ICETI 2018 07-11 MARCH BUDAPEST www.iceti.org
II. INTERNATIONAL CONFERENCE ON ENGINEERING TECHNOLOGY AND INNOVATION

The Impact of the Use of Different Slabs on the Rough Construction Cost of the Same Architectural Reinforced Concrete Buildings

Latif Onur Ugur[1], Mursel Erdal[2]

Abstract

The floor is divided into floors and walked on; to the structural members carrying the loads and their own weight to the supports. Reinforced concrete carcasses convey the loads from the beams to the beams, the loads coming on the beams to the columns, the columns and all the loads on the foundation. Among these structural elements, the slab can be designed in many types according to the desired characteristics. In this study, it is aimed to compare the rough building costs when four different twenty-storey buildings with the same architectures use different types of slab. For this purpose, the architectural project prepared previously was utilized. Also IDECAD program was used for modeling of buildings. Models are shown in figures. The cost analyzes were compared taking into account the rough construction costs. The costs of rough construction elements are calculated according to 2017 Unit Price Ranges of Turkey. According to the analysis results, the building designed with waffle slab; 21.12% from the design with beam slab, it was found that it was costly 1.08% from the building which was designed with hollow-tile floor slab using hollow block as the filling material and 4.76% from the building which was designed with hollow-tile floor slab which used Styrofoam as filling material. The initial investment cost of the slabs used as the filler hollow block is lower but the time to be spent according to the hollow-tile floor slab will be much higher. It also means that the building is less subject to earthquake effects because it is a lighter material than the hollow block. Styrofoam will be a more appropriate decision to be preferred both in terms of safety and workmanship.

Keywords: Construction cost, Slab, Cost Analyses

1. INTRODUCTION

Reinforced concrete carcasses convey the loads from the beams to the slabs, the loads coming on the beams to the columns, the columns and all the loads to the foundation. Among these structural elements, the slab can be designed in many types according to the desired characteristics.

Firstly, to introduce the slab, the floor separates a building from the storeys and walk on it; to structural members carrying loads and their own weight to the supports [1]. Since thicknesses are negligible compared to the other two dimensions, slab is generally considered two-dimensional. In addition, due to the fact that the same floors have equal displacements and rotations, the rigid diaphragm considered in the analyses are the elements that support the acceptance [2, 3].

[1] *Corresponding author: Düzce University, Technology Faculty, Department of Civil Engineering, 34220, Düzce, Turkey.* latifugur@duzce.edu.tr

[2] *Gazi University, Technology Faculty, Department of Civil Engineering, 06500, Ankara, Turkey.* merdal@gazi.edu.tr

There are different kinds of slab systems; slab with is the most common type of flooring used in Turkey. They transfer loads in one direction or in two directions. The second is the waffle slab. It is designed to work in one or two directions and to make frequent small beams. Waffle slab is called as hollow-tile floor slab type in case of being filled with light material between beams. In addition to the disadvantages of the hollow-tile floor slab, due to the architectural preferences such as easy passage of large openings, reduction of formwork cost, obtaining a flat ceiling without beam protrusions, and thus, partition walls can be made at desired locations. The third type is a beamless slab. The use of this slab model, where horizontal and vertical loads are transferred directly to the carrier elements, is not common in Turkey. It is known that plate systems play a very serious role in the ductility of the structure due to phenomena such as high diaphragm stiffness, required lateral resistance and translational stiffness and affect the results of modal analysis [4].

Hollow-tile floor slab is heavier than the slab with beams and the rigidity is different. Slab is rigid in the direction of small beams, where as there is not enough rigidity at the opposite direction. This may cause structural problems. Care should be taken to create a safe structure in the most economical way while forming the carrier system of the targeted structure. Designers should pay more attention to alternatives in order to avoid having the same safety structure at a higher cost as the type of flooring directly affects the building cost. Since the earthquake loads acting on the structure are applied to the building masses, hollow-tile floor slabs are subjected to more earthquake loads than the slab with beams. For this reason, in order to provide required safety levels to the buildings designed with hollow-tile floor slab against relative floor displacements increased column-reinforced concrete shear wall dimensions are needed. This in turn increases overall cost [4, 5].

As a sense; it is expensive to use hollow-tile floor slab. However, with the temptation of architectural preferences, the cost increase is often foreshadowed. Although the ratio of cost overrun has been expressed in a wide range of forum sites based on the specific experience of the designers, no detailed scientific study has been found [5]. As a result of the horizontal and vertical parametric changes, the financial effect of the slab types is investigated parametrically for the selected regular structure by the authors in the same technical specifications. In this study; it is seen that the cost of the hollow-tile floor slab increases from three times up to three storeys, which is independent of the number of openings in the x and y directions, and is close to its cost in slab with beams [6].

