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Designing a prefabricated sandwich composite roofing system Made up of resisting facings and light- weight concrete core with truss-shaped connectors

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Abstract

In this paper, a new roofing system is introduced, which is constructued using the precast composite sandwich panels. This roofing sandwich panels system consists of three kinds of precast concrete sandwich panels including capital panels, beam or between columns panels, and slab or middle panels. The panels are composed of three layers; A high strength reinforced concrete top layer. A thick layer of light- weight concrete as the intermediate layer or core. And a tensile resistant reinforced concrete bottom layer. The panels are connected together by special connectors at the edges. In this research, the influence of shear connector stiffness is studied which is measured according to their diameter on ultimate resistant and combined performance of the panels. The results of finite element analysis by ABAQUS software show a logical behavior of load-deflection curves in shear connectors. Based on the economic and weight comparisons the dead and live loads, the proposed sandwich panel roofing is approximately 44 percent lighter than the conventional steel joist and concrete blocks. This comparison shows the superiority of this roofing system to joists and concrete blocks system and seems to be a good alternative for it. Due to the possibility of prefabrication and industrial production of the panels under factory conditions, and various other technical, economic, and constructional advantages of this roofing system, it is concluded that it can be viable substitute for current roofing systems in low to high-rise buildings and can save a considerable amount of material, labor, time, and cost in building construction.

Keywords: Precast Sandwich Panels, light concrete Core, Resisting facings, Shear connectors, Composite.

1. Introduction

Construction of buildings using non-industrial traditional systems has many shortcomings in both quality and quantity. In the last few years, a considerable number of requirements to increase the efficiency in building sector have indicated the fact that using old building construction systems is not responsive to community needs and using superior technology is quite inevitable in this field. Constructing building systems with potential, industrial, and prefabricated production can meet the quantitative and qualitative needs of the construction industry.

One of the industrial constructions means to lighten buildings and save materials which are taken in to account in civil engineering in recent decades is the application of sandwich layers. Numerous developments and changes have been made to lighten the walls, roofs, fuselages, ship decks, and bridges using sandwich layers in previous years in which these changes are gradually exploited especially in structural and earthquake engineering. In recent years, concerning scientific advances in global level, the weight of every square meter of building roofs, which is the most important portion of the dead load, is gradually being diminished and it led to decreased base acceleration and collapsing forces toward the building as well as lightened ones due to the earthquake effect. Concerning the number of buildings which are going to be built in coming

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years, if economic and optimal methods are met in terms of resistance to forces toward the structure and a quiet environment is created in terms of reducing sound transition, heat, and fire, there will be a significant achievement in saving materials, human resources.

Since the value of earthquake force follows structure weight function (V=CW) and the fact that most part of structure weight (W) is the dead load which is mainly formed by ceiling weight, the lighter weight and in particular lighter ceilings will lead to less force to the structure and reduced total weight and structure cost. Thus, one of the modern technologies is to use the prefabricated sandwich panel with resisting facings and light-weight concrete core.

In the past few decades, a considerable number of researches were conducted concerning prefabricated sandwich panels. Apparently, 3D prefabricated sandwich panels were first introduced and recorded by Victor Wiseman California, the US in 1967 and they were popularized as sandwich panels by Shot Crete in international markets and used in building industry. Among these researches, the study of Benayoune et al. studied the axial resistance capacities (axial load) and the structural behavior of concrete prefabricated sandwich panels in 2007and 2008[1-3].Also, Erika Schaumann et al. studied the light concrete sandwich panel and hybrid FRP to improve prefabricated sandwich slab system in 2008 [4-6]. Ahmad and Mohammad in 2011 studied the structural behavior of light prefabricated concrete sandwich panels concerning environment and structure [7]. Einea Amin et al. in 1994 can be pointed out which studied the prefabricated concrete sandwich panels system with high thermal resistance and optimum structural efficiency [8]. Mohammed Hussin Ali Dawood et al. in 2013 studied Structural Behavior of Composite Sandwich Slab Panels [9]. Noridah, Mohammad et al. in 2014 studied Structural Behavior of Precast Light-Weight Foam Concrete Sandwich Panel With Double Shear Truss Connectors Flexural Load [10]. Mujahid Amran et al. in 2016studied Response of precast foamed concrete sandwich panels to flexural loading Journal of Building Engineering [11]. The objectives of the research is to study deformation behavior, rupture models, and effective development parameters of a model to predict load carrying behavior, improve and develop hybrid sandwich concrete slab for ceilings and construction applications which can be easily installed in the building and provide a new designing engineering method. Also, making buildings light is possible by taking advantage of sandwich panels with resistant external layers and light interlayers which is an interesting and famous topic in structural engineering.

2. System prefabricated sandwich roof

Concerning the behaviors of ceiling subjected to the weight forces, the roof behaves like Figure 1. It means that pressure concrete on the roof, and steel or tensile bars are important in the middle of the ceiling, and these forces are vice versa in edges. Due to compression or rupture of the roof, the orange parts at the top and the bottom of the roof are called tensional region where reinforced concrete steel should be palced. The green parts are called compressive regions where concrete material can sufficiently carry the loads.

The suggested sandwich slab primarily developed structures for use in whereas it can also be used in the construction requirements. This roofing system consists of three kinds of precast concrete sandwich panels including capital panels, beam or between columns panels, and slab or middle panels. The panels are composed of three layers; a high strength reinforced concrete top layer, a thick layer of light- weight concrete as the intermediate layer or core, and a thin, flat or corrugated steel plate, and or a tensile resistant reinforced concrete or reinforced plaster bottom layer.

Based on the economic and weight comparisons under the code dead and live loads, the proposed sandwich panel roofing is approximately 44 percent lighter than the conventional steel joist and concrete blocks. This comparison shows the superiority of this roofing system to joists and concrete blocks system and seems to be a good alternative for it. [12]

This sandwich system can be used as the floors and roof for structural systems such as shearing-bearing masonry wall systems, reinforced concrete frames with shear- wall systems, and rigid or braced structural steel frames. If the vertical and lateral load carrying system of the structure is made of the masonry load bearing walls or reinforced concrete frame, then one- way or two-way slab type panels are used for covering of the floors or roof. When the vertical and lateral load carrying system is made of the structural steel frames, then the steel columns can be made up of hollow rectangular boxes, structural pipes or composite columns made up of double steel channels or I-beams, and the lateral load carrying system can be rigid or braced frames. In this case, the sandwich roofing acts similar to precast Flat-Plate roofing systems in reinforced concrete structures and can be considered as a replacement for this kind of roofing system.

