Süleyman Demirel Üniversitesi
Fen Bilimleri Enstitüsü Dergisi

Suleyman Demirel University
Journal of Natural andAppliedScience

19(2), 97-103, 2015

Diaphragm Effect of Steel Space Roof Systems in Hall Structures

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(Alınış Tarihi: 30.06.2015, Kabul Tarihi: 22.07.2015)

Keywords:
Diaphragm effect,
steel space roof systems,
hall structures.

Abstract: Hall structures have been used widely for different purposes. They have are reinforced concrete frames and shear wall with steel space roof systems. Earthquake response of hall structures is different from building type structures. One of the most critical nodes is diaphragm effect of steel space roof on earthquake response of hall structures. Diaphragm effect is depending on lateral stiffness capacity of steel space roof system. Lateral stiffness of steel space roof system is related to modulation geometry, support conditions, selected sections and system geometry. In current paper, three representative models which are commonly used in Turkey were taken in to account for investigation. Results of numerical tests were present comparatively.

1. Introduction

Diaphragm behavior is defined with structural behavior of joints and the frames in lateral dimension. In other words, diaphragm behavior is a combination of frame and joint interaction in slab level due to any lateral effects. The structural behavior is a combination of all structural members and slabs. Load effects play an important role as well as the structural members and slabs.

Due to any high magnitude earthquake effects, diaphragm behavior becomes more effective in lateral dimensions. Lateral rigidity is critical for all structural frames in the lateral dimension. Due to computational difficulties, slabs are considered as loads in frame analyses, instead of considering diaphragm effects. Not considering diaphragm behavior mislead the analysis results. The unique solution would be considering slabs as a structural member and considering diaphragm effects.

After 1994 Northridge earthquake, most of the building got severe damages or collapsed due to extreme displacements [Iverson JK, Hawkins NM, 1994]. Therefore, there are limitation given in most of design codes and specifications for displacement and story drift ratios. Due to any lateral loading, lateral stability can be defined with diaphragm behavior. Diaphragm behavior plays an important role in lateral dimensions. Diaphragm behavior is directly related with external loads and internal effects of the loading. Structural stability is also definition of interaction between slabs and structural members. There are various research works for diaphragm effects for steel structures, effects were also researched by various researchers [Mazzolaniet all, 1998]. For residential buildings and bridges, there are also various studies for diaphragms effects [Lee, et all, 2005, 2007, Zahrai, andBruneau , 1998, 1999].

The main function of roof systems is to support gravity loads (covering material and snow loads) and to transfer these loads to columns and walls. The other function of them is to play a role in the distribution of wind and seismic forces to structural system. The horizontal loads such as seismic and wind loads are transferred by means of the building floors and roof to column and frame systems and wall of structure. [Chilton, J. 2000]. Diaphragm behavior of structures is depending on loading and building proportions, rigid diaphragm behavior, flexible diaphragm behavior and semi rigid diaphragm behavior. The distribution of horizontal forces by the horizontal diaphragm to the various vertical lateral load resisting elements depends on the relative rigidity of the horizontal diaphragm and the vertical lateral load resisting elements. A diaphragm is classified as rigid if it can distribute the horizontal forces to the vertical lateral load resisting elements in proportion to their relative stiffness. In the case of rigid diaphragms, the diaphragm deflection when compared to that of the vertical lateral load resisting elements will be insignificant. A diaphragm is called

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flexible if the distribution of horizontal forces to the vertical lateral load resisting elements is independent of their relative stiffness. In the case of a flexible diaphragm, the diaphragm deflection as compared to that of the vertical lateral load resisting elements will be significantly large. A flexible diaphragm distributes lateral loads to the vertical lateral load resisting elements as a series of simple beams spanning between these elements. No diaphragm is perfectly rigid or perfectly flexible. Reasonable assumptions, however, can be made as to a diaphragm's rigidity or flexibility in order to simplify the analysis. If the diaphragm deflection and the deflection of the vertical lateral load resisting elements are of the same order of magnitude, then the diaphragm cannot reasonably be assumed as either rigid or flexible. Such a diaphragm is classified as semi rigid. [Naeim, F. 2003]

In the design of the hall buildings, space steel construction and R/ C structural members are considered separately. This separation could mislead the analysis results. The difficulty in the combination causes this separation. In general, first, spare steel structures are defined and solved. Then R/ C structural members are designed according to computed space steel frame loads. In considering diaphragm effect is causing problems in terms of structural definitions and determinations. In reality, space steel frame is affecting structural lateral stability. However not considering space steel behavior in lateral direction causes errors in structural analysis. With the diaphragm behavior definition, more reliable solutions are available.