To briefly describe the construction of the slab, the slab formworks are usually prepared together with the joints or beam formworks to be made. It is supported under the floor to carry the weight of the reinforced concrete coming on it. To prevent tensile stresses, the pulling section is provided with a construction steel so that it will be a straight bars. The distribution steels are made up and connected perpendicular to the direction of the main steels. With the dismantling of the formworks within approximately 21 days, the laying process is finished [7]. There are five different types of slabs. These are beam-slab, cantilever slab, ribbed slab, hollow-tile floor slab and waffle slab [8, 9].

Beam-slab: It is a plate with a thickness of 5-20 cm with at least one edge sitting on the beam. Loads and edges are generally preferred in volumes that are not very large (in rooms). The short edge can be 6-7 m. Construction is easy and economical. It is the most commonly used floor type in residential buildings [10].

Cantilever slab: It is a 20-40 cm thick plate without beams, sitting directly on the columns. Formwork work is low. Since there is no dangling beam, a flat ceiling appears when you look up. This type cannot exhibit a good structural behavior. There is a risk of column punching. Collar head is used to prevent punching in heavy floors (industrial buildings, bridges). Earthquake behavior is bad, is not a suitable slab system for Turkey [9].

Ribbed slab: It is a slab formed by placing parallel beams within main beams at 40-70 cm intervals and making

a very thin plate on it. The width of the ribs is 10-15 cm and the height is 25-35 cm. The plate is 5-7 cm, thick. Earthquake behavior is not good [10].

Hollow-tile floor slab: Spaces between ribs (small beams) filled with light material. The ceiling looks flat. Earthquake behavior is not good. Formwork cost is low. It is healthy because there are no indentations to hold the dust. Sound and heat are less transmitted. There is additional block weight. It also increases the additional cost due to the cost of the block [9, 10].

Waffle slab: It is constructed like a ribbed slab. Normal-sized beams are used instead of small beams. Distance between the beams is about 50-150 cm. The opening may be 15-25m [10].

In this study; three model reinforced concrete buildings with different types of slabs were designed, with the same architectural projects, 20 storey, slab classes earthquake zones and basic types. For each design, rough construction quantities and discoveries were made. The rough construction costs of these three buildings were calculated and the effect of the slab type change on the rough building costs was investigated.

2. DIFFERENT SLAB TYPES HAVING SAME ARCHITECTURE

The buildings that were designed as examples in this study were built on the same architectural project. In this architectural project used, one floor is a living room with two floors, the left room is a living room with three rooms, and the right room is a living room with four rooms and a living room with a total floor area of 347.18m^2.

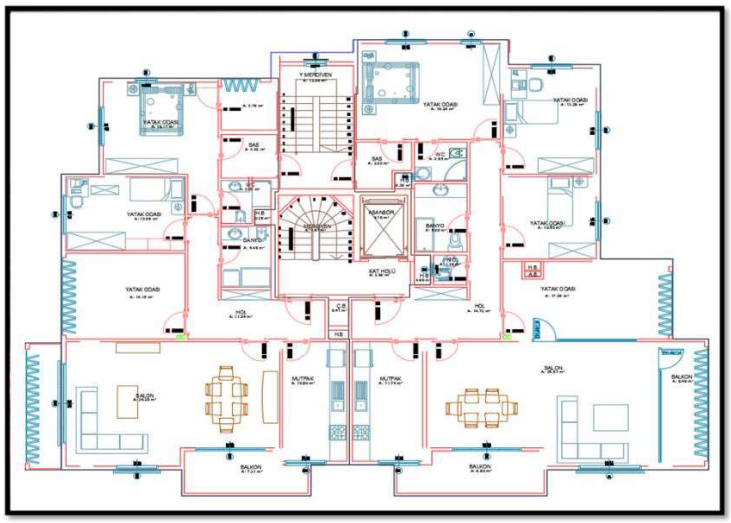


Figure 32. Floor plan used in sample buildings

2.1. Reference Properties of the Building Designed with Beam-Slab

In the structure columns; 30×50 cm, 30×60 cm, 30×70 cm, 30×80 cm, 30×85 cm, 30×90 cm, 40×90 cm, and 50×50 cm sizes were selected for this study. The shear walls that are placed at suitable places are; 25×175 cm, 25×220 cm, 25×280 cm, 25×300 cm, 25×430 cm, 30×210 cm, 30×290 cm and 30×320 cm dimensions. All the beams in the building were selected in dimensions of 25 × 60 cm. The slab thickness is 15 cm, the mat foundation thickness is 50 cm and S420 steel is used in the building elements. C35 class was chosen for concrete in calculations. The structural system type of reinforced concrete ductility is high.

