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

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Abstract

In recent years, the use of lightweight concrete in the world has grown exponentially. The reason is the lightening of the building and as a result the reduction of dead load and seismic force on the structures as well as better performance in terms of thermal insulation and energy saving. Therefore, it is necessary to study the potentials of using lightweight concrete in the construction industry. In this article, which is the result of analytical and experimental results about a special type of lightweight aggregate called Leica, the aim is to first achieve a lightweight concrete mixing design that has the necessary conditions as lightweight structural concrete. In this paper, during laboratory research, using Leica concrete grain style with an approximate compressive strength of 20 MPa and a specific gravity of approximately 1800 kg / m3 was obtained. Secondly, we investigated the structural behavior of concrete beams made with Leica lightweight aggregate experimentally and numerically. For this purpose, the first 5 concrete beams were made and examined in the laboratory, and finally, using ABAQUS finite element software, a suitable model was found to model such beams, which is in good coordination with the laboratory results. The compatibility of the results obtained from the modeling with the laboratory results is proof of the accuracy of the constructed model.

Keywords: Lightweight concrete beam, Finite element analysis, Laboratory study, Bending behavior of beams, ABAQUS

1. Introduction

Concrete includes aggregates, cement, and water, since aggregates account for 60 to 70% of the weight of concrete, so the idea of lightening them to produce lightweight concrete has been proposed. One of the main problems in the design and construction of buildings is the significant weight of the dead load, which is mainly due to the weight of the roofs and partition walls. Obviously, the use of lightweight materials reduces the dead load and thus reduces the weight of beams, columns, and foundations, which will ultimately lead to the economy of the design[1].

In recent years, the use of lightweight concrete in various forms such as lightweight concrete, fine-grained concrete, or concrete with air bubbles, has become very common and due to its unique advantages such as low specific gravity and good thermal insulation, in many cases, it has replaced ordinary concrete [2].

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 it. Lightweight concrete that has sufficient strength and other physical properties have been improved due to weight loss will create a huge change in the use of this concrete. By consuming high-quality grains under special conditions, light concrete with a compressive strength of up to 500 kg/cm^2 can be obtained, and with the help of micro silica and superplasticizers, they have been able to increase the compressive strength of light concrete up to 700 kg/cm^2 and in some cases up to 1000 kg/cm^2 increase.

Grains weighing less than 1120 kg/cm^3 are generally considered light grains [3]. For comparison, themost common aggregates such as sand and gravel weigh about 1520 kg/cm^3 to 1680. The light grain has a low specific gravity due to its high porosity. Grains are classified according to their sources, production methods, and final application.

In general, the properties of lightweight aggregates and their products such as lightweight aggregate concrete including expanded clays, pumice, perlite, etc. can be summarized as follows:

- Low specific gravity, which reduces the dead load of the building and thus changes the physical characteristics of the design.
- Heat and sound of this property is due to the pores in the grain.
- Fire resistance; It is usually unlikely that the temperature of the fire will be higher than the temperature produced by these materials (about 1200 ° C).
- Qualitative resistance to freezing and re-melting.
- Neutral chemically.

Lightweight concrete refers to concretes that have a specific weight between 300 and 1850 kg/m^3. 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 lightweight concrete. The second method of producing lightweight concrete is based on creating several pores inside the concrete or mortar. These pores must be clearly cleaned of very small pores with air bubbles. This type of concrete is known as "sponge concrete", "aerated concrete" or "aerated concrete". The third method of producing lightweight concrete is to remove fine aggregates from the concrete mix so that numerous pores are created between the particles, and generally coarse aggregates with normal weight are used. This type of concrete is called "fine-grained concrete".

Despite the high cost of lightweight aggregates and the additional initial cost of using lightweight concrete, the total cost of a structure made of lightweight concrete is lower than conventional concrete. The use of lightweight concrete in prefabricated structures reduces its weight by half, which saves transportation costs. This savings well offsets the additional costs of lightweight aggregates. Sometimes the dead load is a prefabricated piece close to or more than the crane used in the factory or workshop. It also reduces crane movements. The economic advantages of using lightweight concrete are as follows [4]:

- Saving energy consumption and the possibility of using simple and technical labor.
- Saving energy consumption required to move building materials and transport them to different floors.
- Save on iron consumption.
- Significant savings in transporting building materials from the factory to the place of consumption.
- Saving energy consumption during the life of the structure.
- Impact of environment and climate on energy savings due to reduced air pollution.
- Saving during the construction of the building.
- The building becomes more resistant to earthquakes due to the reduction of dead load.

