Malaysian Journal of Civil Engineering 28(1): 69-90 (2016)

FINITE ELEMENT SIMULATION OF SPACE TRUSSES UNDER SEISMIC LOADS

Hala Bakr, Boshra Eltaly*, Maher Elabd, & Kameel Kandil

Civil Engineering Department, Faculty of Engineering, Minufiya University, Egypt

*Corresponding Author: *boushra_eltaly@yahoo.com*

Abstract: The space truss is one of the most important structural systems that it is very often adopted in modern buildings of large dimensions. The study of the dynamic behavior of space structures has become an important part of the design process to this type of structures. The objective of the current research is to study the behavior of non-composite and composite space trusses with top ferrocement and concrete slab under earthquake loads. A finite element simulation was presented in the current research to study the linear and nonlinear behavior of the space trusses under seismic loads. This simulation was estimated by comparing the results of these simulation by previously published results on the space trusses and gives good results. Also, three types of real space truss models of the square on square (SOS) configuration were designed to cover 52.0 × 52.0 m area. The three space truss systems are different in the locations of supports namely; corner supports, two-edge corner supports and full edge supports. Each truss was studied in three cases; non-composite space truss and composite truss with top concrete or ferrocement slab. The analysis included the modal analysis, linear and nonlinear time history analyses. From the current study results, it can be concluded that introducing the composite action in space trusses improves their seismic behavior.

Keywords: *Space trusses, space truss connections, composite action, finite element method, modal analysis, time history analysis*.

1.0 Introduction

Space trusses have been widely employed in several types of buildings with large column-free areas and long spans such as sports gymnasiums, exposition centers, airplane hangars, workshops and warehouses. Space trusses consist of two planar networks of members (top and bottom layers parallel to each other) interconnected by vertical and inclined web members. They can be formed in a flat or a curved surface (Iffland, 1982; Iffland, 1987; Chilton, 1999; Ramaswamy *et al.*, 2002 and Lan, 2000). The available space truss systems can be classified into two main groups according to their connection system. The first system (typical space trusses) is a system with short chord members joined together by node connectors; The MERO connection and Butler Triodetic Hob are examples. The second system is a system with continuous chord members that do not need nodes for their assembly. This type of joint is the simplest and therefore cheaper to manufacture than the first system. On the other hand, it has two main disadvantages: the generated eccentricity force and a reduction of stiffness in the bar due to the end-flattening process (EL-Sheikh, 1996).

Space truss compression members typically fail with a brittle type of failure caused by buckling. After buckling of a compression member, no further load can be applied. If the adjoining structure causes additional member shortening, the member will deflect laterally (Schmidt *et al.*, 1976). This is the problem of the space trusses. The typical methods to solve this problem are over-strengthening top chord members and using top slab acting compositely with the top chord member (El-Sheikh, 1991; Shaaban, 1997; El-Sheikh and Shaaban, 1999 and Eltaly, 2010). In general, composite action has been found to improve joint stability and truss reliability; thus leading to significant enhancements to truss stiffness, strength and ductility.

Although static analysis is important for determining the strength and stiffness of structures, dynamic analysis is also very important (Tedesco *et al.*, 1999). Several researches covered dynamic analysis of space trusses. Noor and Peters (1980) introduced a computational procedure to predict the dynamic response of space trusses with both geometric and material nonlinearities. They used a mixed system of algebraic and differential equations to derive the forces in the members, nodal velocities and nodal displacements to check the accuracy of the proposed technique in predicting the dynamic responses of structures. Malla and Wang (1993) replaced the failed member by its internal forces applied at the end joints and abruptly dropping the force to zero or a reduced value to enable tracing the resulting dynamic response of the truss structure. Zhu *et al*. (1994) tested a two-bay cantilever truss under sinusoidal forcing function with 4.5×10^{-4} N amplitude and 0.01 s period. Their study recorded an increase in the displacements and a reduction in the member forces by the inclusion of the material and geometric nonlinearities in the dynamic analysis.

In the current research, Finite Element (FE) models were employed using ANSYS software to study mode shapes, linear and non-linear time history behavior of the composite and non-composite space trusses. A comparison between the results of the employed FE models and previous published results are presented. Also in the current work, three types of real space truss models of the square on square (SOS) configuration were designed. An area 52.0×52.0 m was considered to be covered with three space truss systems different on the locations of supports namely; corner supports, two-edge supports and full edge supports. Each system included three space truss models. The first one was non-composite space truss while the composite action was applied to the other two models using concrete and ferrocement decks; respectively.

2.0 Finite Element Simulation

A finite element software package, ANSYS, 2009 was used to simulate the nonlinear behavior of composite and non-composite space trusses under the seismic loads. Mainly two types of elements were used in the FE simulation of the non-composite truss; Link8, and Mass21 elements. Link8 elements are used to represent the truss members. Link8 element may be used in different engineering applications. It may be used for example to model trusses, sagging cables and springs. It has three degrees of freedom at each node (translations in the nodal x, y, and z directions). By using this element, plasticity, creep and large deflection capabilities may be considered in the analysis. *Mass21* element is used to model the lumped mass. The mass element is defined by a single node; it has six degrees of freedom, translations in the nodal x, y, and z directions and rotations about the nodal x, y, and z axes (ANSYS, 2009 and Bakr, 2014). Furthermore Shell63 elements were used to simulate the top slabs in the case of the composite space truss. Shell63 element has six degrees of freedom at each node: translations in the nodal x, y, and z directions and rotations about the nodal x, y, and z-axes. Stress stiffening and large deflection capabilities are included by using this element.

The procedure for analyzing nonlinear transient behavior in ANSYS is similar to that used for nonlinear static behavior. The load was applied in incremental steps, and the program performs equilibrium iterations at each step. The main difference between the static and transient procedures is that time-integration effects can be activated in the transient analysis. Thus, "time" always represents actual chronology in a transient analysis. The automatic time stepping and bisection feature are also applicable for transient analyses.

3.0 Solved Examples

Three different space trusses were numerically studied in the further coming sections to evaluate the current FE models in determining the modal parameters and linear and non-linear time history of space trusses.

3.1 Space Truss #1

This truss is a non-composite space truss and it was experimentally and numerically studied by Elabd (2010) The dimensions of the truss are indicated in Figure 1. The members were double-layer square on square offset (SOS) with overall dimensions of 1400× 1400×150 mm. The truss members were made of solid aluminum round bars of diameter 4.0 mm for diagonals and lower chord members and 5.0 mm for upper chord members. Support constraints were simple supports at each lower chord perimeter joint. Masses were added to the space truss by connecting lead masses (1.35 Kg) to every upper joint. Lead was selected due to its high specific weight, which allowed the use of small mass sizes. Shaking table tests were presented by Elabd (2010) to evaluate the time history by producing waves as shown in Figure 2. This acceleration was used in the current FE simulation. Elabd (2010) carried out experimental tests on individual members to estimate their behavior. From the tensile member behavior, the modulus of elasticity and Poisson's ratio of the truss were considered in the current FE simulation as 64.39 kN /mm2 and 0.3; respectively. Elabd (2010) employed a numerical model using the finite element software, ABAQUS, to indicate the nonlinear behavior of the truss.