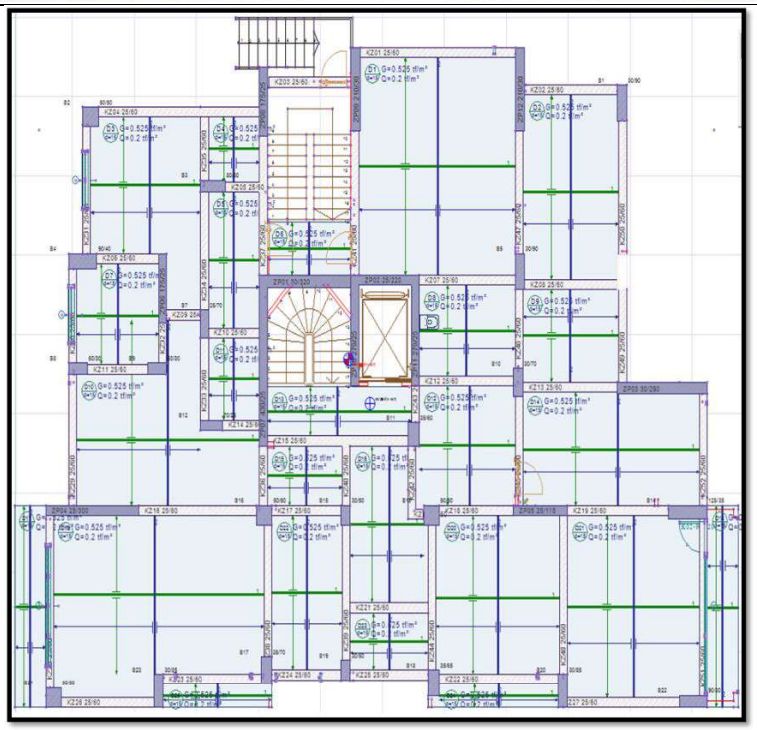


Figure 2. Formwork plan of the building made of beam-slab

Table 1. Features of the designed building (Beam-slab)

Floor heights	3.00 m
Number of floors	20
Building importance coefficient (I)	1
Earthquake Zone	2nd Degree
Effective ground acceleration coefficient (A_0)	0.51
Local Soil Class	Z2
Bearing system behavior coefficient (R)	7
f_{cd} (Concrete strength to be used in the calculation)	23000 kN/m^2 (C35)
f_{yd} (steel yield strength to be used in calculation)	365000 kN/m^2 (S420)
E_c (Elasticity Modulus)	33000 N/mm^2
$\gamma_{concrete}$ (Concrete unit volume weight)	25 kN/m^3

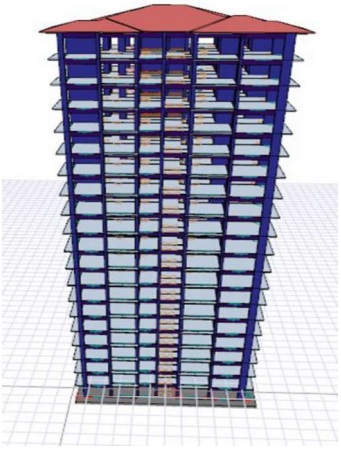


Figure 3. Three-dimensional view of the building

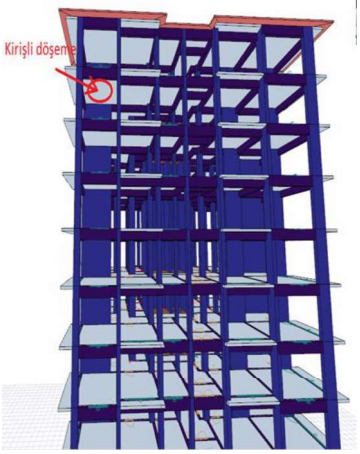


Figure 4. View of beam-slab

2.2. Properties of the Building Designed with Hollow-Tile Floor Slab

In the structure columns; 25×60 cm, 25×100 cm, 30×60 cm, 30×70 cm, 30×90 cm, 40×90 cm, 50×50 cm, 50×70 cm and 50×125 cm have dimensions. The shear walls that are placed at suitable locations are; 25x175 cm, 25x220 cm, 25x280 cm, 25x300 cm, 25x430 cm, 30x210 cm, 30x310 cm, and 30x320 cm dimensions. All the beams in the building were chosen as 50×35 cm and 25×50 cm. The slab thickness is 10 cm, the mat foundation thickness is 50 cm and S420 steel is used in the building elements. C35 class was chosen for concrete in calculations. The structural system type of reinforced concrete ductility is high, earthquake loads are taken as buildings and buildings carried by shear walls.



