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Determination of structural performance of 3D steel pipe rack suspended scaffolding systems

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Abstract. This study investigates the structural performance of 3D steel pipe rack suspended scaffolding systems. For the purpose, a standard full scale 3D steel pipe rack suspended scaffolding system considering two frames, two plane trusses, purlins and wooden floor is constructed in the laboratory. A developed load transmission system was placed in these experimental systems to distribute single loads to the center of a specific area in a step-by-step manner using a load jack. After each load increment, the displacements are measured by means of linear variable differential transducers placed in several critical points of the system. The tests are repeated for five different system conditions to determine the structural performance. The means of system conditions is the numbers of the tie bars which are used to connect plane trusses under level. Finite elements models of the 3D steel pipe rack suspended scaffolding systems considering different systems conditions are constituted using SAP2000 software to support the experimental tests and to use the models in future studies. Each of models including load transmission platform is analyzed under a single loading and the displacements are obtained. In addition, to calibrate the numerical models some uncertain parameters such as elasticity modulus of wooden floor and connection rigidity of purlins to plane trusses are assessed experimentally. The results of this work demonstrate that when increasing numbers of tie bars the displacement values are decreased. Also the results obtained from developed numerical models have harmony with those of experimental. In addition, the scaffolding system with two tie bars at the beginning and at the end of the plane truss has the optimum structural performance compared the results obtained for other scaffolding system conditions.

Keywords: 3D steel pipe rack suspended scaffolding system; developed load transmission platform; experimental test; finite element model; laboratory model; structural performance; tie bar

1. Introduction

In the world, many workplaces have potential injuries from accidents due to negligence by workers or employers, or due to the inherently dangerous conditions in various places of work. These workplaces are filled with heavy equipment and other dangerous materials and conditions, all of which can cause serious injury or even death. One of the reasons of these injuries is the pipe rack suspended scaffolding systems (Url-1 2017).

The pipe rack suspended scaffolding systems are built to elevate workers or materials to a height. They are used to carry loads coming from workers' self-weight, live or other loads. These systems are so important for the workers' safety. The constructed pipe rack suspended scaffolding systems without considering requirements should be caused work accidents. According to the report of the Bureau of Labor Statistic US in 2007, 88 fatalities occurred from scaffolds. In its recent study, it was reported that 72% of workers injured in scaffold accidents were caused either by support giving away or by employee slipping or being struck by a falling object. Meanwhile, around 50 people die each year in the United Kingdom because of scaffolds that have collapsed and over 4,500 are injured due to faulty or defective scaffolds (Collins *et al.* 2014, Url-2 2017). According to the Bureau of Labor Statistics of Census of Fatal Occupational Injuries (CFOI), 54 accidents occurred in the year 2009 from scaffolds. In these scaffolding accidents, nearly 70% of workers injured either to the planking or support giving way or to the employee slipping or being struck by a falling object (Url-3 2017). For the purpose, structural safety of these systems have to be investigated and needed precautions have to be taken during construction and operation of these systems.

Researchers investigated about scaffolding systems due to the importance of the subject. Khudeira (2008) told about the death and injured peoples due to the fell of the scaffold set up one of the highest buildings in 2002 in Chicago. So, Chicago building officials reviewed the regulations to protect workers and the public. It is also said that in the study, as a result of this accident a scaffolding ordinance was introduced and passed the city council. In another study, Pisheh and her friends (2009) highlighted that major reasons for disasters during construction of massive concrete structures is the failure of weak and defective scaffolding systems. In the study, they investigated that main causes of an accident considering in-situ and numerical examples. They modeled and analyzed a forming system including scaffold grids by finite element method.

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A case study is performed related to the design of suspended scaffold structural support elements and lifeline anchorages according to the Federal Occupational Safety and Health Administration (OSHA) Requirements (Hill *et al.* 2010). In the study, it is examined the performance of a large full-scale scaffold frame shoring subjected to pattern loads with various load paths. In the study, it is told about that a portal-type scaffold system with three bays, five rows, and three storeys was built. The sandbags were placed on the top of the scaffold frame shoring to simulate the weight of fresh concrete during construction. The test results show that the axial tube forces of scaffolds just below the location of a newly placed sandbag increase sharply (Peng *et al.* 1997, Hill *et al.* 2010).

Chunyang and Luli (2011) researched on the finite element model of a scaffolding system to see the influence of different bowl-scaffold joint stiffness on scaffold overall stiffness and load distribution at the bottom of bowl-scaffold. It is emphasized from the study that the joint stiffness has the noticeable influence on load distribution and so, in the design of the scaffolding systems connection between bowl-scaffold members must not be ignored.

Romera *et al.* (2013) highlighted that many construction accidents are caused by deficiencies in the project design phase. They also informed that designers should be more involved in the decisions and actions were taken during the project stage to have a clear and coherent definition of construction equipment safety in the site (Rubio et al. 2005, Toole 2005). So they researched about 146 construction sites to examine the scaffolding surfaces. In the study, each scaffolding in the site compared European standard and with those older (nonstandard) scaffolding. Both types were qualitatively evaluated to ascertain their safety levels. It is emphasized from the study that standardization of scaffolding equipment had a direct and positive impact on work safety conditions at construction sites (Romero *et al.* 2013).

Beale (2014) published a review related to scaffolding and falsework structures performed last forty years. In the review included that finite element modeling and testing procedures of scaffoldings; recommendations for modeling connections; different loadings on the scaffolding systems. Also, it is wanted to emphasize that the majority of failures occurred due to inadequate site conditions and weak designing.

Besides the studies given above, the studies related to the structural performance of steel systems are investigated by the researchers (Kaveh *et al.* 2014, Erdem 2015, Kaveh *et al.* 2015, Lian *et al.* 2015, Altunışık and Kalkan 2016, Davani *et al.* 2016, Sevim *et al.* 2017).