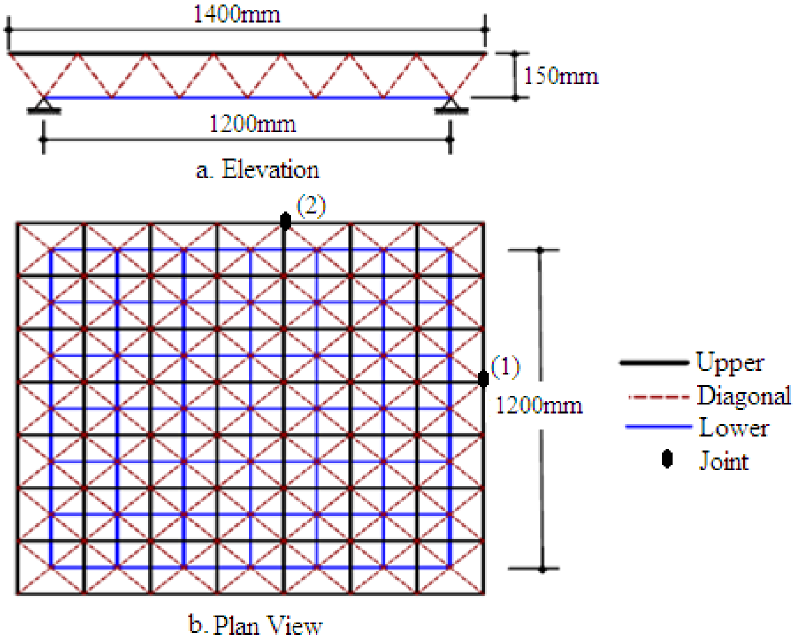


Figure 1: Layout of space truss#1

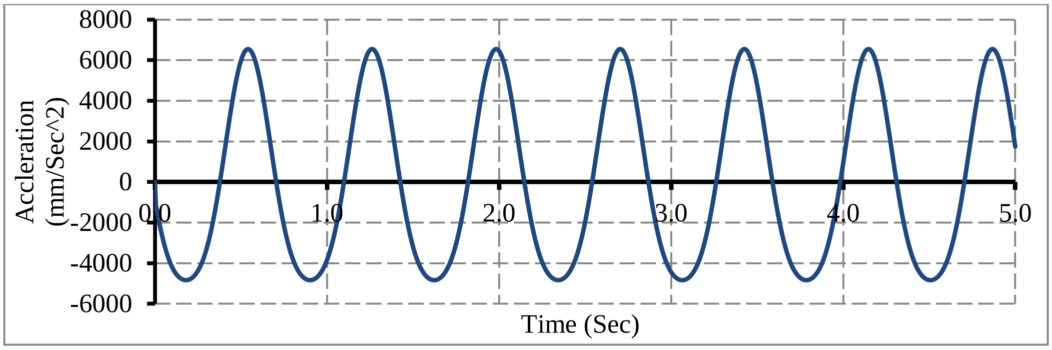


Figure 2: Output shaking table platform acceleration (ELabd [18])

The results of modal analysis for the first five mode shapes conducted on the current FE simulation and the results of Elabd (2010) experimental and numerical model are shown in Table 1 and Figure 3. From this figure and table, it can be indicated that the results of modal analysis of the current FE simulation for the first five mode shapes are satisfied with Elabd (2010) experimental and numerical results. According to conclusions of Elabd (2010) research, the truss behavior did not reach nonlinear behavior so that the results of the time history analysis that was carried out in the current research did not consider the non-linearity. Figure 4 shows the lateral horizontal displacement at selected joint#1 as obtained from Elabd (2010) experimental and numerical wok and the current linear time history analysis. The comparisons between the maximum lateral displacements as obtained from Elabd (2010) experimental and numerical model and the current analysis are presented in Table 1.

Table 1: Results of modal analysis (Frequency (Hz)) for space truss#1

Mode No.	Direction	Elabd experimental test [18]	Elabd numerical model [18]	Current analysis
1	Z	14.847	14.779	14.304
2			17.465	16.328
3			17.465	18.236
4			23.272	22.724
5			23.272	24.028

3.2 Space Truss #2

The truss in this example was studied experimentally and numerically by Elabd (2010). This truss was similar to space truss#1 in dimensions, geometry and material behavior except that the truss has an upper deck to achieve composite action. The aluminum sheet deck of 1.2 mm thickness was used in covering the space truss roof.

The results of modal analysis as obtained from the current FE simulation and Elabd (2010) experimental and numerical analysis for composite space truss with aluminum deck are briefly introduced in Figure 5. From this figure, it can be concluded that the results of the current modal analysis are satisfied with Elabd (2010) experimental and numerical results. Figure 6 and Table 3 show the lateral displacement at joint#1. From Figure 6 and Table 3, it can be seen that the current numerical model gives good results comparing with Elabd (2010) experimental and numerical results. The percentage difference between lateral displacements that obtained from the current numerical model and Elabd (2010) works does not exceed than 6.45%.

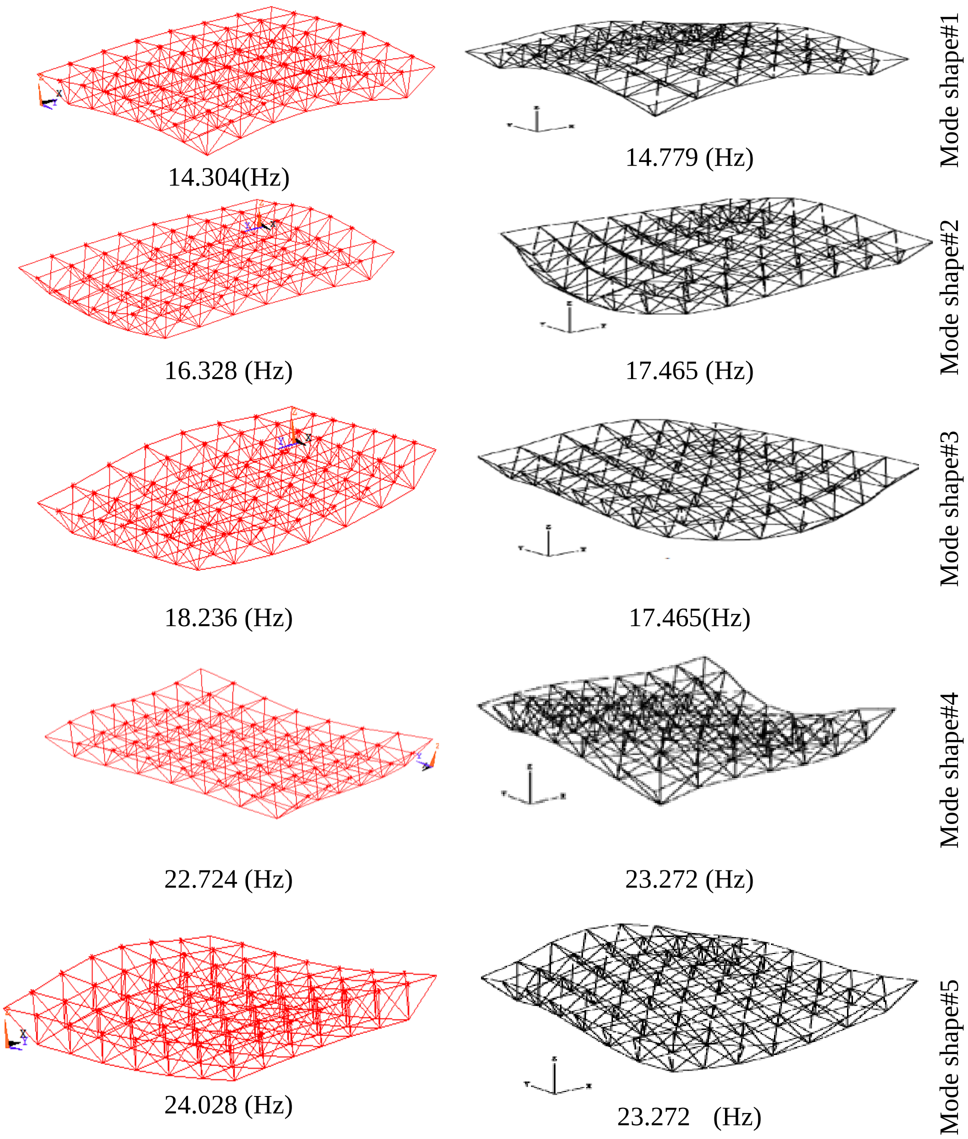


Figure 3: Mode shapes for truss #1; Current FE model (left) and Elabd, 2010 numerical model (right)

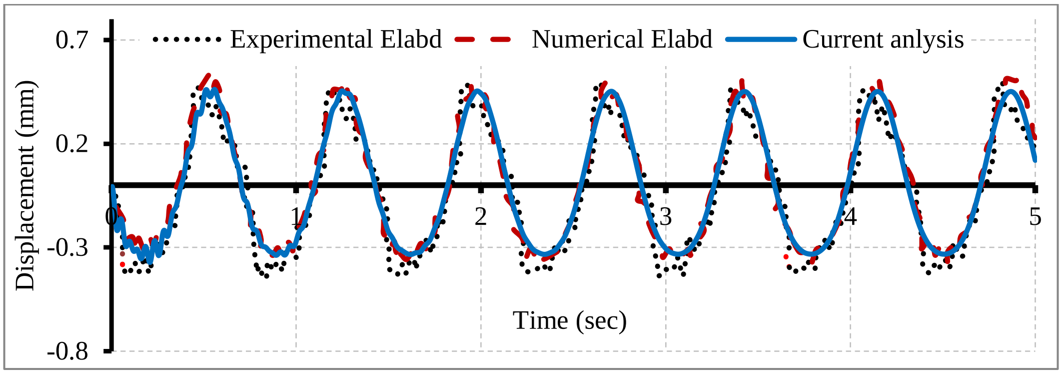


Figure 4: Lateral displacement of studied space trusses#1 at joint (1)