Due to the general desire to optimally design the structure so that while maintaining the durability and stability of the structure, costs are also reduced, so the use of lightweight concrete is a good solution in addition to reducing the dead load on the structure, the seismic force Significantly reduces. Therefore, in this study, we decided to study the structural behavior of lightweight concrete beams in a laboratory and then in order to develop studies and due to laboratory limitations and time and volume of testing, a finite element model suitable for test beams. We have found it so that it can be used for further studies in the future.

The second part of this article is an overview of light concrete research. In the third part, the studies were described, which are in two phases of laboratory and modeling with ABAQUS software. In the fourth part, the obtained results are examined, and finally, in the fifth part, the general conclusion is given.

2- Related Works

In [5] the flexural behavior of beams of lightweight concrete structures has been investigated and the flexural deformation, cracking behavior, and development of strains in the mill have been investigated. In this experiment, calcareous aggregates were used as lightweight coarse grains to produce lightweight concrete. Also, 6 different beams were made for the experiments. The test results showed that in the elastic stage and the beginning of the first stage is larger than the other stages Lightweight concrete beams This stage is larger than the other stages and the reinforcement of lightweight concrete beams surrenders before the reinforcement of ordinary concrete beams. Also, crack distribution behavior and rupture behavior are similar for lightweight concrete structural beams and ordinary concrete.

In [6] Experimental research on the flexural behavior of structural beams made of lightweight concrete with oil palm pumice was performed, which examined features such as flexural deformation, cracking behavior, and ductility indices. The use of palm oil in lightweight concrete not only helps to solve the problem of disposal of these solid wastes but also helps to preserve natural resources. A total of 6 structural beams with different reinforcement ratios (0.52% to 3.9%) were used. All lightweight concrete beams show the usual structural behavior in bending in beams with low reinforcement before Compression of compressive concrete in the area of pure bending, flowing occurs in tensile reinforcement. They also show good ductile behavior and the width of the cracks in the loads do not exceed the allowable limit.

In [7], the flexural behavior and the effect of beams made of lightweight concrete structures were investigated. In this experiment, six bending beams with different dimensions and variable reinforcement ratios (from 0.33% to 1.3%) were used. Took. The designed compressive strength of concrete was 34 MPa. The test results showed that lightweight granular concrete beams have the same load capacity and fracture mode as normal weight concrete beams, but show greater flexural deformation and flexural ductility. The flexural ductility of both types of concrete beams decreases as the reinforcement ratio increases. On the other hand, increasing the beam dimensions leads to increased loading and flexural deformation in the flow strength and ultimate strength.

In [8], the bending behavior of structural beams made of lightweight concrete and ordinary concrete is predicted. In this study, the structural neural network (ANN) method was used to predict the flexural deformation values of the beams and compare the test results. In this test, 6 beams of concrete structures with rectangular cross-sections were prepared and subjected to net bending. Lightweight concrete structural beams had advantages over conventional concrete structural beams such as lower weight, lower seismic forces due to reduced volume, good thermal and acoustic insulation. The analytical results were compared with the test results and predictions by the neural network process in determining the amount of flexural deformation.

In [9] examines the applicability of shear models for deep beams with lightweight aggregate concrete. Tests were conducted to investigate the effects of shear span-to-effective depth ratio (a/d), ranging from 0.26 to 1.04, and an effective span–depth ratio (le/h), ranging from 2 to 3, on the failure mode and shear behavior of deep beams. Failure from the flexure mode showed a dominant pattern with increasing a/d. The le/h value minimally influenced the diagonal cracking and ultimate strength of deep beams. In contrast, a/d significantly affected the beam strength. These comparisons indicated that all of these shear methods can be used to predict the shear strength of lightweight aggregate concrete deep beams.

3- Laboratory Studies and Modeling

The main purpose of this study is to achieve lightweight structural concrete with lower specific gravity and higher compressive strength. Accordingly, in this experiment, 5 cubic samples were made of 10 × 10× 10 cm and after 28 days of curing in water, its specific gravity and compressive strength were determined.

