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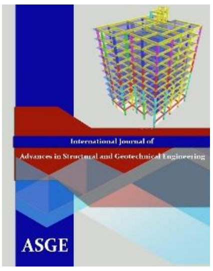

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NUMERICAL PREDICATION OF SIZE EFFECT FACTOR FOR DIFFERENT COMPRESSIVE STRENGTH LEVELS

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ABSTRACT

Compressive strength is one of the most important mechanical properties of concrete. Both of shape and size of specimens affect on the value of compressive strength which varies according to the country where test occurred and standard specimens used. A numerical investigation in this work by using one of the powerful and famous finite element analysis program, ANSYS, was done to predict a real size factor

In the present work, a numerical program using ANSYS to study the effect of specimen size on the stress and strain behavior of concrete specimens was conducted. Cubic concrete specimens of six sizes 70,100,150, 200, 250 and 300 mm and cylindrical specimens of four sizes 70,100,150 and 200 mm in diameter with aspect ratios one and two were idealized under monotonic loading condition. Three different strength levels including 30, 50 and 70 MPa were investigated in this work. Studying the behavior of stresses and strains under strain condition for each level of concrete strength was conducted.

For the investigated shapes and sizes there is a decrease in the value of ultimate stresses and strains with increase in specimen size. The effect of specimen size is very small in cylindrical specimens with aspect ratio equals two and does not clear in cylindrical specimens with aspect ratio equals one. The numerical data were analyzed and correlated for cubic specimens to obtain a mathematical formula through which could be predicted the size effect factor for any cubic specimen size. Acceptable agreement between the predicted data and previously published experimental results was found.

Keywords: Size factor; 3D-Finite element; Compressive strength; Vertical Stress; Vertical Strain; Lateral Stress; Lateral Strain

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INTRODUCTION

By far the most common test carried out on concrete is the compressive strength test. Testing standard requirements use different geometries of specimens to determine the compressive concrete strength. The most used geometries are cylinders with slenderness equal to two and cubes. Shape and size effect factor that affecting on compressive strength has been widely studied [1]. Mei Li and Hong Hoa [2] studied different sizes of cubic and cylindrical concrete specimens under compressive stress with different loading rates. Cubes dimensions of 50 mm and cylinder with 50 mm in diameter with various lengths-to- diameter ratios were tested. They found that the cube gave slightly lower compressive strength than the cylinder one because the stress concentration at the corner of the cube and they found when the height of cylinder decreased with the same diameter the compressive strength increased.

Jae_IISim,Keun_Hyeok Yang [3] studied the size and the aspect ratio of specimen that affect on compressive strength of lightweight concrete. The aspect ratios of specimens for circular and square sections were 1 and 2. The dimensions of specimens vary from 50 mm to 150 mm. That study reached to the strength decreases when the specimen size increases. Josef Fladr and Peter Bily [4] studied the relationship between the specimen size and mechanical properties of high-strength fiber- reinforced concrete (HSFRC). The compressive strength ranged from 100 to 175 MPa. They used four sizes of cubic specimens 40, 100, 150 and 200 mm. Compressive strength was measured on cubes specimens with loading rate 0.5 MPa/s. Their study reached that whatever size increases the strength decreases up to grade 130 after that the curve seem to be close to straight line.

Four variables shape, size, curing and different strength levels, Level 1 (30-54 MPa) level 2 (50-73 MPa) were studied in Ref [5]. Using cylinder 100x200 and 150x300 and cubes 100,150 and 200 mm. Calculated conversion factors for two levels of strength and used the data fit version 9 to find the relation between the conversion factors and cross section of specimens .Curves of specimens which were cured in air were third order polynomial model. Curves of specimens which cured in water were third order inverse polynomial model.

Three types of specimens shape, cubic, cylindrical and prism were studied in Ref [6]. The cube dimension 50,100,150 and 200 mm, the cylinder diameter 50,100,150 and 200mm with aspect ratio 2 and prism had square cross section with length 50,100,150 and 200 mm and height equals to two of cross section length. The compressive strength value of concrete was 20, 40, 60 and 80 MPa. The testing program applied by hydraulic testing machine using displacement control method of 0.003 mm/s velocity. They reached to the relation between f_{cu} / f_c (cube strength / standard specimen strength) and the specimen sizes was inverse relation and could obtain equation with correction coefficient 0.94 .

$$f_{cu}(d) = \frac{1.17\, f_c}{\sqrt{1+d/2.6}} + 0.62 f_c \qquad (1)$$

Where f_{cu} (d) is the compressive strength of cubes with size d, f_c is the compressive strength of stander specimen in MPa and d is the size of cube in cm.