Figure 5. Formwork plan of building made with hollow-tile floor slab

Table 2. Features of the designed building (Hollow-tile floor slab)

Floor heights	3.00 m
Number of floors	20
Building importance coefficient (I)	1
Earthquake Zone	2nd Degree
Effective ground acceleration coefficient (A_0)	0.51
Local Soil Class	Z2
Bearing system behavior coefficient (R)	7
f_{cd} (Concrete strength to be used in the calculation)	23000 kN/m^2 (C35)
f_{yd} (steel yield strength to be used in calculation)	365000 kN/m^2 (S420)
E_c (Elasticity Modulus)	33000 N/mm^2
$\gamma_{concrete}$ (Concrete unit volume weight)	25 kN/m^3

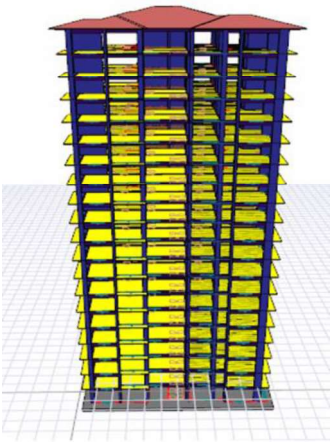


Figure 6. Three-dimensional appearance of the building

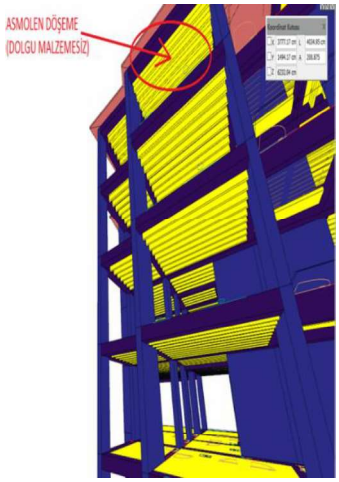


Figure 7. View of hollow-tile floor slab

2.3. Features of the Building Designed with Waffle Slab

In the structure, columns; 25×60 cm, 25×100 cm, 30×60 cm, 30×70 cm, 30×90 cm, 40×90 cm, 50×50 cm, 50×70 cm and 50×125 cm dimensions. The shear walls that are located at suitable places are; 25x175 cm, 25x220 cm, 25x280 cm, 25x300 cm, 25x430 cm, 30x210 cm, 30x310 cm, and 30x320 cm dimensions. All the beams in the building were chosen as 50×35 cm and 25×50 cm. The slab thickness is 10 cm, the mat foundation thickness is 50 cm and S420 steel is used in the building elements. C35 class was chosen for concrete in calculations. The structural system type of reinforced concrete ductility is high.



Figure 8. Building plan made with waffle slab

Table 3. Features of the designed building (Waffle Slab)

Floor heights	3.00 m
Number of floors	20
Building importance coefficient (I)	1
Earthquake Zone	2nd Degree
Effective ground acceleration coefficient (A_0)	0.51
Local Soil Class	Z2
Bearing system behavior coefficient (R)	7
f_{cd} (Concrete strength to be used in the calculation)	23000 kN/m^2 (C35)
f_{yd} (steel yield strength to be used in calculation)	365000 kN/m^2 (S420)
E_c (Elasticity Modulus)	33000 N/mm^2
$\gamma_{concrete}$ (Concrete unit volume weight)	25 kN/m^3

