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Analytical and Experimental Study of Load-bearing columns Made of Lightweight Concrete

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Abstract

In recent years, studies have been started for the use of light-grained concrete in conventional reinforced concrete structures, it is expected that the use of light-grained concrete without having a negative effect on the use of the structure will reduce the costs in construction and reduce the structural mass. As a result, the earthquake load will be reduced. In this research, concrete with an approximate compressive strength of 18.24 megapascals and an approximate specific weight of 1800 kg/m3 was obtained by using Lika grain style. In order to evaluate the structural behavior of lightweight concrete, 5 concrete columns were built in the laboratory and were subjected to axial load and the results related to these columns were presented, and then a suitable model for these columns was presented by Abaqus finite element software and analytical studies It was done on the relevant results, which are in good agreement with the laboratory results. The agreement of the results obtained from the modeling with the laboratory results is a proof of the accuracy of the built model. (DOI:**https//doi.org/10.52547/JCER.4.4.41**)

Keywords: lightweight concrete column, finite element analysis, laboratory study, compressive behavior of columns, Abaqus.

1. Introduction

In recent years, the use of lightweight concrete in its various forms, such as lightweight concrete, concrete without fine grains or concrete with air bubbles, has become very common, and due to its unique advantages such as low specific weight and good thermal insulation, in many cases It has replaced ordinary concrete. In this connection, it is possible to mention the implementation of some high-rise buildings and large bridges with this material, such as 15 large span bridges made of lightweight Leica concrete in the Netherlands,

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Wellington Stadium in New Zealand, and a 73-story commercial tower in Los Angeles.

The low strength of lightweight concrete has been an important factor in limiting the scope of application of this type of concrete and taking advantage of its advantages. Lightweight concrete that has sufficient strength and its other physical properties are also improved due to weight reduction will bring about a huge change in the application of this concrete.

Aggregates with less weight are generally considered as light grains [1]. For comparison, most common aggregates such as sand and gravel weigh up to 1680. The light grains have a low apparent specific gravity due to high porosity. The classification of seed styles is based on their sources, production methods and final use.

The main materials in the style of natural grains are diatomite, pumice, scoria (pumice stone), ash and volcanic tuff, all of which except diatomite are of volcanic origin. Diatomite has a sedimentary origin. Considering that natural grain styles are found only in some places, therefore, due to the problems of access to resources and transportation issues, this type of material is not widely used and has limited applications. Pumice has been used more than other types of these materials [2].

Artificial seed styles are often known by their different trade names. But the best grouping is based on the raw materials used and the production method. Artificial aggregates are produced in four ways. In the first method, artificial aggregates are obtained by heating and expanding clay, diatomaceous earth, perlite, vermiculite and opsidin. In the second method, molten slag from slag furnaces is obtained. By spraying controlled amounts of water, it expands with the help of a water jet. In the third method, industrial welds obtained from coal furnace ash are used. In the fourth method, light grains are produced from organic compounds such as expanded polystyrene. In Iran, only the first method is used to produce expanded clay and expanded perlite.

The properties of different grain styles are widely variable. For example, the strength of concrete made with expanded clay (Leica) and expanded shale is relatively high and comparable to normal concrete. Of course, the amount of cement used in light concrete is more than its amount in ordinary concrete. Pumice, scoria and some expanded welds produce concrete with medium strength. Perlite, vermiculite and diatomite produce concrete with very low resistance, but the insulating properties of low resistance concrete are better than high and medium strength concrete. The insulation value of high resistance style concrete is almost 4 times that of ordinary concrete. In practice, there is a complete spectrum of grain styles with a weight of 80 to 900.

Very porous aggregates are generally weak and are more suitable for making non-structural insulating concrete. It is the grain style that has less porosity, if the structure of the porosity is in the form of small pores and with uniform distribution, then the grain style has strength and is therefore suitable for structural concrete.

