COMPARATIVE ANALYSIS OF THE INFLUENCE OF SIZE ON THE BEAMS OF DIFFERENT STRUCTURES OF CONCRETE

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Abstract—Application of fracture mechanics at design of RC buildings will provide significant benefit. It will contribute that different size of premises to have the same security. In this way, the security and the cost of construction will be enhanced. There will exist a greater possibility of applying new designs and materials. Especially in large RC buildings, as well as in high-strength premises, the premises made of concrete with the steel fibers, prestressed concrete, large concrete dams, nuclear power plants, the facilities that require high safety, whose damage can cause a disaster, the application of fracture mechanics is of great significance.

The impact of size, which relies on mechanical fracture can be defined as the theory of fracture which for the design of RC elements take into account resistance and energy of fracture.

Keywords—impact of size, compressive strength of concrete, fracture, interpolation, beam.

I. INTRODUCTION

Today many scientists, both experimentally and theoretically, deal with an important part of fracture mechanics and its impact of size. Most research of this topic was done in USA at the Northwestern University Bazant, Barr in England, u Carpinteri in Italy, Nemačkoj Reinhardt in Germany, Witmann in Switzerland and Mihashi in Japan [3-13, 27-45, 47]. We will list some of the most important papers:

The impact of size in RC beam on fracture shear, impact of size on laboratory and analytical fracture of reinforced and unreinforced beams by torsion, the effect of size of the test desks, the influence of size of the high-resistant beams, the impact size of concrete caused by the distribution of the crack, the impact of size in the fracture of brittle materials, the effect of size when drawing armature of concrete cubes, the effect of size and finding of energy fracture in the zone of fracture, fracture zone and energy zone with variable size of slots [3-13, 27-45, 47].

In parallel with this work, also at the Gazi University in Ankara, at the Department of Civil Engineering are carried out the theoretical and practical research on the topic of the impact of size.

We will mention some of these works:

1) Other theories of fracture (elastic-plastic) do not use the energy criteria of fracture, the impact sizes use the energy of fracture. The formation and expansion of cracks require energy. The impact of size in the anchoring zone in direct tension, the impact of the size of the anchoring zone in indirect loads, the impact of size on the beams with the slot of concrete with steel fibers, the impact of size on the concrete beams loaded by torsion.

In 1913, Inglis started the fracture mechanics on homogenous materials (glass) and in 1921 was followed by Griffin. The application of the fracture mechanics started much later. In 1960, Kaplan (Cape Town) was the first who started the application of fracture mechanics related to concrete. The most important in the application of the fracture mechanics related to RC is that in different materials of similar geometric shape, with an increase of the size of the stress is reduced.

The reasons for the use of theory of the impact of size are [1, 2, 14-26, 46]:

1) Other theories of fracture (elastic-plastic) do not use the energy criteria of fracture, the impact sizes use the energy of fracture. The formation and expansion of cracks require energy.

2) In the elements of different dimensions the conduct after the biggest load, resistance criteria of previous theories do not consider a fracture but the mechanics take it into account.

3) In the elements of different sizes of the similar geometric shapes, the effective stress at the moment of fracture, according to the criteria of resistance does not change, remain the same, while the actual behavior is the nonlinear effect of the size and by increase of the dimension the stress is reduced.

4) In various thicknesses (impact size) may be various results. In the two-dimensional elements (constant thickness) there is no change in test results.

5) In the slotted elements, coarser material is further away from the slots and smaller near the slots. Inability of equal dispersion of coarse material is another effect size.

There are two types of impact size; first form is the result of the use of different sizes in the final analysis of elements. The second form is a size impact as an structural dimensions.
The effect of the size can be explained by a comparison of the fracture load (P) with the elements of the various sizes of similar geometric shape.

\[ \sigma_f = \frac{c_b}{bD} \] – with two-dimensional elements (slab)

\[ \sigma_f = \frac{c_b}{bD^2} \] – with three-dimensional elements (cylinder)

where:

- \( \sigma_f \) – effective stress fracture
- \( b \) – thickness of two-dimensional elements
- \( c_b \) – coefficient of conformity
- \( D \) – characteristic dimension

In RC elements the impact size is visible with the linear elastic fracture mechanics (LEFM) located between the theory of elasticity and the theory of capacity.

In the plastic and elastic analysis \( \sigma_N \), fracture stress is completely independent from the dimension element. Bending, shear and torsion are calculated by elastic or plastic theory.

