CIVIL AND ENVIRONMENTAL ENGINEERING REPORTS

E-ISSN 2450-8594

CEER 2020; 30 (3): 0265-0280
DOI: 10.2478/ceer-2020-0044
Original Research Article

ANALYTICAL STUDY ON THE BEHAVIOUR OF COMPOSITE SPACE TRUSS STRUCTURES WITH OPENINGS IN A CONCRETE SLAB

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A b s t r a c t

A space truss structural system is a three-dimensional arrangement of linear elements in a pyramid pattern forming a Double Layer Grid (DLG) system. Space trusses are an elegant and economical means of covering larger areas such as roof systems, in a wide variety of applications such as a stadium, aircraft-hanger, assembly hall, etc. The major problem encountered in using the space truss as a roofing system is the sudden failure of the whole structure due to critical buckling of the top chord member. Earlier research has shown that the optimal solution to overcome such a failure is by providing a small thickness of concrete slab over the space truss, so that the space truss with concrete slab (Composite Space Truss) will act as a floor system for the multi-storey building. For better ventilation and lighting in the building, the need for openings in the composite space truss is unavoidable; however, providing an opening in the concrete slab will reduce the load carrying capacity of the structure. The analysis of a composite space truss of size 30m x 30m with all possible locations of openings for four different support conditions was carried out using ANSYS in order to study the load - deflection behaviour. Further, the ductility factor and energy absorption capacity of the composite space truss with different locations of slab openings were compared.

Keywords: space truss, slab openings, maximum load, maximum deflection, ANSYS

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1. INTRODUCTION

Space trusses are used to cover large roofed areas like stadia, assembly halls, airports, etc. and are normally used to enable construction of column-free structures. The major problem for the space truss is failure of the top chord members due to the application of excessive load. All the members of the space truss are interconnected by means of so-called Mero node connectors, through which load is transferred to the members. A concrete slab of smaller thickness, ranging from 40 mm to 70 mm, placed over the space truss can help resist load and avoid the buckling of the top chord member. Thus, a composite space truss can also be used as a floor system to provide floor area for the occupant. Experimental investigation was carried out to study the behaviour of a 5 m x 5 m composite space truss without openings and a parametric study was conducted using ABAQUS for composite space trusses with openings [1]. The behaviour of a composite space truss of 3 m x 2 m with 50 mm concrete slab up to service load and ultimate load was studied. This indicated that composite action was achieved with steel flat and bolt as shear connectors between the space truss and concrete slab [2- 3]. The parametric study was carried out on a composite space truss of 30 m x 30 m for four different conditions using the finite element software ANSYS and concluded that the finite element model was able to predict the behaviour of the composite space truss [4]. Many researchers [5–13] have studied the behaviour of new space truss systems and their implementation as well as nonlinear analysis of the space truss system.

1.1 Research significance

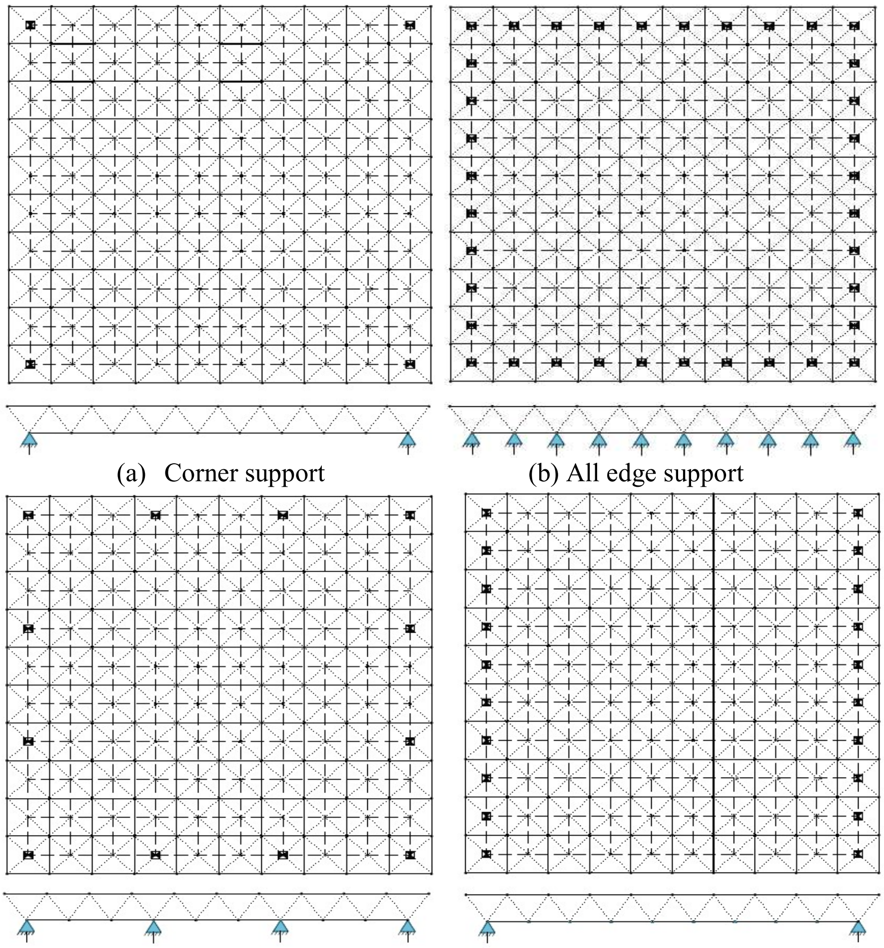
From studies of the literature, it was found that very little work has been presented on the composite space truss structure. Therefore, this paper attempts to analyse a composite space truss of 30 m x 30 m with different end conditions and providing floor openings at different locations. Normally, floor openings are required as vents for lighting and as inspection points for larger floor areas. The behaviour of the analysed composite space truss with floor openings was presented.