Ali Jihad Hamad [7] studied the effect of shape and size of specimen on compressive strength for high performance lightweight foamed concrete (HPLWFC). Using cubic specimens with 50, 100 and 150 mm in length and cylindrical specimens with 100 and 150 mm in diameter and aspect ratio equals two. Using foam agent (organic material) to obtain lightweight concrete and four ratios of glass fiber equal 0, 0.06, 0.2 and 0.4.that study reached to the small size gave higher value of compressive strength compared to large sizes.

NiloufarZabih [8], worked on a variety of variables like size and shape of specimens, different curing conditions and different testing ages 7, 28 and 56 days. Worked on cylinder dimension 100x200 and 150x300 mm and cube sizes are 100,150,200 mm. it was found that the increase in cube size offset the increase in compressive strength. They explained that with the increase in the cube size, the samples need to absorb the higher energy to reach the point of failure. Wojciech Mazur, ŁukaszDrobiec, RadosławJasiński [9], used nonstandard specimens to obtain the equation which connect between the compressive strength obtained from cube 150x150x150 mm and the compressive strength for any specimen.The greatest strength was found in specimens with the smallest volume.

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Cubic and cylindrical concrete specimens with different strength range from 20 to 100 MPa were tested in Ref [10]. The cube dimension of 100 and 150 mm and cylinder diameter of 100 mm with aspect ratios 1&2 and of 150 mm with aspect ratio 2 were used. The cube150 mm was considered as a reference. They found that the ratio between the standard cube strength to other specimen strength decreases when level of concrete strength increase and the size of specimen decreases.

In this work, a numerical program was designed to investigate the effect of specimen size on the behavior of stresses and strains of compressive concrete specimens. Based on the given results in this program the size effect factor was predicated and compared with previously published experiment results.

IDEALIZATION

The ANSYS is a powerful and famous finite element analysis program with high ability to represent the studied issue; no matter how complicated it was started in 1970 and is developed annually. It is used in most parts of the world in various fields such as static structural, steady state thermal, thermal-electric, fluid, explicit dynamics……….etc. In this work recent version of ANSYS, ANSYS19 was used.

Material library in ANSYS contains at least 150 different material types. Each type has a unique code and number [11]. Concrete was modeled using 3-D 20-nodes solid element. The solid element used is SOLID186. The element is defined by 20 nodes having three translation degrees of freedom at each node in the x, y and z directions as shown in **Figure 1**.

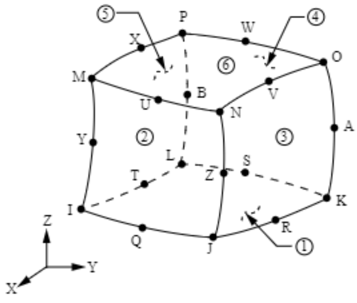


Figure 1: SOLID186 element

In the present work, three levels of concrete strength were used 30, 50 and 70 MPa. The elastic properties of the concrete are given in **Table 1.**The monotonic stress-strain behavior shown in **Figure 2**. All specimens were loaded by strain rate condition. In level 1 max, displacement ratio is equal to 0.002.while for level 2 max, displacement ratio is equal to 0.0018.Finally for level 3 max, displacement ratio is equal to 0.0016.In order to idealize supporting conditions of compressive test, the upper and lower surfaces of test specimen were constrained in lateral directions. During loading the cracking considered when the principle stress in any direction lies outside the failure surface. [12].

Table 1: property for different levels of concrete [13]

	Level 1	Level 2	Level 3
Compressive strength, MPa	30	50	70
Tensile strength, MPa	4	4.5	5.6
Modulus of elasticity, MPa	29250	35100	43875
Passion`s ratio	0.2	0.18	0.18

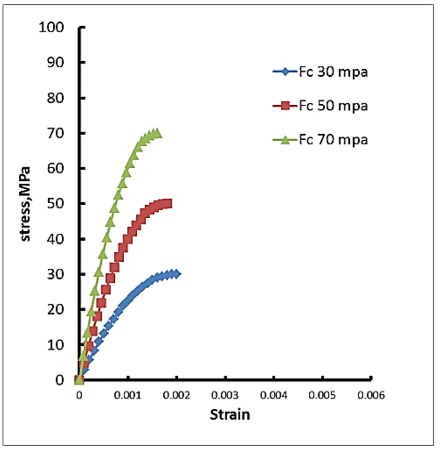
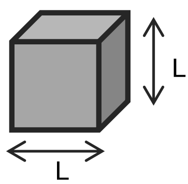
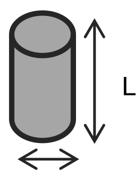
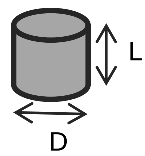