3.1. Consumable materials

In this research, the cement used is Portland type 2 Neka and the water used is drinking water in Babol city. The micro-silica used in this research was in the form of a powder produced by Vand Shimi Company, whose specific particle surface is 20 m2 / gr. In this study, 10% of the weight of cement was replaced with micro silica and the amount of cement was reduced by the same amount. PCE superplasticizer was also used. Consumed sand was first passed through a sieve with a score of 4, so 0-5 mm of sand was used in concrete. Its modulus of softness is equal to 2.6 The grain size of the consumed sand has acceptable compliance with the allowable range related to natural sand.

In this research, in order to clean the sands, first, the existing sands were washed and then sieved and used in the concrete mixing design. Natural sand has been used instead of 0.5 mm Leica grains. The one-hour water absorption of Leica seeds is 11.3%. For granulation, 500 g of Leica was selected. The light aggregate tested does not have acceptable compliance with the allowable range for light aggregate sand with a maximum size of 12.7 mm. Due to the granulation, the consumed Leica is of coarse light grain type.

Internal reinforcement is ribbed and types AIII. The flow stress of size 20 and 8 rebars are equal to 4624 and 4930, respectively. In this research, 10 × 10 × 10 cm cubic samples have been used to determine the compressive strength. The cube shape of the molds, the size of the sides, and the smoothness of the surfaces inside the mold must conform to the recommended specifications [10]. After performing several initial mixing designs to prepare lightweight concrete with suitable structural strength for the desired beams, the mixing design of Table 1 has been used:

Table 1

Lightweight concrete mixing plan for one cubic meter of concrete

cement (kg)	Micro-silica (kg)	Super lubricant (kg)	Water (kg)	Sand (kg)	Leica (kg)	Percentage of water to cement	Size of Leica (mm)	Special Weight (kg/cm3)
475	47/5	7	199/5	803	268	0/42	5-10	1800

3.2. Structural design and how to test the beams

All beams are made with a length of 100 cm and cross-sectional dimensions of 20 × 20 cm. All beams have 6 rebars with a diameter of 20 mm and the joints are designed according to the Iranian concrete regulations. According to this regulation, we have:

$$V_s < 2V_C \rightarrow S_{max} = {}^{d}/_{2}$$

$$V_s > 2V_C \rightarrow S_{max} = {}^{d}/_{4}$$

Therefore, in the middle 1.3 of the beam, because the amount of cut is less, so the braces are considered with a distance of 8 cm, and at the two ends of the beam, the distance of the braces is equal to 4 cm. closed stirrup with a diameter of 8 mm is also used in the design. A schematic of the four-point bending test system and the details of the beams are presented in Figure 1. The specific weight of the resulting concrete is 1800 and the compressive strength of the cube sample is 245.7. Figure 2 also shows the modeling of longitudinal and transverse beams in ABAQUS software.

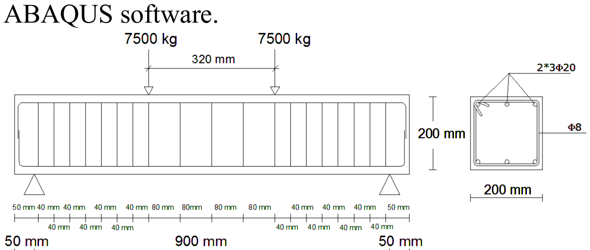


Fig. 1. Schematic of the test system and details of the beams

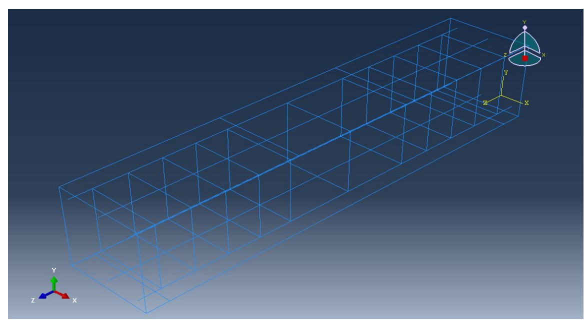


Fig. 2. Modeling of longitudinal and transverse beam reinforcements in ABAQUS

All beams were tested after 90 days from the date of concreting. To determine the path of cracks caused by the application of load, the surface of the beam was covered with white lime and after determining the exact location of the load (distances of one-third of the supports), the location of the displacement was marked. After placing the beam in the device, the load was applied to the upper beam by a jack with a capacity of 100 tons and entered the tested beam through it. In order to read the load (in terms of kg) and its related displacement, a load gauge and displacement meter were used, respectively, and for each amount of load applied by the hand jack, the relevant load and displacement were read and recorded.