According to the literature review, many researchers underlined that more numerical and experimental studies should be done related to scaffolding systems to decrease the accident risk caused by deficiencies in design. So in this study, it is aimed to determine structural performance of scaffolding systems. The paper firstly presents the literature review of scaffolding systems given above. Secondly, the scaffolding types and standards used in the design is explained in the study. Then, a full scale 3D steel pipe-rack system is described. After experimental testing, finite element analysis of scaffolding systems performed. Lastly, experimental and numerical results compared and discussed.

2. Scaffolding types and standards

Scaffolding systems are used to carry loads due to workers or other work materials. They are also used to support the formworks in the construction site. They are generally temporary structures. They should be classified several systems according to the intended use. However as mentioned above, design and construction of these systems so important due to caused many injurious accidents. So scaffolding systems have to be designed by standards. Also, the design parameters used in design should be checked by numerical and experimental studies. General scaffolding types and standard parameters used in the design are given below:

One of the scaffolding types is pipe-rack suspended scaffolding. This is used in industrial areas. It provides manufacturing and assembly intermediate-tier areas which have no ability to reach from the ground. That is also used in pipe bridges in petrochemical plants. The system consists of scissors, pipe and pipe fittings members. When considered necessary, a special connection with the side of the existing steel I beam system, the system can be connected with the clamps (See Fig. (1)a) (Url-4 2017). Another scaffolding type is H type façade system which is consisted of H frame, horizontal and diagonal components (See Fig. 1(b)). Auxiliary components are nipple, pin, and plank. The system is fixed to the building by wall tie and to the foundation by base spindles. This type scaffolding is generally produced 42*2,5 mm pipes for frame and 27*2,5 mm pipes for diagonal braces according to Turkish Standards (TSE EN 12810-1 2005, TSE EN 12810-2 2005,

a) Pipe-rack suspended scaffolding   b) H type façade scaffolding   c) Flanged-wedges type scaffolding   d) Practical type scaffolding

Fig. 1 The views of the general scaffolding types used in construction sites

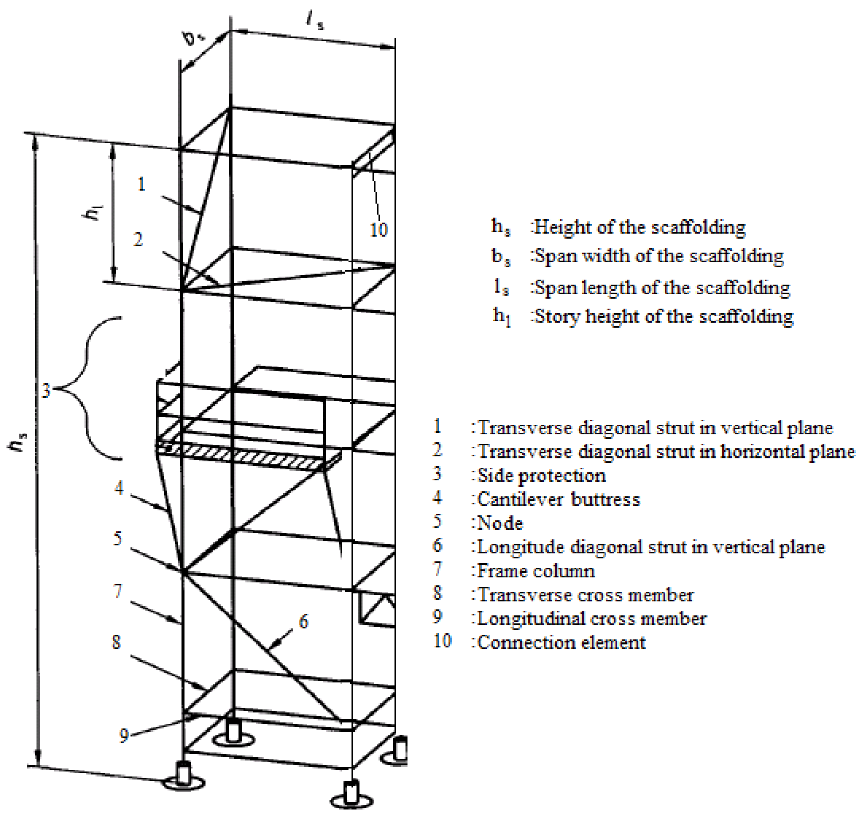

Fig. 2 General view of a scaffolding systems and its elements

TSE EN 12811-1 2005, TSE EN 12811-2 2005, Url-5 2017, Url-6 2017).

Flanged-wedges type façade system is another scaffolding type. The system is used for carrying slabs or as a façade operational scaffolding. It is consisted vertical and horizontal elements (See Fig. 1(c)). Vertical components are produced 48*3 mm pipes. Horizontal components are produced 48*2,5 mm pipes. The connection points have consisted of flanges, wedge heads and wedge (Url-4 2017, Url-5 2017). Another scaffolding type is practical type scaffolding system which is comprised of vertical and horizontal paneled connections (See Fig. 1(d)). The system is fixed to the façade by making use of wall resting elements. It is a multi-purpose scaffolding system that may be used in facade plastering and painting works, facade siding and coating works, silo productions, open air advertisements, elevator shafts, ship building, and maintenance works and tribune and stage work as well as the high screen constructions like dams and tunnels (Url-6 2017). On the other hand, there are still several scaffolding types used for several aims in construction sites such as other flanged type facade scaffolding systems, movable type scaffolding systems, and cup-lock scaffolding systems (Url-4-6 2017).

