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OVERVIEW OF RESEARCH RESULTS OF THE INFLUENCE OF GRAIN SIZE ON BEAMS OF DIFFERENT STRUCTURES OF CONCRETE BY INTERPOLATION

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***Abstract*—**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 kN and the sensitivity of 100 N fractured (load cell), in the middle, deformations were measured at the point of load and the top of each slot of 50 mm with the sensitivity instrument of 100x10-6 mm LVDT (Tokyo Sokki Kenkyujo 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 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 mm, smaller fraction is 3 to 4,76 mm. First, sand is put into a mixer, followed by gravel and cement in the dry state and this is going to be mixed for about 2 minutes, after that, the water is added and mixing is going to be carried out for about 2 minutes.

From the same samples were set aside the 3 samples in the molds of cylindrical forms with a diameter of 150 mm and a height of 300 mm to determine the brand of concrete. There was used the portland cement (350).

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

I. INTRODUCTION

ANALYSIS of the proporties of concrete as a building material is difficult in many ways. Theoretically, the aggravating circumstances can be classified into 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. The reasons are evident:

1. *Surface of the cube shape sample and the strength in relation to the cylindrical sample is larger, and the force of fracture is approximately 40 % higher.*
2. *Due to the shrinkage of the concrete on the sharp edges of the cube may come to nakedness of stress.*
3. *In samples of the cube form, fracture begins with the inclined cracks and with the increase of load these cracks increase and the fracture occurs in the form of a pyramid. This method of fracture occurs because the axial load of the sample due to the effects of friction between the sample and the touch panel press for load comes to the effect of force perpendicular to the axial force.*

However, if the touch surface of the sample and the touch panel press for load smear with oil, there occurs a reduction in friction, it was observed that the fracture mode changes. In this case, the sample is fractured, as it is expected to be under the influence of the axial load, a cracks normally occur on the axis of the load, and it has been observed that the strength is reduced to 50 %.

The impact of forces created as the action of friction between the sample and the surface of the press, is reduced with removal from the surface, where the load is carried out. It is natural that as a result of this action, as higher is the ratio of height and the cross section, the effect of friction on the fracture is smaller.

For this reason, the cylinder samples are credible because the ratio of height and the cross section in the cylinder is 2,0 while this ratio at cubes is 1,0. Standards recommend that in order to reduce the friction of surface of the sample and presses ought to be smeared with sulfur and paraffin (Fig. 1).

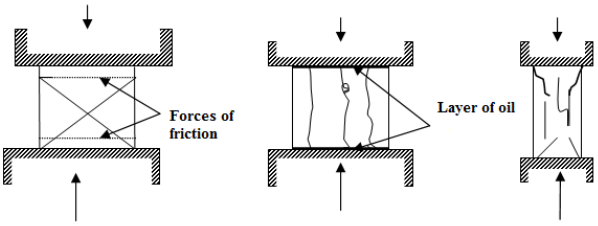

Fig. 1. Compressive strenght of concrete.

Compressive strenght of concrete depends on the following factors:

1) *dimensions and geometry of the sample,*
2) *speed of load,*
3) *other impacts.*

It is expected that with the load at one point occurs a fracture in a certain place, with loads at two points is expected that the failure occurs between the loaded points. Due to the greater possibility of a weak point in the infinite length with respect to a single point, the load 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.

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.

$\sigma_N=c_nP/bD$ – with two-dimensional elements (slab)
$\sigma_N=c_nP/D^2$ – with three-dimensional elements (cylinder)
wherein:
σ_N – effective stress fracture
b – thickness of two-dimensional elements
c_n – 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 σN, 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.

The reasons for the use of the impact size theory 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.*

II. Preparation of Test Samples

A. *Ordinary concrete*

According to T.S. 500 ordinary concrete is concrete with a compressive strength between 16 and 25 MPa [43-45]. For making this concrete is being used only aggregate, cement and water. Ordinary concrete is a semi-solid material and in calculation should be relied on fracture mechanics.

