

Effect of Type of Connection on Dynamic Response of Double layer Grid Space Frames

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ABSTRACT:One of the important issues that must be taken into consideration in the analysis and design of space frames is the dynamic excitation. The dynamic behaviour of a space frame can be studied first through the vibration characteristics of the structure that is represented by its natural frequencies. One way to view the dynamic structural behaviour of orthogonal square pyramid space grid is to apply dynamic wave load. Finite element analysis package SAP2000 V.15.01 Ultimate was used to study the dynamic behaviour by means of time history function. This paper is aiming to investigate the structural behaviour of orthogonal square pyramid space grid under dynamic load, in which pyramid units with a square base are used. However, the structural behaviour depends on the type of connection. The results showed that for orthogonal square pyramid space grid, the type of connection has no effect on the collapse load and maximum displacement.

KEYWORDS: Space Frames, Double Layer Grid, Dynamic Response, Type of Connection

I. INTRODUCTION

The definition of space frame can be quoted from working group on spatial steel structure of International Association on Shell and Spatial structure in 1984 : "Space frame is structural system assembled of linear elements, so arranged that the forces are transferred in a three dimensional manner". In some, the constituent element may be two dimensional. Macroscopically a space frame often takes the form of flat or curved surface [1]. Also there is a second definition that can be also quoted from the American society of civil engineers report in 1976 entitled lattice structures: state -of-the-art report as space frame defined as lattice structure: "a latticed structure is a structure system in the form of network of elements (as opposed to a continuous surface). Rolled, extruded or fabricated sections comprise the member elements. Another characteristic of the latticed structural system is that their load carrying mechanism is three dimensional in nature" [2].

II. RELATED WORK

A lot of studies were implemented on the space frames to investigate the behaviour of space frames under static load. One of these studies were introduced In [1975], by Gregorian [3], this study proposed to apply plastic method of analysis to the design of pin connected, double layer space grids, simply supported along the sides of a rectangle and carrying a uniform concentration of normal nodal loading applied to the upper layer of the structure. The results showed that the failure load would be given by the smallest of the three values of collapse load intensities of tension, compression and web element strength, and presented sufficient information of the selection of basic members. In [1984], Ermopoulos [4], suggested a simple relation for the direct estimation of space trusses height by presenting a series of calculations for estimating of the optimum height of space trusses at the stage of preliminary design, the procedure used does not require the use of computer. In [1988], Yu and Shanmugam [5], presented a modified stiffness matrix method for obtaining the elastic buckling load of semi rigid space frames and this method applied to semi rigid plane frames. This method considered the effect of flexure on axial stiffness, geometric changes and the effect. Parametric studies were made for single storey and double storey single bay space frames. The results have been shown

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that the elastic critical load can be increased even by marginal increase in fixity factor; further increase in fixity factor did not affect the elastic buckling capacity. In the same year, El-Sheikh [6], presented two approximate dynamic analysis of space trusses based on beam analogy and plate analogy techniques. The result showed that this methods yield accurate natural frequency predictions. In [2001], Kaveh and Servati [7], trained the efficient neural networks for design of double layer grids. The evaluation of the maximum deflection, weight, and design of double layer grids done by training efficient neural networks that employed by backpropagation algorithm. The result showed that in design of double layer grids, the networks trained can be used. The method can also be employed for training networks for other types of space structure. In [2002], Makowski [8], studied jointing systems developments for modular prefabricated steel space structures and the most common types of the jointing systems around the world, their advantages, disadvantages and the appropriate types of space frames to use with the jointing systems. In [2004], Moghaddam [9], presented the results of dynamic analyses of double layer barrel vaults with different configuration and supporting conditions subjected to a severe earthquake and highlighted some basic influential elements in seismic performance of the space structure. The results showed that light weight, appropriate geometry, redundancy and large reserve strength were the key element of the space structures exhibiting an great performance in severe earthquake. Space structures of non-plane geometry (like domes and barrel vaults) higher modes and vertical modes contributed in dynamic response effectively. In [2009], Bezerra and et al. [10], proposed a numerical and experimental studies on steel space trusses with end flattened connections. This study introduced a method to improve the end flattened connection by using spacer and reinforcement plate to avoid the disadvantage of eccentricities and stiffness reduction of the member when using this type of connection. The results of studying nine experimental lab tests of prototype space truss and computer simulation using the commercial SAP2000, that there will be an increase in load capacity up to 68% and for the global collapse the strength increased by 17%.