There are three general methods of producing lightweight concrete. In the first method, light porous materials with low specific gravity are used instead of ordinary aggregates. The resulting concrete is called light grain concrete. The second method of producing light concrete is based on the creation of multiple pores inside the concrete or mortar. These pores should be clearly cleaned from very small pores with air bubbles. This type of concrete is known as "sponge concrete", "aerated concrete" or "gas concrete". The third method of producing light concrete is to remove small aggregates from the concrete mixture so that many pores are created between the particles and generally coarse aggregates with normal weight are used. This type of concrete is called "concrete without fine grains".

Despite the high cost of light grains and the additional initial cost of using light concrete, the total cost of a structure made with light concrete is less than normal concrete. The use of lightweight concrete in prefabs reduces its weight by half, which saves transportation costs. This savings well covers the additional costs of light grain materials. Sometimes, the dead load of a prefabricated piece is close to/or more than the crane used in the factory or workshop. By using light grains, due to weight reduction, the use of a special crane is not necessary and it is possible to make larger pieces than normal concrete. be It also results in a reduction in crane movements. The economic advantages of light concrete can be divided into 2 categories:

One is the points due to less dead load, and the other points are points due to properties such as: more thermal insulation, resistance to fire, freezing, etc.

According to the studies conducted in recent years, to use light-grained concrete in conventional reinforced concrete structures, considering maintaining the durability and stability of the structure and reducing costs in construction, using light-grained concrete is a suitable solution, which in addition to reducing costs In construction, it reduces the structural mass and consequently reduces the earthquake load. Therefore, in this research, we evaluated the structural behavior of columns made of light-grained concrete, and then analytical studies were conducted on the results of these columns using Abaqus finite element software, and conclusions were drawn.

The second part of this research is an overview of the research done in the field of lightweight concrete. In the third part, the studies were described, which are in two phases, laboratory and modeling with Abaqus software. In the fourth part, the obtained results are analyzed and finally, the fifth part deals with general conclusions and suggestions for future studies.

2. Related works

Myatt et al [3] investigated the behavior of spiral structural columns made of lightweight concrete under central axial loading. In this experiment, Lika was used as lightweight coarse aggregate to produce lightweight concrete. A total of 11 columns were evaluated under short-term loading. The columns were made with a height of 900 mm and a diameter of 250 mm. The studied parameters include diameter and spiral reinforcement. The final strength of the columns is reduced, also the area of the longitudinal reinforcement does not affect the ductility of the column, in addition, the steel fibers in the spiral reinforcement of the columns leads to an increase in the final fineness of the column, although it has a small effect on the ductility.

Galeota et al. [4] investigated the ductility and resistance in the performance of structural columns made of light-grained concrete. that the arrangement of transverse reinforcement, spacing of transverse reinforcement and the ratio of longitudinal reinforcement in the structural performance of columns made of light-grained concrete under uniform off-center loading were investigated, the experimental results show that the use of reinforcement arrangements The following transversal leads to significant improvement in structural performance.

Kan et al. [5], which evaluated the behavior and size effect of structural columns made of light-grained concrete and 3 other square columns made of ordinary concrete in different sizes, the test results showed that the columns Made of light-grained concrete, they have the same failure mode as the columns made of ordinary concrete. Also, under the same axial load, they show a larger displacement than the columns made of ordinary concrete. Measurement of the ultimate strength of the column. made of light-grained concrete with small and medium sizes were obtained close to the calculated values of the ACI nominal strength, which shows that the ACI equation is only suitable for the design of small and medium-sized columns.

Qonem et al. [6] conducted an experimental study on steel pipes filled with light-grained concrete, and these experiments were carried out on steel tubular columns with circular and rectangular sections filled with light-grained concrete and In this study, columns filled with light-grained concrete show local buckling, when the column reaches the breaking load, a global buckling takes place. However, the effect The negative local buckling does not significantly decrease the capacity with the bearing capacity of the column, but the columns filled with ordinary concrete show global buckling without any signs of local buckling before failure, also the sections with larger dimensions of the bearing capacity. It shows that according to these results, there is a good possibility of replacing normal concrete with light-grained concrete due to its low specific weight and thermal conductivity.

