ANNALS OF THE UNIVERSITY OF ORADEA
Fascicle of Management and Technological Engineering
ISSUE #2, AUGUST 2014, http://www.imtuoradea.ro/auo.fmte/

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 it's 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 othese works:
The impact of size of 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 fraction 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 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.

$\sigma_N=c_nP/bD$ – 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 [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 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) [2, 17-20, 23-25].

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), a0 = h 0,2, S = 4,75 h, 0.2 h = the dimension L of test samples. Here is a0 = 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 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)

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.

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 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).

III. COMPARATIVE ANALYSIS OF TEST RESULTS

Analysis of the proporties 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 $(f_t/\sigma_N)^2$ 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 $(f_t/\sigma_N)^2$ depending on D is drawn the linear interpolation anda re calculated the values of B and D_0. In the diagrams is represented dependence of $\log(\sigma_N/Bf_t)$ of the log log β. In this paper, the diagrams $(f_t/\sigma_N)^2$ 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.

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, $Y=(f_t/\sigma_{NU})^2$. In linear analysis I is analyzed X=D, $Y=1/\sigma_{NU}^2$. In linear analysis II is analyzed X=1/D, $Y=1/\sigma_{NU}^2 D$.

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 existance of the impact of size. Has there not existed the impact of size A=0, the line should be in horizontal position (Table I).

Table I: Calculation of interpolation of ordinary concrete

Variable	**Unit**	**Name of sample**								
		NS1	**NS2**	**NS3**	**NS4**	**NS5**	**NS6**	**NS7**	**NS8**	**NS9**
D	mm	136	136	136	68	68	68	34	34	34
σ_{NU}	MPa	13,73	14,84	13,36	20,47	20,03	16,42	19,45	19,58	32,06
X	ln D	4,91	4,91	4,91	4,22	4,22	4,22	3,52	3,52	3,52
f_t	MPa	1,67	1,67	1,67	1,67	1,67	1,67	1,67	1,67	1,67
Y	$\ln(f_t/\sigma_{NU})^2$	-4,21	-4,37	-4,15	-5,58	-4,96	-4,57	-4,90	-4,92	-5,91
10^3X	D, m	136	136	136	68	68	68	34	34	34
10^3Y	$1/\sigma_{NU}^2$, MPa^{-2}	5,30	4,54	5,60	2,39	2,49	3,71	2,64	2,61	0,97
X’	$1/D, m^{-1}$	7,35	7,35	7,35	14,71	14,71	14,71	29,41	29,41	29,41
Y’	$1/\sigma_{NU}^2 D$ $(MPa\sqrt{m})^{-2}$	0,039	0,033	0,041	0,035	0,037	0,055	0,078	0,077	0,029

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 existance 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 II: Calculation of interpolation of the ordinary concrete (retest)

Variable	**Unit**	**Name of sample**								
		NS01	NS02	NS03	NS04	NS05	NS96	NS07	NS08	NS09
D	Mm	136	136	136	68	68	68	34	34	34
σ_{NU}	MPa	12,56	12,56	13,65	12,06	18,57	12,79	11,81	13,26	19,03
X	Ln D	4,91	4,91	4,91	4,22	4,22	4,22	3,52	3,52	3,52
Y	$\ln(f_t/\sigma_{NU})^2$	-4,05	-4,05	-4,21	-3,96	-4,82	-4,08	-3,92	-4,15	-4,87
f_t	MPa	1,66	1,66	1,66	1,66	1,66	1,66	1,66	1,66	1,66
10^3X	D, m	136	136	136	68	68	68	34	34	34
10^3Y	$1/\sigma_{NU}^2$, MPa^{-2}	6,34	6,34	5,37	6,88	2,90	6,11	7,17	5,69	2,76
X’	$1/D, m^{-1}$	7,35	7,35	7,35	14,71	14,71	14,71	29,41	29,41	29,41
Y’	$1/\sigma_{NU}^2 D$ $(MPa\sqrt{m})^{-2}$	0,047	0,047	0,039	0,101	0,043	0,090	0,211	0,167	0,081

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 existance 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 interpoalation of the high-strength concrete

Variable	**Unit**	**Name of sample**								
		HS1	HS2	HS3	HS4	HS5	HS6	HS7	HS8	HS9
D	mm	136	136	136	68	68	68	34	34	34
σ_{NU}	MPa	12,23	16,57	14,40	19,30	13,52	16,42	19,04	19,04	17,62
X	Ln D	4,91	4,91	4,91	4,22	4,22	4,22	3,52	3,52	3,52
f_t	2,04	2,04	2,04	2,04	2,04	2,04	2,04	2,04	2,04	2,04
Y	$\ln(f_t/\sigma_{NU})^2$	-3,58	-4,19	-3,91	-4,49	-3,78	-4,17	-4,47	-4,47	-4,33
10^3X	D, m	136	136	136	68	68	68	34	34	34
10^3Y	$1/\sigma_{NU}^2$ MPa^{-2}	6,69	3,64	4,82	2,68	5,49	3,71	2,76	2,76	3,26
X’	$1/D, m^{-1}$	7,35	7,35	7,35	14,71	14,71	14,71	29,41	29,41	29,41
Y’	$1/\sigma_{NU}^2 D$ $(MPa\sqrt{m})^{-2}$	0,049	0,027	0,035	0,039	0,080	0,055	0,081	0,081	0,095

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 existance of the impact of size. Has there not existed the impact of size A=0, the line should be in horizontal position (Table IV).