III. MATHEMATICAL MODEL

To understand the dynamic behaviour of the structure, it is necessary to develop structures models under the influence of dynamic loads such as winds, blasts, earthquakes and heavy rotating machinery, etc. The mathematical model may provide complete and accurate knowledge of dynamic behaviour of the model itself but in practice the information acquired from the analysis of the model may be sufficient to study the behaviour of the real system including design. To determine the dynamic behaviour there are four important elements: inertia force, restoring force, damping force and exciting force [11]. The dynamic analysis of structure is direct extension of the static analysis cause the structure behave dynamically when subjected to loads and displacements according to Newton's second law, When the loads or the displacements are applied very slowly that the inertia forces can be neglected the static analysis can be apply in this case. The difference between the elastic stiffness matrix of dynamic analysis and the static analysis is that at the joints mass of the structure should be lumped. For the dynamic analysis the external load that applied to structure must be equal to the sum of the kinetics and strain energy plus the energy dissipated in the structure. The most critical step of creating a computer model is to create a model with finite number of massless members and finite number of node displacements that will be used to simulate the structure of finite potential number of displacement. The dynamic loading and the energy dissipation properties and boundary condition are the most difficult to estimate for the structure, So to overcome the error of approximation different loading, boundary condition and computer models can be used in the analysis of the structure [12].

IV. APPLICATION AND RESULTS

4.1 GENERAL :

This part describes the model and analysis results of a double layers grid space frame of type square on square space grid under dynamic load as shown in Fig. (1). after choosing the type of model, the depth and module size were determined. The depth was determined according to span-depth ratio, $(\frac{L}{d} = \frac{510-L}{34} \pm 2)$, while the module number was determined according to Specification for the Design and Construction of Space Truss issued in china. A finite element analysis package SAP2000 V.15.01 Ultimate was used to carry out the linear dynamic analysis. The model members defined as a steel frame under the specification of ASTM (American Society of Testing and Material) A500 Grade B, Fy42 (HSS round) for cold folded steel. Frame sections used in the model was a round pipe of a 3 inch diameter. The total wave force was applied at one node. The wave force was applied at different loading condition, the first condition

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is to apply the total load at one node, second, third and fourth condition is to divide the force by two, three and four, then apply it at two, three and four nodes respectively. Analysis was repeated in each load condition to study the behaviour of space frame under different load conditions. Wave force was applied at node after defining the time history function and modifying the wave load case by choosing the time history Type direct integration. Damping effects was neglected in this study.

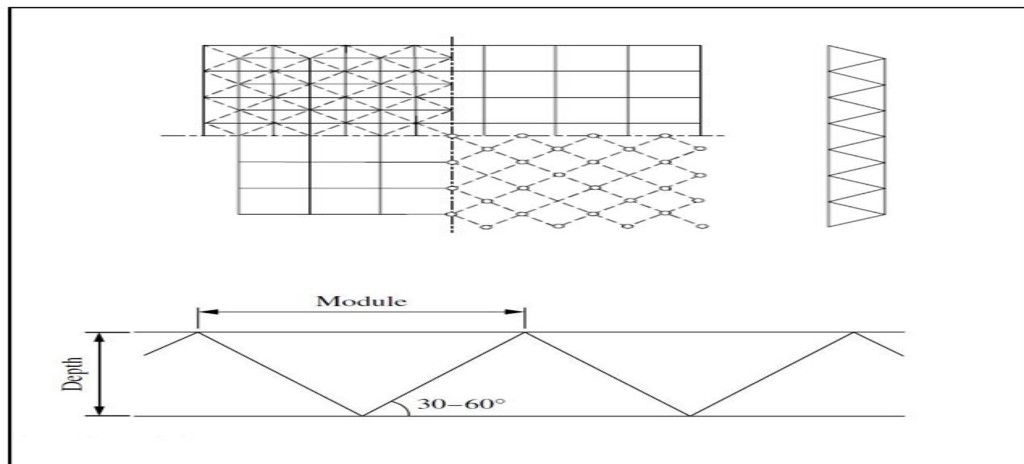


Figure (1) Double layers grid space frame.

4.2 MODEL DISCRIPTION:

Double layers grid space frame type orthogonal square pyramid space grids as shown in Fig. (2). It has a dimension of 18×18m , module angle of 30° , module length of 3m and 0.9m total depth. The member of the space frame is consisted of standard round shape section cold folded steel. One element per member was considered in this study. The decision to use one element only is based on checking the response of the structure with different number of elements per member. It is found that using one element per member gives accurate results. SAP2000 V.15.01 Ultimate software was used to obtain the first twelve undamped natural frequencies and the corresponding mode shapes as shown in Fig.(3).