2. MATERIALS AND METHODS

The form of space truss with a double layer grid configuration was chosen to analyse its behaviour. Ten modules of 30 m x 30 m, each of size 3 m x 3 m, were assembled to provide a floor system, along with a concrete slab of 50 mm thickness. The study was carried out with two major varying parameters being different support conditions and different floor openings.

2.1. Support condition

The four different support conditions tested were corner support (four column support at the corners), all edge support (all the exterior nodes are provided with column support), partial edge support (selected exterior nodes are provided with column support), and opposite edge support (all the nodes on the opposite edges are provided with column support). Figure 1 clearly shows the plan view of the different support conditions of the composite space truss.
support conditions of the composite space truss.



(a) Corner support (b) All edge support

(c) Partial Edge Support (d) Opposite Edge Support

Fig. 1. Position of the supports on the composite floor system

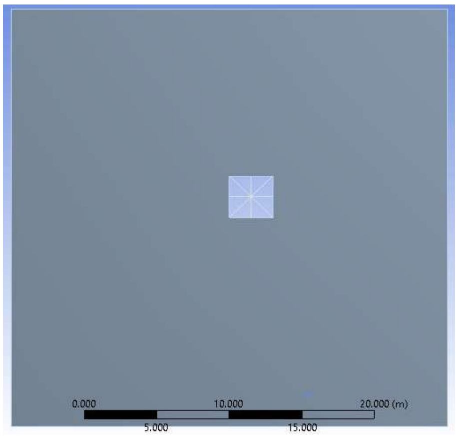
2.2 Location of floor opening

Four different locations of floor openings were chosen, and the results were also compared with a space truss without opening. The floor openings on the space truss were numbered based on modules and three support conditions; corner, all edges, and partial edges, grouped as one case, and opposite edges alone, numbered separately. Figure 2(a) and Figure 2(b) show the numbering of the floor opening for three support conditions (corner, all edges, and partial edges), and opposite edge support conditions, respectively. The plan views of floor openings on the space truss with different support conditions are shown in Figures 3(a) to 3(d). Figure 3 (a) shows the opening near to the centre, named as opening 1 (four modules surrounding the central node). Figure 3 (b) shows the opening at the corners, named as opening 11/25. Figure 3(c) shows the openings on the edges, named as opening 15/5, and Figure 3 (d) shows the opening at locations 4/13, named as opening 4/13.

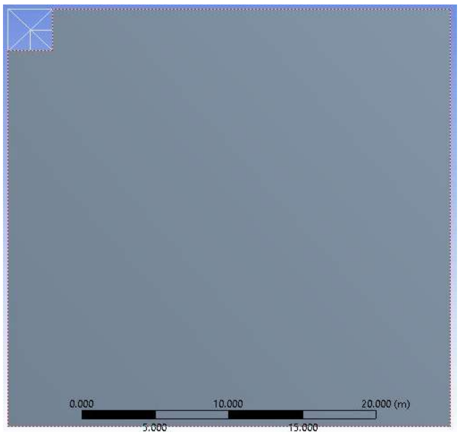
11	12	13	14	**15**	**15**	14	13	12	**11**
12	7	8	9	10	10	9	8	7	12
13	8	**4**	5	6	6	5	**4**	8	13
14	9	5	2	3	3	2	5	9	14
15	10	6	3	**1**	**1**	3	6	10	15
15	10	6	3	**1**	**1**	3	6	10	15
14	9	5	2	3	3	2	5	9	14
13	8	**4**	5	6	6	5	**4**	8	13
12	7	8	9	10	10	9	8	7	12
11	12	13	14	**15**	**15**	14	13	12	**11**