There are several Turkish Standards related to scaffolding systems such as TS EN 12810-1 (2005), TS EN 12810-2 (2005), TS EN 12811-1 (2005), TS EN 12811-2 (2005), and TS EN 12811-3 (2005). In these standards, TS EN 12810-1 (2005) includes products specifications of façade scaffolding systems made of prefabricated components; TS EN 12810-2 (2005) includes methods of particular design and assessment of façade scaffolds made of prefabricated components. TS EN 12811-1 (2005) is related to performance requirements and general design of scaffolds at temporary works. According to TS EN 12811-1 (2005), schematic view of a general of a scaffolding system and its elements is given in Fig. 2. TS EN 12811-2 (2005) gives general information on materials of scaffolding systems at temporary works, and TS EN 12811-3 (2005) considers the load testing on scaffolding systems used temporary works.

In all of these standards, the outer diameter of steel pipe is 48.3 mm and the minimum yielding stress of this pipe is 315 MPa in case thickness of scaffolding systems at temporary works, and TS EN 12811-3 (2005) considers the load testing on scaffolding systems pipe is 2.7 or 2.8 mm. If the thickness of the pipe is bigger than 2.9 mm, the minimum yielding stress is 235 MPa. The steel pipes which have outer diameters different from 48.3 mm have to be the thickness of pipe bigger than 2 mm and have to be yielding stress bigger than 235 MPa.

3. Experimental testing and numerical modeling of the 3D steel pipe rack suspended scaffolding system

3.1 Description of scaffolding system

In this study, a full scale 3D steel pipe-rack suspended scaffolding system constructed in laboratory conditions to investigate the structural performance. The system is built with two plane trusses which are impended on two plane

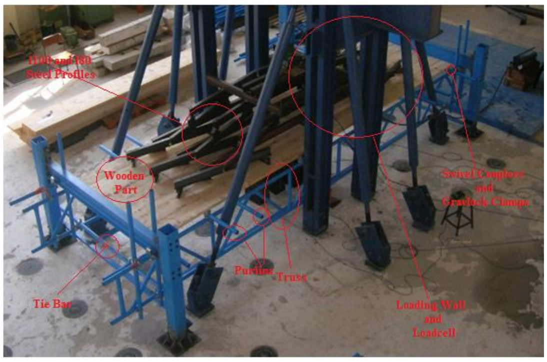

Fig. 3 The photograph of the full scale 3D steel pipe-rack suspended scaffolding system

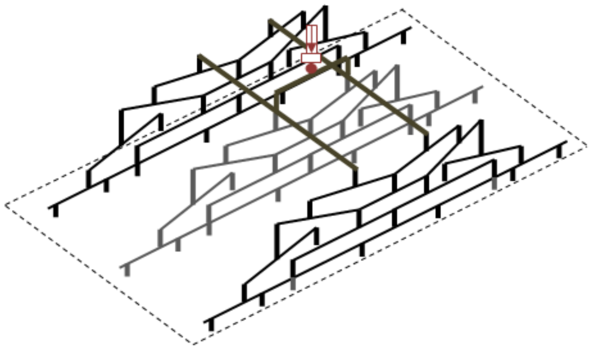

Fig. 4 Schematic view of the developed load transmission platform

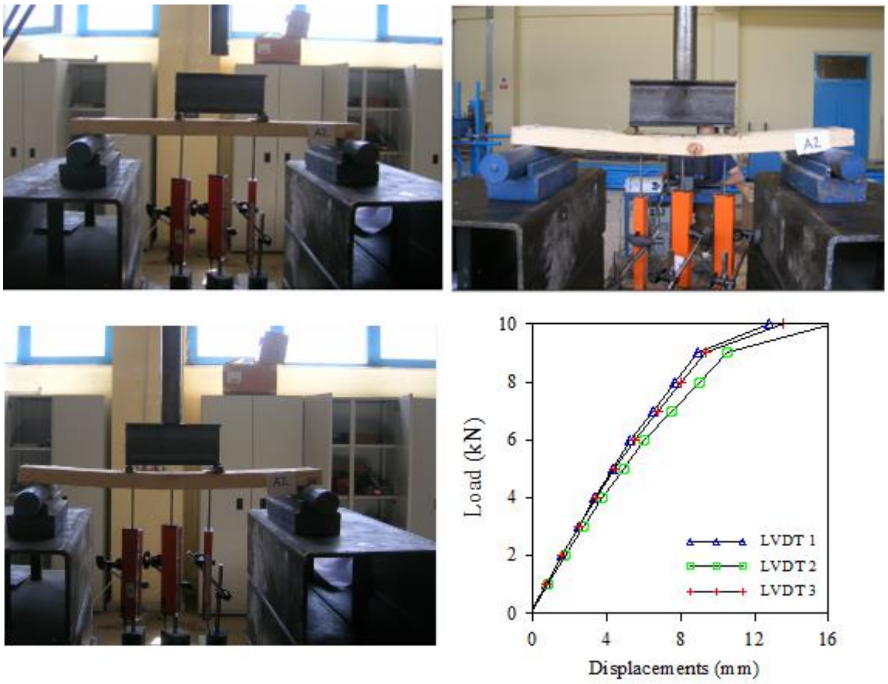

Fig. 5 Some photographs from the loading test of wooden and load-displacement curve

frame systems (See Fig. 3). Plane trusses are connected with purlins and there is a wooden board over the purlins. In the formwork system, the frame systems are not restrained to the soil, but the beam and column elements of the frame have rigidity connection. The purlins are connected to plane trusses and the plane trusses are connected to frame system. The connections in the system are provided using swivel couplers 48/48 and girder gravlock clamps. The wooden board is replaced to purlins as freely. In the study, span width and span length of the scaffolding system are selected as 1.6 m and 6 m, respectively. In the system, outer diameter and thickness of pipe of plane truss are selected as 48.3 mm and 3.2 mm, respectively.