In concrete fracture begins at the point before the cracks and ends up somewhere in the final zone. This indicates that the fracture expands and has its own flow. In linear elastic fracture mechanics (LEFM) is assumed that fracture occurs at the top of a crack in a small area. It is assumed that the other parts of the element are resilient [21, 22, 26, 46].

II. PREPARATION OF TEST SAMPLES

In order to research the influence of the dimensions there have been used the samples of slotted beams on two supports and loaded by force capacity of \( P = 200 \text{kN} \) and the sensitivity of \( 100 \text{N} \) fractured (load cell), in the middle, deformations were measured at the point of load and the top of each slot of \( 50 \text{mm} \) with the sensitivity instrument of \( 100 \times 10^{-6} \text{mm LVD} \) (Tokyo Sokki Kenkyuyo Co.SDP-50C). During load all deformations are directly stored with the data logger (30 channels Bucem) that is constantly connected to the computer. The thickness of all samples is constant \( t = 4 \text{cm} \) and the other two dimensions of height \( h \) and length \( L \) are changed proportionally.

For testing are used three different sizes of the beams and from each sizes are used the three samples. To a mixture of concrete were used two aggregate fractions. A large fraction is \( 4,76 \) to \( 10 \text{mm} \), smaller fraction is \( 3 \) to \( 4,76 \text{mm} \). First, into the mixer is put sand, gravel and cement in the dry state, this is going to be mixed for about 2 minutes and after that the water is added and mixed again for 2 minutes.

From the same samples were set aside the 3 samples in the molds of cylindrical shape with a diameter of \( 150 \text{mm} \) and a height of \( 300 \text{mm} \) to determine the brand of concrete. Portland cement has been used (350), \( a_0 = h \times 0,2, S = 4,75 \text{h}, 0.2 \text{h} = \text{the dimension} \ L \text{ of test samples. Here is } a_0 = \text{length of slot before starting the test.}

B. High strength concrete

According to TS 500 high-quality concrete is concrete with a compressive strength of \( 30 \text{MPa} \) or more [43-45]. The purpose of high-strength concrete is bearing of high strength concrete. These concretes are very brittle and construction calculations should be based on fracture mechanics.

The shape and dimensions of the samples are the same as in ordinary concrete, but in order to increase the strength are added silicate fumes and plasticizers. The ratio of the concrete mixture is water/cement/sand/gravel/super plasticizers/silica fumes = \( 0,5/1,87,3,13/0,05/0,11 \) (ratios are according to weights).

The coarse fraction is from \( 4,76 \) to \( 10 \text{mm} \), the finer fraction is \( 3 - 76 \text{mm} \). First, into the mixer is put sand, gravel and cement in the dry state, then mixed for about 2 minutes after that the water is added and mixed again for 2 minutes.

From the same samples were set aside the 3 samples in the cylindrical molds with a diameter of \( 150 \text{mm} \) and a height of \( 300 \text{mm} \) to determine the brand of concrete. Portland cement was used (350)

C. Lightweight concrete

Lightweight concrete can be produced from the following lightweight aggregates: blast furnace slag, coal slag, clay and perlite, fly ash from wood shavings, diatomite, etc.

For calculations are used TS 2511 [43-45]. "The mixture of supporting lightweight concrete." The mixture of concrete with lightweight aggregate with a water/cement ratio based on calculation is not a satisfactory accuracy and therefore this concrete should be made based on a number experimental mixture. The mixture should be used for the same volume of coarse and fine aggregate in the free state. Due to possible problems the cement amount shrinkage would not have to exceed \( 450 \text{kg} / \text{m}^3 \).

In order to provide the desired amount of water to determine the consistency of the test assays. For the various aggregates to ensure the subsidence of about \( 5 \text{cm} \) to \( 1 \text{m}^3 \) is used between \( 180 \text{kg} \) and \( 270 \text{kg} \) of water.

To calculate the concrete mixture CM 16 of which will
be used the lightweight aggregate. For concrete will be used PC with a specific gravity of 3.1. Volume density of coarse aggregate is 650 kg/m³, fine aggregate is 720 kg/m³. Specific gravity of coarse aggregate is 124 kg/m³, and 146 kg/m³ of fine aggregate. Humidity of aggregate is zero.

D. Fibrous concrete

Composite materials with the fibers are successfully used in various areas. The survey results are also various fibers concrete. Most widespread of these composite materials are:

1) concrete with glass fibers,
2) concrete with steel fibers,
3) concrete with plastic fibers,
4) concrete with polymer fibers,
5) concrete with mica fibers.