Figure 2: Stress – strain curve for the used concrete in finite element program

NUMERICAL PROGRAM

Two different geometries; cube and cylinder were idealized in this work. Specimens divided in three groups as shown in Table 2. For each group, the three levels of concrete strength 30, 50 and 70 MPa were considered. Group 1 contains cubic geometry, group 2 contains cylindrical geometry with aspect ratio 2 and group 3 contains cylindrical geometry with aspect ratio 1. All geometry were meshed into 10 mm in 3D as shown in Figures 3 and 4. Geometrical paths parallel to loading direction were used to compare between different geometries and obtained stresses and strain for this path.

Table 2: shape and dimensions of specimens used in the work

	Group 1	**Group 2**	**Group 3**
Shape	Cube 	Cylinder  L= 2D	Cylinder  L= D
Dimensions	L= 70,100,150,200,250,300 mm	D = 70,100,150,200 mm	D = 70,100,150,200 mm

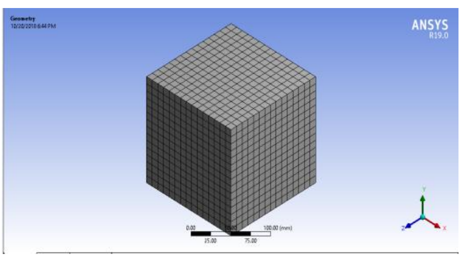


Figure 3: typical mesh in cubic specimen

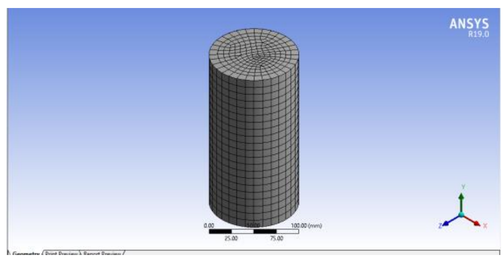


Figure 4: typical mesh in cylindrical specimen

RESULTS AND DISSUASION

Cubic Geometry

Figure 5 shows the behavior of vertical stress in MPa against cube size in cm. The results in Fig.5 indicate that a decrease in the value in vertical stresses with increase in specimen size. This trend is similar for the three levels of concrete strength. Typical behavior was presented in Ref [1]**.** The data in Fig, also, show that the rate of decreasing in normal stress is affected by the specimen size and concrete compressive strength level. For σ_c 70 MPa and for sizes less than 15 cm as specimen size increases from 7 cm to 10 cm and from 10 cm to 15 cm the normal stresses decrease by 10.35% and 3.827%, respectively. For σ_c 30 MPa and for sizes less than 15 cm as specimen size increases from 7 cm to 10 cm and from 10 cm to 15 cm the normal stresses decrease by 10.788% and 3.98%, respectively. This finding clearly proved that as the concrete strength increases the size effect decreases. A similar result was found in Ref [4]. One can note from Fig. 5, for given concrete strength and specimen size more than 15 cm, the decrease in normal stress is going to be steady state condition. This behavior means less effect of specimen size.

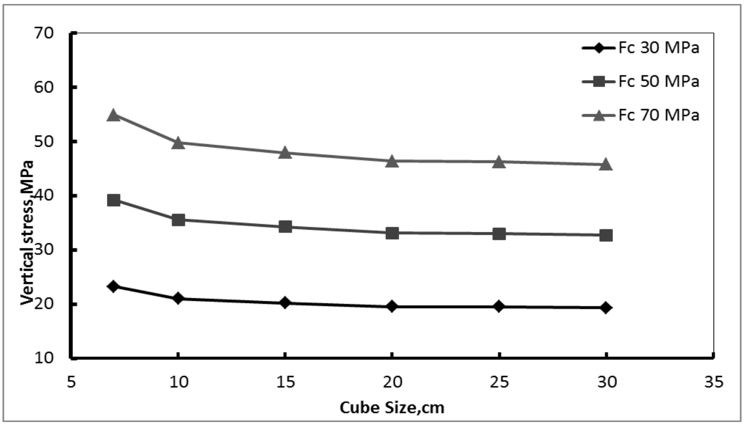


Figure 5: The relation between vertical stress and cube size for different concrete levels