Moli and Khalafi [7] investigated the strength and axial capacity of steel columns filled with light-grained concrete, and this test was a set of 2 hollow rectangular steel sections with dimensions of 120x80 mm and 150x100 mm and different heights. These sections were filled with ordinary concrete and light-grained concrete, natural pozzolan was used as lightweight aggregate in the second concrete, and in this test, the performance of steel samples filled with light-grained concrete compared to steel samples It was made of ordinary concrete. The test results showed that the breaking load is affected when the height of the samples increases from 100 mm to 200 mm, and also the presented lightweight concrete has a higher resistance than ordinary concrete.

3. Laboratory studies have been carried out

The main goal of this research is to achieve structural light concrete with lower specific weight and higher compressive strength. Based on this, in this experiment, 5 cubic samples of 10x10x10 cm were made and after 28 days of curing in water, their specific weight and compressive strength were determined.

3.1. Consumable materials

The cement used was Portland type 2 neka and potable water was used to make concrete. Consumable micro-silica is in the form of powder produced by Vand Chemical Company, and the specific surface area of its particles is 20. In this research, 10% of the weight of cement was replaced with micro-silica and the amount of cement was reduced by the same amount. PCE super plasticizer was also used. The amount of PCE is about 1.5-4% of cement materials. At the beginning, the sand used was passed through a sieve with a score of 4, therefore, sand with a size of 0-5 mm was used in the concrete. Its modulus of elasticity was equal to 2.6.

In table (3-4) the sand classification is presented. The granulation of used sand has an acceptable match with the permissible range of natural sand.

In this research, the size of 5-10 mm and discontinuous granulation was chosen. Natural sand has been used instead of 0-5 mm Leica grains. One-hour water absorption of Leica seeds is 11.3%. For granulation, 500 grams of Leica was selected. The tested fine grain does not have an acceptable compliance with the permitted range of fine grain sand with a maximum size of 12.7 mm. According to the granulation, the Leica used is coarse-grained.

The inner armature is ribbed and type AIII. The yield stress of rebar grade 10 is 4800 and the yield stress of rebar grade 8 is 4930.

After carrying out some preliminary mixing plans for preparing light concrete with suitable structural strength for the intended columns, the mixing plan of Table 1 has been used:

Table 1

Light concrete mixing plan for one cubic meter of concrete

micro-silica (kg)	475
Cement (kg)	47.5
Water (kg)	7
Super lubricant (kg)	199.5
Leica (kg)	803
Sand (kg)	268
Leica size (mm)	0.42
Percentage of water to cement (kg)	10-5
Special Weight (kg/m^3)	1800

3.2. How to make concrete

The amount of weight of the materials for the design of mixing light concrete for a certain amount of concrete in such a way as to provide the volume of concrete required to perform the tests was calculated and then the materials were weighed. These materials were poured into the concreting machine in the order of coarse grain (Lika), natural sand, cement and micro-silica, and the machine was kept on for 3-5 minutes to mix the dry materials without water. Then first, all the water and a part of the super-lubricant are gradually added to the dry materials inside the Betonir Roshan machine. Finally, the remaining amount of super-lubricant is added to ensure proper performance and the desired slump.

With numerous and preliminary experiments, it has been concluded that correct mixing, both in terms of mixing and mixing time, has a significant effect on the strength of concrete, therefore, the mixing time was based on this and with the appropriate number of rotations of the concrete Try to mix all the ingredients well. After finishing the mixing and making of concrete, some of the concrete is used to supply the slump. The produced concrete was poured into clean and lubricated cubic molds of 10x10x10 cm in three layers and each layer was vibrated for 20 seconds with the help of a vibrating table. After being vibrated for 16-24 hours, the samples were kept inside the mold with a damp cloth cover, and then they were removed from the molds with great care and without damaging the mold, and were kept in the water basin with water until the test. The temperature is maintained at 20±2˚C.