Samples for testing were the same as for ordinary concrete. The mixing ratio is water/cement/sand/gravel = 0,5/1/1,87/3,13/ (ratio given according to weights). Steel concrete. The mixing ratio is water/cement/sand/gravel = and steel fibers to evenly disperse the fibers and then is used (350).

A large fraction is 4,76 to 10 mm, smaller fraction is 3 to 4,76 mm. They are made of two mixtures, the first mixture is without steel fibers in the molds of cylindrical shape and a diameter of 150 mm and the height of 300 mm to determine the brand of concrete. The second mixture is with steel fibers, first to the mixer is put gravel and steel fibers to evenly disperse the fibers and then is put sand, cement and water. And, from the second mixture is taken samples in molds of cylindrical shape and a diameter of 150 mm and the height of 300 mm to determine the brand of concrete. Portland cement was used (350).

III. COMPARATIVE ANALYSIS OF TEST RESULTS

Analysis of the properties of concrete as a building material is difficult in many ways. The aggravating circumstances theoretically can be classified in three main groups.

1) the load-deformation relationship is not linear.
   In case of multi-axial stress, the load-deformation relationship is very complex,
2) due to the constant cracking of concrete during the load is difficult to formulate the law of fracture,
3) shrinkage and expansion are the cases that change the behaviour of the concrete during the time.

For these reasons, this research used an empirical formula with certain mitigating assumptions (such as linear-elastic).

Instead of the cylindrical molds may be used and the molds in form of cube 200 x 200 x 200 mm. To make the comparison of the strength of concrete samples in the cylinder and cube are performed a lot of laboratory tests.

There has been come to the conclusion that the strength of concrete in cylindrical molds/strength of concrete in molds is in shape of cubes 0.80 ~ 0.85. On the basis of successfully completed tests it was discovered that it is better to use the mold shape, the European Committee for Concrete (ECC) as a standard sample has accepted cylinder.

In the analysis results were used equations of approximate impact of the size recommended by Bazant. First was done the linear interpolation of the data given by the equation, and then the results are processed in the form Y = AX + C and plotted as graphs.

In the coordinates system of X and Y of the X-axis dimension X=H, and the Y-axis (f/f0) In the equation Y=AX+C value of C must be positive and different from zero. Best performance impact of size is Bazant’s logarithmic curve. Here in this chart is possible to see the transition between the criteria of strength in reinforced concrete and LEFM. For linear interpolation is used Excel program.

The suitability of the results was tested of equation of the impact size σn=β/(1+β)^2/2 obtained by linear interpolation on the dependence of D, the obtained line cuts the vertical axis at the point 1/B^2 and slope is 1/B^2 D^n. In the diagrams (f/f0)^2 depending on D is drawn the linear interpolation and are calculated the values of B and D^n. In the diagrams is represented dependence of log(σn/Bf) of the log log β. In this paper, the diagrams (f/f0)^2 depending on D is seen the impact of size. Have the test results of impact size reached the limit of plastic analysis, the line on the graph would be horizontal.

In the diagrams r - correlation coefficient, A - slope of the line C - shows the line where it cuts the axis Y. The existence of lines inclined to chart shows the existence of a size effect. The slope of the line from the 1/2 shows a linear elastic fracture mechanics.

The calculation of interpolation is presented through the analysis of impact of size, wherein are used the three different methods [1, 15].

1) Non-linear analysis
2) Linear analysis I
3) Linear analysis II

In non-linear analysis is analyzed X=ln D, Y=(f/f0)^2. In linear analysis I is analyzed X=D, Y=1/σn^2. In linear analysis II is analyzed X=1/D, Y=1/σn^2 D. Results of the linear interpolation of beams loaded in one point are presented in tables.

A. Analysis of the impact of size in ordinary concrete with constant width of support

Based on test results of ordinary concrete and formed tables is shown an overview of the impact of size on the basis of the Bazant’s law related to impact of size.

Evaluating the results of the experimental test has been noticed the existence of the impact of size. Has there not existed the impact of size A=0, the line should be in horizontal position (Table I).
Beams with variable width of support: Based on the test results of ordinary concrete (retest) and the formed tables, an overview of the impact of size is performed on the basis of the Bazant’s law related to impact of size.

Evaluating the results of the experimental test has been noticed the existence of the impact of size. Has there not existed the impact of size A=0, the line should be in horizontal position (Table II).