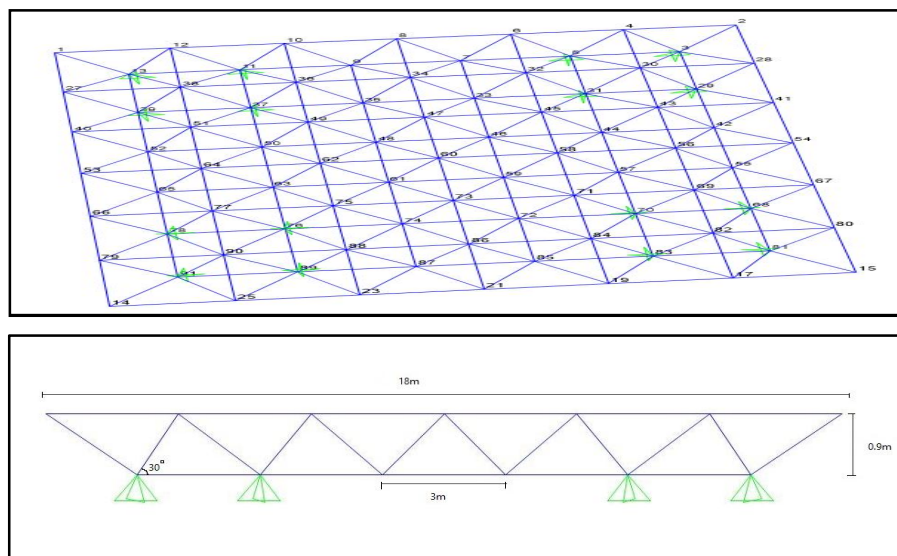
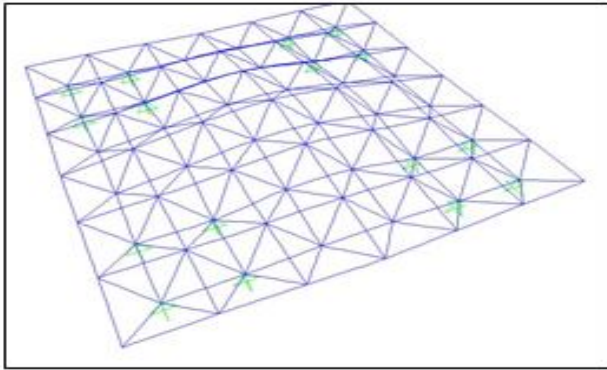


Figure (2) Model Descriptions

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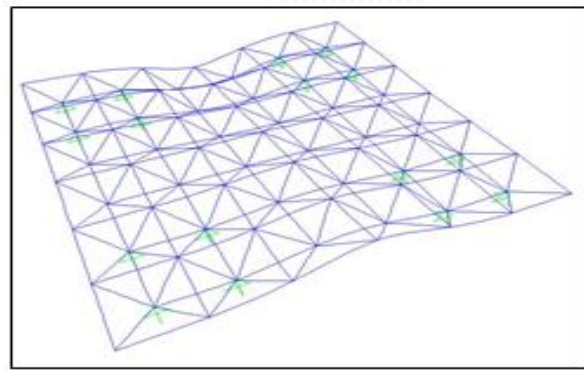
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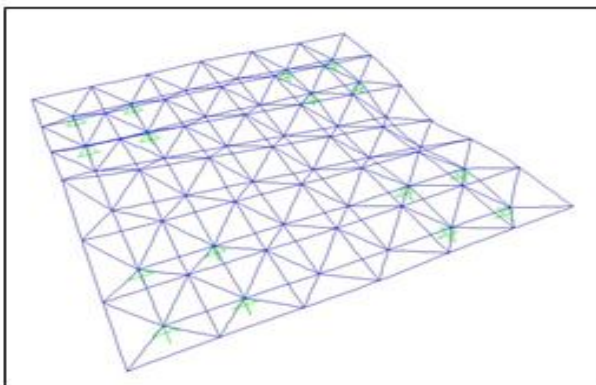
Mode (1)

Natural frequency=20.991(cyc/sec)



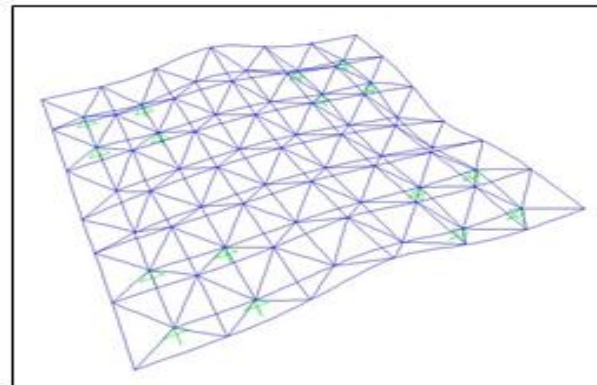
Mode (2)

Natural frequency=29.986(Cyc/Sec)



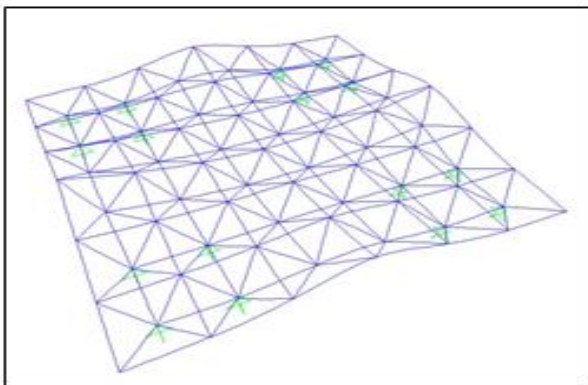
Mode (3)