25	20	15	10	**5**	**5**	10	15	20	**25**
24	19	14	9	4	4	9	14	19	24
23	18	**13**	8	3	3	8	**13**	18	23
22	17	12	7	2	2	7	12	17	22
21	16	11	6	**1**	**1**	6	11	16	21
21	16	11	6	**1**	**1**	6	11	16	21
22	17	12	7	2	2	7	12	17	22
23	18	**13**	8	3	3	8	**13**	18	23
24	19	14	9	4	4	9	14	19	24
25	20	15	10	**5**	**5**	10	15	20	**25**

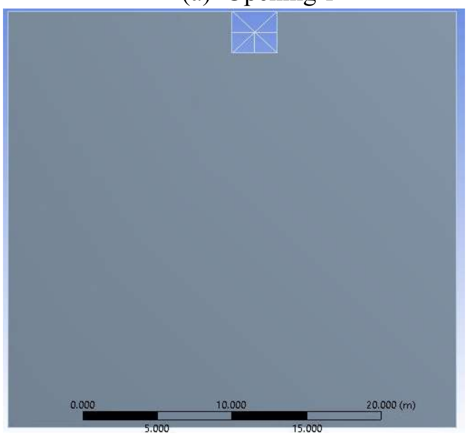
Fig.2. Floor opening numbers (a) Corner, all edge, and partial edge support (b) Opposite edge support



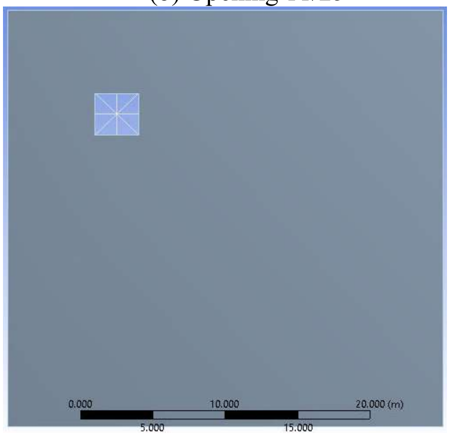
(a) Opening 1



(b) Opening 11/25



(c) Opening 15/5



(d) Opening 4/13

Fig. 3: Position of the floor opening in the composite space truss

The plan position and the verticality of the sheet piles after installation should be in accordance with the typical recommended values given in Table 1. Values given in Table 1 are for normal cases [9].

2.3 Finite Element Model

All the composite space trusses were modelled using ANSYS 16. The non-linear analysis was then carried out. Figure 4 shows the fully-developed model of the composite space truss.

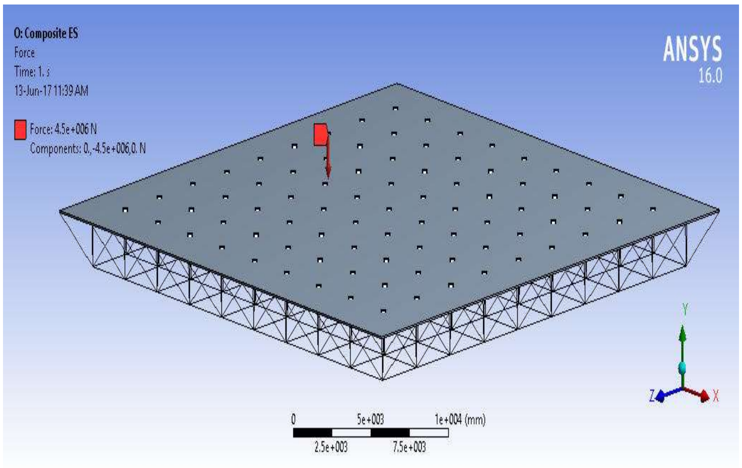


Fig. 4. Model of the composite space truss

3. RESULTS AND DISCUSSION

3.1 Effect of floor opening locations for different support conditions

The graphical plot is made between the various locations of opening and maximum central deflection for four different support conditions, as shown in Figure 5. The corner support condition with opening locations at 1, 3, 6, 10, and 15 has a slightly higher effect in the reduction of load carrying capacity. The same is true of the opposite edge support condition with opening locations from 1 to 5 and 16 to 25. All edge and partial edge support conditions behave in an almost similar fashion with the presence of an opening, having the load reduction effect only at the opening locations 1 and 3. It is, thereby, inferred that the opening location at the centre of the slab only influences the load carrying capacity of all edge and partial edge conditions, whereas in corner and opposite edge conditions, it influences central opening locations as well as the edge of the slab.