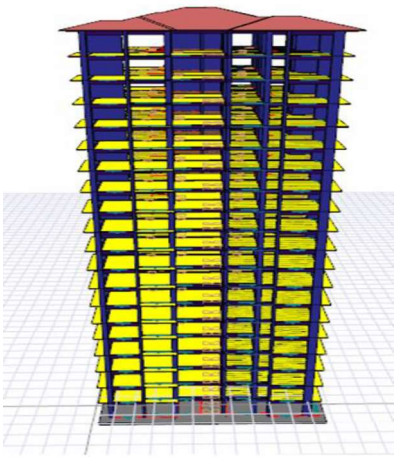


Figure 9. Three-dimensional appearance of the building

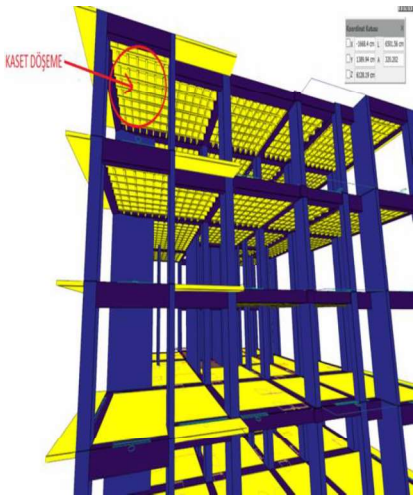


Figure 10. View of hollow-tile floor slab

3. MATERIAL QUANTITIES AND COSTS USED IN BUILDINGS WITH DIFFERENT SLAB TYPES

3.1. Quantity and Cost of Materials used for Building Designed with Beam-slab

The amount of material used in buildings designed with beam slab is given in Table 4 and the cost of rough construction is given in Table 5. All rough construction costs are calculated according to the unit prices of the year 2017.

Table 4. Quantity of materials used for buildings designed with beam-slab

	Unit	Floor	Beam	Shear wall	Column	Raft foundation	Total
Formwork	m^2	4915.70	3368.63	3611.38	2744.97	43.22	14683.90
Concrete	m^3	737.356	430.345	474.285	331.8	231.008	2204.794
Steel reinforcement	ton	51.799	97.711	80.554	84.722	59.727	374.514

Table 5. Cost of rough construction of the building designed with beam-slab

	Unit	Quantity	Unit price (₺)	Cost (₺)
Formwork	m^2	14683.90	39.63	581922.96
Concrete	m^3	2204.794	165.20	364231.97
Steel reinforcement (thin)	ton	107.656	61.65	6636.98
Steel reinforcement (thick)	ton	266.858	75.82	20233.19
Total				973025.09

3.2. Quantity and Cost of Materials used for Building Designed with Hollow-Tile Floor Slab

The amount of material used in buildings designed with hollow-tile floor slab is given in Table 6. In case of using styrofoam as the building material designed with hollow-tile floor slab, the rough construction cost is given in Table 7. In the case of hollow brick, Table 8 is given.

Table 6. Quantity of materials used for buildings designed with hollow-tile floor slab

	Unit	Floor	Beam	Shear wall	Column	Raft foundation	Total
Formwork	m^2	299,49	8293,98	2662,96	3432,33	2358,9	43,22
Concrete	m^3	29,949	620,807	428,383	429,75	302,7	231,008
Steel reinforcement	ton	28,962	44,701	145,136	82,308	79,447	61,733
Hollow block	m^2	-	-	-	-	-	3400,00
Styrofoam	m^3	-	-	-	-	-	1190

Table 7. Cost of rough construction in case of using hollow block as building material which is designed with hollow-tile floor slab

	Unit	Quantity	Unit price (₺)	Cost (₺)
Formwork	m^2	17090.76	39.63	677306.82
Concrete	m^3	2042.596	165.20	337436.86

Steel reinforcement (thin)	ton	131.221	61.65	8089.77
Steel reinforcement (thick)	ton	311.067	75.82	23585.11
Hollow block (35x20x40cm)	m^2 (12.5 number)	3400.00	23.13	78625.00
Total				1125043.56

Table 8. Cost of rough construction in case of using styrofoam as building material which is designed with hollow-tile floor slab

	Unit	Quantity	Unit price (₺)	Cost (₺)
Formwork	m^2	17090.76	39.63	677306.82
Concrete	m^3	2042.596	165.20	337436.86
Steel reinforcement (thin)	ton	131.221	61.65	8089.77
Steel reinforcement (thick)	ton	311.067	75.82	23585.11
Styrofoam (35x100x40cm)	m^3	1190	100.44	119523.60
Total				1165942.16

3.3. Quantity and Cost of Materials used for Building Designed with Waffle Slab

The amount of material used in buildings designed with waffle slab is given in Table 9 and the cost of rough construction is given in Table 10.