Natural frequency=29.986(cyc/sec)



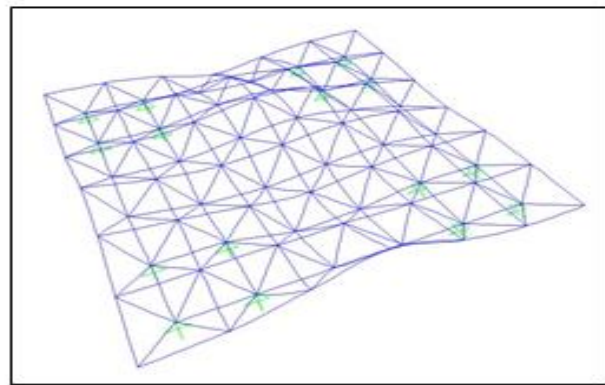
Mode (4)

Natural frequency=30.873(cyc/sec)



Mode (5)

Natural frequency=31.402(cyc/sec)



Mode (6)

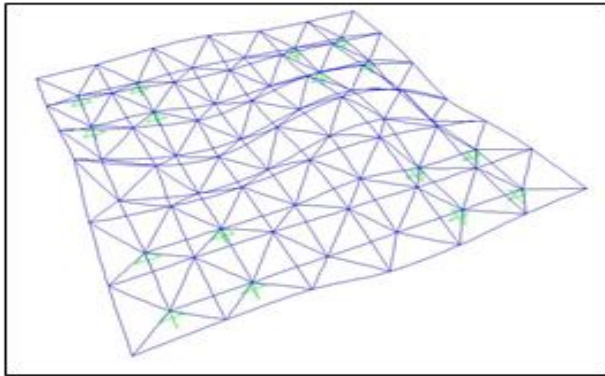
Natural frequency=39.853(cyc/sec)

Figure (3) Natural frequencies of space frame and associated mode shapes

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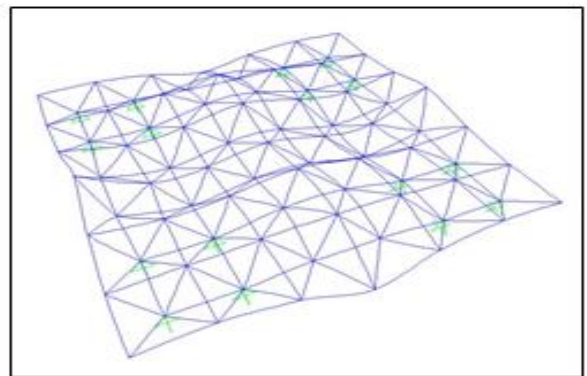
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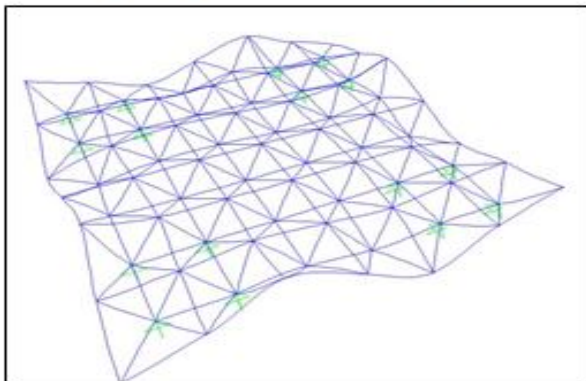
Mode (7)

Natural frequency=39.853(cyc/sec)



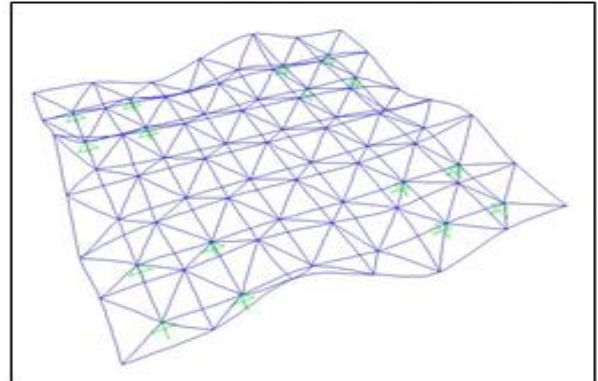
Mode (8)

Natural frequency=52.016(cyc/sec)