Table 2: Maximum and minimum displacements for space truss#1

displacement (mm)	Experimental Elabd, 2010	Numerical Elabd, 2010	Current analysis
Max.	0.543	0.535	0.444
Min.	-0.439	-0.322	-0.355

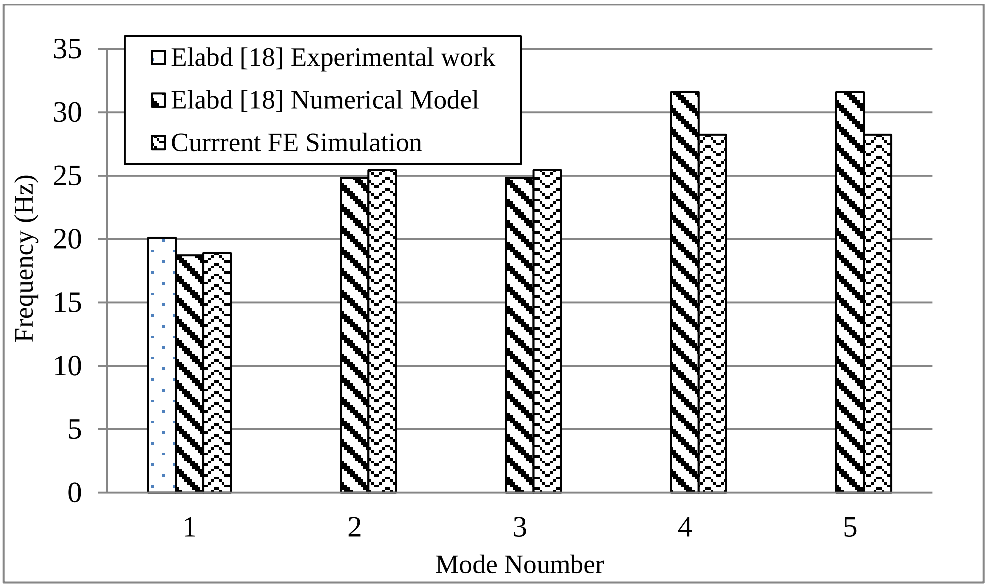


Figure 5: Results of modal analysis of composite space truss with aluminum deck (space truss#2)

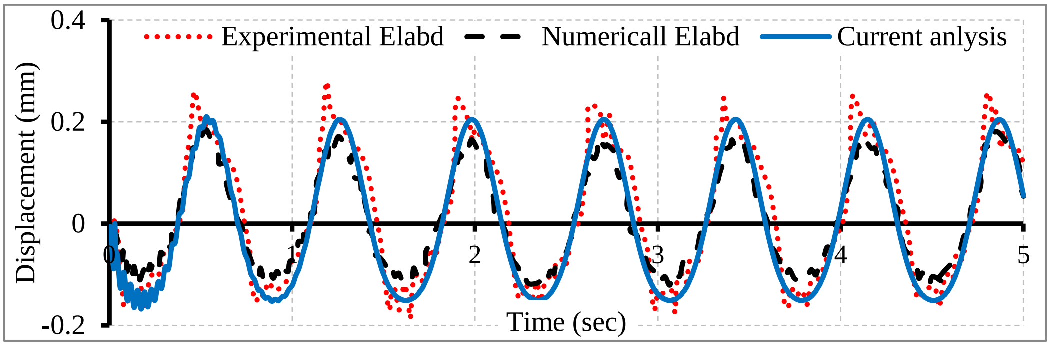


Figure 6: Lateral displacement of space truss #2

Table 3: Maximum and minimum displacements for composite space truss#2

Displacement (mm)	Elabd, 2010 experimental work	Elabd, 2010 numerical model	Current numerical
Max.	0.222	0.173	0. 205
Min.	-0.126	-0.13	-0. 137

3.3 SpaceTruss #3

Two different trusses were numerically studied by Tai Thai and Eock Kim (2011). They investigated the nonlinear time-history analysis of these space trusses including geometric nonlinearities. The two numerical examples were presented and discussed using The El-Centro earthquake record as input data as shown in Figure 7. The mass and stiffness-proportional damping factors were chosen based on the first two modes of the structure so that the equivalent viscous damping ratio was equal to 5% for the verification purpose. They used ABAQUS Software to carry out their numerical analysis.

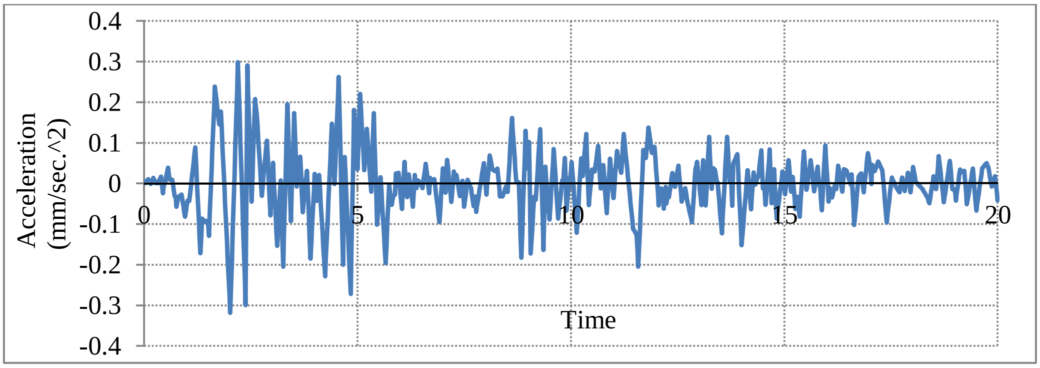
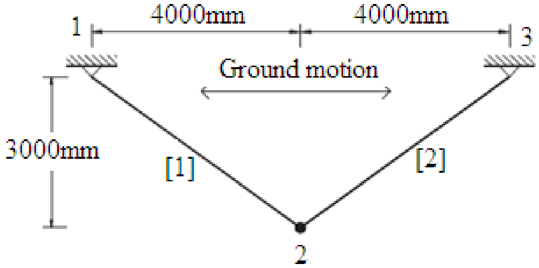


Figure 7: El-Centro earthquake record

The first example was a toggle truss as shown in Figure 8. The truss masses were considered as 5×10^4 N*s ^{2}/mm lumped mass at the free node (node#2). This truss was simulated in 2D. In the current analysis, the truss member is represented by Link1 element. This element looks like Link8 except that this element is used in representing the truss members in 2D. The relationships between horizontal displacements and time at node 2 as given from nonlinear elastic (NE) Tai Thai and Eock Kim (2011) analysis and the current FE results are presented in Figure 9. From this figure, it can be observed that there are big differences between the results of the current analysis (using ANSYS program) and Tai Thai and Eock Kim, 2011 analysis, using another software package, SAP2000N (2000) to verify the truss simulation. SAP2000N is a general purpose finite element program which performs static or dynamic, linear or nonlinear analysis of structural systems. The truss was built in SAP2000N using frame elements and the lumped mass was inserted at the joints. Moments were released at the end of each truss member to simulate the truss joint. From the results of SAP2000N analysis, it can be concluded that SAP2000N and ANSYS results were the same, as shown in Figure 9.



$A=31400.16mm^2$
$I=19.630e7mm^4$
$E=2e3GPa$
$\sigma_y=600MPa$

Figure 8: Toggle truss

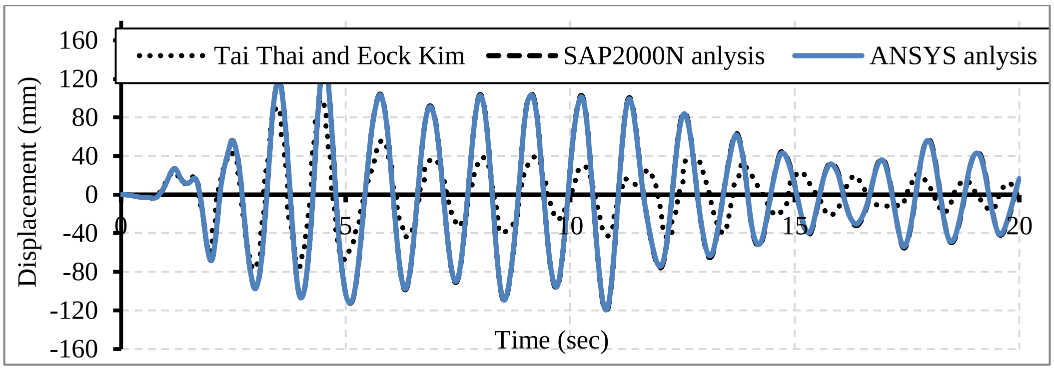
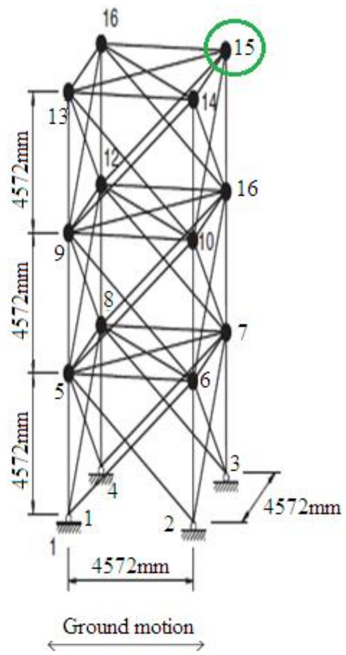


