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The investigation was performed for estimation of influence of steel fibers to local compression of concrete. Evaluation the fact that the reinforced concrete structures quite a lot could be loaded by local impact, the research of local zone strengthening with steel fibers were performed. It is known that the state of stress and strain in local zone of concrete loaded by concentrated forces is quite difficult. For that reason the experiments carried out to obtain the main parameters of local zone described by design standards and the results were compared with theoretical. There are investigated the stress-strain mode of fracture, increasing of local compression strength and the influence of fibers content.

KEYWORDS: concrete, local compression, steel fibres, mode of fracture.

Introduction

The investigation was provided for estimation of influence of steel fibers to local compression of concrete because such kind research is not quite popular. In practice there a lot situation when the reinforced concrete structures are loaded by local force, so, it's important to investigate the strengthening possibilities of such sections. Nowadays more popular became concrete reinforced by steel fibres. After concrete consist review, we can notice that several decades more and more fibres reinforcement is used for various building structures even for load bearing structures. Assuming that steel fibres can to increase the resistance of local concrete area, it is possible to avoid the built-in parts in reinforced concrete structures. Analyzing the behaviour of flexural reinforced concrete elements, we can notice that steel fibres are quite important factor not only for development of cracks but for increase of strength also (Kaklauskas G., et. al., 2012, Di Prisco M., et.al. 2009, Jones P. A. et. al., 2008, Timinskas E., Jakubovskis R., 2011). But that factor is not described in design standards. The EC2, STR and SNiP standards are based on data of Bach and Bauschinger experiments. Also, the classic Flaman, Mitchell, Boussinesq and Hertz solutions could be used. Each method has some limitations and some advantages (Venckevičius V., Keras V., 1974). The standards are updating from time to time, but there is no presented algorithm of local compression strength calculation for concrete reinforced by steel fibres. As before, such algorithm could be prepared after performing a lot of experiments and summarizing of obtained results. The author's takes it into account and performed some experiments with short term loading. In such investigations was used only one kind of concrete and steel fibre, but different content of fibres.

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Methods

For local compression testing were prepared 36 concrete specimens reinforced by different content of fibres. The dimension of specimens was 150x150x150. All specimens were hardened in the same conditions. As concrete aggregate were used the granite break stone by 5/20 fraction and sand by 0/4 fraction. The length of steel fibre with hooked ends (**Fig.1**) was 50 mm, diameter – 1 mm and tensile strength 1150 MPa.

The specimens were formed by 4 series with different content of fibres: in the first series were mixed 0.32 % (25 kg/m^3), in the second – 0.38 % (30 kg/m^3), in the third – 0.44 % (35 kg/m^3) and in the fourth – 0.50 % (40 kg/m^3). Each series includes 9 specimens. The composition of concrete presented in **table 1**.

The specimens of each series were loaded by polished steel plates with two different dimensions 53x53x23 and 30x30x20mm because it affect the load bearing of concrete (Ince R., Arici E., 2004, Hawkins N., M., 1974). The plates were quite small for reason to evaluate the confinement effect. The specimens were loaded uniformly until local zone failure. Tests were performed by test hydraulic press machine with force velocity control.

Fig. 1

The steel fibres with hooked ends were used for test

Table 1

The composition of concrete

Materials in 1 m^3			Ratio of water/cement
Granite break stone, kg	Sand, kg	Cement (CEM II-42.5N), kg	
1180	590	425	0.48

The use of fibres should strengthen the local zone because according to the ordinary stress-strain diagram of concrete reinforced by steel fibres, presented in **Fig. 2**, can be seen that the steel fibres decrease the brittle failure character and let to develop quite high residual strain because of plasticity of steel and micro cracking in concrete (Kaklauskas G., et. al., 2012). The fibres quite effective operate to restrict the development of normal cracks so, it's should be effective for inclined cracks in local zone also.