The results of vertical strain against cube size in cm are shown in Fig 6.The results in Fig.6 indicate that a decrease in the value in vertical strains with increase in specimen size. This trend is similar for the three levels of concrete strength. Typical behavior was presented in Ref [1]. The data in Fig, also, shows that the rate of decreasing in vertical strain is affected by the specimen size and concrete compressive strength level. For σ_c 70 MPa and for sizes less than 15 cm as specimen size increases from 7 cm to 10 cm and from 10 cm to 15 cm the vertical strains decrease by 6.614% and 2.79%, respectively. For σ_c 30 MPa and for sizes less than 15 cm as specimen size increases from 7 cm to 10 cm and from 10 cm to 15 cm the vertical strains decrease by 6% and 2.74%, respectively. This finding clearly proved that as the concrete strength increases the size effect decreases. One can note from Fig. 5 for given concrete strength and specimen size more than 15 cm, the decrease in normal stress is going to be steady state condition. This behavior means less effect of specimen size.

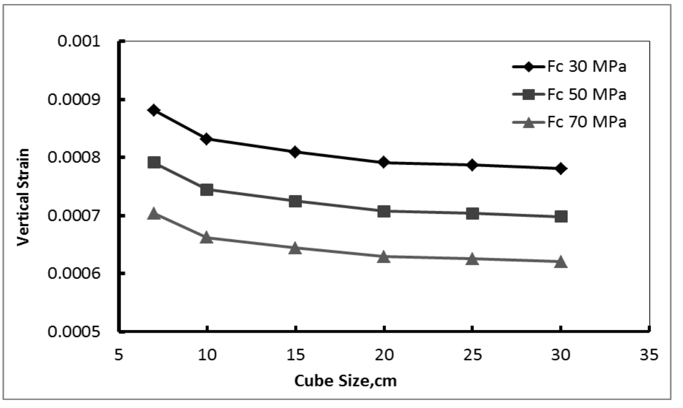


Figure 6: The relation between vertical strain and cube size for different concrete levels

Figure 7 shows the values of lateral stress in MPa against cube size in cm. The results in Fig 7 indicate that the value of lateral stress increases when specimen size increases from 7 cm to 10 cm after that the value of lateral stress decreases with increase in specimen size. This trend is similar for the three levels of concrete strength. The data in Fig also shows that the rate of decrease in lateral stress is affected by the specimen size and concrete compressive strength level. For σ_c 70 MPa as specimen size increases from 7 cm to 10 cm the lateral stress increases by 5.2%.Moreover as specimen size increases from 10 cm to 15 cm the lateral stress decreases by 22.33%. For σ_c 30 MPa as specimen size increases from 7 cm to 10 cm the lateral stress increases by 5.65%. After that as specimen size increases from 10 cm to 15 cm the lateral stress decreases by 19.678%.By comparing the data in Fig.5 with that in Fig.7, as the specimen size increases, one can notice that the rate of decreasing in value of lateral stress is more than that of the rate of decreasing in value of vertical stress.

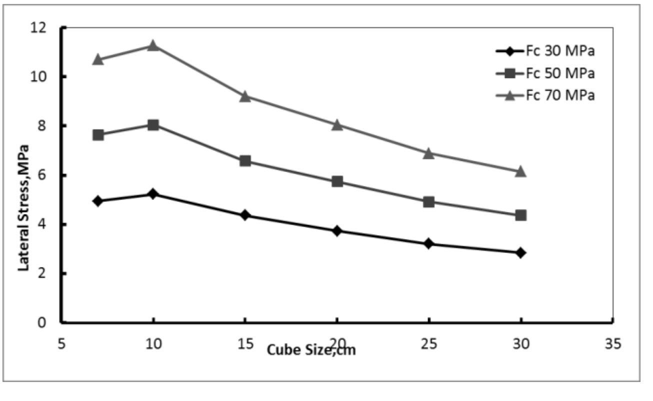


Figure 7: The relation between lateral stress and cube size for different concrete levels