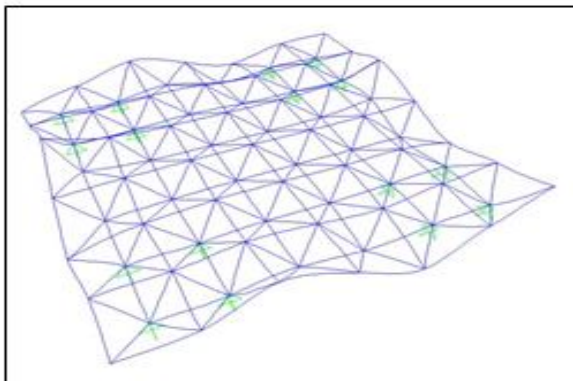
Mode (9)

Natural frequency=53.828(cyc/sec)



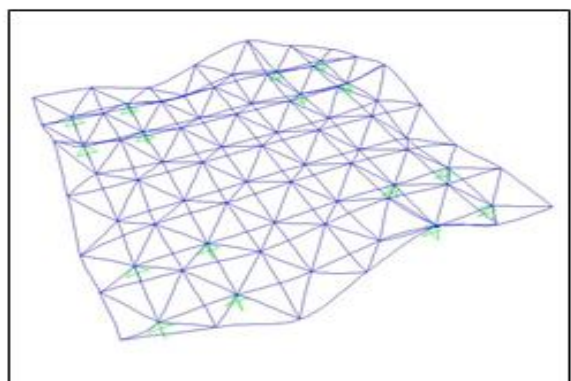
Mode (10)

Natural frequency=53.863(cyc/sec)



Mode (11)

Natural frequency=54.108(cyc/sec)



Mode (12)

Natural frequency=54.108(cyc/sec)

Figure (3) Continued.

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4.3 RESULTS:

4.3.1 EXCITING AND COLLAPSE LOAD:

The effect of joint connection type on the exciting and collapse loads was explored. Two different types of joint connection, fixed and hinged connection were used. Exciting, maximum and collapse loads of the model were obtained. The Maximum load that can be applied to model before collapse was used in dynamic analysis. Table (1) shows the effect of type of joints connections on the value of exciting and collapse loads for this model. It's clear that there are no changes in the values of exciting and collapse loads were observed when the type connection change from fixed to hinge. This is because of the internal distribution of load on members in space frames.

Table (1) Load capacity

Loads(kN) Type of joint connections	Maximum	Collapse	Exciting
Fixed	109	110	65
Hinged	109	110	65

3.3.2 MAIXIMUM DISPLACEMENT:

Table (2) shows the effect of type of connection on the maximum displacement of the nodes under four types of loading condition. Small increases in the maximum displacement for each loading condition were observed when the type of connection changes from fixed to hinge.

Table (2) The maximum displacement (mm) at maximum loading for different loading condition.

Loads(kN) Type of joint connections	1 Point Load	2 Points Load	3 Points Load	4 Points Load
fixed	17.28	13.290	11.960	10.360
hinged	17.36	13.350	12.010	10.400

4.3.3 EFFECT OF LOAD DISTRIBUTION ON DYNAMIC RESPONSE:

Harmonic wave force ($F(t) = P \sin \omega t$) is applied at nodes 60, 58, 73 and 71 at different loading condition where $F(t)$ in (kN) and ω is ($\frac{t}{s}$), to find the dynamic response of the structure including the maximum displacement. The first loading condition is to apply the total wave force ($F(t) = 109 \sin \omega t$) at node 60 only, second condition is to divide the wave force by two ($F(t) = 54.5 \sin \omega t$) and apply it at nodes 60 and 58, the third is to divide the wave force by three ($F(t) = 36.33 \sin \omega t$) and apply it at nodes 60, 58 and 73, the fourth is to divide the wave force by four ($F(t) = 27.25 \sin \omega t$) and apply it at nodes 60, 58, 73 and 71.

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4.3.4 REDUCTION OF MAXIMUM DISPLACEMENT:

Table (3) shows the reduction of the maximum displacement under different loading condition. It can be noticed that the maximum displacement reduced by 23.09%, 30.8% and 40%, when the wave force was applied at two, three and four nodes respectively.

Table (3) The reduction percentage (%) of maximum displacement at different loading condition.

Loads(kN)		1 point load	2 points loads	3 points loads	4 points load
Model	fixity cond.				
Model 1	fixed	0	23.090	30.787	40.046
	hinged	0	23.099	30.817	40.092

3.3.5 DYNAMIC RESPONSE OF NODES UNDER DIFFERENT LOAD CONDITIONS AND DIFFERENT TYPE OF JOINTS CONNECTIONS:

Dynamic response of some selected nodes in the models was study. Some of these nodes where selected near to position of applied forces and the others were selected far of the position of applied load and near to the supports locations to study the internal forces distribution in the space frame members. Effect of different load conditions and different type of joints connections on the vertical displacement of these nodes were study.