Figure 9: Lateral horizontal displacement-time history curve at node#2 of toggle truss

The second truss of Tai Thai and Eock Kim, 2011 was illustrated in Figure 10. The truss was simulated by the current employed FE model and by SAP2000N. The horizontal displacement at node#15-time curve from the current FE simulation (ANSYS program), SAP2000N analysis and Tai Thai and Eock Kim, 2011 is presented in Figure 11. From this figure, it can be noted that the horizontal displacements in the first 2.5 sec from the current analysis (ANSYS program and SAP2000N program) and Tai Thai and Eock Kim (2011) are similar and after 2.5sec differences in the displacement time histories from the three analysis methods appear.



Vertical plane member: L5x5x5/16
Horizontal plane member: L4x4x1/4
Lumped masses: 50 N.sec.^{2}/mm
E=2e3GPa
σ_y=600MPa

Figure 10: Space truss of Tai Thai and Eock Kim, 2010

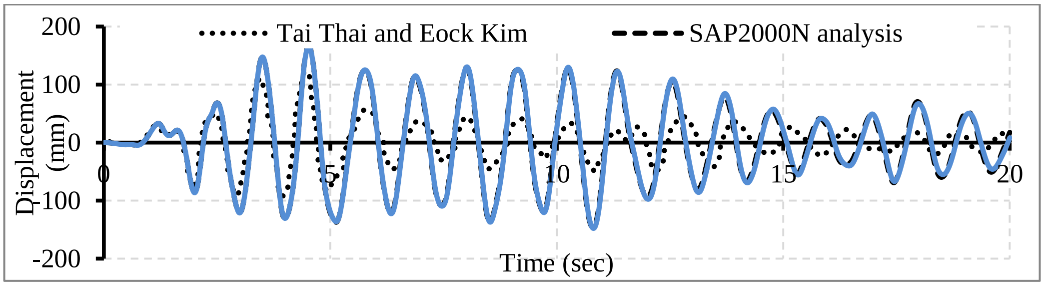


Figure 11: Lateral horizontal displacement-time history curve at node#15 of Tai Thai and Eock Kim (2011) second truss

4.0 Study on the Real Space Trusses

In the current research, real space trusses were designed using both Egyptian Code of Practice (ECP), 2012 and British Code (BS5950, 2011)and were studied numerically under dynamic loads to evaluate the influence of composite action of space trusses with top ferrocement slabs. The real space trusses were assumed to cover an area of 52.0 x 52.0 m. Three cases of support conditions were considered namely; corner supports, two-edge corner supports and full edge supports. Both of composite and non-composite actions with top deck were considered during the analysis. The overall dimensions of the truss (with corner supports) are illustrated in Figure 12. The truss has overall dimensions 52000 x 52000 mm and depth of 2830 mm.

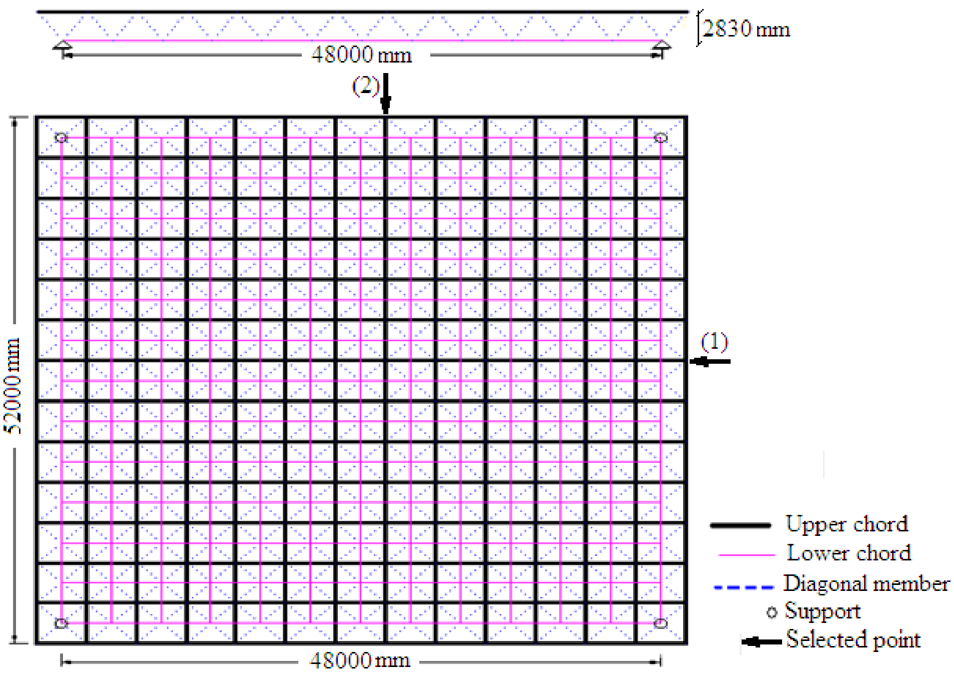


Figure 12: Layout of real space truss without deck

SAP2000N, 2000 was used to perform the linear analysis that was used in the design of the real trusses. Dead loads resulting from the 120 mm-thick concrete slab covering self- weight of the truss were assumed. Live loads of 100 kg/m^2 as inaccessible rigid roof were considered according to the Egyptian Code, 2012. The loads are concentrated at each upper chord joint. The modulus of elasticity, yield stress and Poisson’s ratio of the space truss material were considered as 200GPa, 600MPa and 0.3; respectively. The truss members are circular steel tubes with dimensions (Dimension (D) and Thickness (T)) as shown in Table 4. Two different top slabs; concrete deck (composite#1) and ferrocement deck (Composite#2) were used to study the effect of the composite action on the seismic behavior of the space truss. The concrete deck was designed to cover the three types of the real space trusses using Egyptian code, 2012. The slab thickness was taken 120 mm with reinforcement of assumed 5φ8mm/m. The modulus of elasticity and Poisson's ratio of the concrete deck material were considered as 20 GPa and 0.2; respectively.

Ferrocement is a type of reinforced concrete. It consists of cement mortar matrix and was reinforced with closely spaced, multiple layers of mesh or fine rods completely impregnated with cement mortar. Its reinforcement may be woven wire mesh, welded wire mesh or expanded metal mesh. It has been used in a wide range of applications, including aqueducts, boats, buildings, bus shelters, bridge decks, food and water storage containers and so on (Ali, 1995; Al-Kubaisy and Jumaat, 2000; Robles-Austriaco *et al.*, 1981; Aboul-Anen *et al.,* 2009; Shaheen *et al*., 2014).

The ferrocement was designed according to ferrocement model Code (2001) with 50 mm thickness. One layer of welded wire mesh made from welded galvanized wires with diameter 0.7 mm and with 12.5x12.5 mm openings size and 5φ6mm/m were assumed as main reinforcement. The modulus of elasticity and Poisson's ratio of the ferrocement deck material were assumed to be 30GPa and 0.2; respectively.