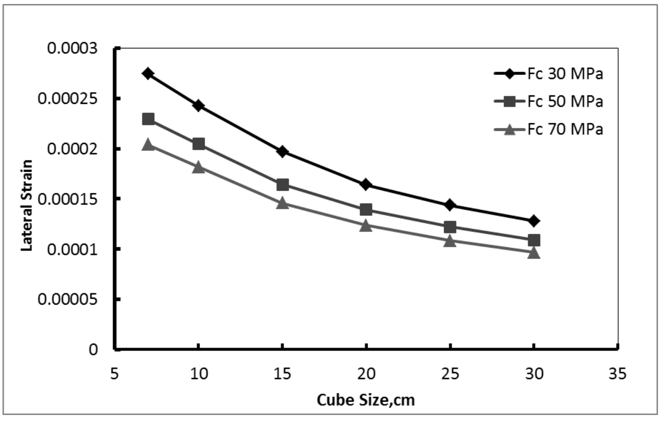
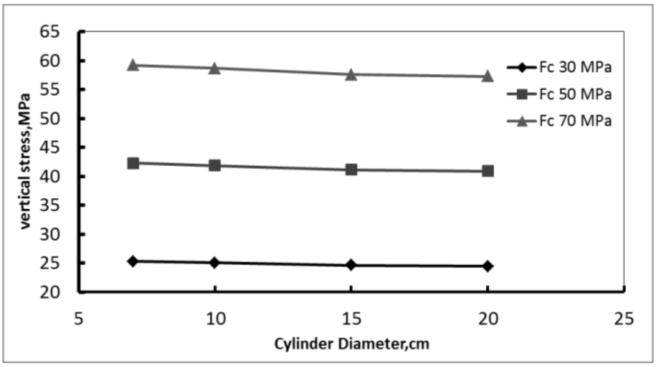


Figure 8: The relation between lateral strain and cube size for different concrete levels

The results of lateral strain against cube size in cm are shown in Fig 8. The results in Fig.8 indicate that a decrease in the value in lateral strains with increase in specimen size. This trend is similar for the three levels of concrete strength. The data in Fig also shows that the rate of decreasing in lateral strain is affected by the specimen size and concrete compressive strength level. For σ_c 30 MPa and for sizes less than 15 cm as specimen size increases from 7 cm to 10 cm and from 10 cm to 15 cm the vertical strains decrease by 12.934% and 23.297%, respectively. For σ_c 70 MPa and for sizes less than 15 cm as specimen size increases from 7 cm to 10 cm and from 10 cm to 15 cm the vertical strains decrease by 12.266% and 24.55%, respectively. These results, also, clearly proved that as the concrete strength increases the size effect decreases.

Cylindrical specimens with aspect ratio equal one

Figure 9 shows the values of vertical stresses in MPa against cylinder diameter in cm. The results in Fig.9 indicate that a slight decrease in the value in vertical stresses with increase in specimen size. This trend is similar for the three levels of concrete strength. Typical behavior was presented in Ref [1, 6]. The data in Fig, also, shows that the rate of decreasing in normal stress is affected by the specimen size and concrete compressive strength level. By comparing the data in Fig.5 with that in Fig.9, as the specimen size increases, one can notice that the rate of decreasing in value of vertical stress in cube specimen is more than that of in cylinder specimen. For σ_c 70 MPa as cube size increases from 7 cm to 10 cm the stress decreases by 10.35%. But in cylinder when size increases from 7 cm to 10 cm the stress decreases by 0.933%. The reason for that may be attributed to uniform distribution of stresses along cross section of the cylindrical specimen compared to that established in the cubic specimens. In cylindrical specimen, the stresses along cross section area are uniform, while in cubic specimen the stresses along cross section are concentrated at corners [1].



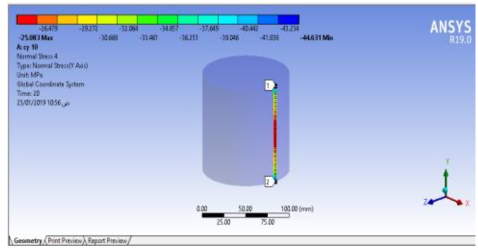
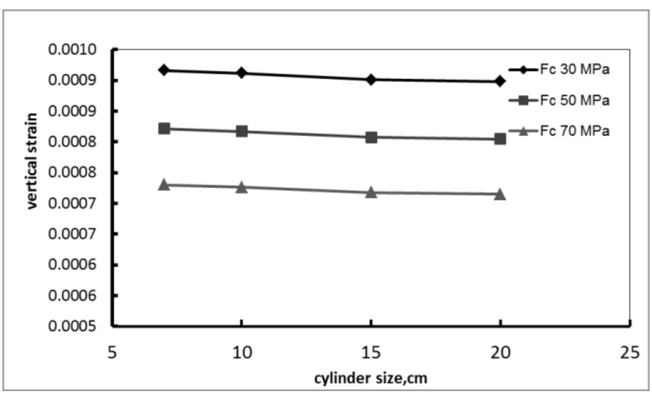