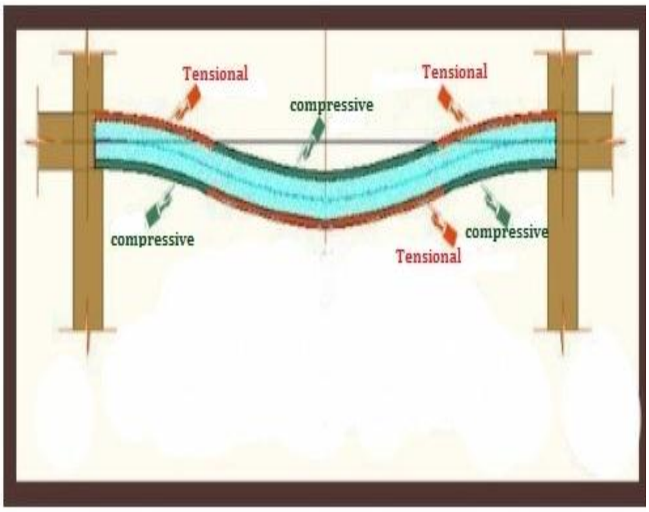


Figure 1. Imaginative figure of roof reformation with analysis which applied forces in neutral level. (no earthquake and lateral forces)

2.1- Different types of prefabricated sandwich panels

In this research, after designing and comparison of various prefabricated sandwich panels with light core-concrete in ABAQUS software package, the optimal model was selected [13]. The optimal prefabricated concrete sandwich panel consists of two layers including reinforced concrete composed of a resistant concrete level as the top level, a thick light concrete layer, and shear connectors. This model enjoys the best performance in the broad and focused load with simple bearings around as one-way, two-way, and lightning (Figure 2).

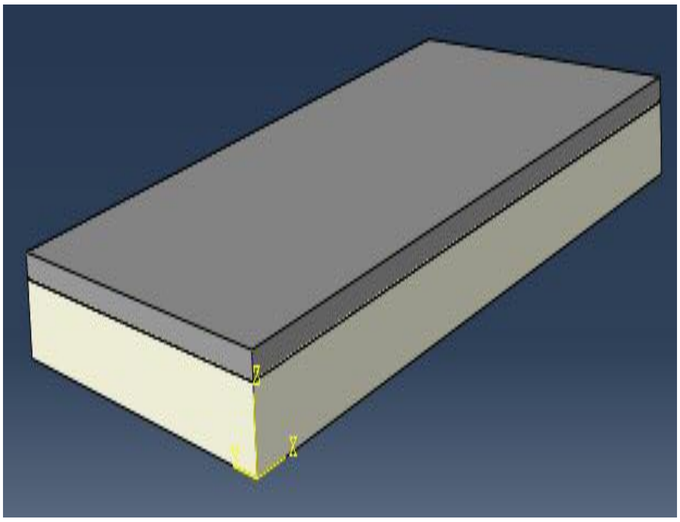


Figure 2. prefabricated concrete sandwich panel with two concrete layers (Optimal slab).

Overall, sandwich roof (Figure 3) is made up of three types of prefabricated sandwich panels as following.

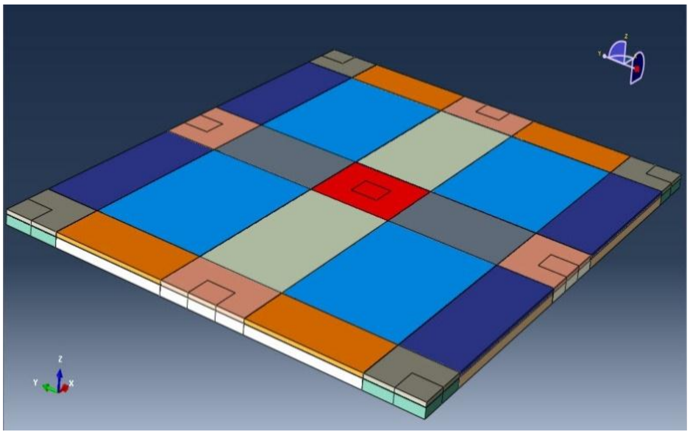
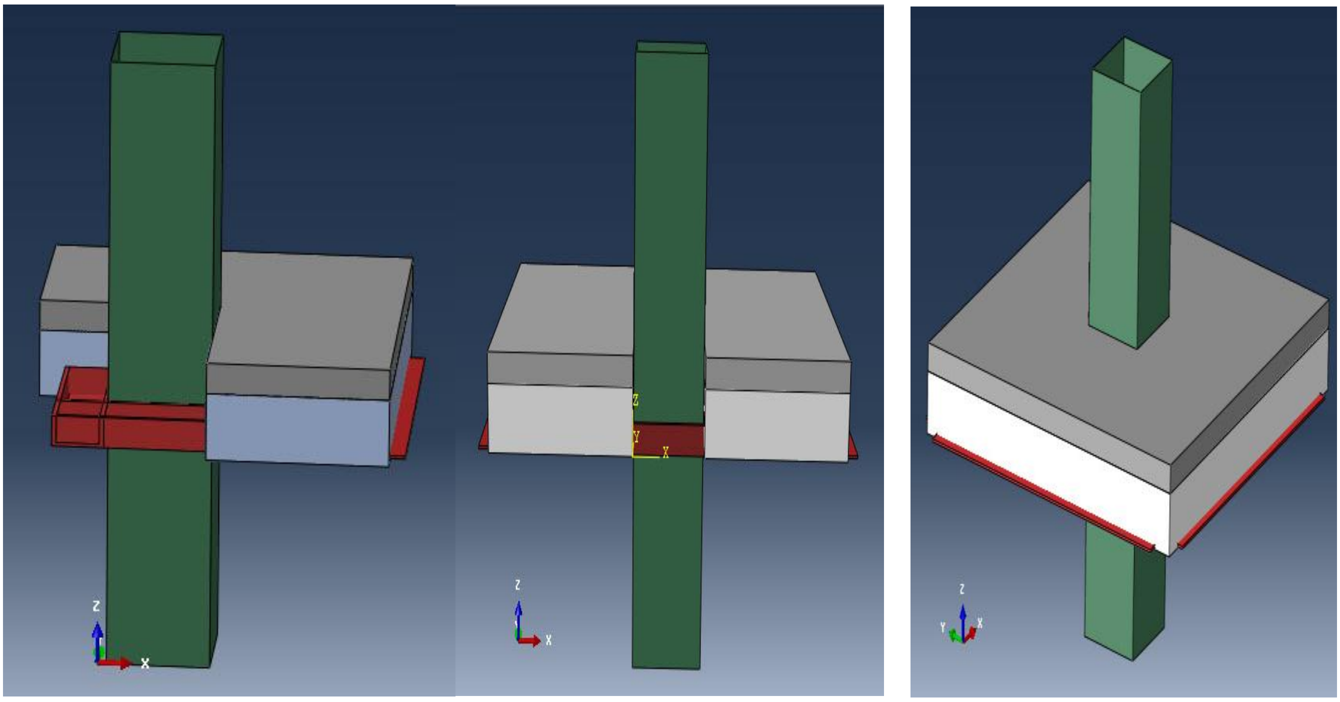