Table 4: The dimensions of the cross section in mm of the real space trusses

Truss type	Upper members		Lower members		Diagonal members	
	D	T	D	T	D	T
Corner supports	500	21	500	21	400	12
Two-edge corner supports	194	10	159	8	159	8
Fully edge supports	159	8	133	8	133	8

The 1940 El Centro earthquake that occurred in southeastern Southern California, presented in Figure 7, was used in the analysis of the three real space trusses. Modal analysis was used to determine the natural frequencies and mode shapes of each structure. Figure 13 represents the first five mode shapes for the real space truss with two-edge supports. Table 5 shows the frequencies of the first five modes for the three real space trusses. From Table 5, it can be concluded that the composite action in the truss with corner supports increases the natural frequency in the concrete slab by about (205.3 - 248)% compared to the non-composite action. It also increases the natural frequency for the truss with top ferrocement slab (Composite#2) by about (55.8 - 245.7) % compared to the non-composite truss. Also in the truss with two-edge corner supports, adding a top concrete slab increases the natural frequency by about (224.9-337)% and adding top ferrocement slab increases the natural frequency by about (205.1 - 422.5) % compared to the non-composite truss. Additionally the natural frequency of the real truss with full edge supports increased by about (260 - 334.6) % with top concrete slab and they increased using a top ferrocement slab by about (82.2 - 541.6) % compared to the non-composite space truss. From Figure 13, it can be observed that the first three mode shapes have the same shape using the composite action. On the other hand the fourth and fifth mode shapes of the truss with top ferrocement slab are different in the mode shape and these modes represent the deformation of the top ferrocement slab.

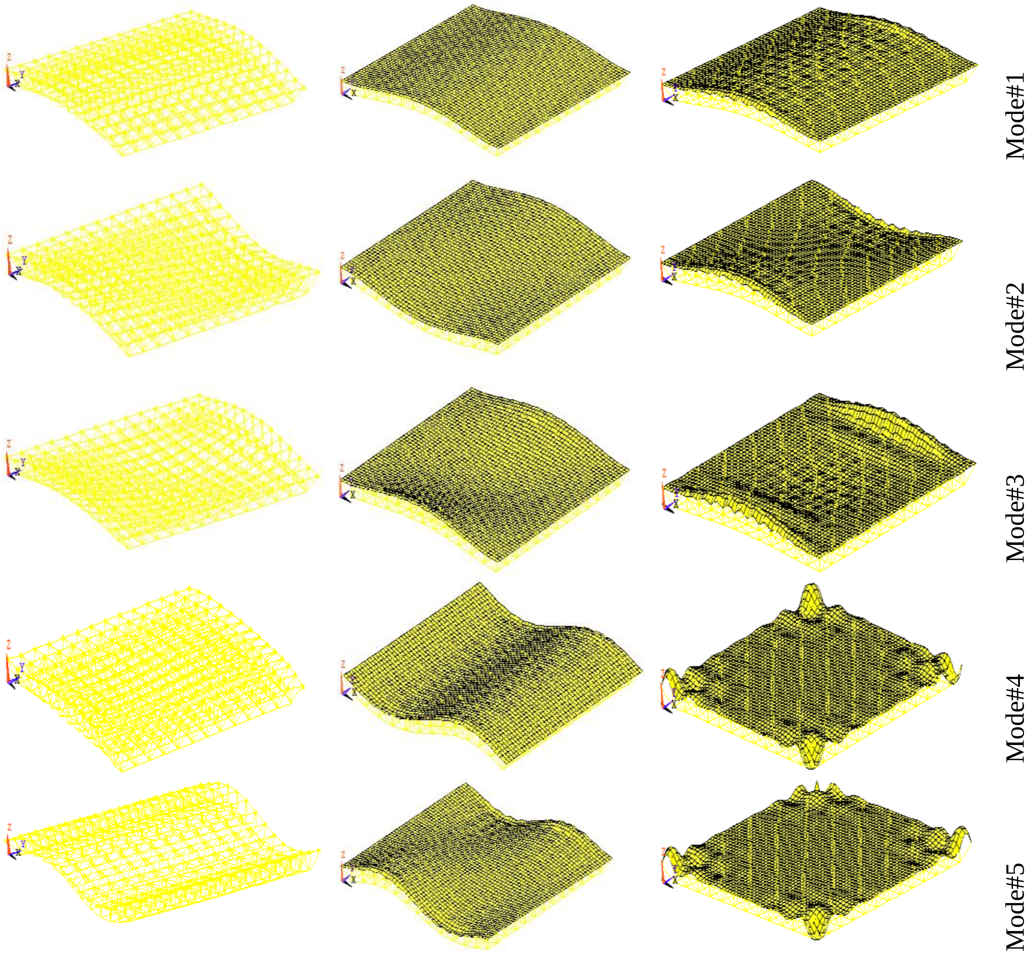


Figure 13: Mode shapes for the real space truss with two-edge corner supports: left is non-composite truss, middle is composite truss #1 and right is composit truss#2

In the following sections, the results from the linear time history analysis for the three types of the real space trusses are illustrated. Figure 14 and Figure 15 illustrate the linear time history of the horizontal displacement (x) of corner supported space truss in the case of non-composite, composite with concrete and composite with ferrocement decks at selected points#1&2 (see Figure 12). From these figures, it can be observed that the seismic response of the corner supported truss with top concrete slab appears to be better than the seismic response of the corner supports truss with top ferrocement slab in the first five seconds, but at the last seconds the seismic response of the first space truss with top ferrocement slab appears to be the best. The effect of the composite action for both top reinforced concrete and ferrocement slabs for the two edge support trusses are presented in Figures 16 and Figure 17. In these figures, there is considerable reduction in the lateral displacement when considering the composite action and the reduction in the dynamic response of the second space truss with ferrocement slab is more than the dynamic response of the two edge support truss with concrete slab. The results of linear time history of the third truss with full edge support are presented at the two points #1 and #2 in Figures 18 and Figure 19; respectively. From these results, it is evident that the lateral displacement at point#2 shows average percent of reduction from non-composite truss to composite truss with ferrocement slab by about (288.8 – 585.7) %, and the results show that the average percent of reduction from non-composite truss to composite truss with concrete slab is about (75 – 242.8) %. All the previous results are indicated in Table 6.

Table 5: Results of modal analysis for the real space trusses

	Truss type	1	2	3	4	5
Corner supports	Non-composite (Hz)	0.4964	0.7605	0.7605	1.3009	1.3743
	Composite#1(Hz)	1.7275	2.6333	2.6333	3.9727	4.6308
	Composite#2 (Hz)	1.7162	2.1379	2.1379	2.1414	2.1416
Two-edge supports	Non-composite (Hz)	0.4707	0.4920	0.7760	1.1623	1.2368
	Composite#1 (Hz)	2.0254	2.1507	3.2597	3.7774	4.6622
	Composite#2 (Hz)	2.4596	2.559	3.4477	3.7729	3.7737
Full edge supports	Non-composite (Hz)	0.5347	1.1396	1.1699	1.5977	2.2638
	Composite#1(Hz)	2.7896	4.7634	4.7634	6.4193	7.5763
	Composite#2 (Hz)	3.4312	4.1256	4.1257	4.1257	4.1265

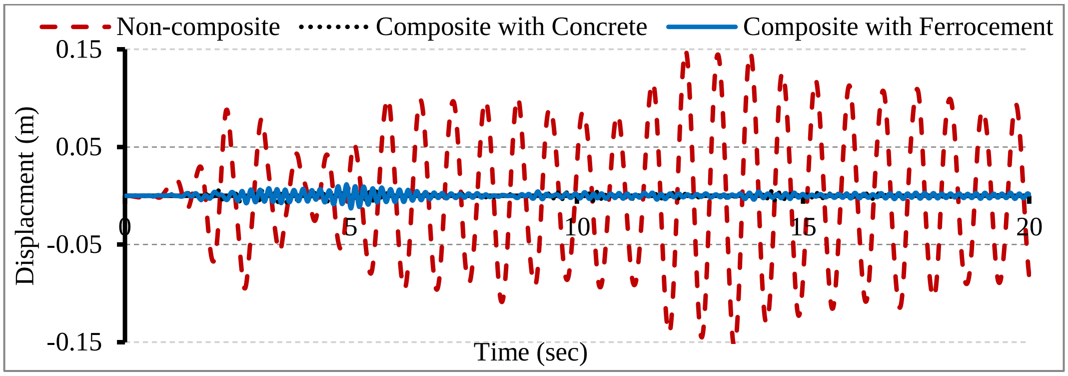


Figure 14.a: Time history of the horizontal displacement at point#1 of corner supports truss

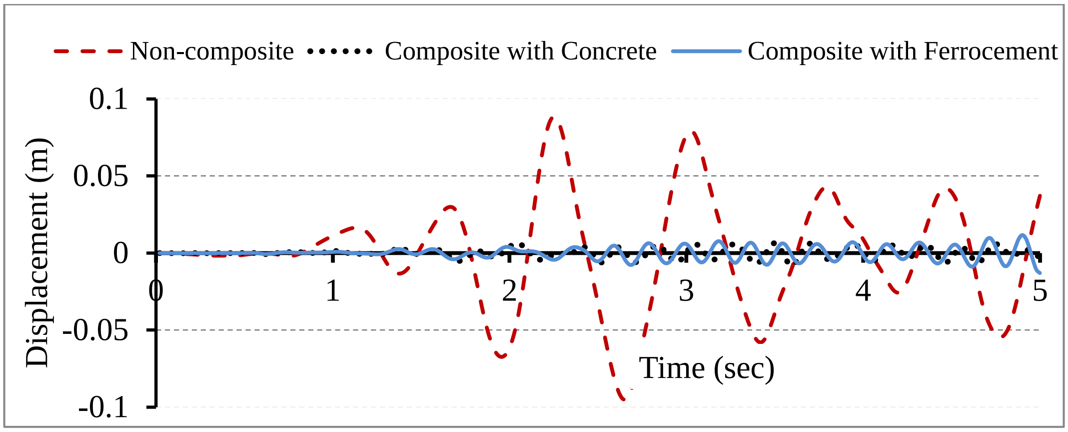


Figure 14.b: Time history of the horizontal displacement at point#1 of corner supports truss for the first 5 sec.