Figure 9: The relation between vertical Stress and cylinder diameter for different concrete levels, L/d = 1

The behavior of vertical strain in against cylinder diameter in cm is given in Fig. 10. By comparing the date in Fig.6 with that in Fig.10, as the specimen size increases, one can notice that the rate of decreasing in the value of vertical strain in cube specimen is more than that of cylinder specimen. For σ_c 30 MPa as cube size increases from 7 cm to 10 cm the strain decreases by 6%. But in cylinder when size increases from 7 cm to 10 cm the stress decreases by 0.92%. This finding is typically similar as mention in the values of the vertical stresses in Fig.9 and can be attributed to the same reasons.



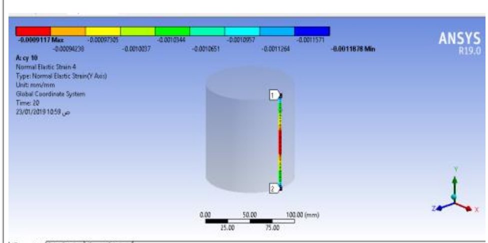
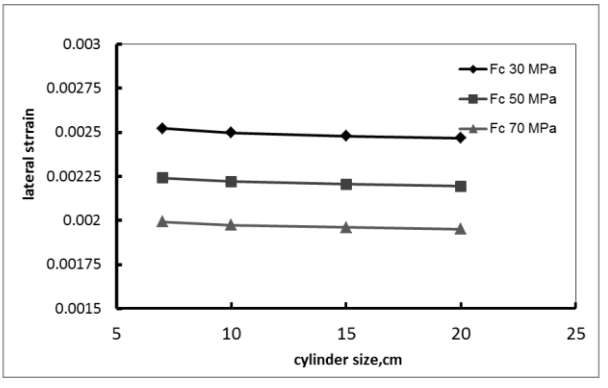


Figure 10: The relation between vertical strain, and cylinder diameter for different concrete levels, L/d =1

The results of lateral strain in against cylinder diameter in cm are shown in Fig 11.The results in Fig.11 indicate that the value of lateral strain slight decreases with increase in specimen size. This trend is similar for the three levels of concrete strength. The data in Fig, also, shows that the rate of decreasing in lateral stress is affected by the specimen size and concrete compressive strength levels. Moreover the rate of decreasing in lateral strain is very small as the specimen size increases.

By comparing the data in Fig.8 with that in Fig.11, as the specimen size increases, one can notice that the rate of decreasing in the value of vertical strain in cube specimen is more than that of the rate of decreasing in value of vertical strain in cylinder specimen. For σc 30 MPa as cube size increases from 7 cm to 10 cm the strain decreases by 12.934%. But in cylinder when size increases from 7 cm to 10 cm the stress decreases by 0.987%.



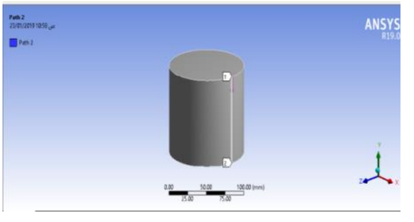
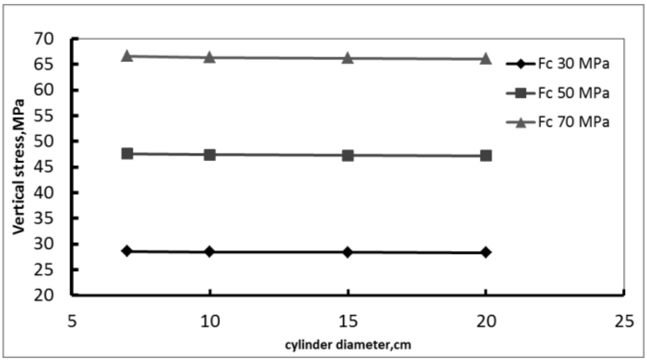


Figure 11: The relation between lateral strain and cylinder diameter for different concrete levels, L/d = 1