2. Steel Space Truss Systems

The most significant expectation for ages has been building structures which are as high as possible, without column and wide-spanned in architecture. Also it is vital to cover these structures are space truss systems. Similarly; economic, rapid, safe and aesthetical solutions in space systems are possible by prefabricated steel space system. In wide-span structures, prefabricated steel space truss systems are preferred instead of classical steel roof constructions, etc. They provide economic solutions in using the wide gaps in diverse geometries passing without columns as indoors. Steel space systems are used in places such as industrial areas, factories, air-plane and helicopter hangars, swimming-pools, sport-centers, storerooms, theater-opera saloons, cinemas, stands, shop, school buildings, laboratories and fair-departments and in addition, they are highly economic structure systems.

Steel space frames are formed by bars in plane and connection bars to the joints. These two bar systems could be in different shapes. The systems are studied by Le Ricolais from the USA, Du Chateau from France, Z. Makowski from England since 1950 [Makowski, 1988]. First, joints were designed bolded or welded. Gradually, different types of connections have been produced in time through development in technology. New technology brought standardization and precast systems. Precast technology is applied for connections, bars or triangular or rectangular built up sections. Hence, modulation brings efficiency and comfort in design. Steel space structures have various beneficial properties, such as lightness and rigidity. Higher degree of hyper static to compensate insufficiency of a member; max efficiency of material; wide area of design; precast design and construction easiness are some of the beneficial structural properties. Different type of constructional difficulties has been solved via various techniques. Design difficulties have also been solved via technological developments. Prefabricated steel space structures have high stability. Different geometries and long spans would be possible to be constructed in an economic way. Moreover, the system can be constructed very fast due to prefabricated construction with minimum problems. Steel space structures, distributes the loads in three dimensions, which increases the stability. In space structures, each joint point, connects there different bars in three dimension. Connections have higher hyper static degree. Therefore, they can be assumed as pinned connections. For long spans, the only reasonable solution is prefabricated steel space structures. In space structures, pipes can easily be placed. Any type of roof sheeting can be applied. Heat transfer is more reasonable considering to others. Since bar lengths are close to each other, joint displacements are reasonably small. Relocation of the structure is also possible due to demonstrability. It allows different combination of the construction. Construction time is less comparing to others that cause an important amount of cost saving. It is more economic many other construction problems are resolved due to its construction easiness. System is economically beneficial for enterprisers and for general. There are a lot of joint types which have been used in engineering practice. These are Wachsman, Oktaplatte, S.D. C, Triodetic, Varitec, Unistrut, Gero, MeroveNodus. In Turkey, Mero node has been commonly used (Figure 1.).

Figure 1. Example of hall structure and their nodes in Turkey.

3. Models

Space steel structures are carried by R/ C members with longer spans. These structures are constructed as swimming pools, sport halls, meeting locations and convention centers. For hall structures, short length is in between 40- 100 meters. For such a long span, steel space structure is the best constructional solution. In Turkey, these structures are widely used in different purposed buildings. Three different types of space steel hall buildings are the most common ones in Turkey. The models are designed according to different types of buildings and construction. The Model buildings were considered in this study. The models are demonstrated in Figure 1, 2, 3 . Three type models are used for numerical investigation. All analysis are in linear elastic region both material and geometry. Under the static loadings, displacement versus both with steel roof system and without steel roof system has been determined by using SAP 2000 –V14 software. Results of analysis of models have been given as tables and graphics. In analysis, concrete class C20, reinforcement S420, Structural steel material is ASTM 36 (f_y = 235 N/mm^2 ,f_{u}= 360N/mm^2)

Figure 2. Model M1 (Vault system- 48m* 40.1 m in plan, h=7 m).