3.3. Test to determine the compressive strength of hardened concrete

In general, two types of samples are used for compression testing, which are cubic and cylindrical. In England (English code, 2009) [8] and many European countries, cubic samples are used, in American standards (American concrete code and the standard for testing the compressive strength of cylindrical concrete samples) [9] and others Countries such as France and Australia are recommended examples of cylindrical shape. In this research, 10x10x10 cm cubic samples were used to determine the compressive strength.
To perform this test, the samples are poured into a steel or cast iron mold. The cubic shape of the molds, the size of the sides and the smoothness of the surfaces inside the mold must comply with the recommended specifications. In cases where the compaction is done by a vibrating device, it is necessary that the connection of the mold body to its bottom is rigid. The inner parts of the mold should be slightly greased with mold oil to prevent concrete from sticking to them. After pouring the concrete into the molds, it should be compacted. Compaction of cubic samples is done with a vibrating table or by hand. The cubes are filled in three layers and after each layer is poured, it is compacted. In compacting with a vibrating table, instead of pounding, after pouring each layer of concrete, the mold is placed on the vibrating table for a certain period of time until the concrete is completely compacted. After processing, the samples are taken out of the mold and kept in the water tank at a temperature of 20 ±2°C before testing.
The samples are removed from the pond before the test and their surface is dried. Then, the tested cubic samples are placed between the two plates of the machine in such a way that the surface of the sample is in contact with the cubic mold. Now, a vertical force is applied to the cubic sample by the device at a constant speed so that the cube is packed due to the compressive force. The force and tension corresponding to it are read and recorded from the digital screen of the device.

3.4. Construction of lightweight concrete beam samples made of Lika

All columns are made with a height of 100 cm and cross-sectional dimensions of 20 cm x 20 cm. All the columns have 4 rebars with a diameter of 10 mm and khamut with a diameter of 8 mm, which are placed at a distance of 75 mm to 150 mm from each other. The schematic of the compression test system and the details of the columns are presented in Figure 1.

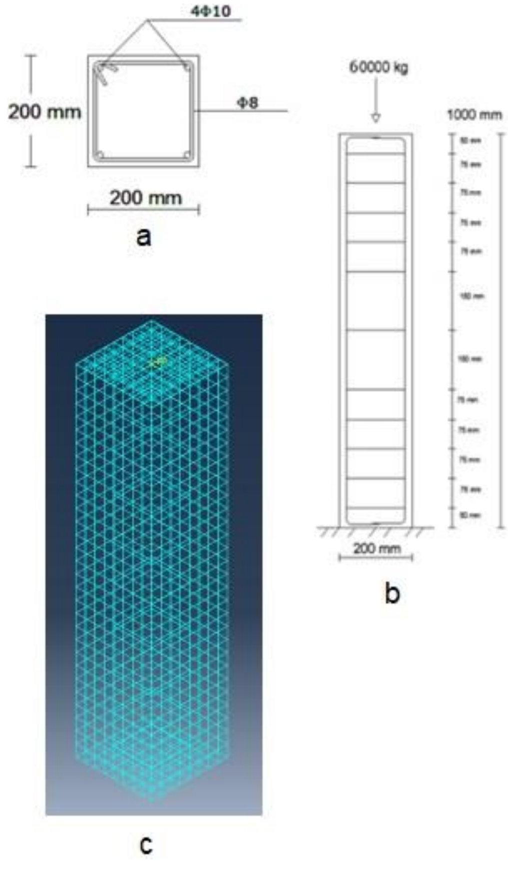

Fig 1. a and b) Schematic of the test system and details of the columns c) Column elementing modeled in Abqus software