The ratio of the concrete mixture is water/cement/sand/gravel=0,5/1/1,87/3,13 (ratios are according to weights). To a mixture of concrete were used two aggregate fractions. A large fraction is 4,76 to 10 mm, smaller fraction is 3 to 4,76 mm. First, into the mixer is put sand, gravel and cement in the dry state, this was mixed for about 2 minutes and after that the water was added and was 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 mm and a height of 300 mm to determine the brand of concrete. Portland cement has been used (350), a_0 = h 0,2, S = 4,75 h, 0,2 h = the dimension L of test samples. Here is a_0 = length of slot before starting the test [2, 17-20, 23-25].

B. *High strength concrete*

According to TS 500 high-quality concrete is concrete with a compressive strength of 30 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

= 0,5/1/1,87/3,13/0,05/0,11 (ratios are according to weights).

The coarse fraction is from 4,76 to 10 mm, the finer fraction is 3 - 76 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 mm and a height of 300 mm to determine the brand of concrete. Portland cement was used (350) [2, 17-20, 23-25].

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 kg/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 cm to 1 m^3 is used between 180 kg and 270 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/m^3, fine aggregate is 720 kg/m^3. Specific gravity of coarse aggregate is 124 kg/m^3, and 146 kg/m^3 of fine aggregate. Humidity of aggregate is zero [2, 17-20, 23-25].

D. Fibrous concrete

Composite materials with the fibers are successfully used in various areas. The survey results are also various fiber 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 fibers are produced by Dramiks Steel. Length of steel fiber is 30 mm and the minimum size of beam is 40 mm, diameter is 0.5 mm and the tensile strength of 1100 MPa. The total weight of the steel fibers is 2 % by weight).

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 with the diameter of 150 mm and a height of 300 mm to determine the brand of concrete. Portland cement was used (350) [2, 17-20, 23-25].

III. Evaluation of Test Results

Results of the impact sizes can be represented by linear and non-linear interpolation (Fig.s 2 and 3) [1, 15].

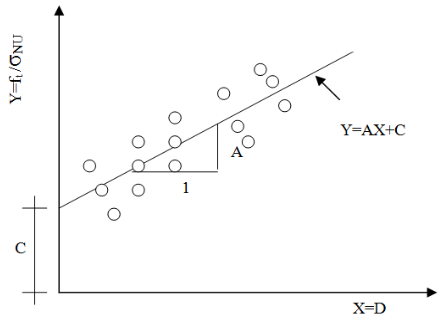

Fig. 2. Linear interpolation.

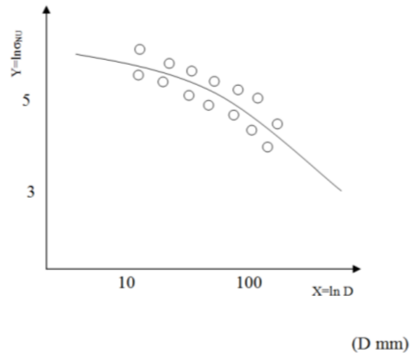

Fig. 3. Non-linear interpolation.

The effect of the size is applicable only to elements made from the same aggregate and the same concrete. If you change the size of the aggregate, there will be changed and the parameters of fracture and the parameters of impact size.

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 $(f_t/\sigma_N)^2$. 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 $\sigma_N=Bf_t(1+\beta)^{-1/2}$, $\beta=D/D_0$. If we draw a graph of the value of length $(f_t/\sigma_N)^2$ 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 $1/B^2 D_o$.

In the diagrams 4a, 5a, 6a, 7a, 8a $(f_t/\sigma_N)^2$ depending on D is drawn the linear interpolation anda re calculated the values of B and D_0. In the Fig.s 4b, 5b, 6b, 7b, 8b is represented dependence of $\log(\sigma_N/Bf_t)$ of the log log β. In this paper, the Fig.s $(f_t/\sigma_N)^2$ depending on D is senn 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 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.

A. The test results of ordinary concrete

Beams with constant width support: Based on the test results of ordinary concrete and presented tables, is shown the impact of size performed in the Fig. 4a based on the impact size of the Bazant's law. In the Fig. 4 as a result of the linear interpolation is obtained the line in form of Y=AX+C.

From equation $Y=(f_t/\sigma_N)^2$, X=D. The constants B and D_0 in the law about the impact of the size are determined from the Fig.s 4a and the equation of impact of the size is shown in the Fig. 4b. In this Fig., on the vertical axis is the value σ_N/Bf_t and on the horizontal axis D/D_0, is shown a transition zone of the impact of size. B=21,82 MPa, D_0=42 mm are the determined values.