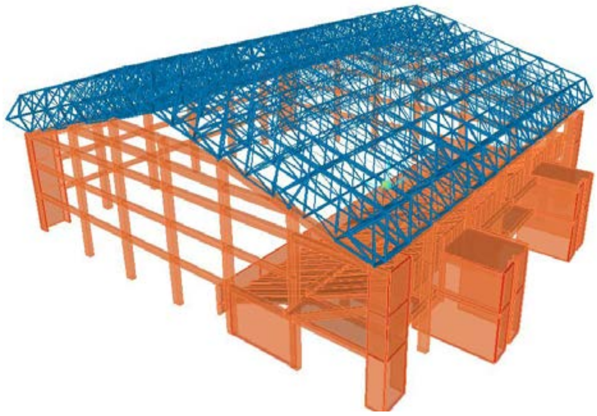


Figure 3. Model M2 (Broken system- 44.7m*51.2m in plan, h=11 m)

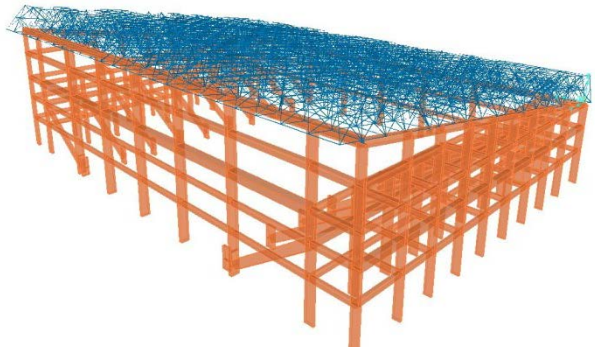


Figure 4. Model M3 (Flat system- 62.5m*45.2m in plan, h=10 m)

4. Numerical Results

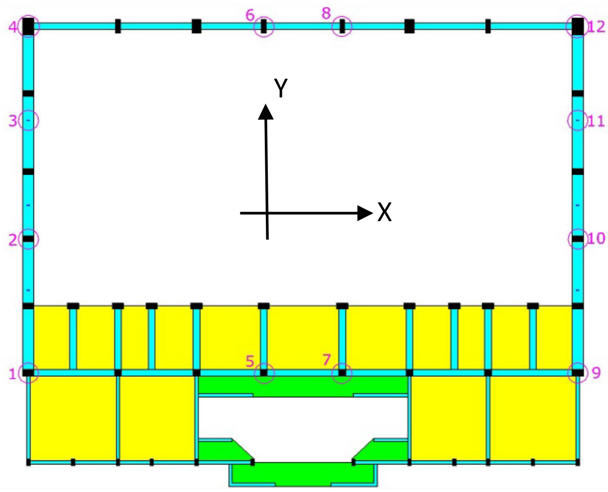
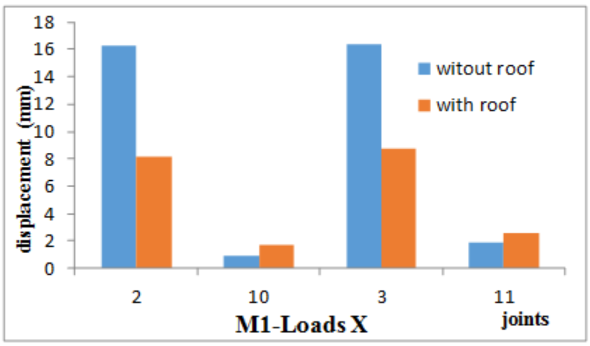
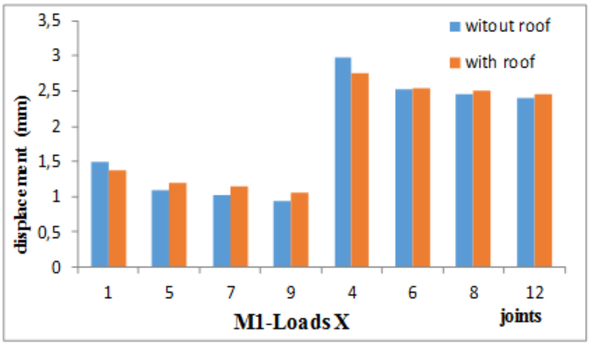