Table 9. Quantity of materials used for buildings designed with waffle slab

	Unit	Floor	Beam	Shear wall	Column	Raft foundation	Total
Formwork	m2	299,49	10744,39	2657,96	3656,22	2358,9	43,22
Concrete	m3	29,949	785,167	427,508	429,74	302,7	231,008
Steel reinforcement	ton	28,56822	32,27847	145,89337	86,22573	79,13587	59,72699

Table 10. Cost of rough construction of the building designed with waffle slab

	Unit	Quantity	Unit price (₺)	Cost (₺)
Formwork	m^2	19760.18	39,63	783095.93
Concrete	m^3	2206.072	165,2	364443.09
Steel reinforcement (thin)	ton	119.636	61,65	7375.56
Steel reinforcement (thick)	ton	312,193	75,82	23670.45
Total				1178585,03

4. CONCLUSION

In this study, three types of buildings having same architectures were designed differently and rough building costs were calculated. When the rough construction costs of the structures are examined; the rough construction cost of the building designed with beam slab is 973025.09 ₺, the rough construction cost of the building designed with hollow-tile slab floor using hollow block as filling material is 1125043.56 ₺, the rough building cost of the building designed with hollow-tile slab floor using Styrofoam as filling material is 1165942.16 ₺. The rough cost of the building designed with and waffle slab was calculated as 1178585.03 ₺. According to the results the building, which has the highest cost, is a building designed with waffle slab. Designed with waffle slab; designed with beam slab, was designed with hollow-tile floor slab using hollow block as filling material 21.12%, and it was found to be 1.08% more costly than building designed with hollow-tile floor slab used as stiffener as filling material 4.76%.

Compared to buildings built with hollow-tile floor slab buildings built using styrofoam seem to cost 3.63% more expensive than hollow block. However, the use of styrofoam as a filler material for flooring has many advantages over using hollow blocks. styrofoam is a lighter material than hollow block, so it does not add too much additional weight to the structure. Therefore, the building, which is filled with Styrofoam, is subjected to less earthquake forces than the building which is filled with hollow block. Since styrofoam does not draw water, there is no risk of reducing concrete strength like hollow block. While workmanship of hollow-tile floor slabs is difficult, workmanship of styrofoam is easier and faster. When filling with hollow block is completed, however there is a lot of wastage, if Styrofoam is used, there is not too much material wastage loss. Moreover, the cost of escaping the concrete into the hollow block during the casting of the fill with the hollow block can be increased. Another advantage of filling with styrofoam is heat and shock insulation. On the other hand, direct use of Styrofoam is prohibited according to fire regulations, so it is necessary to use fire resistant plaster on it. As a result, it has been found that the use of beam-slab in residential buildings is more favorable both in terms of cost and security of the building. Moreover, it is suggested to use less strained and lighter styrofoam filler, which is easier to work with than hollow block filler, because the fill of the hollow-tile floor slab fill the void.

REFERENCES

[1]. http://www.insaathaberleri.net/haber/523-doseme-nedir.html, Son erişim tarihi 11.05.2017.
[2]. B. C. Punmia, "Building Construction". Laxmi Publication, New Delhi, pp.847-848, 2005.
[3]. U. Ersoy, "Betonarme 2". Evrim Yayınevi, İstanbul, pp. 253-255, 1995.
[4]. H. Aygün, "Analysis of dynamic attitude of multi-storey reinforced concrete construction through different flooring systems", M.Sc. Thesis, Istanbul Technical University, Institute of Science, İstanbul, Turkey, 2007.
[5]. www.forum.yapisal.net/dosemeler/30472-asmolendoseme-plak-doseme-maliyet-farki, Son erişim tarihi 11.05.2017.
[6]. M. Bikce, B. Akyol, "Comparison of cost structure of ribbed (hollow block) slab/solid plate in the designed building", *Science and Eng. J of Fırat Univ*., vol. 29, no. (1), pp. 133-144, 2017.
[7]. https://emlakkulisi.com/doseme-nedir/168628, Son erişim tarihi 11.05.2017.
[8]. http://abs.mehmetakif.edu.tr/upload/0420_1813_dosya.pdf, Son erişim tarihi 11.05.2017.
[9]. http://insaatmuh.cbu.edu.tr/db_images/site_115/file/d%C3%B6%C5%9Femeler.pdf, Son erişim tarihi 11.05.2017.
[10]. http://www.mimair.com/asmolendos%D0%B5m%D0%B5n%D0%B5dirasmolendosemeler%D1%96n-%D0%B0v%D0%B0nt%D0%B0j-ve-dezavantajlari-nelerdir.html, Son erişim tarihi 11.05.2017.