Figure 3. 3-D plan of roofing with 25 prefabricated sandwich panels

A. Capital panel: The function of this panel is creating a bearing for the panels among the columns, transferring their load, and shear caused by the weight around the columns. These panels should have high punching shear resistance, and also because negative moments have existed around the columns, they should be able to tolerate this negative moment. In these panels, in order to connect the panel to the column, special connectors are used such as U-beam on their edges whether in restrained or joint form. As shown in the presented figures, they are connected to the columns by U-beam components and they will be resistant to punching shear. (Figure 4)



a: Connecting the capital to the next column. **b**: Connecting the capital to the corner column. **c**: Connecting the capital to the middle column

Figure 4. connecting the capitals to the column.

B. Inter-column panel: The duty of these panels is transferring their load and inter-panel load to the capitals. They play the role of wide beams. They should have the sufficient resistance to carry the edge loads they will receive loads of two-way panels from one side or even two sides. These panels are connected to capital and inter-panel either in restrained or joint form by connecting angles or special connectors on their edges. (Figure 5)

C. middle panel: These panels are aimed at transferring their live and dead load to inter-column panels. In order to connect these panels to capital and intercolumns, special connectors are used such as angles to connect them in either restrained or joint form. (Figure 6)

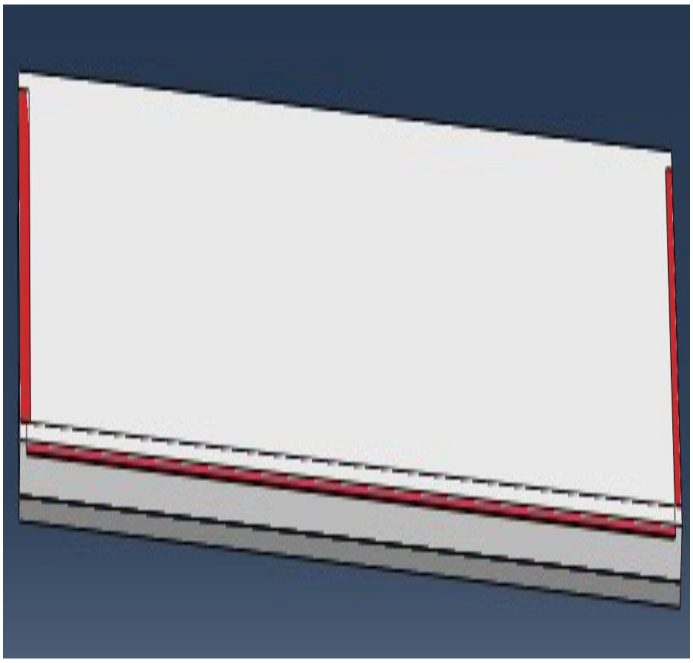


Figure 5. Inter-column paneland the location of connecting angle in panel's lower layer.

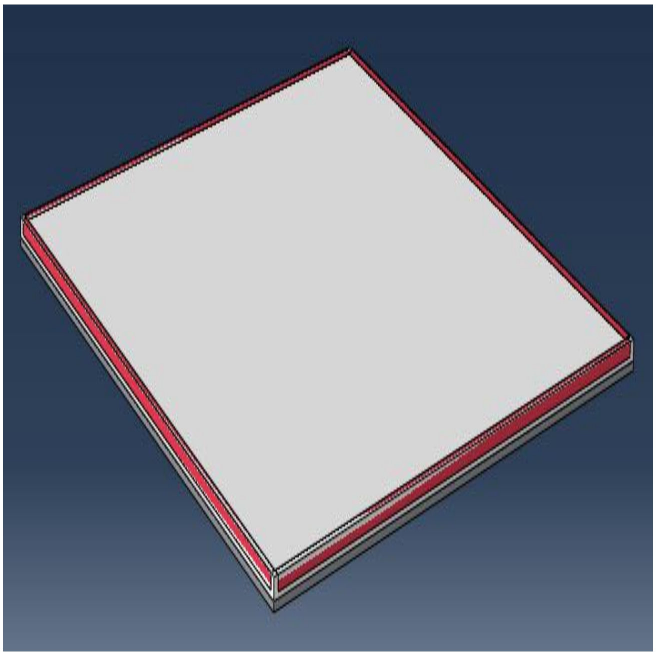


Figure 6. iddle paneland the location of connecting angle in the lower layer.

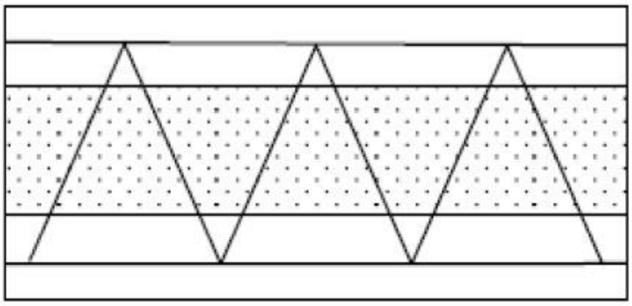


Figure 7. A section of the sandwich panel.

2- 2. Different layers of prefabricated sandwich panels

Precast concrete sandwich panels (PCSP) which are made of resisting facings and light-weight concrete core, were tied together with truss-shaped shear connectors equally spaced along the length of the panel as depicted in Figure 7. The arrangement and spacing of shear connectors vary in PCSP depending on several factors such as desired composite action, applied load, the span of the panel, and type of shear connectors. There are no specific rules for arranging the connectors [14-15]. The structural behavior of the panel depends heavily on the strength and stiffness of the connectors while the thermal resistance of the insulation layer governors the insulation value of the panel. Depending on the degree of composite action, a PCSP may be regarded as fully composite, semi-composite, or non-composite panel [3].