3.2 Experimental and numerical studies

In the study, five loading tests for different systems connection conditions are applied to scaffolding system to determine structural performance. In the tests, a single load from a vertical hydraulic jack with 100 kN capacity is aimed to apply the wooden floor (6×1.6 (m^2)) of scaffolding system. In the literature, there are many studies where single load is applied to the structure (Arslan *et al.* 2008, Ö zcan *et al.* 2009, Ng *et al.* 2012). However, it is difficult to investigate the response under distributed area loading. In the study a platform is developed to transmit to single load to area distributed loading (Bekiroğlu *et al.* 2016). The load transmission platform is constituted with five levels using I100 and I80 steel profiles. The steel profiles are selected considering value of loads, transmission distances, and rigidity transmission. In the tests, the single load via transmission platform is distributed to scaffolding wooden floor, then the loads are carried by purlins and are transmitted to plane trusses. Lastly, the loads are taken from plane frames (See Fig. 4).

Numerical studies are performed considering 3D finite element model of scaffolding systems constituted SAP2000 (2017) software. In numerical studies, elasticity modulus of wooden floor and boundary conditions of connection rigidity between purlin pipes and plane trusses are the

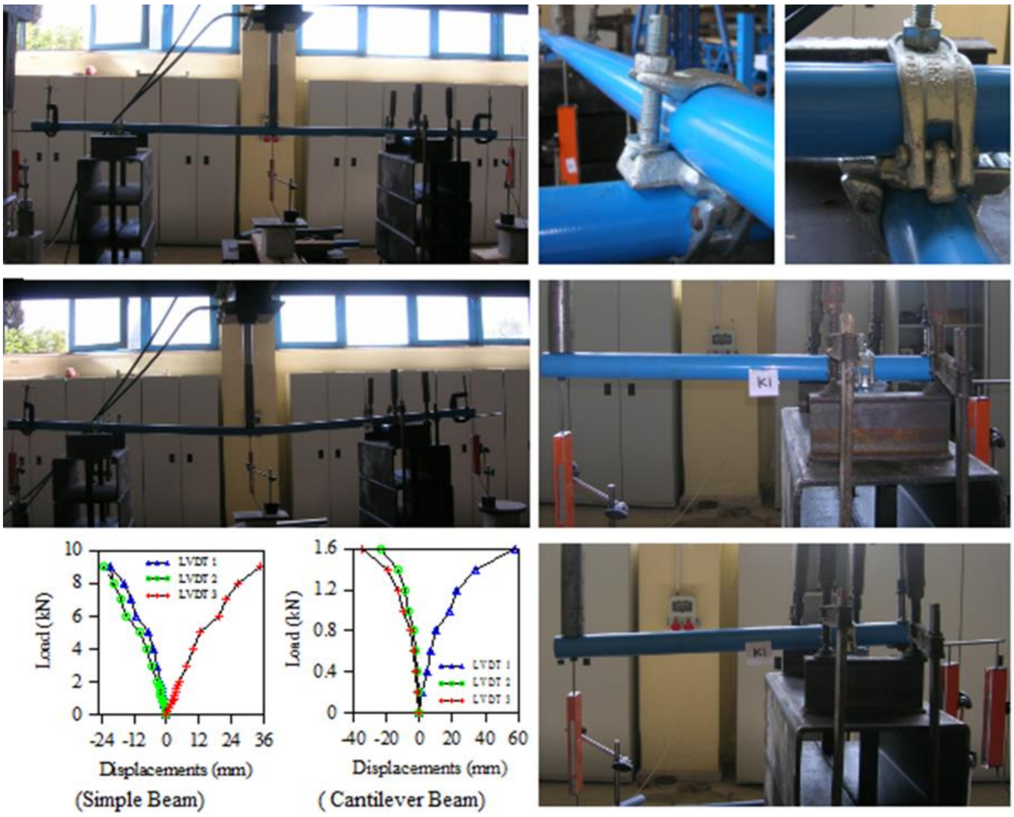

Fig. 6 Some photographs from loading test of purlins and load-displacement curves

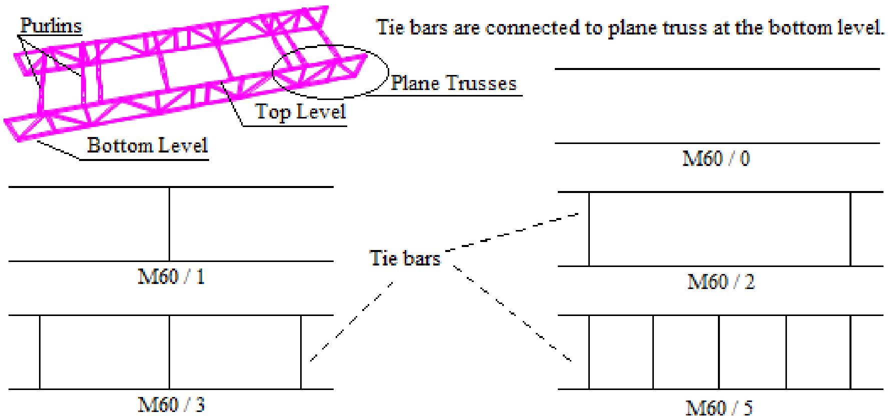

Fig. 7 Different system conditions of the scaffolding used in loading tests

unknown parameters. So experimental investigations are done to determine these parameters. A single load is applied to wooden and displacements were measured using three linear variable differential transducers (LVDTs). Some photographs from the tests and load-displacement curve are given in Fig. 5. From the tests, the elasticity modulus of wooden is calculated as 9485 MPa. The connection between purlin pipes and plane trusses are provided using swivel coupler 48/48. To determine the flexible rigidity of the connection point, both of loading tests on simple beam and cantilever beam were done. Some photographs from the tests and load-displacement curve are given in Fig. 6. It is observed from the test that the swivel coupler 48/48 provides a considerable flexible rigidity between purlin pipes and plane trusses. So purlins and also tie bars are connected to plane trusses as semi-rigidity in finite element modelling of scaffolding systems.