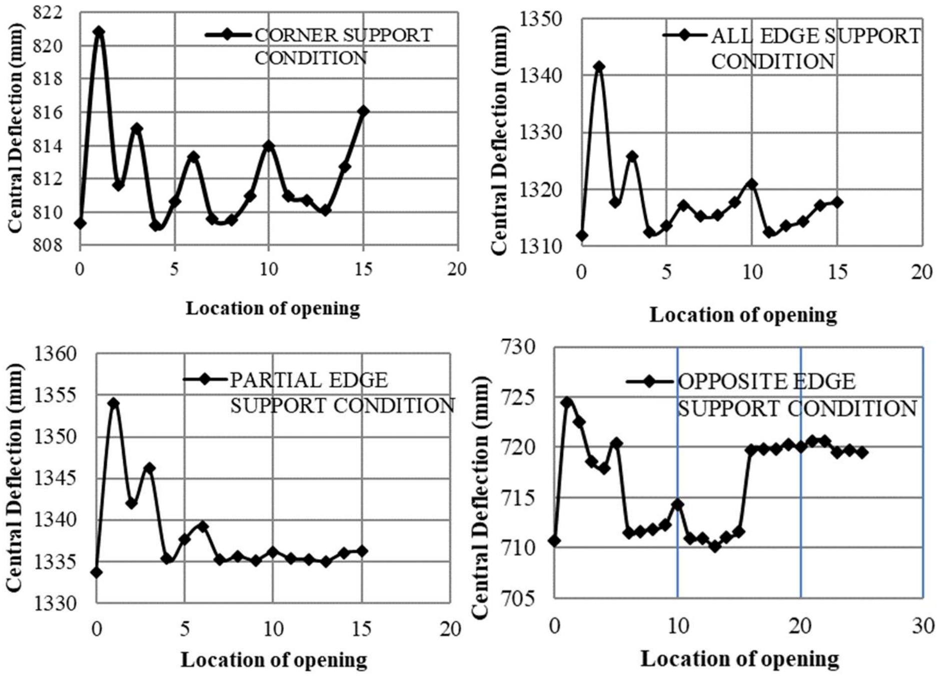


Fig. 5. Comparison between the central deflections of the composite space truss for varying location of openings

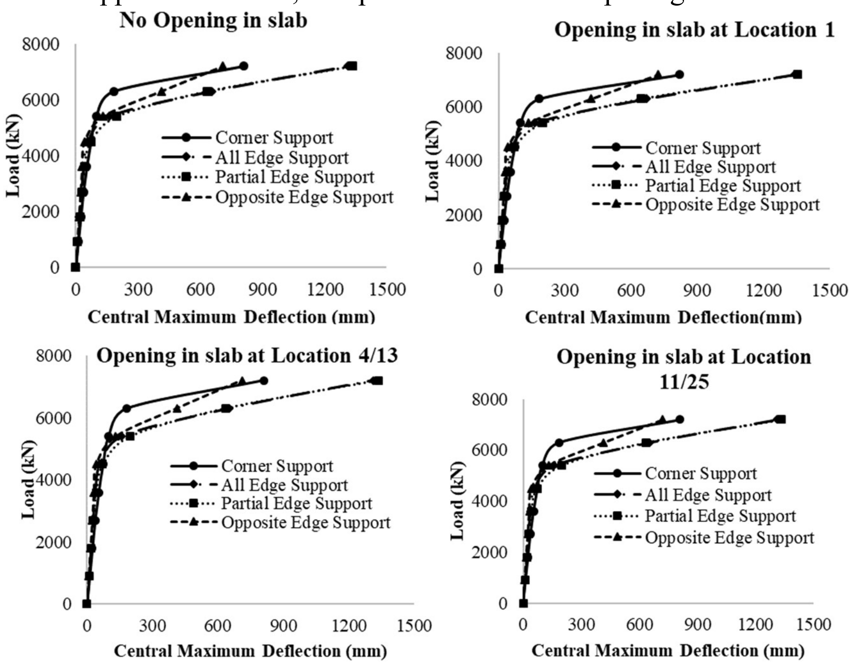
For combined walls, the requirements with respect to the plan position and verticality of the primary elements are generally very strict and, consequently, special measures such as rigid and stable guide frames should be applied.

If the toe levels of the sheet piles and of the primary and secondary elements of a combined wall after driving differ more than 250 mm from the levels specified in the design, it shall be demonstrated that the performance requirements of the design are still satisfied.