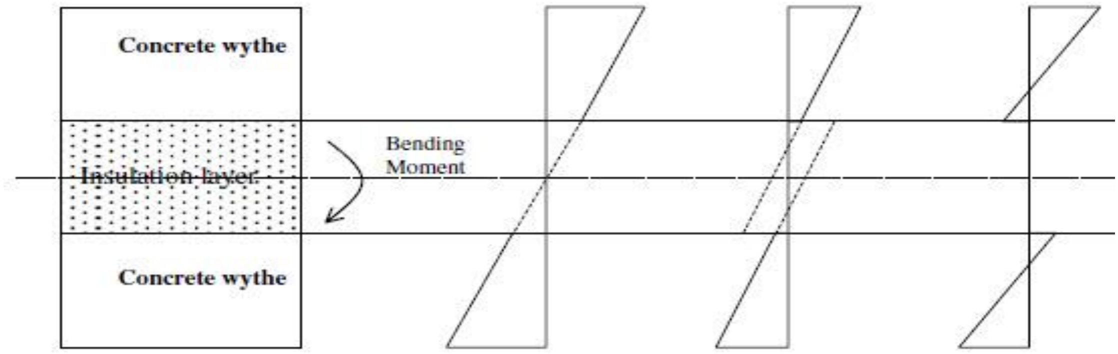
Fully- composite panel: In this panel, two concrete plates work as a similar unit subjected the applied loads until the breaking instant. The fully-composite panel is fractured without rupture of shear connectors as the longitudinal reinforcing bars have flowed or reinforced concrete layer is broken. (Figure 8-a)

Semi- composite panel: In these panels, shear connectors only transfer a part of total longitudinal shear which is transmitted in the state of fully-composite. In these panels, shear connectors are ruptured before the longitudinal reinforcing bars have flowed or reinforced concrete layer is broken. (Figure 8-b)

Non- composite panel: If shear connectors that connect two layers of reinforced concrete to each other do not have the capacity to withdraw full transition of longitudinal shear. The independent performance of the concrete layer leads to the uncombined functioning of the panel. (Figure 8-c)

This roofing sandwich panels composed of three layers; A highly resistant reinforced concrete as the upper layer with the thickness of 50mm, meshes of longitudinal and transversal concrete reinforcing bars with the thickness of 6mm, sink of 100*100 mm, and 25 mm concrete clad on the bars. A thick layer of light- weight concrete with the thickness of 80mm as the intermediate layer or core. The lower layer consists of light- weight concrete with the thickness of 30mm, meshes of longitudinal and transversal tensile bars nominal diameter of 10mm, and concrete clad of 20mm. The two layers of reinforced concrete are connected to each other using truss shear connectors made of 6 mm bars which are in distances of 250mm (Figure 9).

The lower slab pavement concrete has the minimum thickness, since it is only used to cover the steel. Thus, the middle light concrete can be used in these conditions.



a: Fully- composite b: Semi- composite c: Non- composite

Figure 8. Strain distribution of in the bending panel [3]

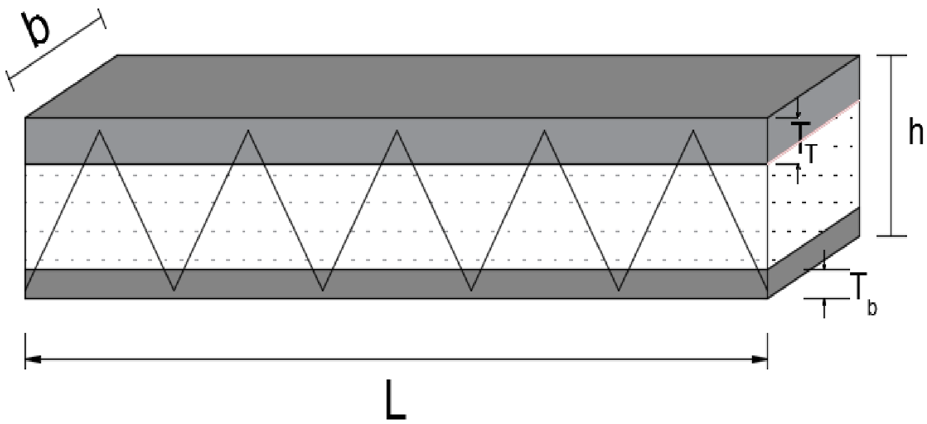


Figure 9. A section of the sandwich panel.

Table 1. Mechanical properties of upper layer

Concrete	Fc=30mpa	r =0.2	E_c =27386mpa	W_c=2400 Kg/m3
Steel	F_y =300mpa	r =0.3	E_s =210000mpa	W_s=7850 Kg/m^3

A. **The upper layer:** This layer is made up of resistant concrete with the thickness of Tt. The interior steel is deployed as a heating control (Table 1).

B. **Middle layer (Core):** As listed in table 2, this layer is made up of light concrete which tends to achieve two purposes. The first one is giving the required height to create the shear head arm in the panel. The higher the altitude is, the more the girder bending resistance would be. The second one is tolerating the shear force throughout the girder and it can also be useful for pressure caused by bending. This fact avoids the bending of pushing components inside the concrete which are formed from cross bars in shape of two-way trusses. Thus, these bars can obtain their maximum compressive strength.

Table 2. Mechanical properties of Middle layer (Core)

Concrete	Fc=7.5mpa	r =0.15	Ec=3000mpa	W_c=800 Kg/m^3

Table 3. Mechanical properties of Shear connectors

Shear Steel	Fy=300mpa	r=0.3	Es=210000mpa	W_s=7850 Kg/m^3

Table 4. Mechanical properties of lower layer

Concrete	Fc=21mpa	r=0.2	Ec =22913mpa	W_c=2350 Kg/m^3
Steel	F_y=400mpa	r=0.3	Es=210000mpa	W_s=7850 Kg/m^3

C. **Shear connectors:** Push- pull two-way trusses bars are inside the light concrete in which their role is shearing especially at two ends of panel. The shearing force is strengthened with light concrete and truss bars (shear connectors). These bars mainly play the role of second-line defending and bearing the extra shear force (See table 3).

D. **The lower layer:** This layer is made up of resistant concrete with the thickness of T_b which would be cracked and its pulling resistance is negligible. However, there is steel inside which plays the role of receiving the stretch caused by bending. The concrete of this layer has only got the role of covering the bars and therefore, has minimum thickness. In some of the states, the light concrete of the inter layer plays this role and thus, the lower layer of resistant concrete can be removed. Mechanical properties of material of the lower layer are listed in table 4.