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

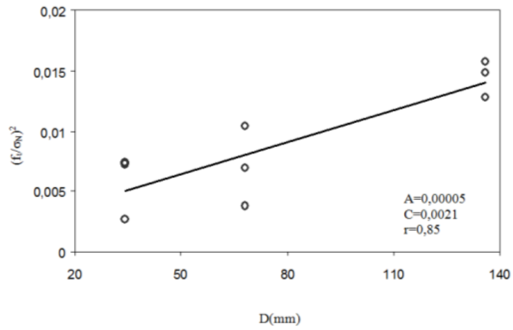

Fig. 4a Ordinary concrete – Linear interpolation

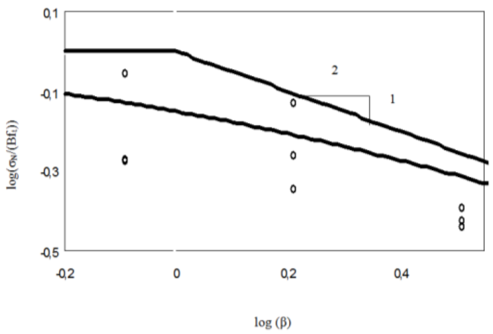

Fig. 4b. Ordinary concrete-Non-linearinterpolation

Beams with constant width support: Based on the test results of ordinary concrete and presented tables, is shown the impact of size performed in the Fig. 5a based on the impact size of the Bazant's law. In the Fig. 5 as a result of the linear interpolation is obtained the line in form of Y=AX+C.

From equation $Y=(f_t/\sigma_N)^2$, X=D. The constants B and D_0 in the law about the impact of the size are determined from the Fig.s 5a and the equation of impact of the size is shown in the Fig. 5b. In this diagram, on the vertical axis is the value σ_N/Bf_t and on the horizontal axis D/D_0, is shown a transition zone of the impact of size. B=8,64 MPa, D_0=670 mm are the determined values.

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

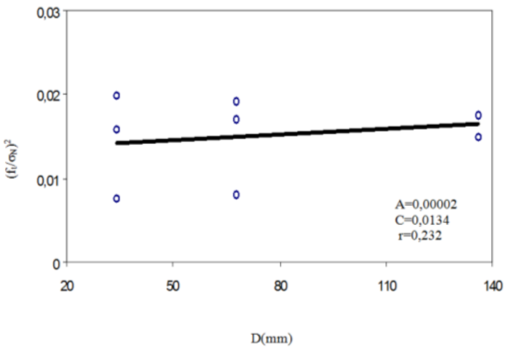

Fig. 5a. Ordinary concrete (variable support), Linear interpolation

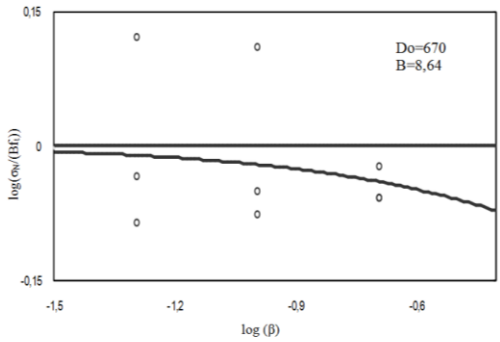

Fig. 5b. Ordinary concrete (variable support), Non-linear interpolation

B. Test results of high strength concrete

Based on the test results of the high strength concerete and the presented tables, an overview of the impact size is done in the Fig. 6a on the basis of the Bazant's law of impact size. In the Fig. 6 as a result of linear interpolation is obtained a line in a form of Y=AX+C.

From equation $Y=(f_t/\sigma_N)^2$, X=D. Constants of B and D_0 in the law of impact size are determined from Fig. 6a and an equation of impact size is presented in Fig. 6b. In this diagram on the vertical axis is the vakue σN/Bft, and on the horizontal axis is D/D_0, where is shown a transition zone of impact size. B=10,05 MPa, D_0=123,75 mm are the determined values.