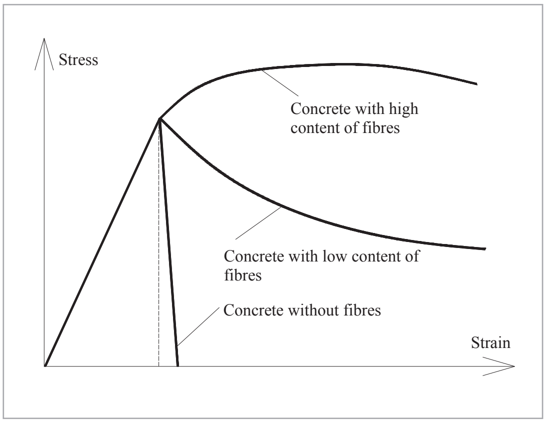

Fig. 2

The stress-strain relationship of concrete reinforced by steel fibres

Results and discussions

The compression strength of concrete reinforced by steel fibres is presented in **table 2**. The scatter of concrete compression strength result is quite a small except the concrete with 35 kg content of fibres. The content of fibres can differently evaluate the compression strength of concrete. It depends on fibres type, bond with concrete, mortar fraction and so on (Neves R. D. Fernandes de Almeida J.C.O, 2005).

Table 2

The compression strength of concrete reinforced by steel fibres

Content of fibres, kg/m^3	Strength, MPa
25	35.32
30	34.58
35	28.15
40	37.08

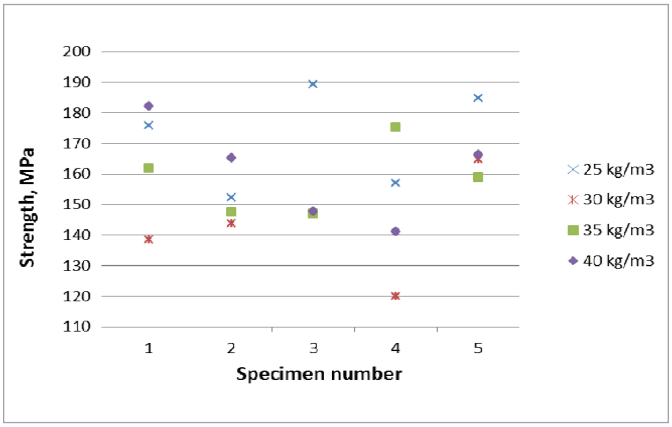

Fig. 2

The distribution of the local compression strength for specimens loaded by 30x30 plate

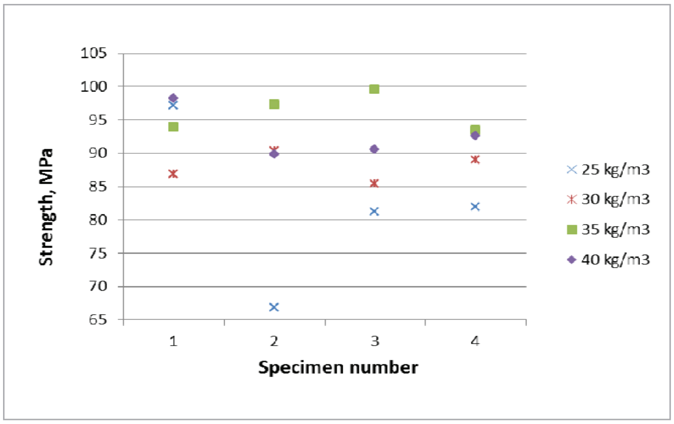

Fig. 3

The distribution of the local compression strength for specimens loaded by 53x53 plate

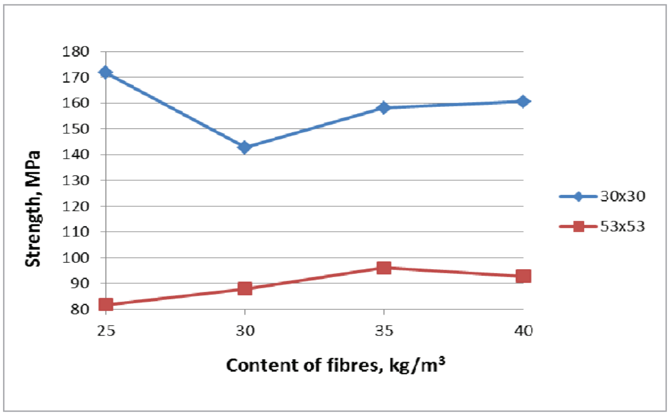

Fig. 4

The distribution of the average local compression strength values according to different loaded area