2- 3. Steel structure building with prefabricated concrete sandwich panels

In the utilized method in this paper, the columns are made of box-section, the bracings are made of double U-beams and the girders are made of IPE. Except for the girders used in bracing opening, all other girders are removed and some prefabricated panel bands with various widths play the role of steel girder among the columns. The connection of the ground to the columns is rigid and the connection among the inter-column panels, inter-panel, and capital is flexible. This method contains floor cast panels, the roof on the ground, and lifting them to their position. After constructing the foundation, installing the columns, placing concrete, and after a required period of time for achieving the desired resistance, first, the capitals are accurately installed in the determined point and altitude, and then inter- column and intermediate panels will be connected to the mechanical connectors and placed on the top of the columns, respectively. Floor slabs are gone up until their successive position. Analyses are done in order to find whether the slabs are accurately placed in the pre- determined points and heights or not. After construction of the roof, steel cross bracings and connecting girders are used in required panels in order to obtain a resistant system to lateral loads caused by wind or earthquake, which are independent to the roof and connected to steel columns (Figure 10).

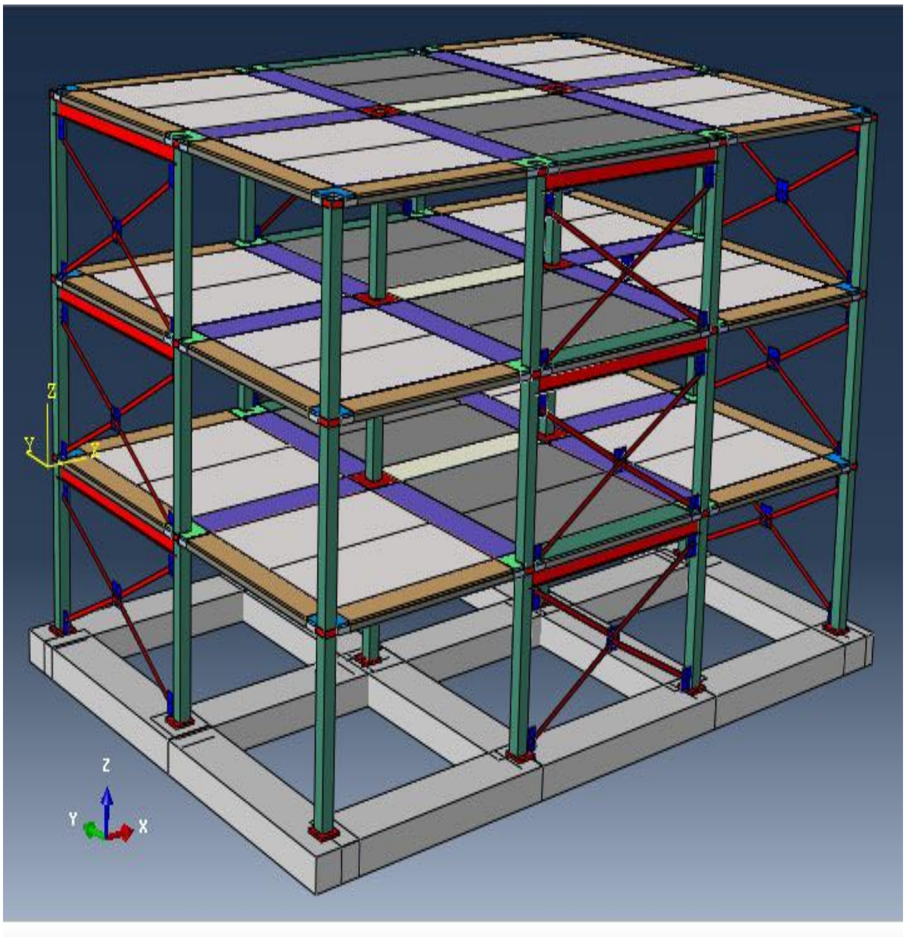


Figure 10. 3-D demonstration from a 3-floor building with steel structure and light prefabricated sandwich panel roofs

2- 4.Features of prefabricated sandwich roof system

In order to design the system, designing, construction analysis, and economic and executive evaluation were considered. The construction of the system is easier than concrete Lift-Slab system because it is not monolithic and it does not require pouring in- place concrete. The roofing system is made of many light components such as column panels, beam panels, and middle panels. So, it does not have to use several heavy cranes for their installation. Under heavy loads or for large spans, the thickness of the column panels, beam panels, and middle panels can be different from each other, thus this system can enjoy some advantages similar to that of Flat-Slabs with drop panels and conical column capitals and slabs on wide beams, too. One of the advantages of this system is the separation of roofing duty from those of structural framing which is responsible for carrying vertical and lateral loads. The lateral load, due to wind or earthquake, are resisted by steel braces and between- column steel beams installed under the roofing panels and connected to the steel columns and are independent of roof panels. Also, all the girders are removed except the ones used in bracing opening and prefabricated panels' bands do the job of girders with different widths. The joint connections in prefabricated sandwich slab lead to no transition of the moments from one panel to another. This is a great benefit since the high amount of bending and torque moments will not transfer to connecting regions, columns, and inter-panel columns in two-way performance panels. In addition, according to its type, the light concrete core can be structural or even non-structural and it is obtained based on light concrete standards that can be from foam concrete type and its role is to create suitable spaces between the lower and the upper layer as well as encompassing middle truss reinforcements and bearing shear. It should be mentioned that this light concrete layer creates a lateral bearing to some parts of truss reinforcements which are under pressure and feasible to ricochet to avoid ricocheting in low forces. On the other hand, other reinforcements help the middle light concrete avoid precocious cracking and disjointing due to shear. Furthermore, inside reinforced bumps of the light concrete connected to the upper reinforced network placed in the upper concrete level, work as shear head and increase slip resistance of the two layers. The computational results show that the interaction of these two components leads to the total resistant increase of slab. In addition, upper layer pavement can be embellished by appropriate flooring which doesn’t need stonework, tiling, as well as no requirement to increase the floor layers.

3. Modeling and analysis of nonlinear finite element ABAQUS software

In this research, ABAQUS software is used due to features such as "appropriate graphical environment, creating complex models, accuracy and high speed, ease of application and a change in the different modules of the program and the possibility to define compensation and very versatile output and so on” [16]. On the modeling, it has been an effort to minimize the simplification and geometric model and other characteristics are completely similar to the original and applicable model.

While the loads are static, due to the crunchy and nonlinear material behavior, the analysis is conducted using the central difference method and using a dynamic explicit step (Dynamic Explicit) that is one of the best option in dynamic methodthe for changing large forms and complex contact problems. It has a top speed of solution, the proper convergence in a smaller time period, automatic call detection, the higher permeability of two pieces, the capability to the easier analysis of very large forms deformation, better ability at non-linear cases.

For modeling of concrete solid- element and steel rebar's the wire element is used. That upper and lower network layers and the shear bar connecting two panels used in the Module Assembly are linked together using the Merge. At all samples to determine the bearing capacity slab of the one spot (RF) Reference is considered in the center of it, to measure the maximum displacement of the span and the ability to draw suitable graphs. On the Mesh module using a second-order equation for concrete layers in all samples the elements Hex (6 sided 20-node cubic elements) is used. Mesh size in all samples due to the complexity of the model and the accuracy of the analysis are assumed to be 5 cm.