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

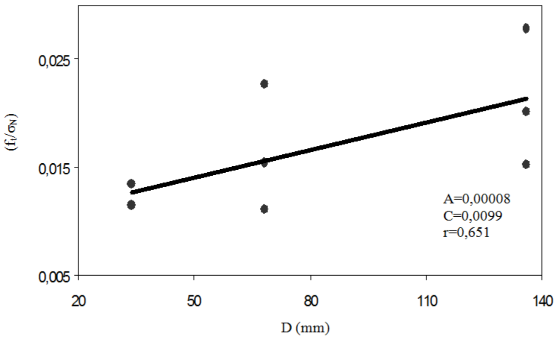

Fig. 6a. High strength concrete - Linear interpolation

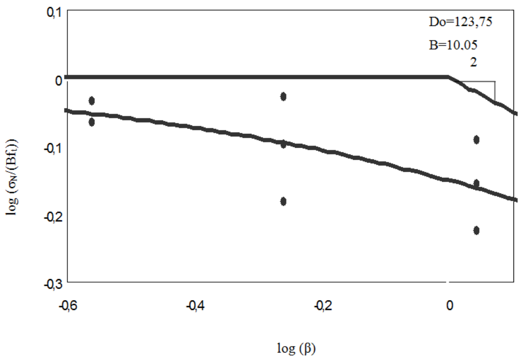

Fig. 6b. High strength concrete – Non-linear interpolation

C. *Test results of lightweight concrete*

Based on the test results of the lightweight strength concerete and the presented tables, an overview of the impact size is done in the Fig. 7a on the basis of the Bazant's law of impact size. In the Fig. 7 as a result of linear interpolation is obtained a line in a form of Y=AX+C.

From equation $Y=(f_t/\sigma_N)^2$, X=D. Constants of B and D_0 in the law of impact size are determined from Fig. 7a and an equation of impact size is presented in Fig. 7b. In this diagram on the vertical axis is the vakue of σN/Bft, and on the horizontal axis is D/D_0, where is shown a transition zone of impact size. B=12,80 MPa, D_0=61 mm are the determined values.

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

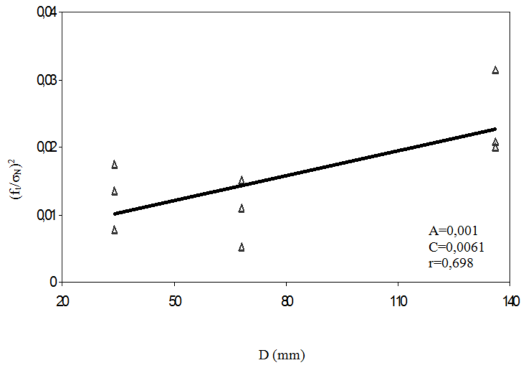

Fig. 7a. Lightweight concrete – Linear interpolation

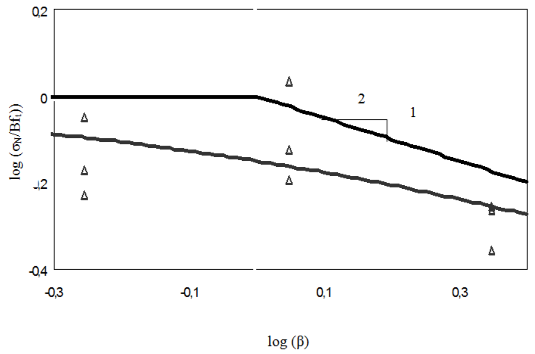

Fig. 7b. Lightweight concrete – Non-linear interpolation

D. *Test results of concrete with steel fibers*

Based on the test results of the lightweight strength concerete and the presented tables, an overview of the impact size is done in the Fig. 8a on the basis of the Bazant's law of impact size. In the Fig. 8 as a result of linear interpolation is obtained a line in a form of Y=AX+C.

From equation $Y=(f_t/\sigma_N)^2$, X=D. Constants of B and D_0 in the law of impact size are determined from Fig. 8a and an equation of impact size is presented in Fig. 8b. In this diagram on the vertical axis is the vakue of σN/Bft, and on the horizontal axis is D/D_0, where is shown a transition zone of impact size. B=0,51 MPa, D_0=565,98 mm are the determined values.

Unlike ordinary concrete the fracture did not occur with the first cracks, in all samples occurred a plastic fracture. In these samples due to lack of steel fibers as well as in reinforced concrete do not occur a complete separation of the two parts, and in addition to fraction of beam they can still carry a small load. In these beams were observed cracks that move vertically. In these types of concrete fracture was observed size effect.