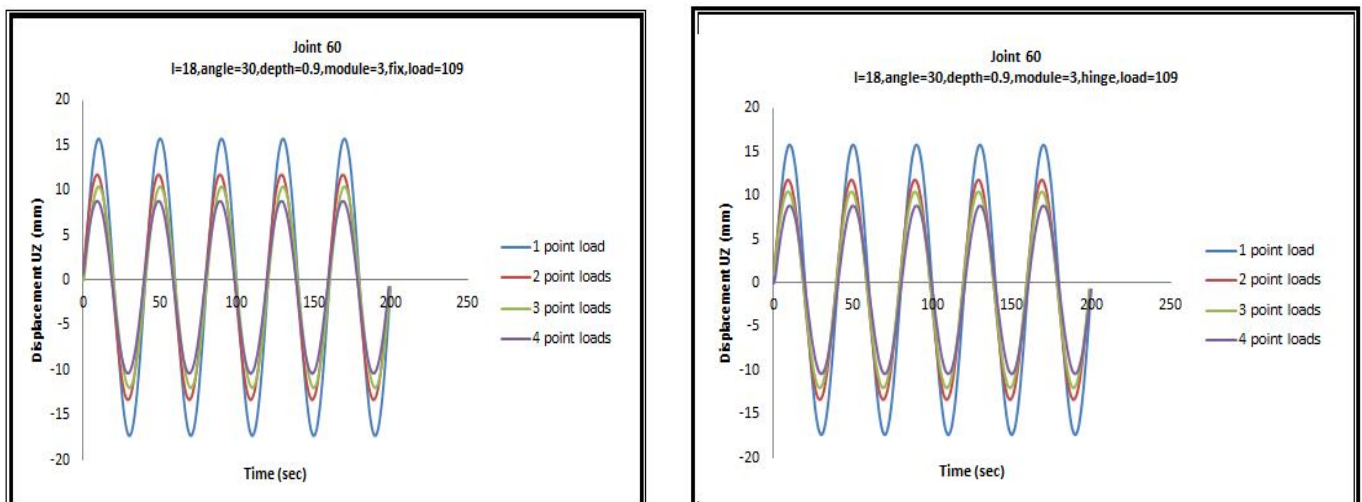


Figure (4) Vertical displacement under different loading condition and different joint connection for node 60

Figure (4) shows the vertical displacement of node 60 under different loading conditions and different types of joints connections. The highest value of vertical displacement was observed when the total load applied at one node. Other loading conditions show decreasing in the values of vertical displacements because of load distribution on the structural

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element. There is no effect on the values of vertical displacements were observed when types of joints connection change from fixed to hinge.

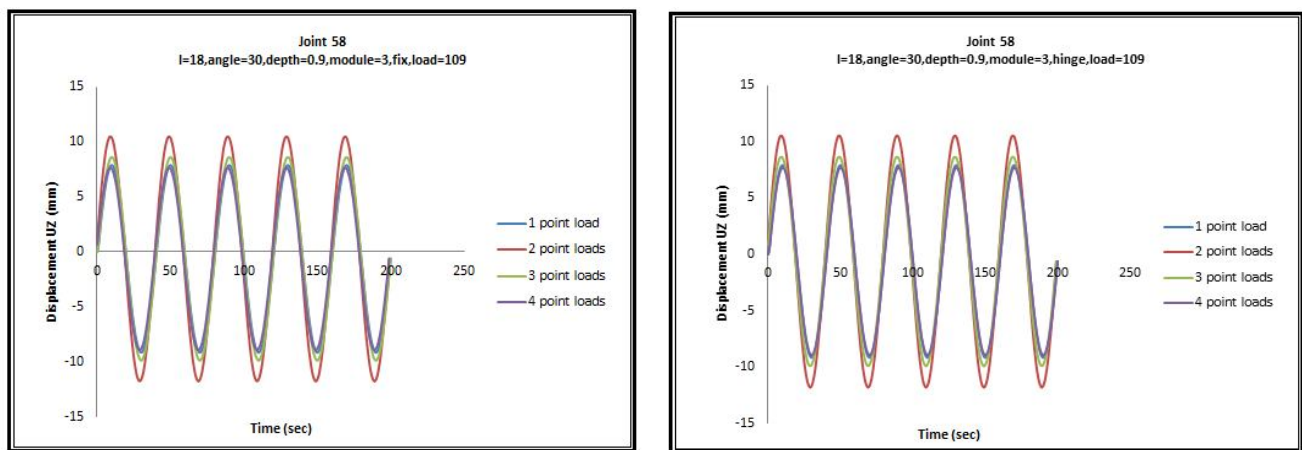


Figure (5) Vertical displacement under different loading condition and different joint connection for node 58

Figure (5) shows vertical displacement of node 58 under different loading conditions and different types of joints connections. The highest value of vertical displacement was registered in the second loading conditions (Total load divided on two and applied on two nodes). This is because one of these loads was applied directly on node 58. In the other loading conditions, the values of vertical displacements were decreased because of load distribution and the decreasing the value of load which applied directly on this node. Also, there is no effects on the values of vertical displacements were observed when the types of joints connections change from fixed to hinge.