3.3. Modeling using ABAQUS software

Since ABAQUS is a widely used general modeling tool, its use is not limited to mechanical analysis of solids and structures (stress-displacement). Using this software, various issues such as heat transfer, mass penetration, thermal analysis of electrical components, acoustics, soil mechanics and piezoelectric can be studied.

Using ABAQUS software, although it provides a very wide range of capabilities to the user, is a relatively simple task and by which the most complex issues can be easily modeled. For example, problems involving more than one component can be modeled by creating a geometric model of each component and then attributing the behavior of the material to each component and then assembling the various components. In most modeling, even models with high nonlinear degrees, the user has to determine only the engineering data such as the geometry of the problem, the behavior of the material concerned, the boundary conditions and the loading of the problem. In this dissertation, ABAQUS / CAE has been used for modeling.

In this paper, Dynamic Explicit analysis method is used. In this method, in the implicit solution method, a set of equations must be solved simultaneously and as a system of equations. Now for the problems that depend on time and we want to solve them by implicit method, the set of equations mentioned must be solved in any time development. As mentioned, in the explicit method, the dynamic equation (or the equation of motion) was applied at the beginning of each temporal evolution (at time t). Alone could be solved. But in the implicit method, which uses Newton's iterative method, the dynamic equation of equilibrium is written at the end of the temporal evolution (at time t + Δt). This causes the internal forces, in addition to acceleration, to join the set of unknowns, which makes it impossible to solve the equation of each node alone, and the equations must be written for all nodes and then solved simultaneously.

This method automatically selects the temporal development size. Of course, this value can also be selected by the user because the implicit solution method, unlike the explicit method, is convergent without any conditions. For this reason, the size of the development time in implicit solution is usually larger than the explicit solution method. For a nonlinear problem, the set of equations obtained in a time pattern is solved iteratively, and in each time pattern, several iterative steps are required to obtain an answer within the set tolerances.

4- Review and Compare the Results

In this section, the structural behavior of laboratory and modeled beams is investigated, the results of compressive strength and four-point bending tests (load diagram - displacement diagram) are explained, and then the results of finite element analysis using the model The samples are made in the software, and finally, a comparison is made between the laboratory results and the modeling.

In order to study the structural behavior of beams, five concrete beams including Leica light concrete with the amount and arrangement of rebars, cross-sectional dimensions, amount of cementitious materials, and the ratio of water to the same cementitious materials have been made, which are detailed in Section 3.

4.1. Compressive Strength and Specific Weight

The results of the compressive strength test of cube samples of 10 × 10 × 10 cm and their specific gravity are presented in Table 2.

Table 2

Compressive strength and specific dry weight of tested samples

Beam	f_{cu} (N/mm^2)	Dry specific gravity (kg/m^3)
B1	24/62	1795
B2	23	1790
B3	25/62	1798
B4	26	1801
B5	23/62	1792

4.2. Investigation of the Structural Behavior of Laboratory Beams

In this section, the flexural behavior of the beams is investigated. Table 3 presents the results of the four-point bending test of laboratory beams.

To investigate the displacement of the beams, the load-displacement curve is examined. These curves are shown in Figure 3. As can be seen in these figures, the curves of Leica lightweight concrete beams are linear up to 12500, 11600, 13100, 13200, 10400 kg, respectively, but then the slope of the curve decreases, which indicates the flow of longitudinal rebars.

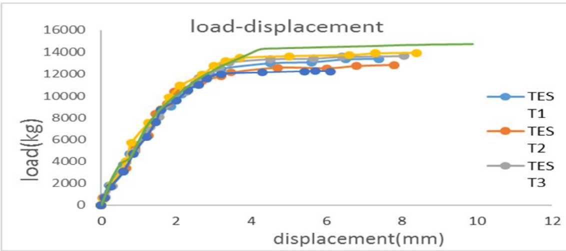


Fig. 3. Load-displacement curves for laboratory and modeled samples

According to the manual calculations, we know that the tensile steel has flowed while the steel that is in the compression zone has not yet flowed, and due to the flow of tensile steel, the cross-section failure is flexible. As can be seen in the above figures, after the steel starts to flow, many displacements occur without a significant increase in load, which indicates the good formability of Leica lightweight concrete.