3.3 Experimental tests

The loading tests were done for five different system conditions to determine the structural performance. The means of system conditions are the numbers of the tie bars which are used to connect the plane trusses at the bottom level (See Fig. 7). Fig. 7 also includes the plane trusses and purlins of the scaffolding systems. In the system, the plane truss is called shortly as M and it has 60 cm height. So the name of the tests is presented with M60 and number of tie bars used for each system. The mean of the each test name is explained below:

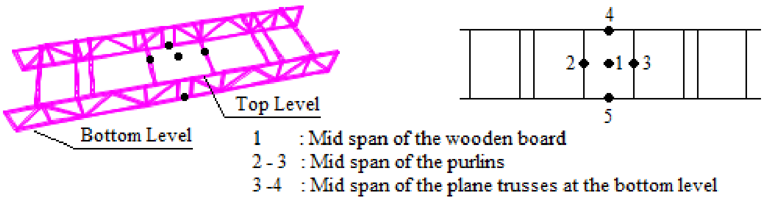

Fig. 8 Location of the linear variable differential transducers during the loading tests

Fig. 9 Some photographs from the loading tests for each system condition

- **M60 / 0:** There is no tie bar in the system
- **M60 / 1:** There is only one tie bar at the middle of the plane truss
- **M60 / 2:** There are two tie bars at the beginning and at the end of the plane truss
- **M60 / 3:** There are three tie bars at the beginning, at the middle and at the end of the plane truss
- **M60 / 5:** There are five tie bars with equal distances from the beginning to end of the plane truss

The tests were performed with the vertical hydraulic jack by loading to the center of the transmission platform for each system condition given above respectively. After each testing, the system was unloaded, the system was brought into the startup and the tie bars were connected to the other system condition. In the tests, the load is not applied to scaffolding systems as exceeding load capacity due to unknown of failure time and failure mode of the scaffolding systems. But the system is loaded as much as

Table 1 The maximum loads applied to the scaffolding systems and measured displacements

		Critical Points					
		1		Average of 2-3		Average of 4-5	
		Load (kN)	Disp. (mm)	Load (kN)	Disp. (mm)	Load (kN)	Disp. (mm)
System Conditions	M60/0	49.00	50.12	49.00	44.76	49.00	14.84
	M60/1	55.32	41.21	55.32	38.18	55.32	18.18
	M60/2	57.56	39.96	57.56	36.50	57.56	13.82
	M60/3	54.92	35.81	54.92	31.20	54.92	12.53
	M60/5	63.91	46.52	63.91	41.88	63.91	14.59

possible considering steel profiles and connection rigidities. The load-displacement curves for each test were obtained at five critical points of the scaffolding system where linear variable differential transducers (LVDTs) were taken into place (See Fig. 8). The first point is midspan of the scaffolding system and it is on the wooden floor. Second and third points are on the midspan of purlins and fourth and fifth points are on midspan of the plane trusses. Some photographs from the loading tests are shown in Fig. 9.

During the tests, the maximum loads applied to the scaffolding system and measured displacements are listed in Table 1. As seen in Table 1, the ultimate displacements measured on the wooden board (point 1) are bigger than those of the purlins (average of 2-3 points), and the ultimate displacements measured on the purlins are bigger than those of plane trusses (average of 4-5 points) for each scaffolding system condition. As though the load transmission is from the wooden board to the plane trusses via the purlins. So, such a result should be normally expected. On the other hand, the ultimate displacements measured for each system condition on the plane trusses (average of 4-5 points) are nearly three times smaller than those of wooden board and purlins. So it can be concluded the system will be damaged due to insufficient strength of wooden board or insufficient stability between purlins and plane trusses when considering the material properties of the structural elements of scaffolding system.

In addition, as seen in Table 1, the maximum displacements on critical point are measured for M60 / 0 system condition which has no tie bar in the system. The maximum displacements have a decreasing trend when increased the tie bars in the scaffolding system. However, the displacement measured for M60 / 5 system condition which has most tie bars are bigger than those of M60 / 1, M60 / 2, and M60 / 3. It is considered that the reason of the result is more of the loading value on this test and the fatigue of the system due to cyclic loadings. However, when Table 1 is examined it is seen that M60 /2, M60 / 3 or M60 / 5 system conditions which have two, three and five tie bars respectively are suitable for sufficient structural performance of the scaffolding system. However, the cost of M60 / 2 and M60 / 3 system conditions are cheaper than the cost of M60 / 5.

The load-displacements curves obtained for each scaffolding systems on the critical points are illustrated in Figs. 10 and 11. As seen in Fig. 10 the displacements measured on the critical points for each system condition except M60 / 0 have an increasing trend linear elastically.

It is clearly seen in Fig. 10 that the displacements measured on the wooden board (point 1) and purlins (average of 2-3) are near to each other. However, they are approximately three times bigger than the displacements measured on the plane trusses (average of 4-5). When examined Fig. 11, it is appeared that the displacements obtained on the wooden board (point 1) and purlins (average of 2-3) for M60 /2, M60 / 3 and M60 /5 system