Table IV: Calculation of interpolation of the lightweight concrete

Variable	Unit	Name of sample								
		LW1	LW2	LW3	LW4	LW5	LW6	LW7	LW8	LW9
D	mm	136	136	136	68	68	68	34	34	34
σ_{NU}	MPa	7,19	7,03	5,73	9,72	14,06	8,28	7,68	11,58	8,69
X	Ln D	4,91	4,91	4,91	4,22	4,22	4,22	3,52	3,52	3,52
f_t	1,01	1,01	1,01	1,01	1,01	1,01	1,01	1,01	1,01	1,01
Y	$\ln(f_t/\sigma_{NU})^2$	-3,92	-3,87	-3,46	-4,52	-5,26	-4,20	-4,05	-4,87	-4,30
10^3X	D, m	136	136	136	68	68	68	34	34	34
10^3Y	$1/\sigma_{NU}^2$, MPa^{-2}	19,34	20,23	30,46	10,58	890	14,80	16,95	7,46	13,24
X’	$1/D, m^{-1}$	7,35	7,35	7,35	14,71	14,71	14,71	29,41	29,41	29,41
Y’	$1/\sigma_{NU}^2 D$ $(MPa\sqrt{m})^{-2}$	0,142	0,149	0,224	0,156	0,07	0,215	0,499	0,219	0,389

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.

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 seperation 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 V).

Table V: Calculation of interpolation in concrete of steel fibers

Variable	Unir	Name of sample								
		SF1	SF2	SF3	SF4	SF5	SF6	SF7	SF8	SF9
D	mm	134	134	134	68	68	68	33,5	33,5	33,5
σ_{NU}	MPa	0,938	0,966	0,660	0,738	0,792	1,493	0,795	0,907	0,947
X	Ln D	4,90	4,90	4,90	4,22	4,22	4,22	3,51	3,51	3,51
f_t	1,79	1,79	1,79	1,79	1,79	1,79	1,79	1,79	1,79	1,79
Y	$\ln(f_t/\sigma_{NU})^2$	1,29	1,24	2,00	1,77	1,63	0,36	1,62	1,36	1,28
10^3X	D, m	136	136	136	68	68	68	34	34	34
10^3Y	$1/\sigma_{NU}^2$, MPa^{-2}	1137	1072	2296	1836	1594	449	1582	1216	1115
X’	$1/D, m^{-1}$	7,46	7,46	7,46	14,71	14,71	14,71	29,85	29,85	29,85
Y’	$1/\sigma_{NU}^2 D$ $(MPa\sqrt{m})^{-2}$	8,482	7,997	17,13	27,00	23,44	6,597	46,30	35,75	32,80

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 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.

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.

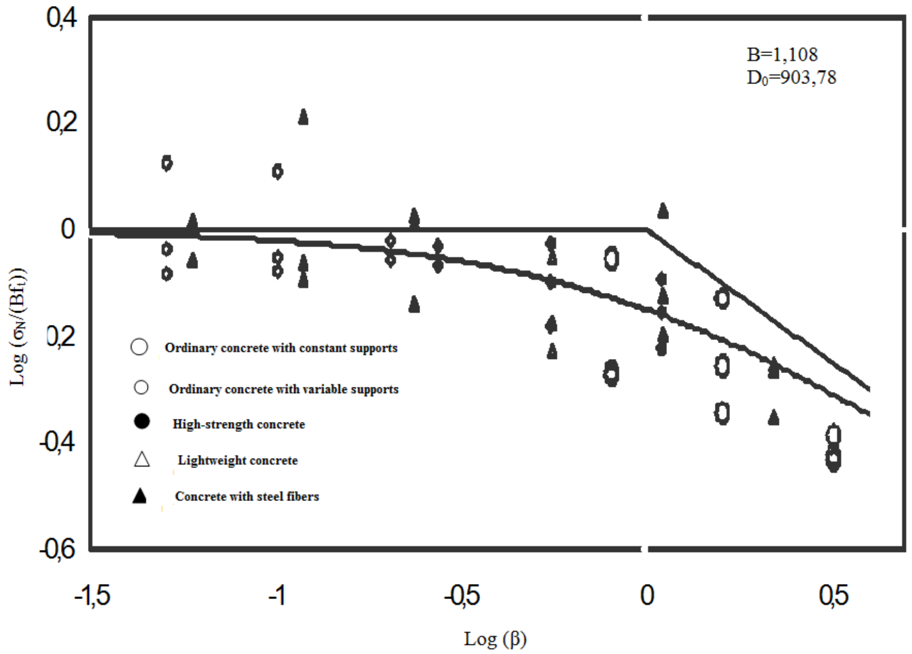

Fig. 6. Results

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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