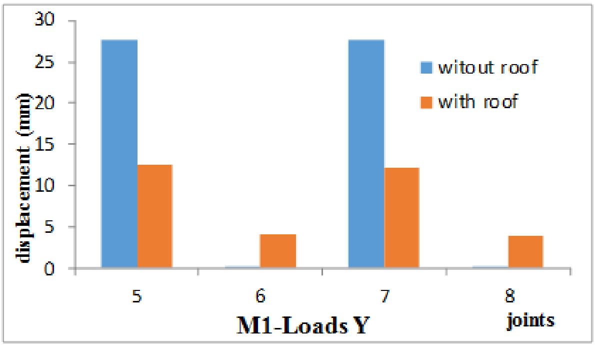
Figure 5. Displacement nodes of Model M1



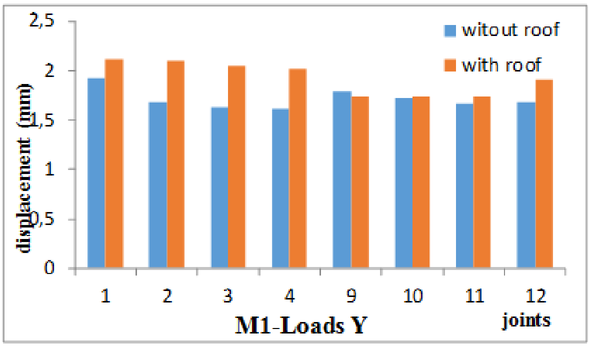
a) X direction displacements of 2-10 and 3-11 nodes



b) X direction displacements of 1-5-7-9 and 4-6-8-12 nodes



c) Y direction displacements of 5-6 and 7-8 nodes



d) Y direction displacements 1-2-3-4 and 9-10-11-12 nodes

Figure 6. Displacements versus some selected nodes of Model M1

Replacement in the x and y direction of the twist nodes on the same axle is given in different graphs. For 2 and 3 nodes which have no connection in x direction, displacement of node without roof is two times long than with roof (Figure 6a). The twist nodes numbered 1-5-7-9 and 4-6-8-12 that are connected each other with connection beam move together, and so replacement of the roofed and roofless situations/conditıons are resulted in closed conclusıons with each other (Figure 6b).We can say the same situation for the y direction (Figure 6c-d).

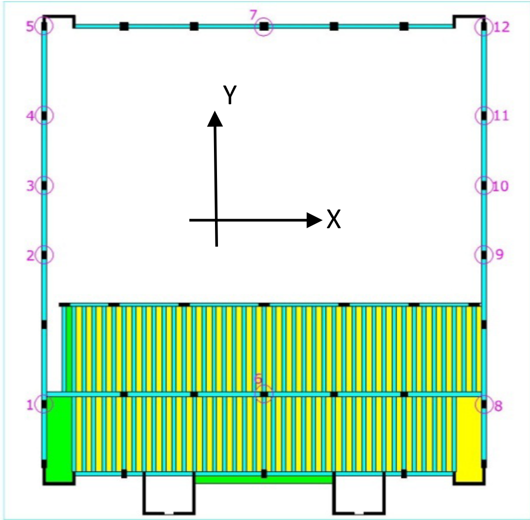
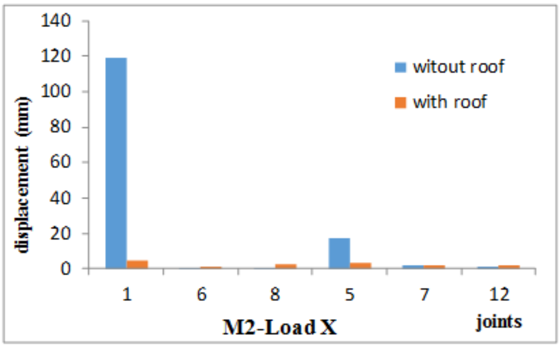
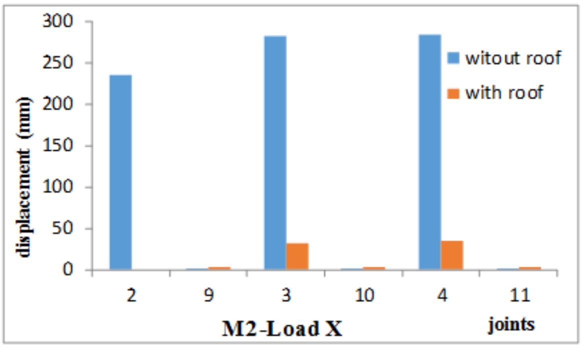