Cylindrical specimens with aspect ratio equal two

Figure 12 shows the behavior of vertical stress in MPa against cylinder diameter in cm. The results in Fig.12 indicated that there is a decrease in the value in vertical stresses with increase in specimen size but the rate of decreasing is very small. That indicated that the effect of size factor is not clear in cylinder. This trend is similar for three levels of concrete strength. Typical behavior was presented in [1, 5]. By comparing the date in Fig.9 with that in Fig.12, as the specimen size increases, one con notice that the rate of decreasing in value of vertical stress in cylinder specimen with aspect ratio equal to two is less than that of the rate of decreasing in value of vertical stress in cylinder specimen with aspect ratio equal to one. For σ_c 30 MPa and cylinder specimen with aspect ratio equal two as specimen increase from 7 cm to 10 cm, from 10 to 15 cm and from 15 cm to 20 cm the normal stress decease by 0.45%, 0.247% and 0.18% respectively. For σ_c 30 MPa and cylinder specimen with aspect ratio equal one as specimen increase from 7 cm to 10 cm, from 10 to 15 cm and from 15 cm to 20 cm the normal stress decease by 0.933%, 1.819% and 0.55% respectively.



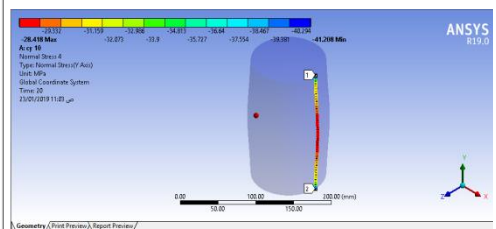
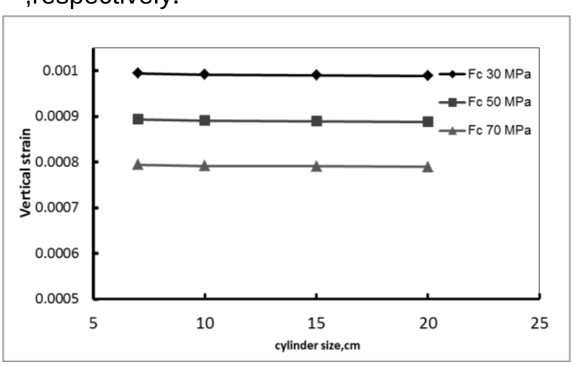


Figure 12: The relation between vertical stress and cylinder diameter for different concrete levels, L/d = 2

Figure 13 shows the values of vertical strain in against cylinder diameter in cm. The results in Fig.13 indicate that a decrease in the value in vertical strains with increase in specimen size but the rate of decreasing is very small. This indicated that the effect of size factor is not clear in cylinder. This trend is similar for three the levels of concrete strength. By comparing the data in Fig.10 with that in Fig.13, as the specimen size increases, one can notice that the rate of decreasing in value of vertical strain in cylinder specimen with aspect ratio equals to two is less clear than that of the rate of decreasing in the value of vertical stress in cylinder specimen with aspect ratio equals to one. For σc 70 MPa and cylinder specimen with aspect ratio equals two as specimen increases from 7 cm to 10 cm, from 10 to 15 cm and from 15 cm to 20 cm the normal stresses decease by 0.308%, 0.147% and 0.114%, respectively. For σc 30 MPa and cylinder specimen with aspect ratio equals one as specimen increase from 7 cm to 10 cm, from 10 to 15 cm and from 15 cm to 20 cm the normal stresses decease by 0.52%, 1.236% and 0.344% ,respectively.



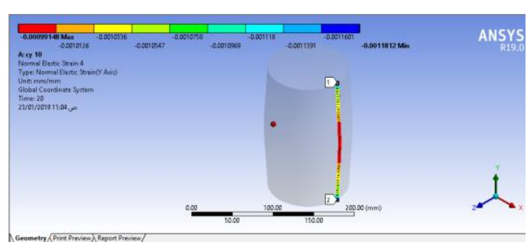
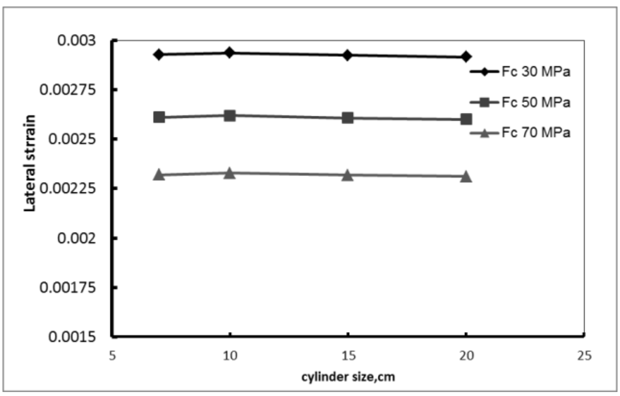