Table 3

Recorded values from Leica lightweight concrete beam test

Beam 1		Beam 2		Beam 3		Beam 4		Beam 5	
load (p)	displacement	load (p)	displacement	load (p)	displacement	load (p)	displacement	load (p)	displacement
(kg)	(mm)	(kg)	(mm)	(kg)	(mm)	(kg)	(mm)	(kg)	(mm)
720	0/06	670	0/08	700	0/12	550	0/07	630	0/05
1800	0/2	1700	0/25	1750	0/3	1800	0/25	1695	0/25
3700	0/6	3050	0/6	3900	0/65	4000	0/65	3350	0/65
4700	0/75	4700	0/85	4550	0/9	5700	0/8	5150	0/9
7250	1/3	6250	1/2	7150	1/3	7500	1/25	6400	1/25
8500	1/55	7600	1/45	8100	1/55	8800	1/6	8350	1/45
9050	1/85	8750	1/6	9550	1/9	9900	1/8	9250	1/75
10100	2/15	9550	2	10350	2/25	10950	2/1	10400	1/95
11100	2/5	10550	2/3	11650	2/6	12000	2/7	11150	2/55
11550	2/8	11050	2/6	11800	2/8	12800	3	11400	2/7
11950	2/9	11600	2/8	12650	3/15	13200	3/3	11800	3/2
12500	3/2	12000	3/2	13100	3/4	13500	3/7	12150	3/45
13000	4/5	12150	4/3	13400	4/5	13650	5	12600	4/7
13100	5/6	12250	5/4	13450	5/65	13750	6/6	12550	6
13350	6/5	12300	5/7	13600	6/4	13900	7/3	12750	6/8
13400	7/4	12250	6/1	13680	8/05	13950	8/4	12850	7/8

The final rupture load of Leica lightweight concrete beams is 13400, 12250, 13680, 13950, and 12850 kg, respectively. Figure 4 shows laboratory tested RC beam and failure 5 shows the shape of arrow 3 (for example) before and after failure.

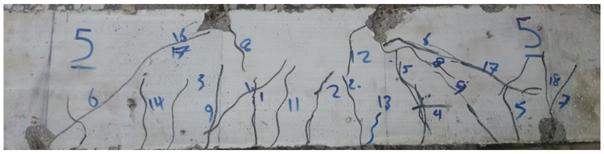


Fig. 4. Laboratory Tested RC beam failure

A. Before failure

B. After failure

Fig. 5. Laboratory beam before and after failure

Comparison of the final load of Leica lightweight concretes shows that although its specific gravity and compressive strength are lower than ordinary concrete, it has an acceptable final strength for use in a structural beam. The weight of concrete, Leica lightweight concrete beam with a specific weight of 1800 kg / m3 and compressive strength of 24.57 MPa is about 25% less than the weight of ordinary concrete, which by making the weight of concrete lighter, significant advantages can be achieved, including forces on The structure shrinks.

Failure of the specimens occurred by creating shear and flexural cracks and flexural shear in the tensile zone and crushing of concrete in the compressive zone.

4.3. Results of Modeled Beam Structural Behavior

In this research, the powerful ABAQUS finite element software has been used for modeling and static analysis on Leica lightweight concrete beam samples.

Figure 3 shows the load-displacement diagram of the modeled beam. Also, the displacement contour obtained for the beam modeled in finite element software is shown in Figure 5.

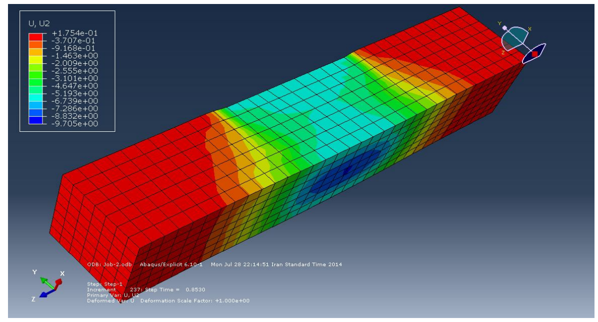


Fig. 6. Displacement contour in the direction of applying force

According to Figure 3, it can be seen that the modeling results are consistently consistent with the laboratory results.