Rebar’s network in the concrete layer to bind Embedded region is defined using bounded and surface to surface contact between two surfaces, with factor friction 0.9 and system as Hard contact is also applied.

Optional modules in ABAQUS software systems: Length (m), force (N), time (s) and other units are based on these units.

4. The behavioral model of the concrete

To describe the nonlinear behavior of concrete of concrete damaged plasticity behavioral model (Hybrid model for plastic - concrete damage) which is the most sophisticated and widely used behavioral model will be used to simulate concrete. This model is able to simulate the cyclic behavior of concrete as well as much more.

In this study, one of the most famous models in the study of the non- confined concrete behavior of the Park, Kent [17] is used. The relation of this model as follows:

$$\sigma_c = F'_c\left[2\left(\frac{\varepsilon_c}{\varepsilon'_c}\right) - \left(\frac{\varepsilon_c}{\varepsilon'_c}\right)^2\right] \tag{1}$$

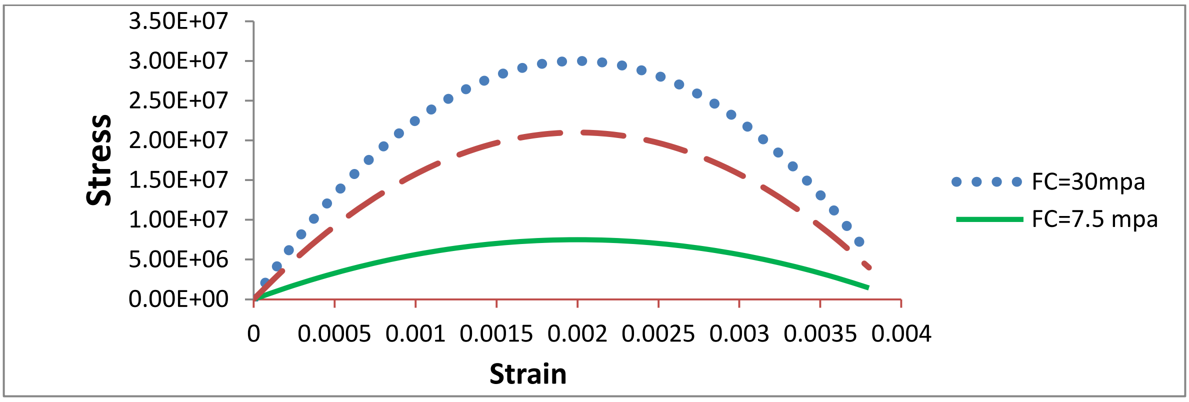


Figure 11. comparison of the graphs of used Stress- strain concrete behavior in the sandwich panels

In this relation, are Compressive stress and strain, respectively, and are the compressive strength of cylindrical specimens of concrete and its corresponding strain respectively. Paulay and Park [18] reported the value of about 0.002. In this study, the value of this parameter is considered equal to 0.002. This relation can make a parabola. Of course, its behavior after reaching the compressive strength of concrete as a nonlinear and on continuing this line cylindrical concrete specimens of compressive strength approximately 20 percent will be continued and disconnect. This is not far from the reality given that High compressive strain of concrete keeps approximately 20 percent of their strength. (Figure 11).

5. Effects of orientation of shear connector

In order to study the effect of truss shear connectors directing, two models of prefabricated concrete sandwich

panel are modeled and analyzed based on the standards in ABAQUS software (Figure 12). This models contains a one-way panel with dimensions of 150*400 cm (P1-6) and a two-way panel with dimensions of 240*400 cm (P2-6) (The first index

shows that the panel is either one- way or two-way and the second one shows the grade of the shear connector bar). The panels are composed of two layers: A high strength reinforced concrete top layer with thickness of 50mm, meshes of longitudinal and transversal concrete reinforcing bars with thickness of 6mm, sink of 100*100 mm, and 25mm concrete clad on the bars. A thick layer of light- weight concrete as the bottom layer with thickness of 110mm, meshes of longitudinal and transversal tensile bars nominal diameter of 10mm, and concrete clad of 20mm. The two layers of reinforced concrete are connected to each other using truss shear connectors made of 6mm bars which are in distances of 250mm (Figure 13). The curve of deflection-force shows the inter-range in directions of X and Y for one-way and two-way panels (Figure 14).