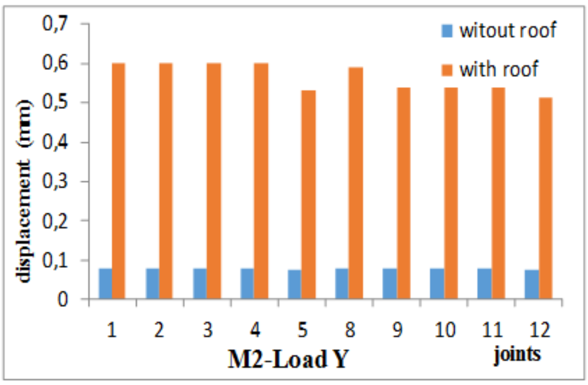
Figure 7. Displacement nodes of Model M2



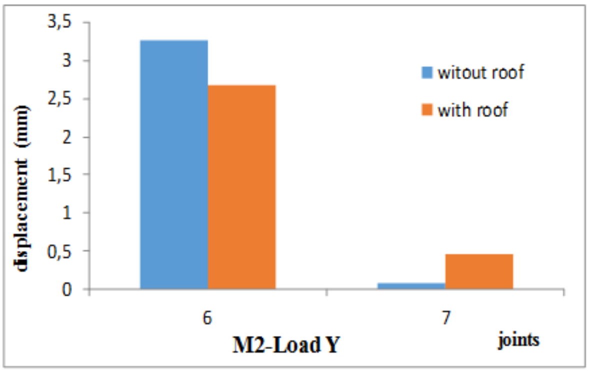
a) X direction displacements of 1-6-8 and 5-7-12 nodes



b) X direction displacements of 2-9, 3-10 and 4-11 nodes



c) Y direction displacements of 1-2-3-4-5 and 8-9-10-11-12 nodes



d) Y direction displacements of 6-7 nodes

Figure 8. Displacements versus some selected nodes of Model M2

Roof items decrease the replacement while helping the movement of the twist nodes together (Figure 8). When we looked at the y dırectıon, we see some replacements on the twist nodes affected by the load, but, as there is no load on the control nodes, replacement in the roofless situation/ condition is less than the roofed condition.

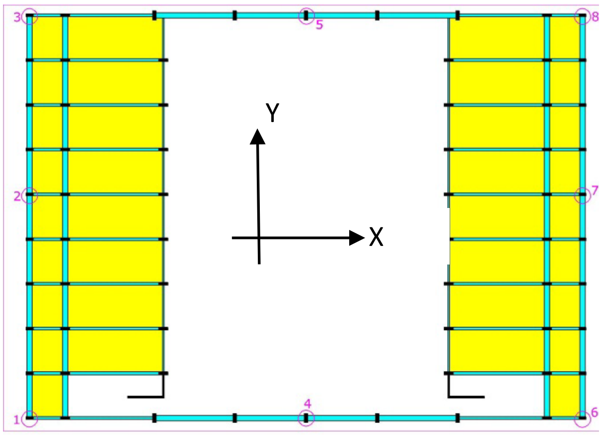
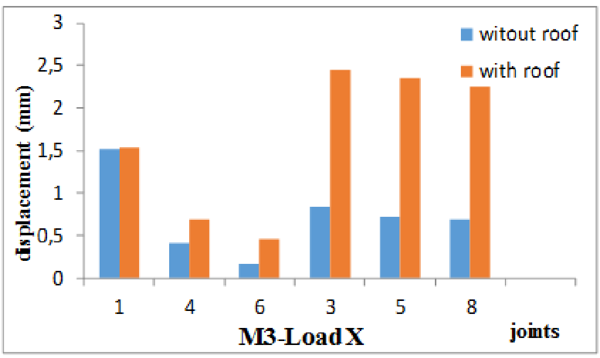
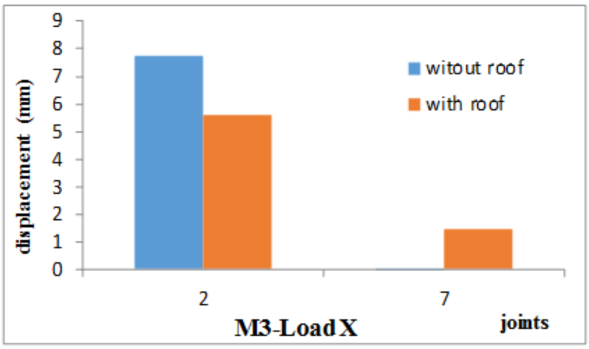