Due to the shape of the above diagrams and the final strength and displacement of the samples, in laboratory samples and modeled samples, it is observed that there is an acceptable match between the results and the accuracy of the software output results can be ensured.

The relationships in the regulations are based on ordinary concrete, while the concrete used in this research is lightweight concrete, so the bearing capacity obtained based on the relationships with laboratory results is not necessarily the same.

There is a possibility of executive errors in the laboratory, so the accuracy of the results is less than the modeling result in ABAQUS software.

4.4. Investigation of Failure Mode of Laboratory and Modeled Beams

Figure 6 shows the main stress distribution in the modeled beam.

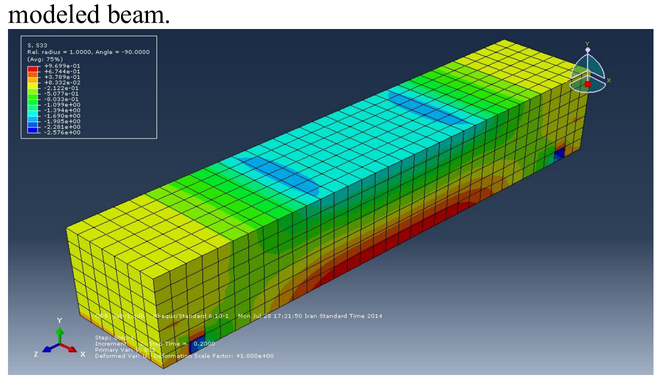
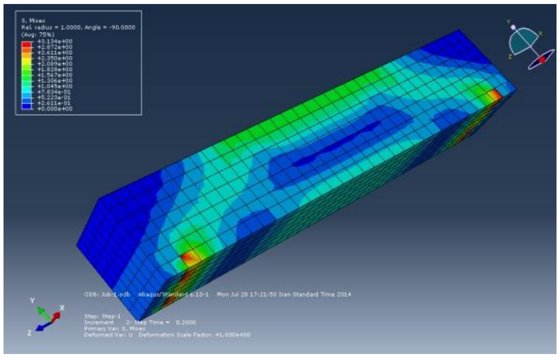
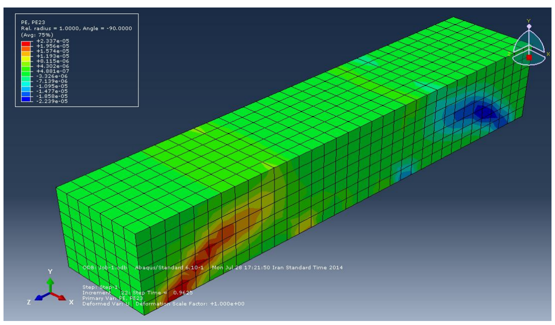


Fig. 7. The main stress contour of the modeled beam (N/mm^2)

As we know, cracking occurs in places where the stress has reached the cracking stress of concrete. Therefore, the distribution of von-mises stress and shear stress of beams is also shown in Figure 7.



A.



B.

Fig. 8. A. Tension contour B. Modeled beam shear stress contour (N/mm^2)

Comparing the laboratory results with the modeling results, we conclude that the crack shape corresponds to the stress distribution resulting from finite element analysis, and this is another testament to the accuracy of the modeling and the reliability of the model.

As can be seen in the figures above, shear cracks have occurred at the endpoints of the beam, in view of what has been said about shear cracks in the beams, and it should be noted that due to laboratory limitations it is possible to perform experiments on beams. There was no higher, such a result is not far from the mind.

As can be seen in the figures above, in places such as supports or loads, local rupture occurs due to the concentration of existing stress, which was not unexpected.

On the other hand, we know that at the moment of final beam failure, in places where the plastic strain has exceeded 0.0035, crushing occurs in concrete. For this purpose, Figure 8 shows the plastic strain distribution of concrete beams.