If the head levels of sheet piles and of primary and secondary elements after driving differ more than 50 mm from the levels specified in the design, it should be demonstrated that the performance requirements (e.g. connections with other elements) are still satisfied. If this is not the case, the sheet piles should be made good in accordance with the execution demands [9-11]. It should be remembered that depending on the type of structure and its subsequent operating conditions, we select the method of measurement [12-17].

3.2 Load-deflection behaviour

From the non-linear analysis carried out using ANSYS, the load-deflection plots were arrived at for four different locations of floor opening. Figure 6 shows the load versus central maximum deflection with no opening and for opening locations at 1, 4/13, 11/25, and 5/15. All edge support conditions can resist larger loads and the central maximum deflection obtained was 1311mm. The partial edge support condition also behaves in a similar manner with slight variation in the central maximum deflection of 1333mm. The opposite edge and corner support have reduced central maximum deflection of 710mm and 809mm, respectively, due to lower resistance against deflection. From figure 6, the stiffness and ductility of the composite space trusses are greater and show similar behaviour for all edge and partial edge conditions when compared to the other two support conditions, irrespective of the floor openings.



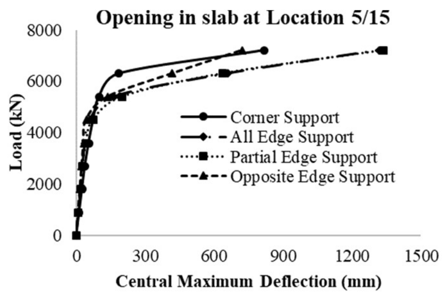


Fig. 6. Load versus maximum central deflection at various locations of openings in the concrete slab

Figure 7 shows the central maximum deflection pattern for the composite space truss with no openings.

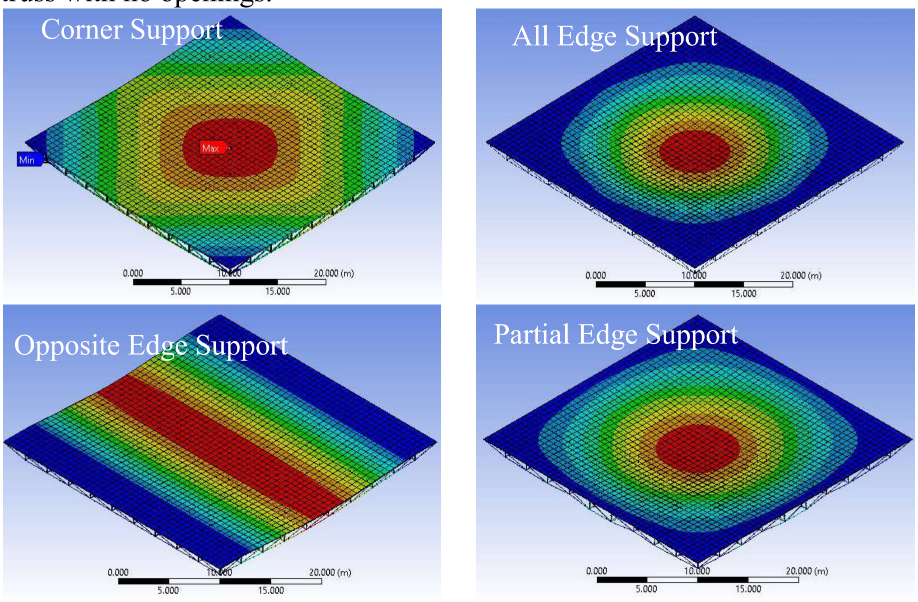


Fig. 7. Central maximum deflection of composite space truss - No Opening

Figure 8 shows the central maximum deflection pattern for the composite space truss with opening location 1.

