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Behaviour of concrete with a disperse reinforcement under dynamic loads

Поведение бетона с дисперсным армированием при динамических воздействиях

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Key words: disperse reinforcement; fiber concrete; combined reinforcement; experimental study; alternating dynamic highly intensive impact

Ключевые слова: дисперсное армирование; фибробетон; комбинированное армирование; фиброжелезобетон; экспериментальное исследование; знакопеременное динамическое воздействии большой интенсивности

Abstract. Disperse reinforcement of concrete greatly contributes to the properties of the latter. Most research has dealt with the properties of disperse reinforced concrete and influence of disperse reinforcement on structures under a static load of one sign or for a regular dynamic load that is not highly intensive. In practice there might well be alternating dynamic impacts that are highly intensive and over the calculated ones, e.g., seismic ones. The paper presents the results of an experiment study of beam structures with a disperse and combined reinforcement under an alternating highly intense dynamic impact. A method of performing an experimental study of beam elements with a disperse and combined reinforcement under an alternating dynamic highly intensive impact that is based on the use of a universal dynamic stand with extra equipment. The results of the experimental studies of cubes and prisms for static and dynamic compression are discussed. The outcomes of the study of the operation of beam elements with a disperse and combined reinforcement under an alternating dynamic highly intensive impact are presented. The operation of fiber concrete structures and ferroconcrete beam elements under similar impacts are compared. The presented results of the experimental studies allow us to conclude that a disperse reinforcement has a great influence on the operation of structures with an alternating dynamic highly intensive impact and the positive effect of a combined reinforcement of structures operating under such impacts. The use of a disperse reinforcement in structures operating under alternating dynamic highly intensive impacts would enable the resistance of structures to resist these impacts.

Аннотация. Дисперсное армирование бетона значительно улучшает свойства последнего. Значительная часть проводимых исследований посвящена изучению свойств дисперсно-армированных бетонов и изучение влияния дисперсного армирования на работу конструкций при статической нагрузке одного знака или при знакопеременной динамической нагрузке небольшой интенсивности. На практике периодически возникают знакопеременные динамические воздействия большой интенсивности, превышающие расчетные, например, сейсмические. В работе представлены результаты экспериментального исследования работы балочных конструкций с дисперсным и комбинированным армированием при знакопеременном динамическом воздействии большой интенсивности. Приведена методика проведения экспериментального исследования работы балочных элементов с дисперсным и комбинированным армированием при знакопеременном динамическом воздействии большой интенсивности, основанная на использовании дооборудованного универсального динамического стенда. Рассмотрены результаты экспериментальных исследований кубов и призм на статическое и динамическое сжатие. Приведены результаты исследования работы балочных элементов с

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дисперсным и комбинированным армированием на знакопеременном динамическом воздействии большой интенсивности. Выполнено сравнение работы фиброжелезобетонных конструкций с работой железобетонных балочных элементов при аналогичных воздействиях. Представленные результаты экспериментальных исследований позволяют сделать вывод о значительном влиянии дисперсного армирования на работу конструкций при знакопеременном динамическом воздействии большой интенсивности и целесообразности комбинированного армирования конструкций, работающих при таких воздействиях. Применение дисперсного армирования в конструкциях работающих при знакопеременных динамических воздействиях большой интенсивности позволит увеличить сопротивляемость конструкций таким воздействиям.

Introduction

In many industrial developed countries there is a lot of focus on studies of concrete reinforced with different fibres: steel, glass, basalt, polypropylene, etc. Such concretes are called disperse reinforced concretes or fibre concretes. According to the data, they have improved characteristics compared to a regular concrete and outperform it by 2 or 4 times in bending. In the standard literature [1, 2] steel fibreconcrete structures depending on their reinforcement are classed into structures with fibre reinforcement (fibreconcrete ones) that are reinforced using only steel fibre that is evenly distributed along the element; with a combined reinforcement (fibreferroconcrete ones) that are reinforced using steel fibres in combination with a steel rod or wire reinforcement.