3.5. How to perform the test and test the columns

According to Iran's concrete code, standard hooks are created on rebars and anchors, and in order for the anchors to be fixed, we tie them to the rebars with strong reinforcement wire, so that they do not move during vibration and are stable. be After that, the molds were adjusted and fixed in the desired sizes, and the walls were coated with a thin layer of oil to prevent the concrete from sticking to the walls of the mold. Then the closed rebars were placed inside the mold and then concrete pouring was done according to the relevant mixing plan. In order to better compact the concrete, a special vibrator was used to vibrate the poured concrete. 24 hours after concrete pouring, while the columns were still in the mold, the surface that was in contact with the air was kept moist, and the columns were removed from the mold after 48 hours, and after being taken out of the mold, they were placed in a pool of water in the laboratory.
All the columns were tested after 90 days from the date of concreting. To determine the direction of the cracks that are caused by the load, the surface of the column was covered with lime and after determining the exact location of the load, the location of the strain gauge was marked. After placing the column in the device, the load was introduced into the tested column by a jack with a capacity of 100 tons. In order to read the load (in Kg) and its related displacement, a load gauge and strain gauge were used, respectively, and for each amount of load applied by a manual jack, the corresponding load and displacement were read and recorded .

4. Checking the test results

Based on the application and physical properties, lightweight concrete is divided into three categories: lightweight concrete, semi-structural, and heat insulation, each of which has its own requirements (the lightweight requirements for use in lightweight structural concrete are given in ASTMc 330) and in the rest of this section, we will deal with the physical and structural characteristics of this type of concrete, which is the result of laboratory and theoretical results, and also examine and compare the results of finite element analysis using the modeling of samples in ABAQUS software and compare with the laboratory results.
Concrete structures are among the strongest and safest structures. However, the unit weight of the high volume of concrete used causes an increase in the dead load of the structure, and its consequence is an increase in lateral loads caused by earthquakes. Therefore, the use of lightweight concrete can play a significant role in reducing the forces on the structure.
In the last decade, with the help of additives and super-lubricants, it is possible to produce lightweight concrete with high strength, the use of lightweight concrete in the construction of slabs, beams, and columns has expanded greatly. In bridges, where the weight of the beam creates lateral loads It is relatively noticeable, the use of light concrete will have a great effect in reducing lateral loads. Also, in cases where for the purpose of repairing or strengthening the beam, the dimensions of the beam and as a result the weight of the structure increases a lot, the use of light concrete will be appropriate.
In this section, the structural behavior of the experimental and modeled column samples is investigated, the results of the compressive strength tests of the cubic samples and the compressive test of the columns are explained. Also, the load-displacement diagram of the columns is drawn. Next, the results of the analysis of finite elements using the modeling of the samples are mentioned in the software, and finally, a comparison is made between the laboratory and modeling results.
In order to investigate the structural behavior of the columns, five concrete columns were made, including light weight concrete with the same amount and arrangement of rebars, cross-sectional dimensions, the amount of cement and the ratio of water to cement, which are discussed in detail in section 3.

4.1. Investigating the structural behavior of laboratory columns

In Table 2, the results of the tests of Lika concrete columns are presented in order. In this section, the compressive behavior of columns is studied.
To investigate the change of location of the columns, the load-displacement curve is investigated. These curves are presented in Figure 2 and compared in the load-displacement results of the laboratory columns

with the result of the modeled sample. As it is clear in the figure, the curve of Lika light concrete columns is linear up to the load of 43645, 43256, 38550, 39745, 41880 kg respectively, but after that the slope of the curve decreases.