Although the both area of loading was small, the tendency of results obtained different and it could be seen in **figures 2, 3 and 4.** In **Fig. 2** presented the results obtained when the plate 30x30 were used and in **Fig. 3** – when the 53x53 plate were used. In that figures the influence of fibres cannot be strictly estimated, and the arising of fibres content differently causes the local concrete strength. The distribution of local strength average values is presented in **Fig. 4** where could be noticed some tendency of fibres influence. When the specimens were loaded by 30x30 plate the maximum strength obtained with 25 kg/m^3 fibres content and when by 53x53 plate – with 35 kg/m^3. So, for specimens with small loaded area the influence of fibres is no significant and it hides in scatter of result data. For specimens with bigger load contact area, the influence becomes noticeable. Reinforcing the concrete with fibres almost is no possibilities to control the direction and distribution. So, the possibility of stratification is real. In most cases the direction of fibres is not optimal to restrict the development of cracks at least for flexural and compressed members (Kaklauskas G., et. al., 2012, Di Prisco M., et.al. 2009, Jones P. A. et. al., 2008). According to this we can state that fibres with different properties (for example with less length) can be more effective to resist the local stress. It maybe could be more effective for concrete under cyclic load (Breitenbucher R., 2007)

In spite of loaded area and content of fibres the failure character was similar to concrete without any fibres. The initial micro cracks appear near corners of steel plate. At that time the steel plate are slumped in concrete. Such stamp in concrete remains and the initial cracks become wider and develop until specimen failures. The failure state is presented in Fig. 5, 6. The load when the first crack appears was not estimated. The failure of the plain concrete is brittle (Keras V., 1972) and happens suddenly. The fibres change the failure to plastic (Fig.2) and failure process becomes longer what is positive to position of structural design.

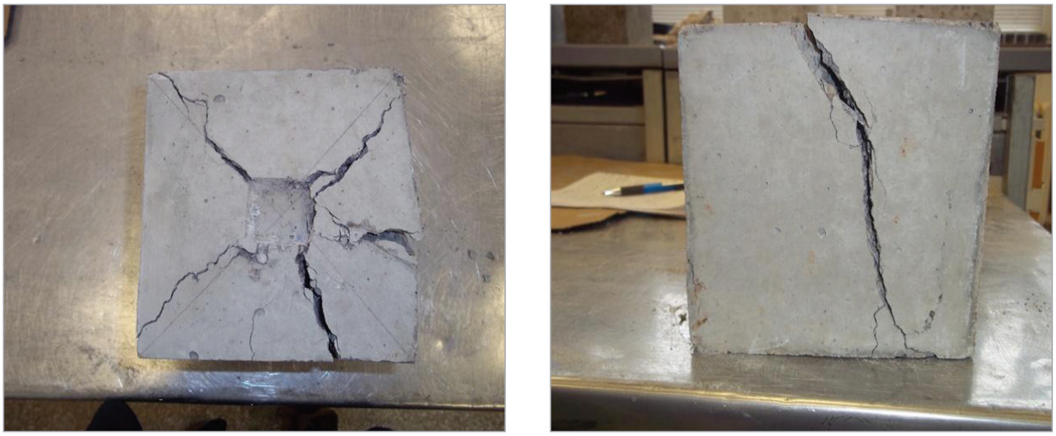

Fig. 5

The failure view of specimen with 30x30 load area

Fig. 6

The failure view of specimen with 53x53 load area

When the loading areas are small, the initial cracks are brighter and wider, but when the areas are bigger there are more cracks which develop in various directions. Some cracks are very narrow and remain such until fully failure. But failure character is similar for both series specimens. The reviewed character of failure can be distinguished in several stages (Fig. 7, 8). In the first stage (1-2) can be seen the process of compaction and the modulus of deformation uniformly increase (Fig.8). In the second stage (2-3) the modulus of deformation remains constant and only the elastic strain develops in specimen. In the third stage (4-5) the micro cracks begin appears and the deformation modulus begins decrease. Such micro cracks begin to connect into the macro cracks and the maximum stress is reached. Of course the distribution of cracks should be a little bit different because of different boundary zones. When the plate 30x30 was used the effective area at the specimen bottom not exceeds the specimen area, but if the 53x53 mm plate were used the effective area exceeds the area of specimen bottom.