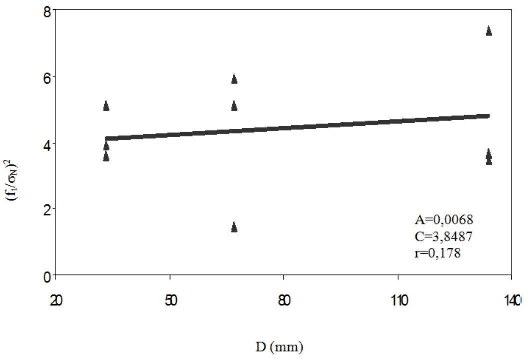

Fig. 8a. Concrete with steel fibers - Linear interpolation

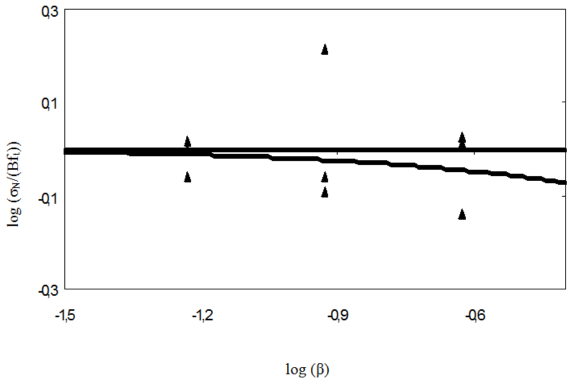

Fig. 8b. Concrete with steel fibers - Non-linear interpolation

Results of all slotted beams were analyzed in the Fig. 9.

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 inconsistencies 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.

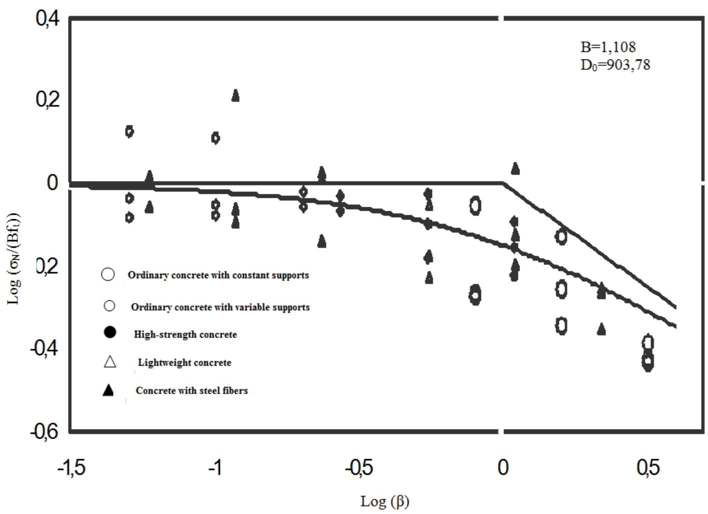

Fig. 9. Results of all beams

IV. CONCLUSION

By applying mechanical fracture at RC building design will bring significant benefits. It will contribute that at a different size of facilities to have the same security. In this way will be increased security and economy of construction. There will be a greater possibility of applying new designs and new materials. Especially in large AB buildings and of high-strength structures, facilities made of concrete with steel fibers, prestressed concrete, large concrete dams, nuclear power plants, with facilities that require high safety, whose damage can cause a disaster so application of fracture mechanics is of great importance.

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

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.*

V. RECOMMENDATIONS FOR FUTURE RESEARCH

In this laboratory paper, trelated to impact of size of the slotted beams has been observed that one should pay attention to a few important things:

1) *The geometry of the sample is important. The used formulas are valid for the samples of the same aggregate by the same calculation.*
2) *When drawing samples from the mold to pay atention to avoid fracture of the sample especially in low strength samples.*
3) *Due to the excess of coarse aggregate in the fibrous concrete leads to the impossibility of normal accommodation of steel fibers and formation of large cavities. In this case, instead of reducing the amount of coarse aggregate it is necessary to increase the amount of fine aggregate.*
4) *In the samples of the same sizes were observed large differences in the force of fracture. In order to prevent this, attention should be paid to compaction of concrete.*
5) *When opening slots at the beams attention should be paid, in the same samples the size of slots should be the same.*
6) *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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