Table 2

Recorded values from the Leica light concrete column test

Column 1		Column 2		Column 3		Column 4		Column 5	
total load)p( )kg(	column displacement) mm(	total load)p( )kg(	column displacement) mm(	total load) p( )kg(	column displacement) mm(	total load) p( )kg(	column displacement) mm(	total load) p( )kg(	column displacement) mm(
3960	0.26	3387	0.308	3548	0.28	3753	0.365	3790	0.48
7920	0.8	7430	0.65	7097	0.66	7506	0.698	8140	0.85
14500	1.85	13305	1.45	12774	1.35	13612	1.45	13486	1.65
18810	2.99	18275	2.52	16865	1.95	17775	1.81	20533	3.45
28512	5.27	25698	4.13	25427	3.8	26775	3.45	26200	5.52
34650	6.86	33695	6.3	31550	5.22	32850	4.85	32197	7.12
38550	8.85	36594	7.66	35650	6.85	36800	6.25	36520	8.23
43645	11.28	40270	10.3	38550	8.23	39745	8.55	41880	10.46
44550	14.53	43256	12.22	39860	11.35	41580	12.2	43132	13.22
46530	17.85	44050	15.06	40340	14.15	42856	15.1	44518	16.8
47720	21.33	44765	19.24	40950	17.9	43250	19.2	46170	19.8

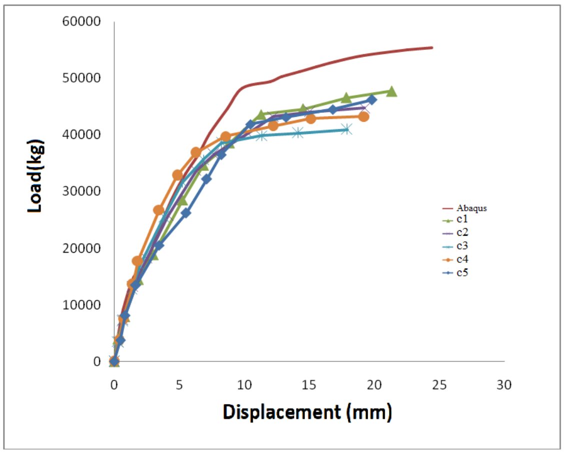

Fig 2. Load-displacement curve of columns and modeled in Abaqus software

The ultimate breaking load of Lika light concrete columns is 47720, 44765, 40950, 43250 and 46170 kg respectively. The comparison of the ultimate load of Leica light concrete shows that although its specific weight and compressive strength is lower than ordinary concrete, it has an acceptable ultimate strength for use in a structural column. The weight of concrete, light concrete column of Leica with specific weight and average compressive strength of 24.18 MPa is about 25% less than the weight of ordinary concrete, which by making the weight of concrete lighter, significant benefits can be obtained, including reducing the forces on the structure. Finds

In Figure 3, the stress-strain curves of Lika light concrete columns are presented and compared with the modeled sample result. The stress created in the column is obtained by dividing the load applied to the sample by the cross section of the column. The strain created in the column is also obtained by dividing the displacement by the length of the sample.

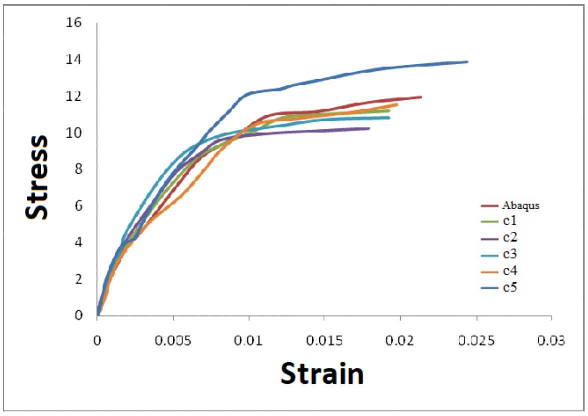

Fig 3: Stress-strain curve of columns modeled in Abaqus software

4.2. The results of the structural behavior of the modeled column and comparison with laboratory columns

In this research, the powerful Abaqus finite element software was used for modeling and static analysis on Lika light concrete column samples. Figure 2 shows the load-displacement diagram of the modeled column. Also, the displacement contour obtained for the column modeled in finite element software is shown in Figure 4.