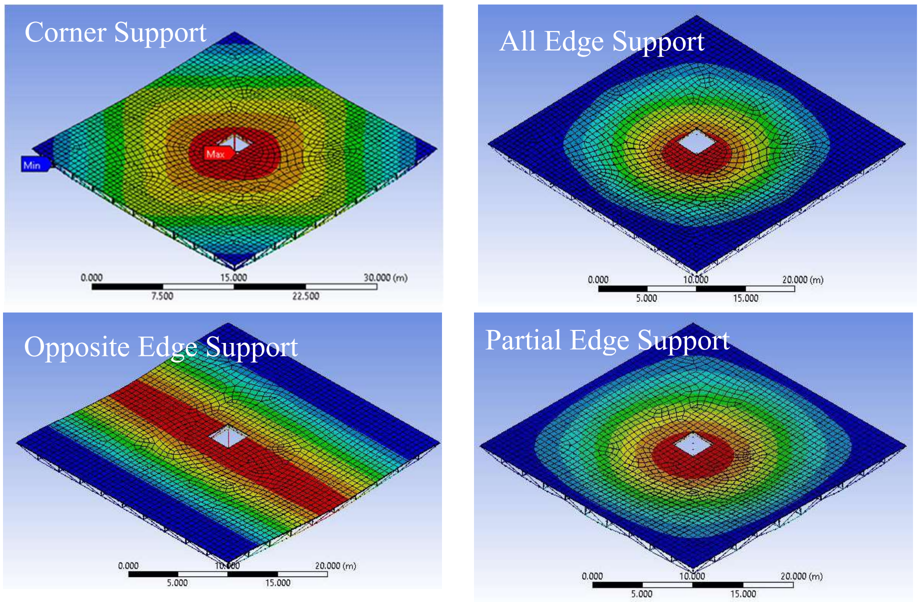


Fig. 8. Central maximum deflection of composite space truss - Opening 1

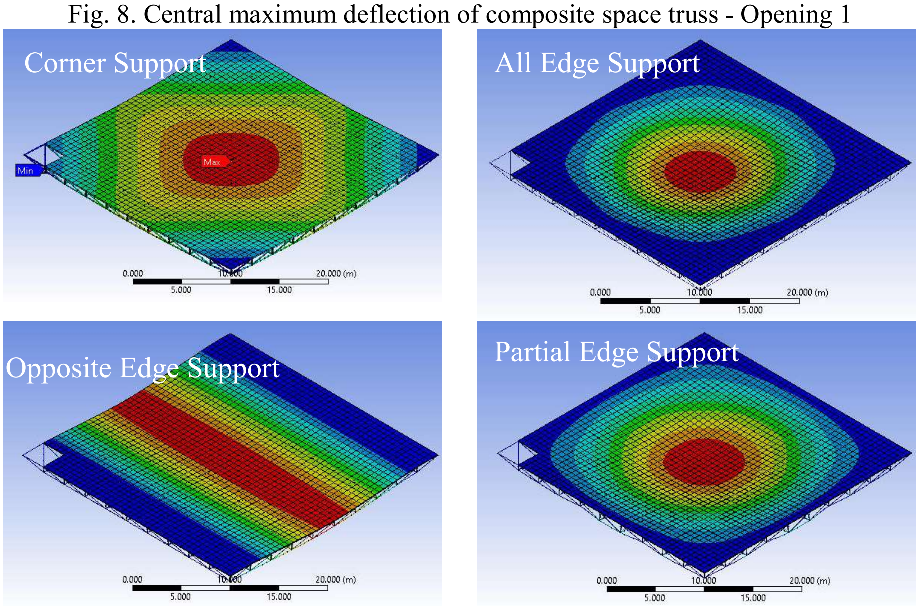


Fig. 9. Central maximum deflection of composite space truss - Opening 11/25

Figure 9 shows the central maximum deflection pattern for the composite space truss with opening location 11/25.