Figure 13: The relation between vertical strain and cylinder diameter for different concrete levels, L/d = 2

The results of lateral strain in against cylinder diameter in cm are shown in Fig 14.The results in Fig.14 indicate that the value of lateral strain slight increases when specimen size increases from 7 cm to 10 cm after that the value of lateral stress decrease with increase in specimen size. This trend is similar for the three levels of concrete strength. By comparing the data in Fig.11 with that in Fig.14, as the specimen size increases, one can notice that the rate of decreasing in value of vertical strain in cylinder specimen with aspect ratio equals to two is less clear than that of the rate of decreasing in the value of vertical stress in cylinder specimen with aspect ratio equals to one.



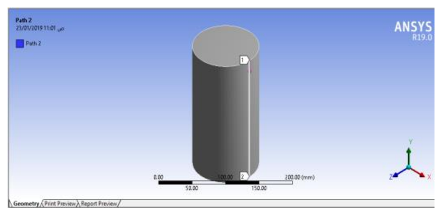


Figure 14: The relation between Lateral Strain and cylinder diameter for different concrete levels, L/d = 2

Correlation

The numerical results in this study were analyzed and correlated for cubic specimens to obtain a mathematical formula through which we can predict size effect factor for any cubic size specimen. The best fit correlation gives the following equation:

$$\frac{\sigma(d)}{\sigma(15)} = e^{1.31\left(\frac{\sigma t}{\sigma c}\right)\left(\frac{d15}{d}-1\right)} \qquad (2)$$

Where: $\frac{\sigma(d)}{\sigma(15)}$ *is the strength for given cube with respect to stander cube, size factor*

d_{15} *is the size of the stander cube equals 15 cm*

d *is the size of given cube*

σ_c *is the compressive strength for the stander cube*

σ_t *is the indirect tensile strength for the stander cube*

In this analysis the ratio between indirect tensile strength and the compressive strength was considered as given in [14]. A comparison between predicted values from equation (2) and some published experimental results is given in Fig.15 in Ref

[6]. The data in figure shows acceptable agreement between the predicted and experimental results.

$(\frac{\sigma t}{\sigma c})$ = 0.091 for compressive strength 30 MPa

$(\frac{\sigma t}{\sigma c})$ = 0.085 for compressive strength 50 MPa

$(\frac{\sigma t}{\sigma c})$ = 0.079 for compressive strength 70 MPa

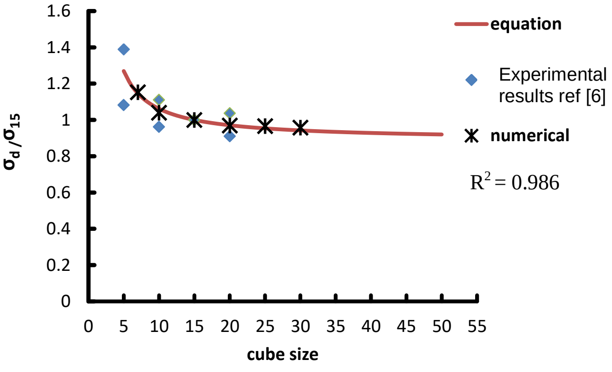


Figure 15: comparison between prediction and numerical results and experimental results in Ref [6]

CONCLUSIONS

In this work the effects of shape and size for concrete specimens with different level of concrete strength were investigated. The following conclusions could be drawn from the study

1- Both of stresses and strains in vertical and lateral directions are affected by the specimen shape, size and the level of concrete strength.
2- For all specimens there are decreasing in the value of stresses and strains with increase in specimen size.
3- In cubic specimens, the rate of decreasing in the value of stresses and strains for sizes more than 15 cm is more than that of sizes less than 15 cm.
4- As the specimen size increases, the rate of decreasing in the value of stresses and strains in vertical direction is more than that of lateral direction
5- The effect of specimen size is very small in cylindrical specimens with aspect ratio equal two and not clear in cylindrical specimens with aspect ratio equal one.
6- The numerical data were analyzed and correlated for cubic specimens to obtain a mathematical formula through which can predict size effect factor for any cubic specimen size. Acceptable agreement between the predicted data and previously published experimental results was found.

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