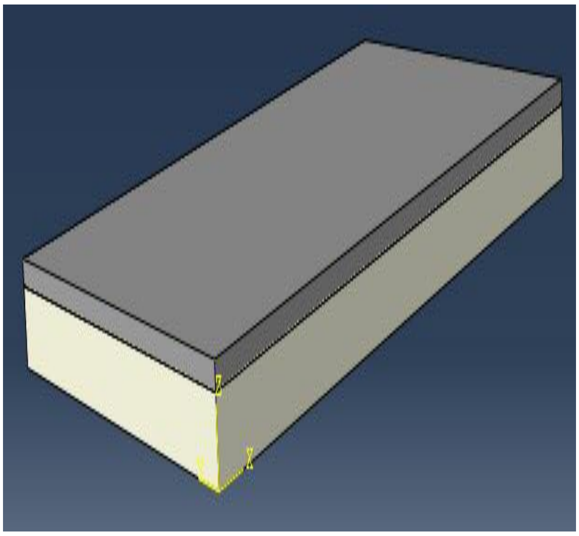


Figure 12. Sandwich panel

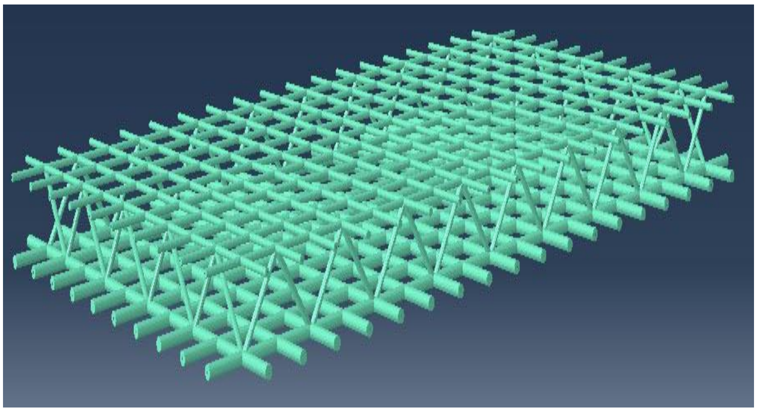
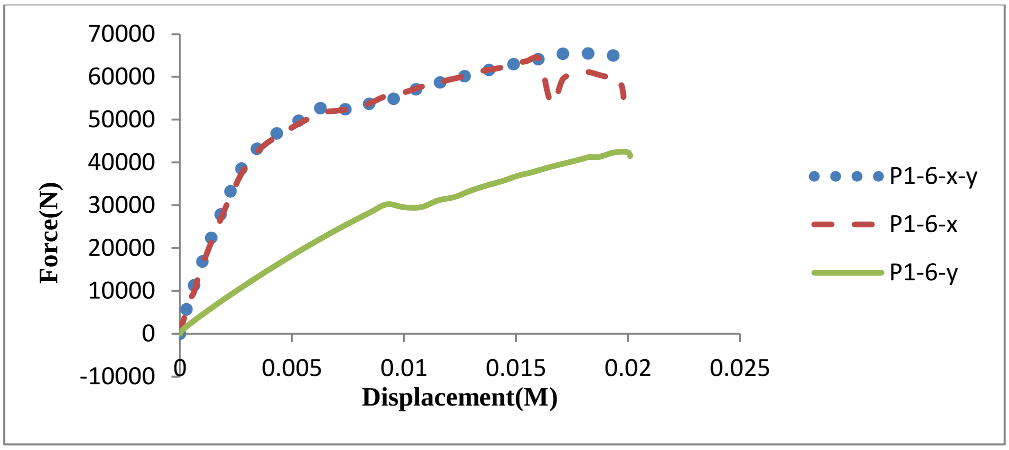
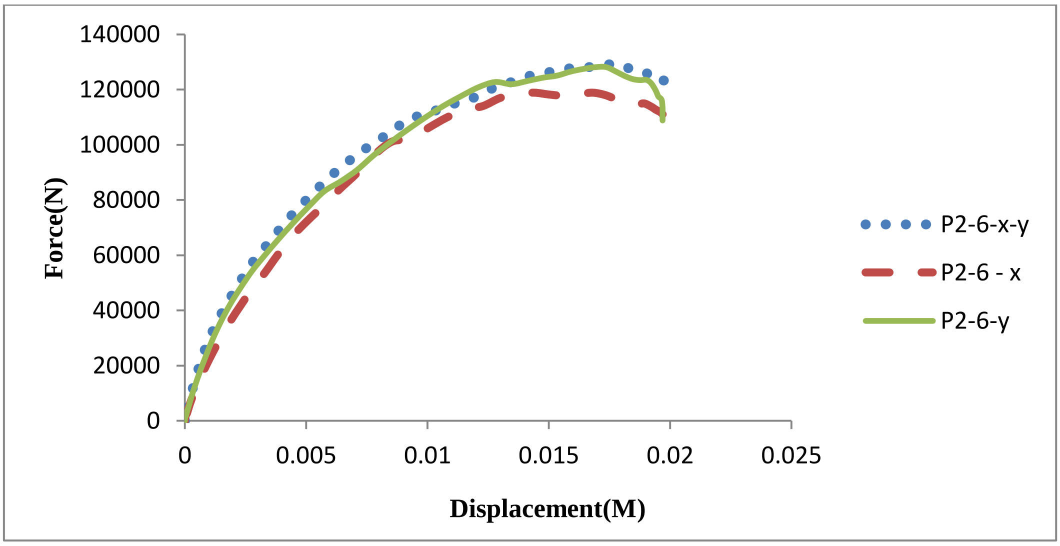


Figure 13. Bar mesh of sandwich panel



A. load-deflection curves of one-way sandwich panel



B. load-deflection curves of two-way sandwich panel

Figure 14. Comparisons on fore-deflection in center of the slab in order to determine the direction of shear connectors in one-way and two-way sandwich panels obtained by ABAQUS software