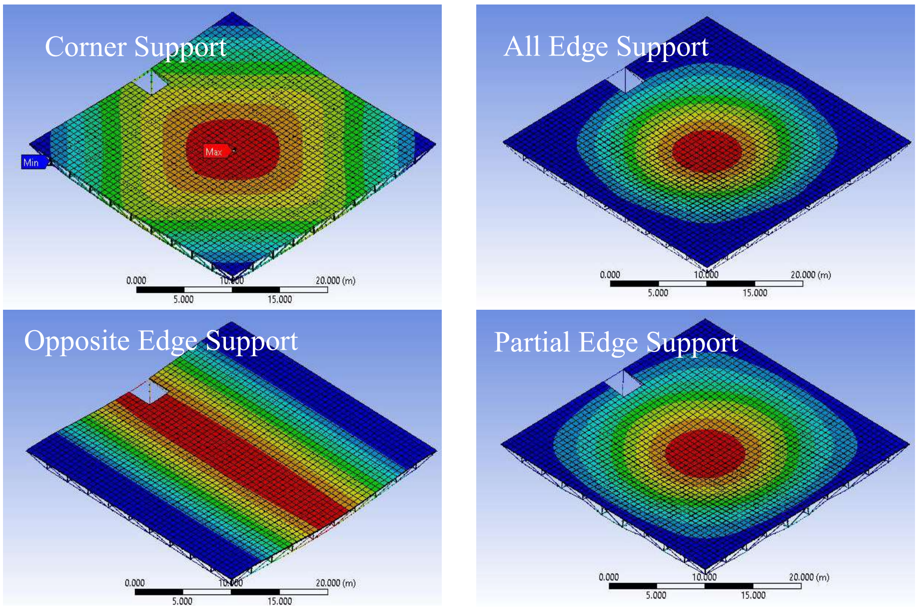


Fig. 10: Central maximum deflection of composite space truss - Opening 15/5

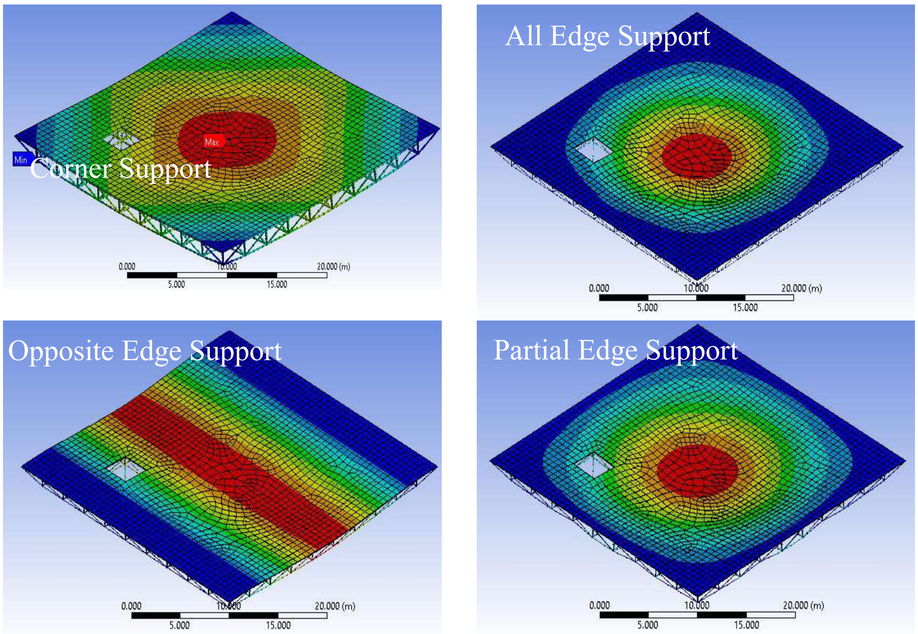


Fig.11. Central maximum deflection of composite space truss - Opening 4/13

Figure 10 shows the central maximum deflection pattern for the composite space truss with opening location 15/5. Figure 11 shows the central maximum deflection pattern for the composite space truss with opening location 4/13

3.3 Ductility Factor

The load-deflection plots were used to calculate the ductility factor at the ultimate load of 7200kN. The ductility factor of the composite space truss with chosen opening locations for various support conditions has been tabulated in Table 1. From Table 1, it can be seen that an increased number of supports results in a higher ductility ratio. All edge support conditions with 36 supports have a higher ductility factor when compared to the corner support condition with only 4 supports. Additionally, the location of support influences the ductility ratio; even the partial edge support condition with 12 supports has a slightly higher ductility factor compared to the opposite edge support condition with 20 supports. Table 1 shows that only very slight deviation is encountered in the ductility ratio for the presence of a single opening, irrespective of the location. It is also inferred that the induced ductile nature of the composite space truss was reduced to a brittle nature with the increased number of openings.

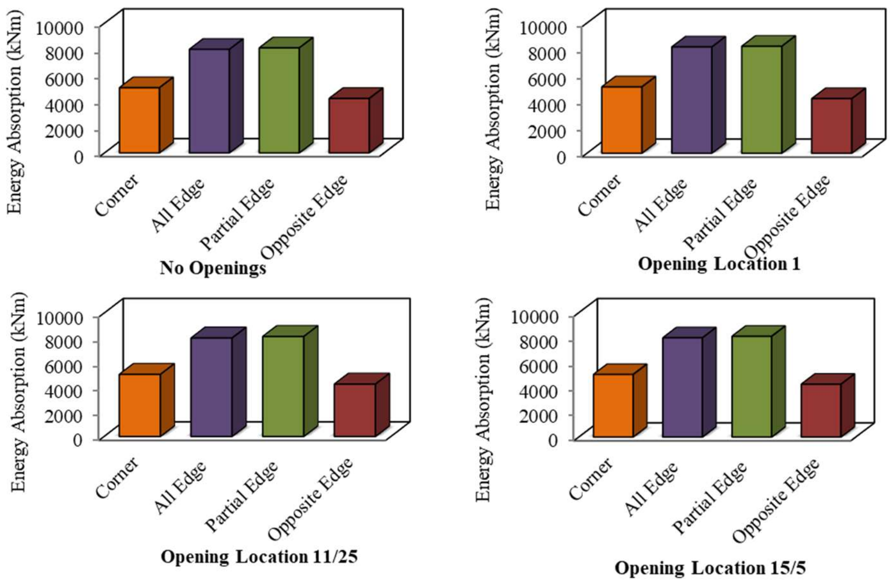
Table 1. Ductility factor of the composite space truss for varying support conditions