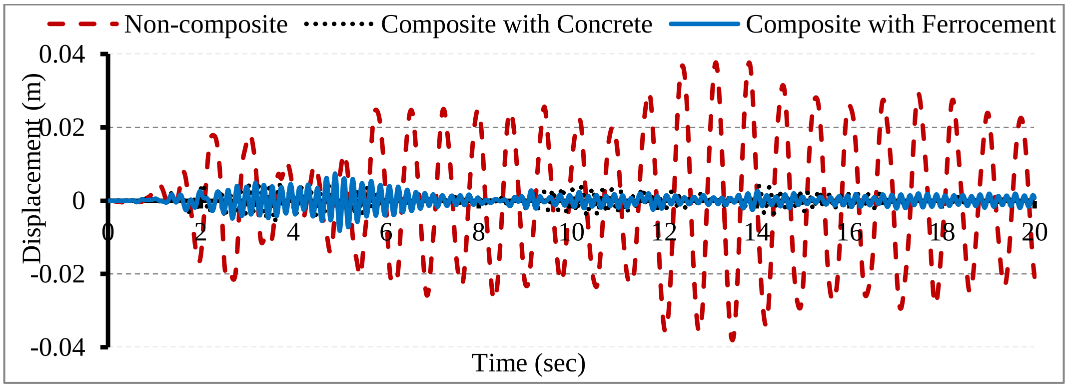


Figure15: Time history of the horizontal displacement at point#2 of corner supports truss

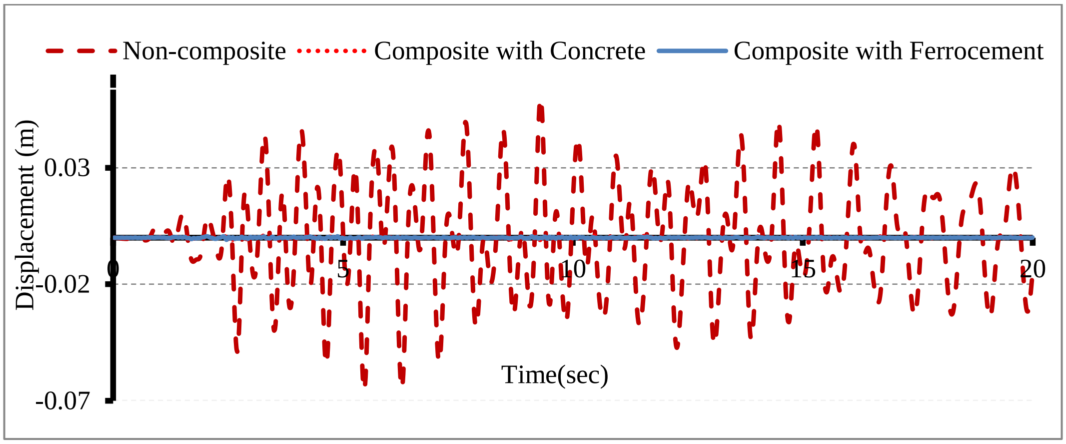


Figure 16: Time history of the horizontal displacement at point#1 for two-edge supports truss

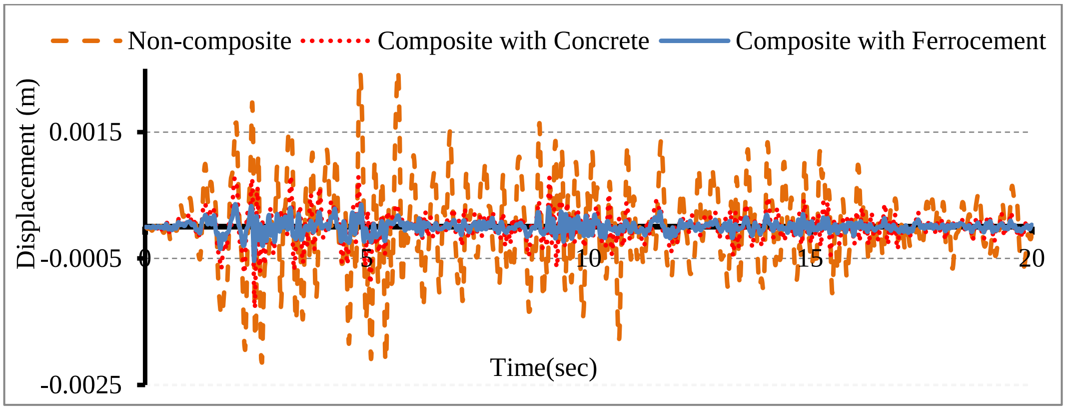


Figure 17: Time history of the horizontal displacement at point#2 for two-edge supports truss

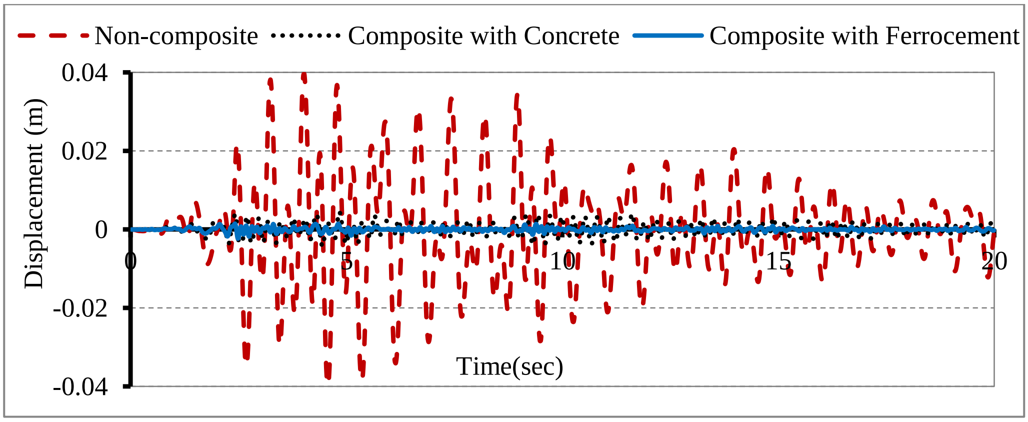


Figure 18: Time history of the horizontal displacement at point#1 for full edge supports truss

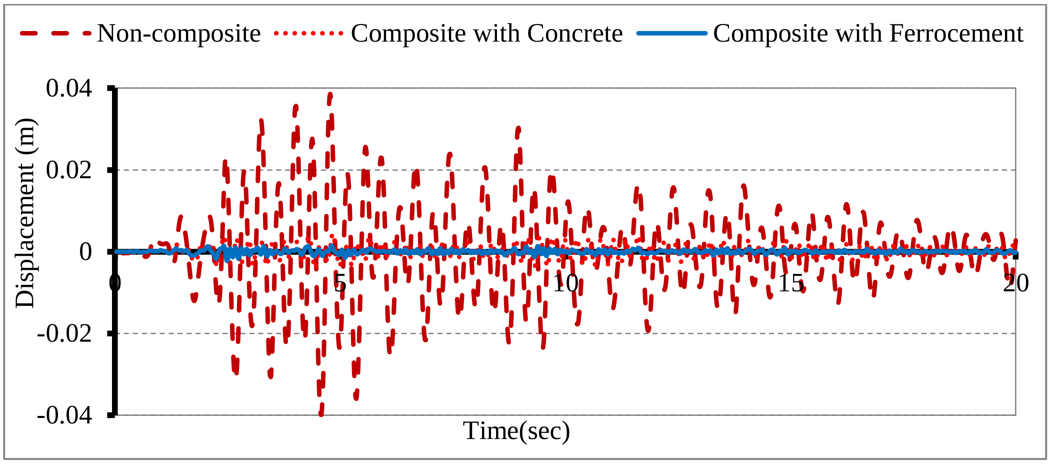


Figure 19: Time history of the horizontal displacement at point#2 for full edge supports truss