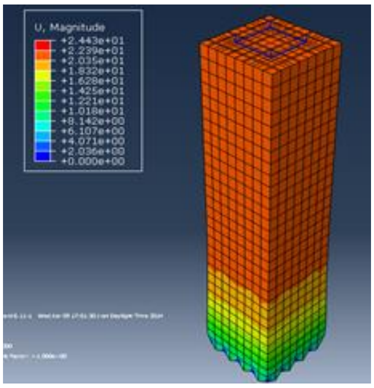

Fig 4. Displacement contour in the direction of force application

According to Figure 2, it can be seen that the modeling results agree with the experimental results with an acceptable approximation. According to the diagrams in Figure 2 and the final strength and displacement of the samples, it can be seen in the laboratory samples and the modeled samples that there is an acceptable match between the results and the correctness of the software output results can be ensured.

The relations in the regulations are based on normal concrete, while the concrete used in this research is of light concrete type, so the bearing capacity obtained based on the relations is not necessarily similar to the laboratory results. In the laboratory, there is a possibility of execution errors, so the accuracy of the obtained results is lower than the result of modeling in Abaqus software.

Also, the main stress contour obtained for the column modeled in the finite element software is shown in Figure 5.

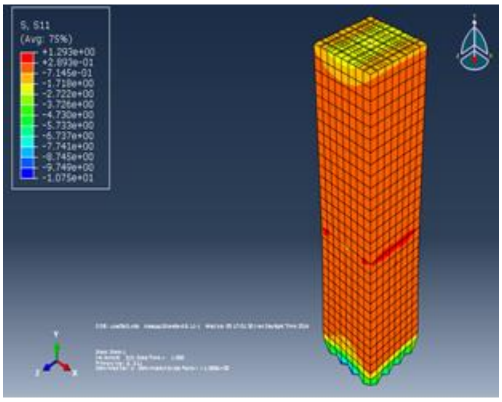

Fig 5. Main stress contour of the modeled column

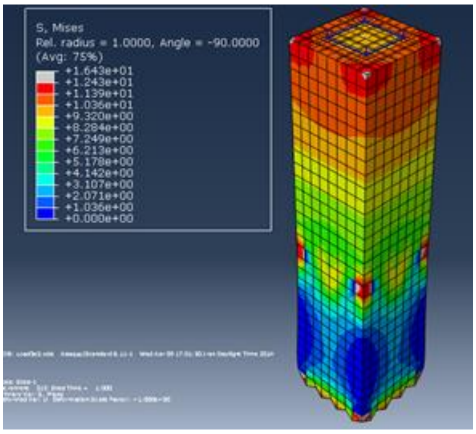

Fig 6. Mizez stress contour

According to Figure 3, it can be seen that the modeling results agree with the experimental results with an acceptable approximation. As we know, cracks occur in places where the stress has reached the cracking stress of concrete. Therefore, the Von-Mises stress distribution of the columns is also shown in Figure 6. On the other hand, the shape of the cracked column in the laboratory is also shown in Figure 7.