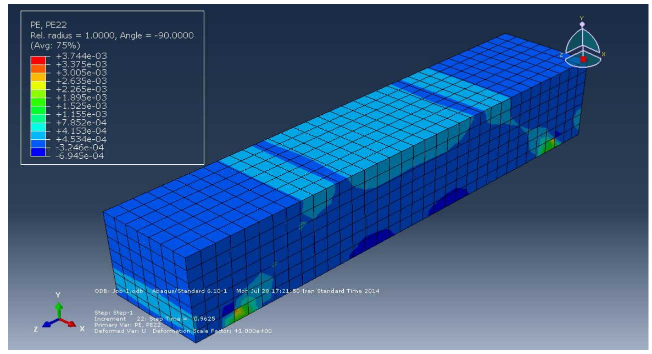


Fig. 9. Plastic strain contour

As can be seen in the figure, at the points where the beam is modeled, the strain is beyond the plastic strain of the concrete, crushing has occurred, which means at the point of support and the place of force application, as shown by the laboratory results in Figure 4. Shown, matches.

5- Result

According to the new approach of the construction industry, which seeks to reduce the dead load of the building and, consequently, reduce the seismic force on the structure, we are witnessing the rapid emergence and flourishing of the use of lightweight concrete in this industry. In this research, laboratory and analytical study of bending behavior of structural beams made of lightweight concrete have been investigated. For this purpose, five structural beams were examined in a laboratory, and finally, one beam was modeled using ABAQUS finite element software. The results of these studies are given below.

Load-displacement diagrams The middle of the span of all beams is drawn, which, regardless of the slight differences observed in the diagrams, can be said to be consistent with each other. The amount of load at which the tensile reinforcements start to flow is about 12/160 tons. The final load that the made beams can withstand is about 13.226 tons, in this case, the displacement of the middle of the span is about 7.55 mm. The ABAQUS finite element software model has acceptable compatibility with laboratory results. The crack distribution in the laboratory samples corresponds to the distribution of stresses obtained from the modeled beam, which is a testament to the accuracy of the modeling. Local failure has occurred at points of the beam that are under load and at the fulcrum, which can be seen in both laboratory and modeling results.

Comparing the results obtained in this study with the numerical results obtained by using the regulatory relations that are for ordinary concrete, we conclude that the bearing capacity of beams with light concrete is less than ordinary concrete, but according to The reduction of sample weight and the fact that this difference in capacity is negligible, the use of lightweight concrete in structural members such as beams or columns is recommended.

References:

[1] Kim HungMo, U. JohnsonAlengaram, Mohd ZaminJumaat. Bond properties of lightweight concrete – A review, Construction and Building Materials, Vol 112, 1 June 2016, Pages 478-496

[2] Karl-Christian Thienel, Timo Haller, Nancy Beuntner. Lightweight Concrete—From Basics to Innovations, 2020, Materials, Vol 13, Issue 5.

[3] Bagheri AS, Rahmani AS, Ruh Shahbaz J. 2001, Laboratory study of engineering properties of lightweight concrete made with natural lightweight aggregate (Pumice), the first international conference on concrete and development.

[4] Yazdi J. "Lightweight concrete and its application in the construction industry", Tabriz Lightweight Insulation Industrial and Mining Company.

[5] Mayasserm. Jomaa'h, Hosam A. Daham, Saad M. Rao' of, Flexural behavior of lightweight concrete beams, European Journal of Scientific Research, 20 II Vol. 58 No. 4, PP. 582-592.

[6] Delsye C.L. Teo, Md. Abdul Mannan and Johan V. Kurian. Flexural behavior of Rein Forced Lightweight Concrete beams made with oil palm shell (OPS), Journal of Advanced Concrete Technology, 2006, Vol. 4, No. 3, PP. 1-10.

[7] Chung- Hao Wu, Yu- Cheng Kan, Chung – Ho Haung, Tsong Yen and Li- Huai Chen. Flexural behavior and Size effect of full Scale Reinforced Light Weight Concrete beam. 2011, Journal of Marine Science and Technology, Vol. 19, No.2, PP. 132-140.

[8] Meh met Kamanli, M. Yassar Kaltakci, Fatih Bahadir. Fatich S.balik, H Hasnu Korkmaz, M Sami Don Duren and M. Tolga Cogurcu, Predicting The Flexural behavior of reinforced Concrete and lightweight Concrete beams by ANN, Indian Journal of engineering & materials Since, 2012, Vol. 19, PP. 87-94.

[9] Tao Wu, Hui Wei, Xi Liu. Experimental investigation of shear models for lightweight aggregate concrete deep beams, Advances in Structural Engineering, 2017.

[10] BSEN. 12390-3: 2009- Testing hardened Concrete Compressive Strength of Test Specimens.