Studies of the properties of disperse reinforced concretes are numerous. In [3] there are the results of studies of physical and mechanical characteristics of dispersing reinforced fine-grained concretes with multifunctional modifying additives. Studies of ceramsitefibreferroconcrete elements that has an extra rough basalt fibre reinforcement are described in [4]. In [5] the combined and individual effects of a polypropylene and glass fibre on the mechanical properties and rheological characteristics of a self-sealing concrete are investigated. The combined effect of a polypropylene and glass fibre improves the compressive, tensile and bending strength.

However, most studies have investigated a metal fibre. A full account of the influence of a disperse reinforcement on the properties of concrete can be found in [6]. It is concluded that the use of steel fibres for strong and durable structures and concrete reinforcement is agreed to be promising all over the world. 300 thousands of tonnes of fibre is used for concrete reinforcement, 50 % of them are steel [7].

The investigations described in [8] show the efficiency of steel fibres. In particular it was suggested that the minimum volume of steel, glass and polypropylene fibres in a concrete matrix that have the best performance is about 0.31 %, 0.40 % and 0.75 % respectively for each type. The efficiency of steel fibres in beam structures for pure bending is described in the papers by H.V. Dwarakanath, T.S. Nagaraj [9]. The results of the studies mentioned by Job Thomas, AnanthRamaswamy [10] indicate that the mutual effect of a metal fibre and concrete matrix largely contributes to the mechanical properties that are improved by a fibre introduced into a concrete matrix.

The results of static studies of fibreferroconcrete beams and their comparisons by other authors are accounted for in [11]. In [12] there are the results of experimental studies of fibreconcrete beams with three types of fibres: a steel fibre with a curved end, a fibre from wavy steel and polypropylene fibres.

In [13] according to the above studies, the introduction of a steel fibre into concrete is reported to improve the limit bending strength of a material. This bending strength goes up as does the amount of fibre in concrete. Quick ash is used as an additive. In [13] there are the results of a study of a fibreconcrete under a dynamic impact load. The outcomes of the investigation of the properties of fibreconcrete with different fibres are also described in [14]. It is also indicated that concrete must be designed so that it saturates the energy of natural forces such as earthquakes.

An extensive analysis of studies of disperse reinforced structures is presented in a monography by F.N. Rabinovich [15].In [16] the methods and results of experimental studies of beam fibreconcrete elements with a synthetic fibrecan be found.

Based on the theoretical and experimental studies of physical and mechanical characteristics of disperse reinforced concrete in a wide range of volumetric saturation with fibres, Yu.V. Pukharenko [17] contributed to the ideas about the structure of fibreconcrete. He also found that the main structural component of disperse reinforced concrete is fibre. In addition, the general method of designing the composition of fibreconcrete was developed and features of its use for different types of concrete reinforced with steel and non-metal fibresare investigated.

The following papers deal with structures under a dynamic alternating impact. In [18] experimental studies of ferroconcrete beams reinforced with fibre and their effect on alternating dynamic loads are presented. The use of metal fibresis shown to have a positive influence of the energy capacity of a failure. In [19] the results of experimental studies of ferroconcrete beams that are statistically determined or not determined with a regular and pre-stressed reinforcement under alternating low-cycle loads of a high level, e.g., seismic ones are described.

The results of dynamic studies of beam elements of a transverse section sized 150 x 200 mm with a pure span of 1 m are identified in [20]. The samples contained metal fibres with the amount of 40 kg/m^3 and 80 kg/m^3. Fibres from stainless steel and carbonaceous steel wire were involved. The experiments were conducted under a static load up to 100 kN and dynamic load up to 80 КN. The results suggest that metal fibres contribute greatly to the properties of fibreconcrete elements under an alternating deformation.

Studies addressing improvement of crack resistance of ferroconcrete structures performed by N.I. Vatin [21, 22] seem promising. They also explore possible improvement of crack resistance of concrete and nanoconcrete in structures by applying pre-stresses. They are generated by placing a reinforced rope in a structure along the distribution of bending moments. The rope that is pulled is pre-stressed without the cohesion with concrete to allow this method to be employed in structures with small sections.