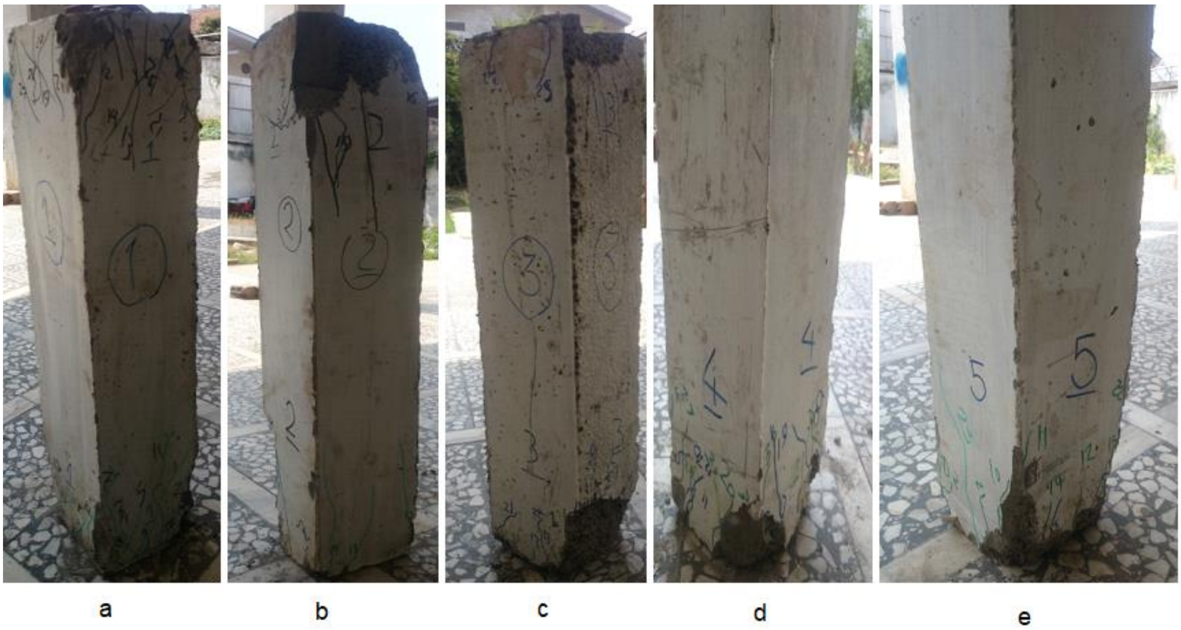

Fig 7. Showing the shape of the cracks after loading the right stones a) column 1 b) column 2 c) column 3 d) column 4 e) column 5

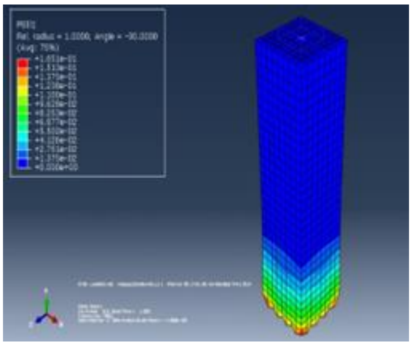

Fig 9. Plastic strain contour

By comparing the experimental results with the modeling results, we come to the conclusion that the shape of the crack corresponds to the stress distribution obtained from finite element analysis, and this is another proof of the accuracy of the modeling and the reliability of the model. On the other hand, we know that at the moment of the final failure of the column, at the points where the plastic strain exceeds 0.0035, crushing occurs in the concrete. For this purpose, the plastic strain distribution of the concrete column is shown in Figure 9.

As can be seen in the figure, at the points where the strain exceeds the plastic strain of the concrete in the modeled column, crushing has occurred, that is, at the support location, which is consistent with the laboratory results shown in Figure 8. Matches

5. The result

This research deals with presenting the results of analytical and experimental studies on columns made of light-grained concrete under the effect of axial load. A total of 5 structural columns made of light-grained concrete were investigated in a laboratory manner, and at the end, one column was modeled using Abaqus finite element software.

The load-displacement diagram of all the columns has been drawn, and the matching of these diagrams indicates that the columns have the same behavior under the effect of axial load. Stress-strain diagrams of all columns are drawn, which are similar to load-displacement diagrams. The final load that the built columns can bear is about 44.57 tons, and in this case, the displacement of the column is 19.5 mm. The model made in Abaqus finite element software has an acceptable agreement with the experimental results. The shape of the cracks in the laboratory samples corresponded with the stress distribution obtained from finite element analysis, and this is a proof of the accuracy of the modeling.

From the comparison of the results obtained in this research with the numerical results obtained by using the relations of the regulations that are for ordinary concrete, we come to the conclusion that the bearing capacity of the column with light concrete is less than that of ordinary concrete, but according to To reduce the weight of the sample and that this difference in capacity is negligible, it is recommended to use light concrete in structural members such as beams or columns.

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