### Table I: Calculation of interpolation of ordinary concrete

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### Table II: Calculation of interpolation of the ordinary concrete (retest)

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B. Analysis of impact of size of the high-strength concrete

Based on the test results of the high-strength concrete and the formed tables, an overview of impact of size is performed on the basis of the Bazant’s law related to impact of size. As a result of the linear interpolation is obtained the straight line in form of Y=AX+C.

Evaluating the results of the experimental test has been noticed the existence of the impact of size. Has there not existed the impact of size A=0, the line should be in horizontal position (Table III).

### Table III: Calculation of interpolation of the high-strength concrete

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C. Analysis of impact of size of the lightweight concrete

Based on the test results and the formed tables, an overview of impact of size is performed on the basis of the Bazant’s law related to impact of size. As a result of the linear interpolation is obtained the straight line in form of $Y=AX+C$.

Evaluating the results of the experimental test has been noticed the existence of the impact of size. Has there not existed the impact of size $A=0$, the line should be in the infinite length with respect to a single point, the load needs to be done consistently in these diagrams. In order to eliminate these illogicallities the load needs to be done consistently with a constant speed, there must not be allowed that in some instances occur a load reduction. When eventually occur possible load reduction in all growing deformation it leads to decrease of deformation and to inconsistencies of the diagram. As can be seen from the graph in the beam (the unloading zone) with the reduction in size plasticity is noticeable.

Unlike of ordinary concrete it did not lead to fracture with the first cracks, in all samples occurred the plastic fracture. In these samples, due to existence of steel fibers, as well as in reinforced concrete it does not lead to complete separation in two parts, and in addition to fracture of the beam they still can support some small load. On these beams have been observed cracks that are moving vertically. In this kind of concrete fracture has been observed an impact of size (Table IV).

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<td>LN D</td>
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<tr>
<td>$Y$</td>
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<td>D, m</td>
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<tr>
<td>$10^Y$</td>
<td>$1/\sigma_{u0}$, MPa$^{-2}$</td>
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<tr>
<td>$X'$</td>
<td>$1/D, m^{-1}$</td>
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<tr>
<td>$Y'$</td>
<td>$1/\sigma_{u0}/D$, (MPa/m)$^{-1}$</td>
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</table>

D. Analysis of the impact of size in concrete with steel fibers

Based on the results of the ordinary concrete and the formed tables, an overview of impact of size is performed on the basis of the Bazant’s law related to impact of size. As a result of the linear interpolation is obtained the straight line in form of $Y=AX+C$.

Results of all slotted beams were analyzed in the diagram 6.

At the center of the beam with the instrument LVDT during the load was measured vertical deformation and at the slot was measured horizontal deformation and is constantly stored in the computer. Using these data are drawn diagrams of vertical and horizontal load deformation. At certain samples were observed inconsistencies in these diagrams. In order to eliminate these illogicallities the load needs to be done consistently with a constant speed, there must not be allowed that in
strength at the two points is less. In simple tensile strength is less than the clamping pressure line through the cleavage. In the axial tension may fracture occurs in any part of the sample. When splitting cylinder there is only one possible plane of the fracture. In that case, is the greater possibility of a weak point of the continuous space in relation to a plane, in this case, on the basis of the much worked tests it is more natural that the average strength of the axial tension is lower.

Fig. 6. Results

IV. CONCLUSION

Results of load fracture and deformation of the test load in one place at 5 different types of concrete and 45 samples, three different dimensions can be counted:

1) in test results at force of fracture of concrete beams was observed an impact of size, 2) despite of disrupted results (irregular schedule) the test of the impact of size is possible to present by the law of Bazant, 3) in the tested samples, the larger samples deposited higher amount of fracture energy which led to brittle (elastic) fracture while the samples of smaller dimensions led to resilient (plastic) fracture, 4) as it was expected in the concrete with steel fibers occurred a ductile fracture while in a high strength concrete occurred a brittle fracture, 5) when reading the size of horizontal strain near the slot on the neutral axis was observed large differences.

In this laboratory work the impact of size on beams with slot was observed that an attention should be paid to certain diagrams of load - horizontal deformation is very difficult to be analysed. The reason for the large difference in the vicinity of the slot when reading horizontal deformation is possible if there is the proximity of the neutral axis. Better horizontal deformation could make reading at the “mouth” of the slot. The observed illogicality in the load diagram - vertical diagram can be prevented with the proper application of the load (do not allow the return of the load). Return of load (load reduction) leads to the fact that deformation which is rising until then suddenly is reduced and there is illogicality in the graph.

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