy for beams with square ducts compared to that with circular ducts for both 8 mm and 10 mm NSM.
- All beams are subjected to shear failure

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