Table 6: Lateral displacement of the real space trusses at the two selected points

Space truss with corner supports						
	Non-composite		With concrete deck		With ferrocement deck	
	point (1)	point(2)	point (1)	point(2)	point (1)	point(2)
Max. displacement (m)	0.1487	0.0377	0.00644	0.0047	0.01166	0.00741
Min. displacement (m)	-0.1551	-0.0381	-0.0078	-0.0057	-0.0129	-0.00822
Space truss with two-edge supports						
	Non-composite		With concrete deck		With ferrocement deck	
	point (1)	point(2)	point (1)	point(2)	point (1)	point(2)
Max. displacement (m)	0.039663	0.03857	0.00444	0.00431	0.00146	0.001437
Min. displacement (m)	-0.398	-.03998	-0.00421	-0.0040	-0.0023	-0.0022
Space truss with full edge supports						
	Non-composite		With concrete deck		With ferrocement deck	
	point (1)	point(2)	point (1)	point(2)	point (1)	point(2)
Max. displacement (m)	0.0599	0.00247	0.00118	0.0007	0.0006	0.00035
Min. displacement (m)	-0.0655	-0.0021	-0.0017	-0.0012	-0.0008	-0.00054

The results of nonlinear time history analysis considering large displacement for non-composite and composite space trusses with concrete and ferrocement slabs and the comparisons between linear and non-linear time history analyses are illustrated in Figure 20 to Figure 22. Figure 23 to Figure 25 indicate the comparison between the results of linear and nonlinear time history analyses for the corner support truss. From the results indicated in Figure 23 to Figure 25, it can be clearly seen that in the non-composite space trusses, the difference between the results are not noticeable between linear and nonlinear time history analysis and they do not exceed 10% of the maximum displacements. On the other hand, there are negligible differences in the composite space trusses with concrete and ferrocement slabs.

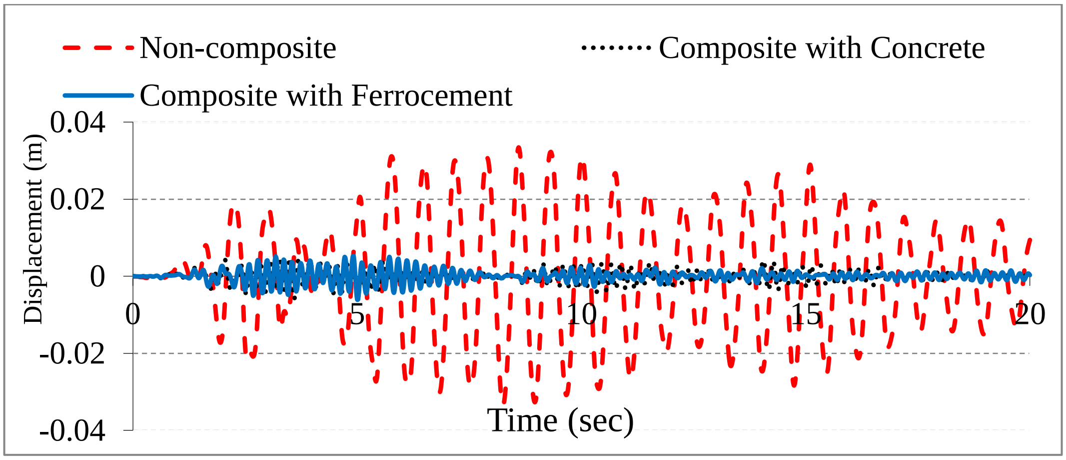


Figure 20: Nonlinear time history of the displacement at point#2 of corner supports truss

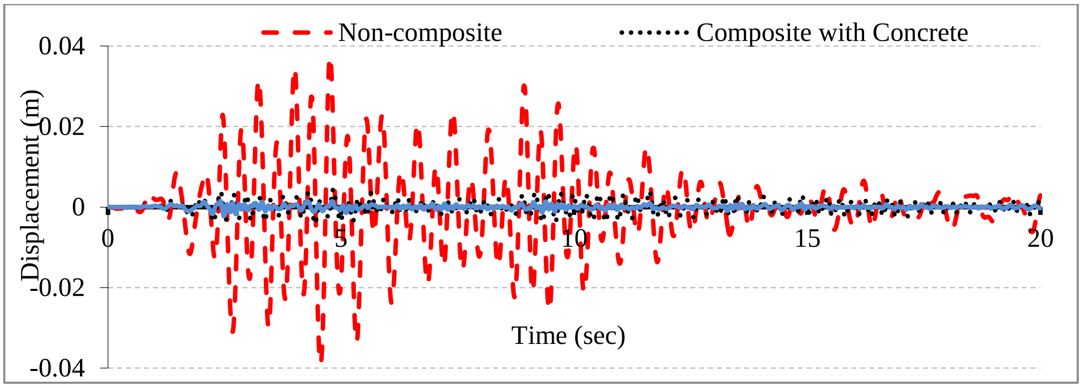


Figure 21: Nonlinear time history of the displacement at point#2 of two edge corner supports truss

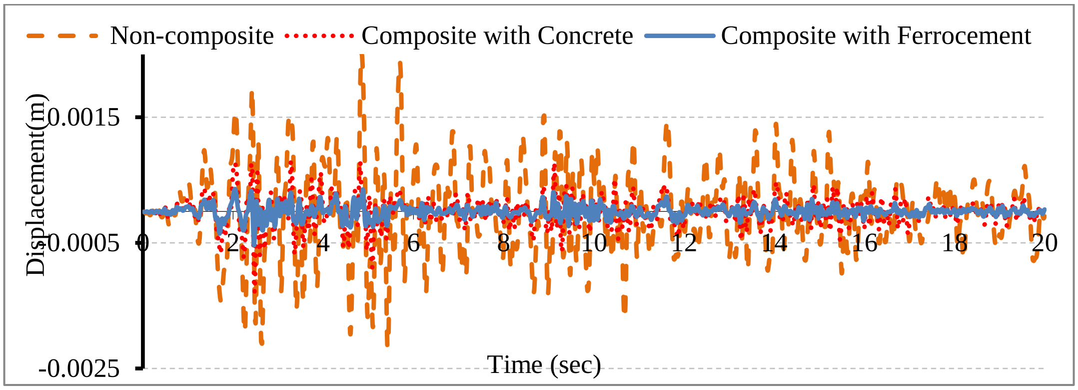


Figure 22: Nonlinear time history of the displacement at point#2 of full edge support truss

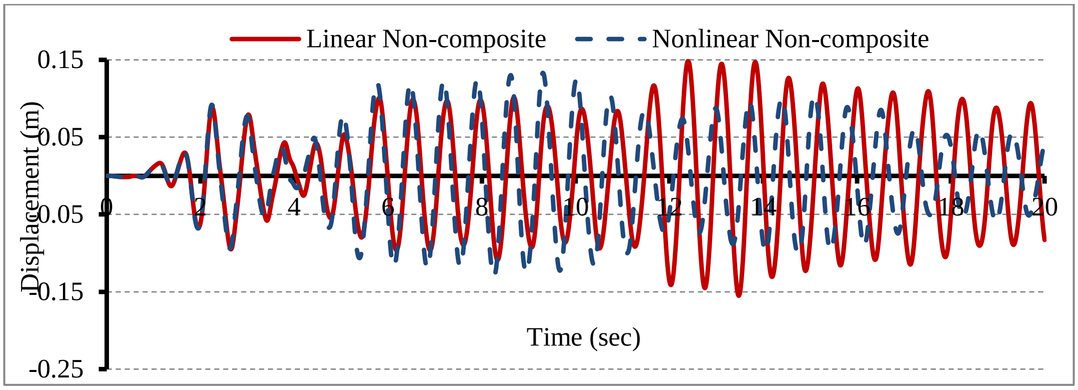


Figure 23: Lateral displacement of non-composite truss from the linear and nonlinear time history analyses at point #1