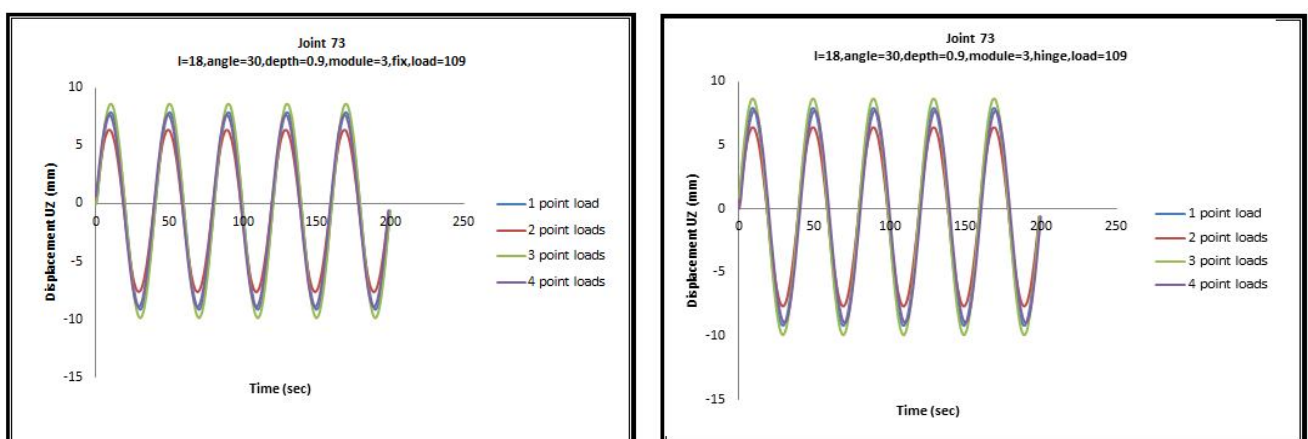


Figure (6) Vertical displacement under different loading condition and different joint connection for node 73

Figure (6) shows results of node 73. The maximum value of displacements was observed under the third loading condition (Total load divided on three and applied on three nodes). This is because one of these loads applied directly on this node. The values of the vertical displacement under the first load conditions were similar to those values of vertical displacement under third loading conditions. Similar behaviour between node 73 and node 58 were observed. Also, there is no effects on the values of vertical displacements were observed when the types of joints connections change from fixed to hinge.

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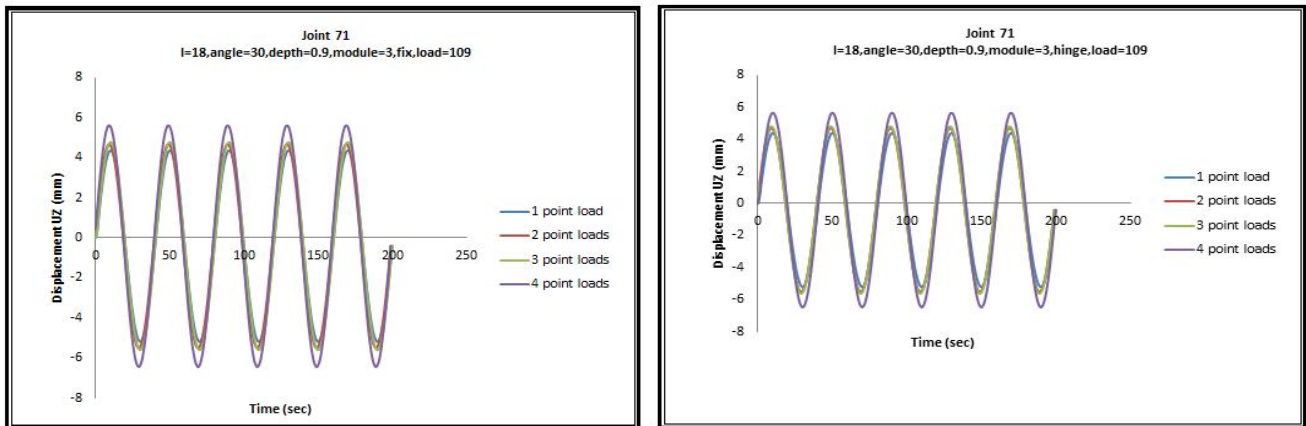


Figure (7) Vertical displacement under different loading condition and different joint connection for node 71

Figure (7) show the response of node 71 under different loading conditions and different types of joints connections. The value of maximum displacement was registered in the fourth loading condition (Total load divided on four and applied on four nodes). This is because one of these loads was applied directly on this node. The first loading condition gave the lowest values of vertical displacements. This is due to the three dimensions load distribution characteristic of space frame. Also, there is no effects on the values of vertical displacements were observed when the types of joints connections change from fixed to hinge.