However, despite a lot of research and materials, most of them have to do with the operation of disperse reinforced construction under a static load of one sign or alternating loads that are not highly intensive. In practice most structures operate under alternating dynamic loads, e.g., under seismic loads that are highly intensive. The properties of the material of a structure are essential to the strength of buildings subjected to seismic loads.

It seems hardly possible to identify seismic forces and their directions on buildings as the Earth's movement during an earthquake depends on a number of factors. While selecting the intensity of an impact on sample structures it is important to note that actual intensity of earthquakes is significantly over the expected one. Therefore in the experiments a special shock stand was employed that allowed one to generate an alternating dynamic highly intensive load on the sample structure.

The objective was to evaluate the effect of a disperse reinforcement of concrete on the operation of structures under an alternating dynamic highly intensive load. For that experimental studies were planned of the operation of fibreconcrete and fibreferroconcrete beam elements under an alternating dynamic highly intensive load and their operation was compared with that of ferroconcrete beam elements.

Experimental sample

All of the sample structures were beams with the length of 1650 mm. Their transverse section was 100 x 100 mm. These sizes were chosen based on the capacity of the laboratory equipment, requirements for the absolute accuracy of measurements and geometric size of the model and actual structures. 4 series of beams were designed with the following reinforcement. The beams of series 1 were reinforced as shown in Figure 1. The beams of series 2 and series 4 had a combined reinforcement as shown in Figure 2, i.e. there was only a transverse operating reinforcement left in them and the rest was substituted with a disperse one at the rate of 1 % and 2 % in the volume respectively.

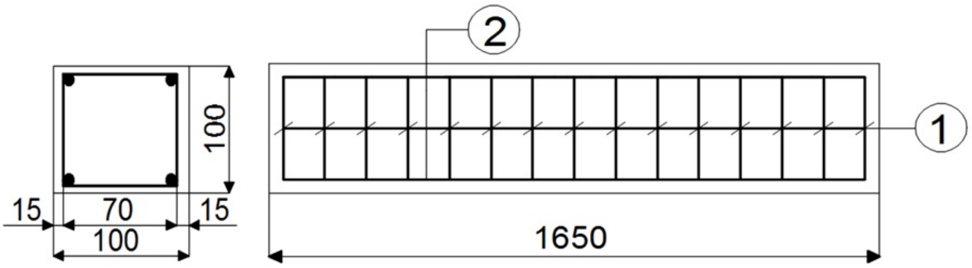

Figure 1. Scheme of the reinforcement of ferroconcrete beams:
1 – reinforcement A – III, diameter 6mm, length 80 mm, 18;
2 – reinforcement A – III, diameter 6mm, length 1620 mm, 4

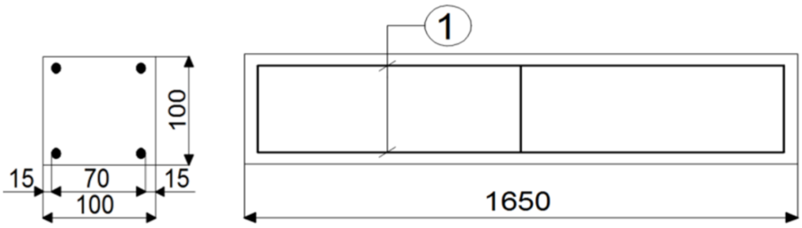

Figure 2. Scheme of reinforcement of fibreconcrete beams:
1 – reinforcement A – III, diameter 6mm, length 1620 mm, 4

The beams of series 3 and series 5 had no rod reinforcement but only a disperse one at the rate of 2 % and 1 % in the volume respectively. Hence the beams of series 3 and series 5 are not indicated in the schemes. Three sample beams were tested in each of the series.

Overall the amount of reinforcement in the beams of the first three series was approximately identical (Table 1). The beams of series 4 and series 5 had an increased and decreased amount of reinforcement respectively.