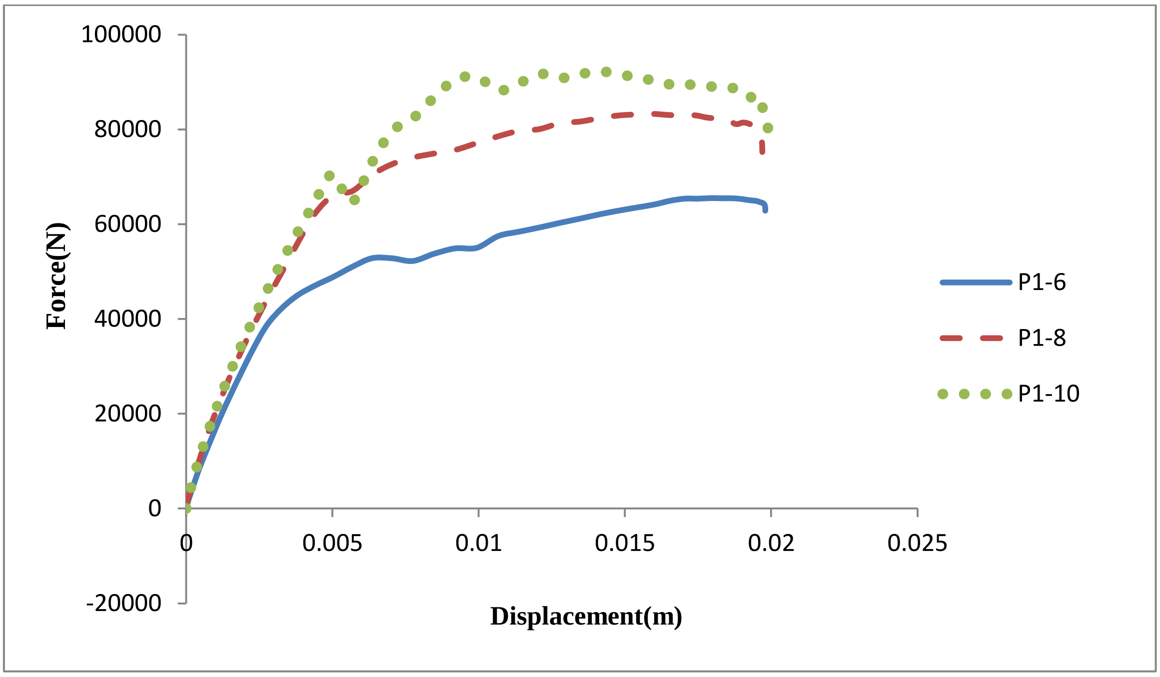


Figure 15. load-deflection curves of one-way sandwich panel

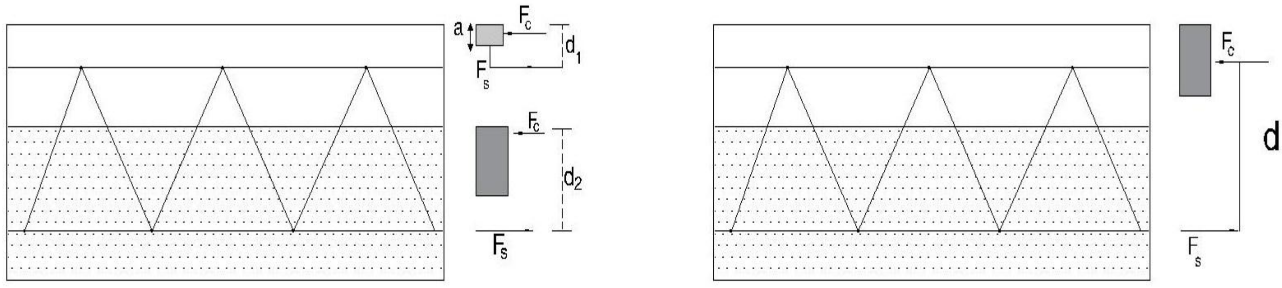
Results show that when prefabricated sandwich panel behaves like a one-way slab, it had better place shear connectors parallel to X axis (bigger dimension) for correlation of two concrete layers in order to function as one unit, and subsequently, it is ought to place the shear connectors parallel to Y axis (smaller dimension) when prefabricated sandwich panel behaves as a two-way slab. Totally, two-way slab is more rigid than one-way slab and therefore, tolerates more ultimate load.

6. Role of shear connectors

The influence of the of shear connector stiffness as measured by its diameters on the ultimate strength and the compositeness of the precast concrete sandwich panels (PCSP) was investigated. One-way panel (Figure 12) was chosen for this study as it was already validated earlier. Non-linear analysis was carried out on the panel with different number of shear connectors (P1-6, P1-8, P1-10). The first index shows that the panel is one-way and the second index indicates the number of shear connectors. The loads were gradually increased till failure of the panel in each case. The load–deflection profiles for the three panels, at mid span, at different load increments are illustrated in Figure 15.

7. Degree of composite action at ultimate stage

In order to analyze the composite behavior of one-way panels P1-6, P1-8, P1-10 in ultimate load, the ultimate load capacity panel with assumption of fully- composite performance and also the amount of ultimate load with assumption of uncombined performance of two layers have been theoretically calculated. The ratio of ultimate load obtained from model analysis (Figure15) to theoretical ultimate load with assumption of fully- composite performance is used as one of the norms to estimate the composite performance of the panel. Concerning Figure 16, ultimate load is calculated in each state.



a: Non- composite action

b: Fully composite action

Figure 16. Non- composite and fully composite panels.

The following calculations were performed at the ultimate strength for the analyzed panels to estimate the composite action of each panel[1].

A: when no composite action is assumed at ultimate strength (Figure16 a), The ultimate flexural capacity of the panel would be calculated as following.

$L = 2\ m b = 0.75\ m$

$F_s 1 = 0.85 A_s F_y = 0.85 \times 169.65 \times 300 = 43261 N$

$F_c 1 = 0.805 F_{cu} b a = 0.805 \times 0.65 \times 30 \times 750 a = 11773 a$

$F_s 1 = F_c 1 \rightarrow a = 3.67 mm$

$d_1 = 28\ mm d_2 = 90\ mm$

$M_{u1} = F_s 1 \left(d_1 - \frac{a}{2}\right) \rightarrow M_{u1} = 1132 N.m$

$F_s 2 = 0.85 A_{s2} F_y 2 = 0.85 \times 471 \times 400 = 160140\ N$

$F_c 2 = 0.84 F_{cu} b a = 0.84 \times 0.65 \times 7.5 \times 750 a = 3071 a$

$F_s 2 = F_c 2 \rightarrow a = 52 mm$

$M_{u2} = F_s \left(d_2 - \frac{a}{2}\right) \rightarrow M_{u2} = 10249 N.m$

$M_u = M_{u1} + M_{u2} \rightarrow M_u = 11381\ N.m$

$w = \frac{8 M_u}{L^2} == 22762$

$P_u = 22762 \times 2 = 45524\ N$

B: when the panel action is fully assumed composite at ultimate strength (Figure 16 b), the ultimate flexural capacity of the panel would be calculated as following.

$F_s 1 == 43261 N$

$F_s 2 = 160140\ N$

$F_c 1 == 11773 a$

a = 9.93

$d = 140\ mm$

$$M_u == 21721.96\ N.m M = \frac{w L^2}{8} \rightarrow w = \frac{8 M_u}{L^2} = 43444 P_u$$
$$= 43444 \times 2 = 86888 N$$

Table 5, the ultimate load capacity has been presented for each Of three panels in two limited states of composite performance and model analysis. It can be seen that composite performance rates in ultimate load for panels of P1-6, P1-8, and P1-10 are 75%, 94%, and 99%, respectively.

Table 5. FEA and hand calculated ultimate strength.

FEM ultimate strength (KN)			**Theoretical calculated ultimate strength (KN)**	
P1-10	**P1-8**	**P1-6**	**Fully- composite**	**Non-composite**
86	**81**	**65**	**87**	**46**

8. Conclusions

1. Joint connections in prefabricated sandwich slab lead to no transition of the moments from one panel to another. This is a great benefit since the high amount of bending and torque moments will not be transferred to connecting regions, columns, and inter-panel columns in two-way performance panels.

2. In prefabricated sandwich slabs, due to mechanical connections such as U-beam on the capital for connecting panel to the columns in fracture level (Control zone) and placing in the shear critical zone, slab's shear punching capacity is high.

3. It seems that this system of the prefabricated sandwich ceiling is completely new and unique. It is one of the industrial systems toward lightening.

4. Because of porous light concrete in the core of the concrete sandwich slab, the weight of sandwich ceiling decreased by 44% compared to other similar systems such as joist and concrete slab. Consequently, it leads to economic saving of structural load-bearing components including columns, girders, and foundation.

5. Ultimate resistance and performance rate of sandwich panels are highly dependent on the rigidity of shear connectors.

6. The amount of ultimate load and combined performance of sandwich panels increase as the number of shear connectors' rows does.

7. When prefabricated sandwich panels behave like a one-way slab, it is better to place the shear connectors parallel to X axis (bigger dimension) for correlation of two concrete layers in order to function as one unit.

8. When prefabricated sandwich panels behave like s two-way slab, it is better to place shear connectors parallel to Y axis (smaller dimension) for correlation of two concrete layers in order to integrate them to gther. Finally, the two- way slab is more rigid than a one-way slab and therefore, bears the more ultimate load.

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