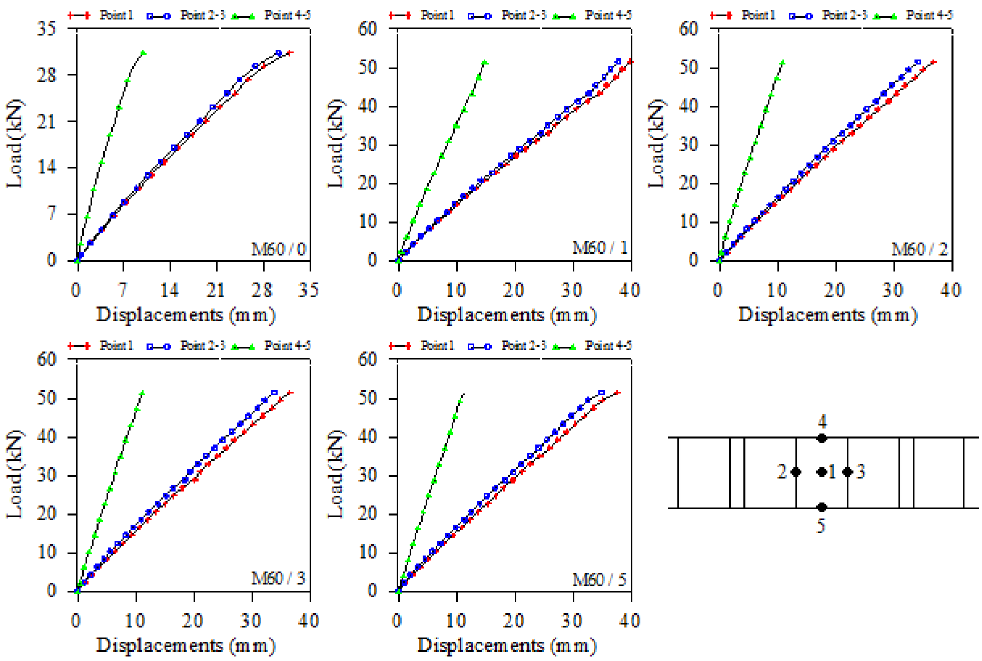

Fig. 10 Load-Displacements curves on the Point, Point 2-3 (aver.) and Point 4-5 (aver.) of the each scaffolding system (the critical points are illustrated in the same graph)

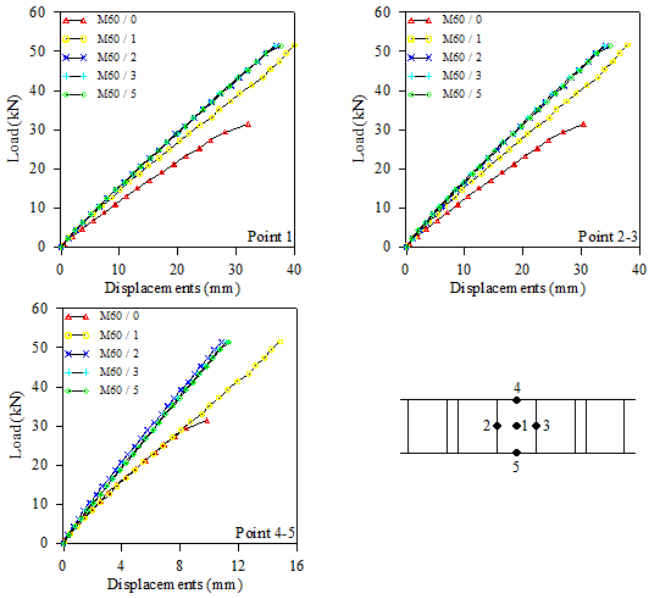

Fig. 11 Load-Displacements curves on the Point, Point 2-3 (aver.) and Point 4-5 (aver.) of the each scaffolding system (different scaffolding systems are illustrated in the same graph)

conditions are near to each other and smaller than those of M60 /1, also the displacements obtained for M60 /1 are smaller than those of M60 /0. Similarly, the displacements occurred on the plane trusses (average of 4-5) for M60 /2, M60 / 3 and M60 /5 system conditions are smaller than those of M60 /1 and M60 /0. The displacements obtained for M60 /1 and M60 /0 system conditions are nearly close to each other However, M60 /0 has started to behave plastically after 30 kN loading. So the system is not loaded to prevent possible damages. In addition, the authors think that when considering economic and safety requirements M60 / 2 and M60 / 3 have the optimum structural performances compared the results obtained for other scaffolding system conditions.

3.4 Numerical modeling and analyses

3D finite element model (FEM) of the scaffolding system for each system conditions and load transmission platform are constituted using SAP2000 (2017) software given in Fig. 12. In the modeling, plane trusses are fixed with simply and movable supports. Purlins are connected to plane trusses with releases considering a rigidity. Similarly, wooden floors are connected to purlins considering releases. Also, the wooden floor is not modeled as a single part, it is modeled part by part as given in experimental setup. The sections of the truss system, wooden board, and purlins are shown in Fig. 12. The elasticity modulus of the wooden board is assumed as 9485 MP in numerical studies which are obtained from experimental loading test (see Fig. 6), also the values are considered as 200000 MPa for steel truss and steel purlin. In the analyses, scaffolding system and load transmission platform are assumed as weightless. The Poisson ratios for wood and steel are considered as 0.2 and 0.3, respectively.

The static analysis of each scaffolding system were performed under vertical loading. The ultimate load values applied in the experimental tests for each system condition were used the numerical models. The ultimate loads values and obtained vertical displacements on the critical points for each system conditions are listed in Table 2. Table 2 is also considered the results of each experimental test results to make a healthy comparison with the numerical results.