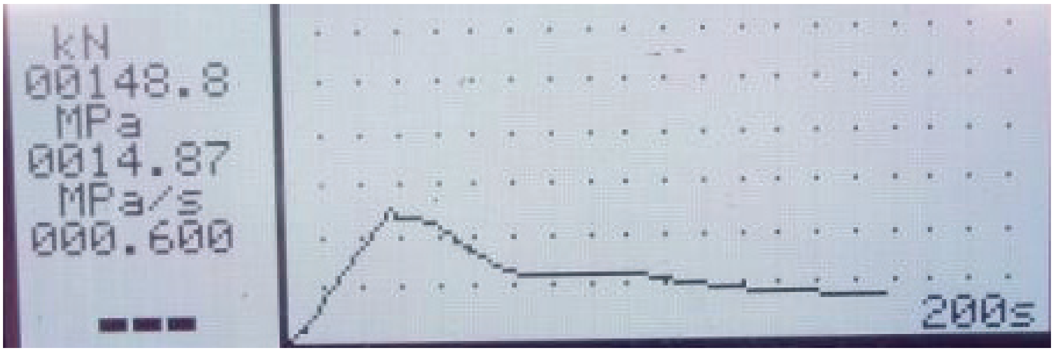

Fig. 8

The stress-strain relationship of specimen with 53x53 load area

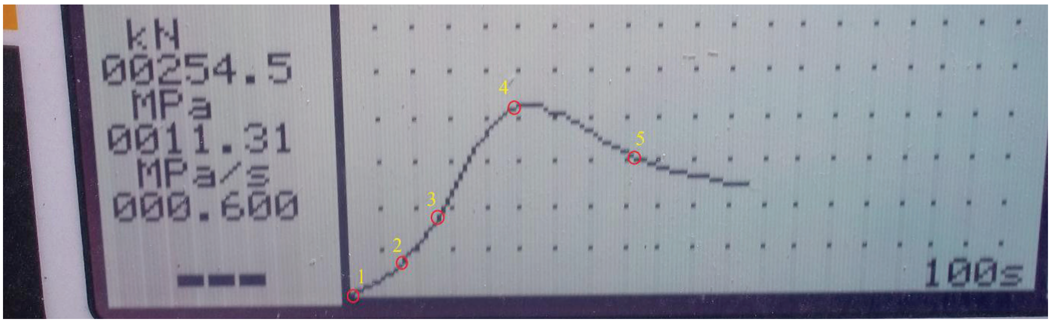

Fig. 7

The stress-strain relationship of specimen with 30x30 load area

After comparing such two different cases we can conclude that the scatter of results could not so differently affect the relation curves. To substantiate it the mean square deviation (MSD) and coefficient of variation (VC) was calculated **(table 3)**.

The variation of results is not high if to compare with flexural members. It's interesting to compare experimental results with theoretical, calculated according to EC2, STR and SNiP codes. The load area is not significant to the local concrete strength at all. The local strength with 30x30 area plates is 141.3, 60.0 and 62.6 MPa according to EC2, STR and SNiP. With 53x53 plate the local strength is 80.0, 60.0 and 60.2 MPa respectively. In calculations were assumed the cylindrical strength of concrete. Also, calculating the local strength by EC2 was assumed that effective area is limited by edges of specimens. According to STR such area should not exceed 90x90 if the loaded area is 30x30.

So, theoretically according to STR and SNiP codes the difference of such two series specimens is not significant, but according to EC2 difference is ~40%. Such difference exceeds the variation of results and the fibres could affect that. Comparing theoretical results with experimental, the EC2 gives best coincidence for both cases. The various factors influent the strength of concrete under concentrated loads are investigated in other articles (Venckevičius V., Lukoševičius K., 2007, Venckevičius V., 2005)

Table 3

The statistical parameters of specimens

Content of fibres, kg/m^3	Compression with plate 30x30		Compression with plate 53x53	
	MSD	VC, %	MSD	VC, %
25	16.49	9.6	12.42	15.18
30	16.10	11.28	2.18	2.48
35	11.73	7.42	2.93	3.05
40	16.29	10.15	3.76	4.05

Conclusions

The failure character is similar in spite of partially loaded area 30x30 or 53x53 and the failure character is like for concrete without fibres. Solving by influence of content of fibres to local strength we can summarize that arising of fibres content does not have influence for specimens loaded by 30x30 steel plates, but for specimens with 53x53 plates the influence is significant and effective until 35kg/m^3 then begin to decrease. In such case the resistance to local stress increase until 15% comparing with plain concrete.

The fibres effect depend on specimens dimensions, content and fibres properties and the rationally area of concentrated load. It, can be seen when the local strength values obtained by different codes is compared, because not all parameters are evaluated when the fibre concrete specimens is use. The best coincidence was obtained by EC2 code although not evaluating the fibres influence.

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