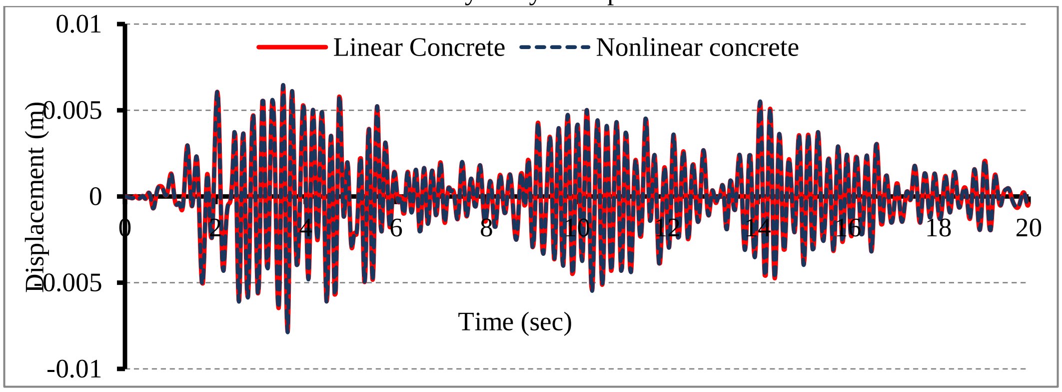


Figure 24: Lateral displacement of composite with concrete deck truss from the linear and nonlinear time history analyses at point #1

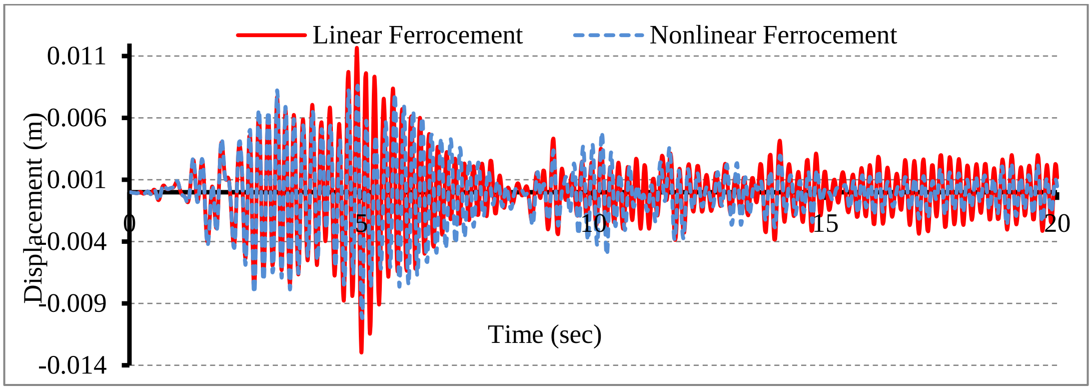


Figure 25: Lateral displacement of composite with ferrocement deck truss from the linear and nonlinear time history analyses at point #1

5.0 Conclusions

The FE model was employed using ANSYS (2009) to study linear and geometric non-linear time history behavior of the space trusses. A comparison between the results of employed FE model and previous published research were presented to demonstrate the validity of the FE model. Additionally, three space trusses with 52000 x 52000 x 2830 mm overall dimensions were studied for three cases: non-composite and composite with concrete and ferrocement decks. The three trusses are different in the locations of supports namely; corner supports, two-edge supports and full edge supports. From this study, the following is a list of conclusions drawn from the numerical study conducted in this research:-

1- The current finite element simulation gives good agreement results when compared with the previously published results.
2- The introduction of composite action to square on square space trusses leads to the increase in vibration frequencies with different support conditions.
3- The use of concrete deck to create composite action with a square on square space truss results leads to reduce lateral displacement for the majority of cases with different support conditions.
4- Using ferrocement deck to achieve composite action with square on square space truss results in a reduction of lateral displacement and an increase of the value of vibration frequency for different support conditions.
5- Increase in location of supports of a composite or a non-composite square on square space trusses leads to an increase in all vibration frequencies.
6- The reduction in the lateral displacement of square on square space trusses with covered ferrocement deck is more than the concrete deck for different support conditions; this is noteworthy more in the two cases of two-edge support and full edge supports square on square space trusses.

7- The nonlinear time history analysis gives results close with linear time history analysis of square on square space trusses.

References

Aboul-Anen, B., El-Shafey, A., and El-Shami, M. (2009). *Experimental and Analytical Model of Ferrocement Slabs.* International Journal of Recent Trends in Engineering 1:25-29.

Ali, A. (1995). *Applications of Ferrocement as a Low Cost Construction Material in Malaysia.* Journal of Ferrocement 25: 123-128.

Al-Kubaisy, M.A., and Jumaat, M. Z. (2000). *Flexural Behavior of Reinforced Concrete Slabs with Ferrocement Tension Zone Cover*. Journal of Construction and Building Materials 14: 245-252.

ANSYS, (2009). *Help and Manual*. 12th Ed., ANSYS Inc, Pa, Usa.

Bakr, H. (2014)..*Nonlinear Behavior of Composite Space Trusses under Earthquake Loads.* Ms.c. Dissertation, Minufiya University, Egypt.

BS5950 (2011) *British Code of Patristic for Structural Use of Steel*.. October, 2011.

Chilton, J., (2000). *Space Grid Structures.* Structural Hand Book, 90 Tottenham Court Road, London, England

Colombini, M.P., Fuoco, R., Giannarelli, S., and Pospísil, L.T. (1998). *Protonation and Degradation Reactions of S-Triazine Herbicides*. Microchemical Journal 59: 239-245.

Egyptian Code for Design and Construction of Concrete Structures. No.203, 2012.

Egyptian Code of Patristic for Steel Construction and Bridges. 205, 2012.

Elabd, M. (2010). *Effect of Composite Action on the Dynamic Behavior of Space Structures.* Ph. D. Dissertation, University of Dundee, UK.

El-Sheikh, A. (1991). *The Effect of Composite Action on the Behavior of Space Structures*. Ph.D. Dissertation, University of Cambridge.

EL-Sheikh, A.I. (1996). *Development of a New Space Truss System*. Journal of Constructional Steel Research 37: 205-227.

El-Sheikh, A.I., and Shaaban, H. (1999). *Experimental Study of Composite Space Trusses with Continuous Chords*. Advances in Structural Engineering 2: 219–232.

Eltaly, B., (2010). *Nonlinear Behavior of Composite Space Trusses*. Ph. D. Dissertation, Minufiya University, Egypt.

Ferrocement Model Code, (2001) Reported by IFS Committee 10. January, 2001; (C) Commentary.

Iffland, J. (1982). Preliminary Planning of Steel Roof Space Trusses. Journal of Structural Division, ASCE 108: 2578-2591.

Iffland, J. (1987). Preliminary Design of Space Trusses and Frames. Building Structural Design Handbook, Wiley-Interscience Publication, New York, 1987.

Lan, T.T. (1999). *Space Frame Structures*. Structural Engineering Hand book, Chen Wai-Fah, Boca Raton: Crc Press Llc.

Malla, R., Wang, B. (1993). *A Method to Determine Dynamic Response of Truss Structures during Sudden Consecutive Member Failure.* 4th International Conference on Space Structures, University of Surrey, Thomas Telford House, Uk: 413-422.

Noor, A.K., Peters, J.M. (1980). *Nonlinear Dynamic Analysis of Space Trusses.* Computer Methods in Applied Mechanics and Engineering 2: 131-151.

Ramaswamy, G. S., Eekhout, M., and Suresh, G. R. (2002). *Analysis, Design and Construction of Steel Space Frames*. Thomas Telford, UK.

Robles-Austriaco, L., Pama, R.P., and Valls, J. (1981). *Ferrocement an Innovative Technology for Housing*. Journal of Ferrocement 11: 23-47.

SAP, (2000). *Program Help and Manual*.

Schmidt, L.C., Morgan, P.R., and Clarkson, J.A. (1976). *Space Trusses with Brittle-Type Strut Buckling*. Journal of Structural Division, ASCE 112: 1479-1492.

Shaaban, H. (1997). *Effect of Composite Action on a Space Truss System with Continuous chord Members.* Ph.D. Dissertation, University of Dundee, Scotland.

Shaheen, Y. Eltaly B. and Abdul-Fataha S. (2014). *Structural Performance of Ferrocement Beams Reinforced with Composite Materials.* Structural Engineering and Mechanics 50: 817-834.

Tai Thai, H., and Eock Kim, S., (2011). *Nonlinear Inelastic Time-History Analysis of Truss Structures.* Technical Report, Department of Civil and Environmental Engineering, Sejong University, Republic of Korea.

Tedesco, J., W., Mcdougal, W. G., and Ross C.A. (1999). *Structural Dynamics Theory and Applications*. Structural Hand Book, Menlo Park, California.

Zhu, K., Al-Bermani, F.A., and Kitipornchai,S. (1994). *Nonlinear Dynamic Analysis of Lattice Structures*. Journal of Computers and Structures 52: 9-15.