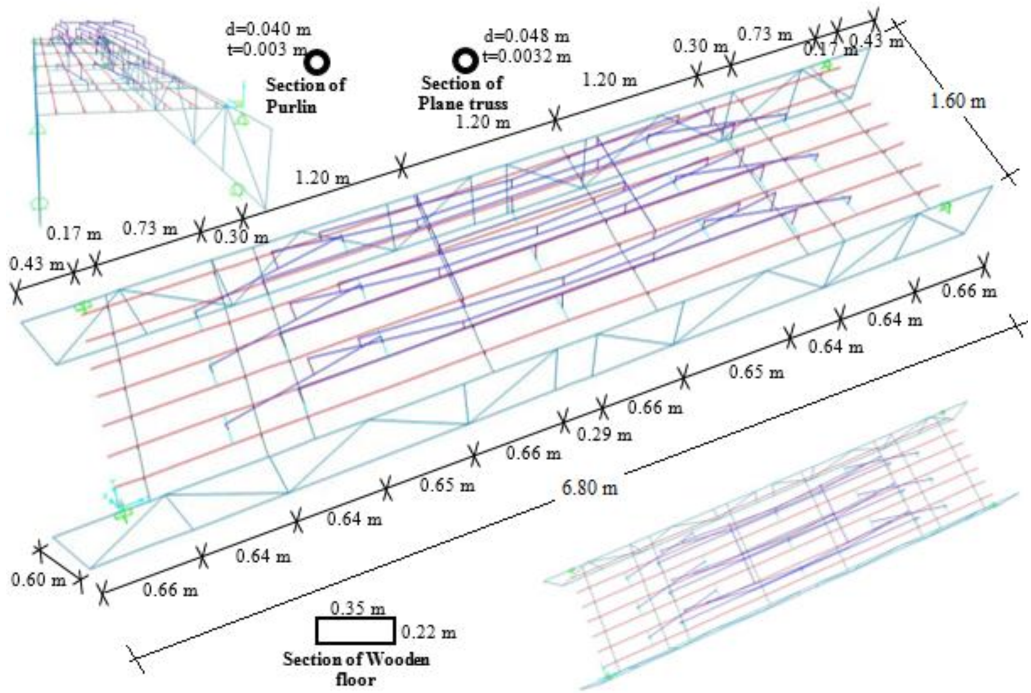

Fig. 12 3D finite element model of formwork system and load transmission platform

Table 2 The ultimate loads applied to the scaffolding systems, measured and obtained displacements on the scaffolding systems

			Displacements on Critical Points (mm)					
			1		Average of 2-3		Average of 4-5	
			Test	FEM	Test	FEM	Test	FEM
System Conditions	M60/0	31.43	31.99	32.15	30.28	28.71	9.85	9.52
	M60/1	51.58	39.86	38.42	37.82	35.60	14.83	16.95
	M60/2	51.48	36.80	35.74	34.17	32.65	10.83	12.36
	M60/3	51.48	36.55	33.57	33.81	29.25	11.11	11.75
	M60/5	51.48	37.60	37.47	34.98	33.73	11.27	11.75

3.5 Evaluation of experimental and numerical results

The experimental and numerical results have similar behaviour for the same system conditions. Also, the displacements occurred on the wooden part are bigger than those of purlins and the displacements occurred on the purlins are bigger than those trusses. On the other hand, it was thought that the displacements of the critical points would change as a decrease from M60 / 0 to M60 /5 because of the increased numbers of tie bars. However the results showed that M60 / 2 and M60 / 3 systems have a good and enough behaviour related to displacements results and economical point of view. Because M60 / 2 has two tie bars compared to M60 / 5 which has five tie bars. But it is important to highlight that the tie bars of M60 / 2 system are taken places at the beginning and at the end of the plane truss. However other systems have one of tie bars on the middle span of the system where single load is applied. Here, it is understood that the structural behaviour is changed due to connection rigidity between tie bars and truss.

Vertical displacement of the truss system is affected by configuration of bottom-tie-bar. The configuration creates stiffness against vertical displacement because of moment capacities of the bottom-ties-bars. Their moment capacities result in boundary conditions for beams semi-connected to truss systems which issue is illustrated in Fig. 13. As seen in Fig. 13 the real system is converted to conjugate model with a reduced system. By means of symmetric property of the reduced system it is evaluated as symmetric which is seen in Fig. 13(c) and Fig. 13(f). Fig. 13(c) illustrates semi-connected joint while Fig. 13(f) pin-connected joint. Since the effect of semi-connection is seen, these two systems are considered for example. Under distributed loading moment diagrams of these systems seen in Fig. 13(d) and Fig. 13(g), respectively, are different because of their connections. When just looked into moment diagrams of upper beam in Fig. 13(h) and Fig. 13(e), the diagram in Fig. 13(e) has negative part. This means that maximum vertical displacement of the beam reduces as seen Fig. 13(h) and Fig. 13(e). Moreover the effect of connection of beam to truss systems is seen in whole truss system given in Fig. 14. As seen in Fig. 14, deformed shapes of bottom chords of the truss system in plane are observed under vertical loading. Configuration of bottom-tie-bars creates different deformed shape of the bottom chords.