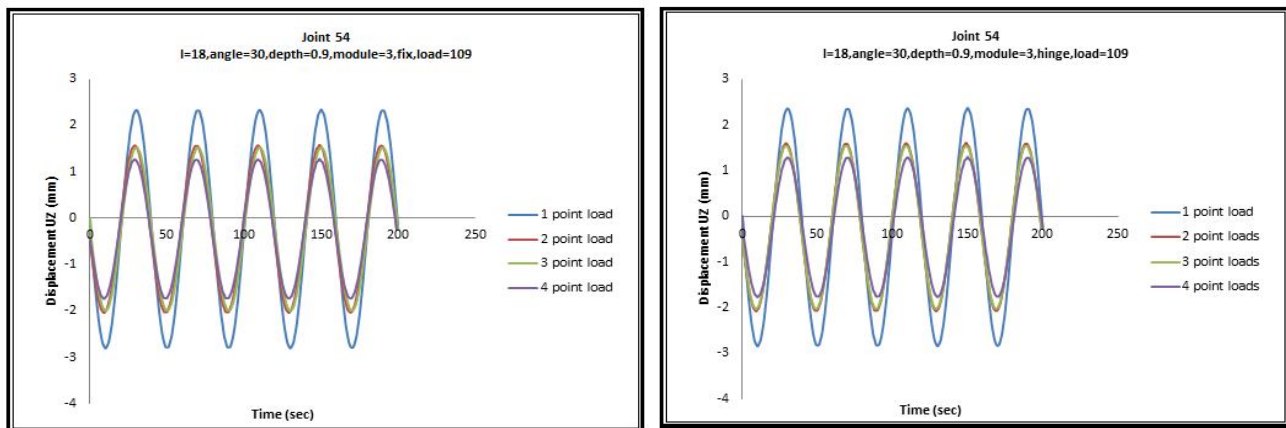


Figure (8) Vertical displacement under different loading condition and different joint connection for node 54

An alternative response was observed at node 54. Figure (8) show the response of this node under different loading conditions and different types of joints connections. Upward displacements were observed at the beginning time of loading because of this node located after the supports in the extreme line of space frame. The highest value of vertical displacement was observed when the total load applied at one node. Other loading conditions show decreasing in the values of vertical displacements because of load distribution on the structural element. There is no effect on the values of vertical displacements were observed when types of joints connection change from fixed to hinge.

IV. CONCLUSIONS

The main concluding remarks that have been achieved from the finite element analysis may be summarized as follows; type of joint connection has no effect on the values of exciting and collapse load. Type of joint connection has no effect on maximum values of displacements. Loading conditions have a big effect on the nodes which is under or near to the

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loading location, While this effect decrease in the nodes which is far from the loading location, especially the nodes which located near to the supports.

REFERENCES

- [1] IASS(International Association for Shell and Spatial Structure) Working Group on Spatial Steel Structures, "Analysis, design and realization of space frame", IASS No.84/85, XXV(1/2), pp.1-114, 1984.
- [2] ASCE task committee on latticed structures of the committee on special structures of the committee on metals of the structural division. Latticed structures: state-of-the-art report. J. Struct. Div., ASCE 102(ST11):2197-2230, 1976.
- [3] Grigorian, M. "Limit analysis of space grids" int. J. Solids Structures, Vol. 2, pp. 295-304, 1975.
- [4] Ermopoulos, J.CH. "The optimum height design of double layer grids at the stage of preliminary design " Journal of Constructional Steel and Research , Vol. 4 , Issue 4, pp. 281-293 , 1984.
- [5] YU, C.H. and Shanmugam , N.E. "Stability of semi-rigid space frames" Computer and Structure , Vol. 28 , No.1, pp. 85-91, 1988 .
- [6] El-Sheikh, A. "Approximate dynamic analysis of space trusses" Engineering Structures, Vol. 22, pp. 26–38, 2000.
- [7] Kaveh, A. and Servati, H. "Design of double layer grids using backpropagation neural networks" Computer and Structures, Vol.79, pp. 1561-1568, 2001.
- [8] Makowski, Z.S., "Development of jointing systems for modular prefabricated steel space structures" Lightweight Structures in Civil Engineer, pp.(17-41) , 2002.
- [9] Moghaddam , H.A., "seismic behaviour of space structures" 13th World Conference on Earthquake Engineering, paper No.523 , 2004.
- [10] Bezerra, L.M., Silva de Freitas, C.A., Matias, W.T. and Nagato, Y. "Increasing load capacity of steel space trusses with end-flattened connections" Journal of Constructional Steel Research, Vol. 65, pp. 2197-2206, 2009.
- [11] Damodarasamy, S.R and Kavitha, S. "Basics of Structural Dynamics and Assismic Design" PHI Learning Private Limited, 2011.
- [12] Wilson, E.L "Three-Dimensional Static and Dynamic analysis of structures" Computer and Structures Inc., Third edition, 2002.