Support Condition	**Location of Opening**	**Maximum Central Deflection(mm)**		**Ductility Factor(μ)**
		δy	**δmax**	**δmax/δy**
Corner	No openings	73.21	809.33	11.05
	Location 1	73.55	820.83	11.16
	Location 11/25	73.52	810.95	11.03
	Location 15/5	73.70	816.03	11.07
	Location 4/13	73.33	809.18	11.03
All Edge @ 3m c/c	No openings	57.98	1311.90	22.63
	Location 1	58.81	1341.50	22.81
	Location 11/25	57.99	1312.40	22.63
	Location 15/5	58.23	1317.70	22.63
	Location 4/13	58.02	1312.50	22.62
Partial Edge @ 9m c/c	No openings	71.93	1333.70	18.54
	Location 1	72.67	1354.10	18.63
	Location 11/25	71.95	1335.30	18.56
	Location 15/5	72.09	1336.20	18.54
	Location 4/13	71.97	1335.30	18.55

Opposite Edge	No openings	42.24	710.70	16.83
	Location 1	42.65	724.40	16.98
	Location 11/25	42.26	719.40	17.02
	Location 15/5	42.61	720.30	16.90
	Location 4/13	42.33	710.10	16.78

3.4 Energy absorption capacity

The area under the load-deflection curve approximates the value of energy absorption capacity of the composite space truss for various locations of opening and different support conditions, which has been graphically represented in Figure 12. Both all edge and partial edge support conditions have nearly equal energy absorption capacity, which is approximately 1.6 times and 1.9 times higher than corner and opposite edge support conditions, respectively. The presence of openings in the composite space truss slab increases the energy absorption slightly, depending upon the location of the opening.



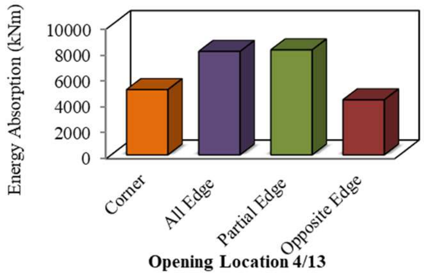


Fig. 12. Comparison of energy absorption capacity of composite space truss with and without openings at different location

4. CONCLUSIONS

This study concluded that removing a part of the concrete slab in a composite space truss will result in a reduction in the load carrying capacity of the structure. However, floor openings have limited effect on the load capacity of the composite space truss. This reduction will be varied for varying support conditions as follows:

- The reduction, in having an opening, on the load capacity of a corner supported composite space truss ranged from 0.16% for an opening at location 4 to 0.66% for an opening at location 15.
- The reduction, in adding an opening, on the load capacity of an all edge supported composite space truss ranged from 0.07% for an opening at location 12 to 1.4% for an opening at location 1.
- The reduction, in adding an opening, on the load capacity of a partial edge supported 9m c/c composite space truss ranged from 0.03% for an opening at location 11 to 1% for an opening at location 1.
- The reduction, in adding an opening, on the load capacity of an opposite edge supported composite space truss ranged from 0.05% for an opening at location 25 to 0.965% for an opening at location 1.
- The worst location for adding openings in a composite space truss will be around the middle edge of the structure in the case of a corner support and in the case of an opposite edge support will be at the centre and middle edge of the structure. In the case of either all edge supported or partial edge supported, the worst location will be central.
- All edge support conditions with 36 supports have a higher ductility factor compared to corner support conditions with only 4 supports and increasing the number of supports increases the ductility ratio of the composite space truss.
- The energy absorption capacity of all edge and partial edge support conditions is 1.75 times higher than corner and opposite edge support

conditions. The presence of openings in the composite space truss slab increases the energy absorption slightly, depending upon the location of the opening. Based on the tests and measurements conducted, the following conclusions can be formulated:

- the test showed that the sheet piling meets the declared accuracy of horizontal and vertical measurement and that the method is suitable for the purposes of geodetic measurement;
- it is important to take into consideration that the actual accuracy achieved can be worse due to unfavourable conditions of the engineering works;
- position and orientation of the sheet piling should be indicated in the driving plan; deviations from this theoretical layout may occur due to rolling tolerances, soil conditions, setting and driving procedures;
- in some cases – and for certain circumstances – tighter tolerances may be specified, as in the case of king post piling, where accuracy is especially important.

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Editor received the manuscript: 08.07.2020