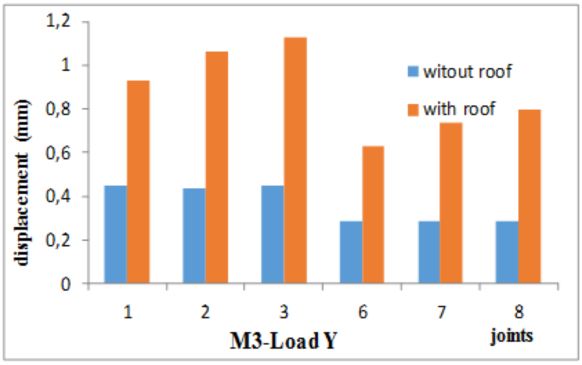
Figure 9. Displacement nodes of Model M3



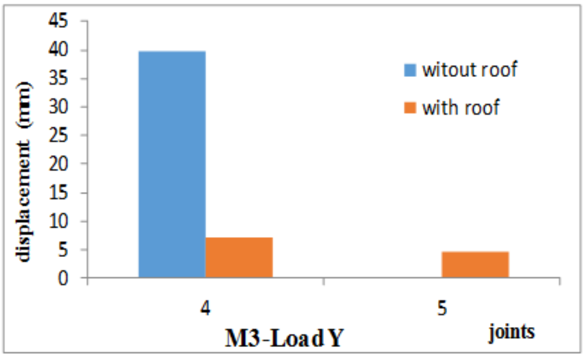
a) X direction displacements of 1-2-3 and 3-5-8 nodes



b) X direction displacements of 2-7 nodes



c) Y direction displacements of 1-2-3 and 6-7-8 nodes



d) Y direction displacements of 4-5 nodes

Figure 10. Displacements versus some selected nodes of Model M3

As it is seen in the Figure 10, replacement in the roofless conditions affected by the load is maximum (twist poınt numbered 4, Figure 10d) Because of the connection by the roof items between the twist nodes, distribution of the load between nodes is delivered to all items. The carrying of the load by all the items decreases the replacement of the twist nodes numbered 4.

5. Conclusions

Space steel structures are playing an important role in lateral stability. Lateral stability capacity is directly related with the behavior of the roof structure. Roof geometry, (For example, broken, vault flat etc.)

module length, module height, boundary conditions (simple support, roller or fixed), support spans, support freedom dimensions, joint types (mero, etc) special construction ratios etc. play an important role in increasing lateral stability. Considering all of these parameters in the present study, roof geometry effect is considered in the stability analyses with different types of three real models.

An exact definition of structural stability by considering diaphragm effect is only possible in case of definition of all different types of parameters. In the literature, there is only limited information is available. Therefore the present study will be very valuable in the structural stability definition of the space steel hall buildings. The study is considering roof geometry effects on diaphragm behavior. Moreover, the effects of roof geometry on lateral stability with different types of diaphragm effects have been researched by using various methodologies.

The following conclusions can be drawn from the present study:

1. Diaphragm behavior of a hall structure is depend on roof geometry(modulation, support conditions, lateral stiffness of roof system, spans of hall structure, roof shapes such as broken, flat an vault)

2. Diaphragm behavior of hall structures with steel space roof system can be defined flexible. Diaphragm behaviors are neither rigid nor semi-rigid.

3. Hall structures have to been analyzed and design with together roof systems.

4. Rigid divisions of hall structures play important role diaphragm behavior of hall structures. Therefore, in the separated analysis, torsional effects have to been taken in to account of design of steel space roof systems.

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