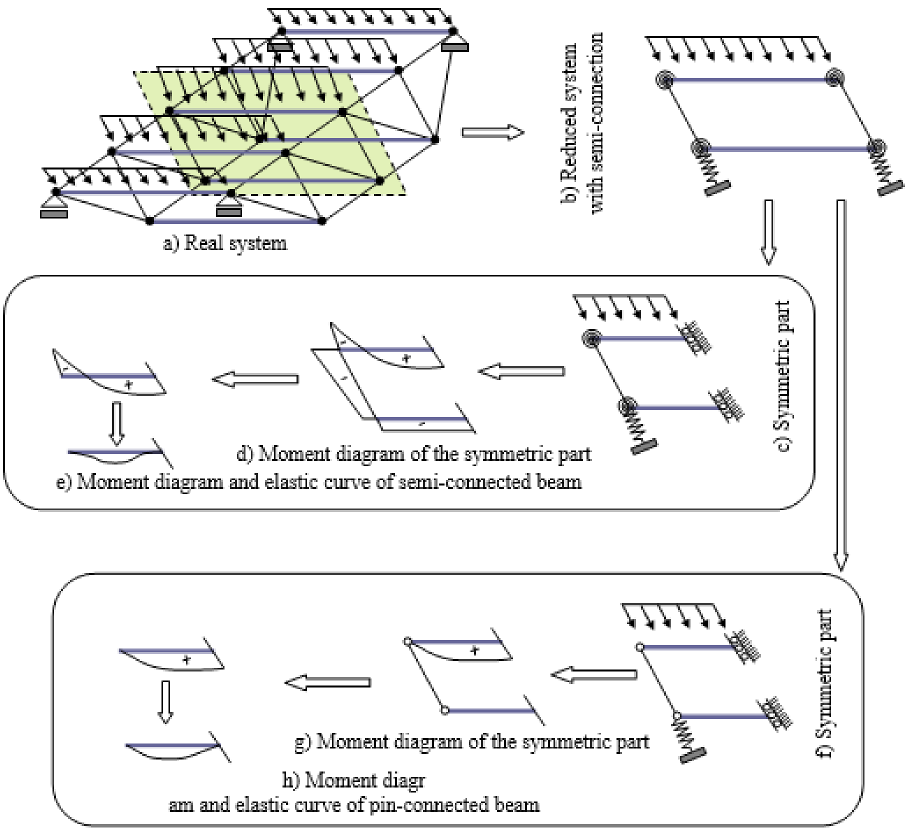

Fig. 13 Schematic view of moment capacities of the tie bars used on the systems

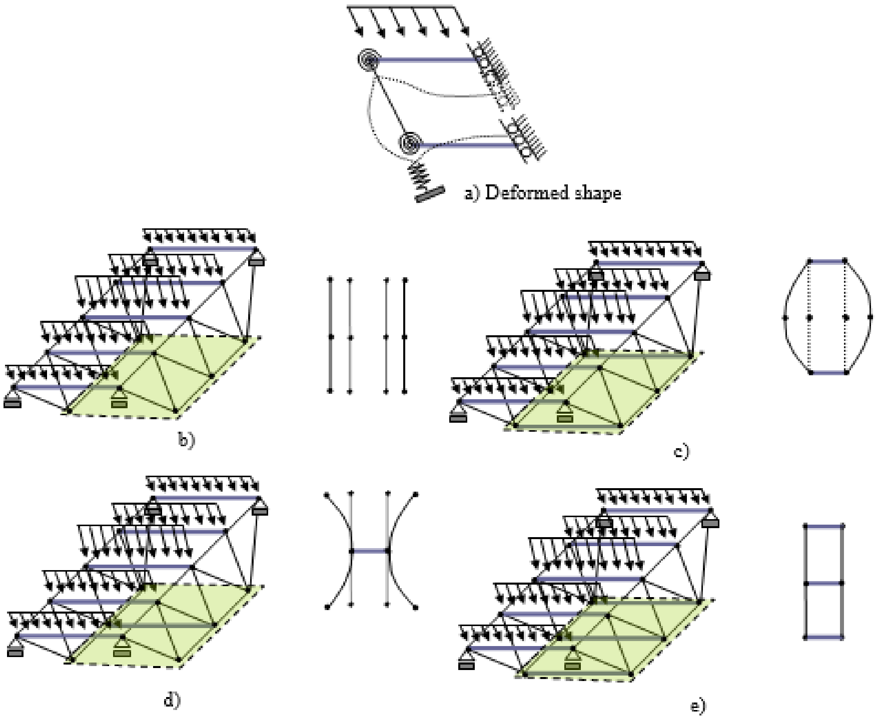

Fig. 14 The deformed shapes of bottom chords of the truss system

4. Conclusions

This study experimentally and numerically evaluated the structural performance of 3D steel pipe rack suspended scaffolding systems under vertical loading is investigated experimentally and numerically. The tests and analyses are performed on a standard 3D scaffolding system for different system conditions which are used to determine structural behavior. In experimental tests, a developed load transmission system is put on the system and the system is loaded on the center step by step using a load jack. In numerical studies, the finite element models of the 3D steel pipe rack suspended scaffolding systems considering different systems conditions are constituted using SAP2000 software to support the experimental tests and to use the models in future studies. In the study, the following results and conclusions are specified below:

- The ultimate displacements measured on the wooden board (point 1) are bigger than those of the purlins (average of 2-3 points), and the ultimate displacements measured on the purlins are bigger than those of plane trusses (average of 4-5 points) for each scaffolding system condition.
- The ultimate displacements measured for each system condition on the plane trusses (average of 4-5 points) are nearly three times smaller than those of the wooden board and purlins. So it can be concluded the system will be damaged due to insufficient strength of wooden board.
- The maximum displacements on the critical points are measured for M60 / 0 system condition which has no tie bar in the system. The maximum displacements have a decreasing trend when increased the tie bars in the scaffolding system.
- The displacements measured on the critical points for each system condition have an increasing trend linear elastically.
- The displacements measured on the wooden board (point 1) and purlins (average of 2-3) are near to each other. However, they are approximately three times bigger than the displacements measured on the plane trusses
- The displacements obtained on the wooden board (point 1) and purlins (average of 2-3) for M60 / 2, M60 / 3 and M60 /5 system conditions are smaller than those of M60 / 1, also the displacements obtained for M60 /1 are smaller than those of M60 / 0. Similarly, the displacements occurred on the plane trusses (average of 4-5) for M60 / 2, M60 / 3 and M60 /5 system conditions are smaller than those of M60 / 1 and M60 / 0. However, although M60 / 1 system condition has a tie bar, the displacements obtained for the scaffolding are bigger than the displacements occurred for M60 / 0 system condition which has no tie bar.
- Considering the displacement responses of all scaffolds studied in this work, M60 / 2 shows the best rigidity and structural responses. While both M60 / 3 and M60 / 5 can satisfy safety requirements, the T60-2 system is recommended when safety and cost-savings are primary considerations.

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