Table 1. Characteristics of reinforcement of the experimental beams

№ of the series	**Names of the beams**	**Percentage of road reinforcement**	**Amount of rod reinforcement, kg**	**Percentage of fibre reinforcement**	**Amount of fibre reinforcement, kg**	**Total amount of reinforcement, kg**
1	Fibreconcrete	0.565	2.5	-	-	2.5
2	Fibreferroconcrete with 1.0 % of fibres	0.565	1.5	1.0	1.2	2.7
3	Fibreconcrete with 2.0 % of fibres	-	-	2.0	2.4	2.4
4	Fibreferroconcrete with 2.0 % of fibres	0.565	1.5	2.0	2.4	3.9
5	Fibreconcrete with 1.0 % of fibres	-	-	1.0	1.2	1.2

In order to make the samples, a fine-grained cement mix with the composition Cement:Sand 1:2.5. The binder was Portland cement M400. The ratio Water/Cement was 0.4. For disperse reinforcement a fibre was used made from a regular low-carboneous wire of a with the diameter 0.8 mm, density 78.5 g/cm^3. Along with cutting the wire fibre on a special machine, their surface was made profiled using rollers. The scheme of the profile of the fibresis presented in Figure 3.

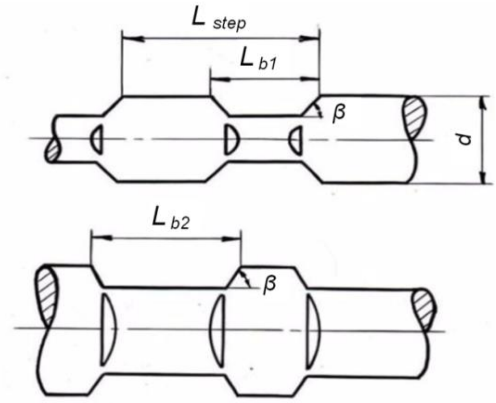

Figure 3. Scheme of the profile of the fibre in two planes:
L_{step} – profiling step of the fibre is 4 mm;L_{b1} – profiling length of the fibre in plane 1 is 1.9 mm;
L_{b2} – profiling length of the fibre in plane 2 is 2.4 mm;β– the bearing angle is 45^0;
***d* – diameter of the fibre**

The length of the fibres was 36 mm due to being able to randomly arrange them in the experimental samples. For larger fibres for these sizes of the transverse sections of the experimental beams when the fibresare distributed in the beams, they are distinctively “squeezed” and there is hardly any volumetric reinforcement left. Hence there is no major advantage of disperse reinforcement any more either. The recommendations on the distance between rods of transverse reinforcements in structures with a combined reinforcement with no less than 1.5 fibre lengths, optimally no less than 2 fibre lengths.

Despite the fact that according to a lot of researchers, the accepted ratio of the fibre length and diameter (*l/d)* is not optimal and lately fibre with the *l/d* 45-60 has been used. E.g., fibre from a cut steel wire “Dramix” produced by the Belgian group Bekaert N.V. with the brand Dramix 3D 45/50BL has the length of 50 mm, diameter of 1.05 mm. *l/d* that is indicated in the fibre labelling is 45. The accepted geometric parameters of the fibre are in agreement with the recommendations by the Committee 544 [23]. In particular, the ratio of the fibre length to the diameter is from about 20 to 100, making a fibre by cutting of a regular wire with the diameter 0.25–1.00 mm. The results of the experiment also showed that for the ratio *l/d* a disperse reinforcement also shows its major advantages.

In addition, the advantages in the technology of producing structures with a fibre of such parameters are out of question. The introduction of such fibres into a concrete mix requires no extra equipment without leaving them clumped. When fibres with the ratio *l/d*≥100 are used, additional introduction of concrete is essential in order to avoid clumping of fibres.

A concrete mix was prepared first with no fibres and then they were gradually introduced.

In order to identify the strength characteristics of concrete and fibreconcrete in the beams and fibreconcrete in the beams of each mixing, three prisms and three cubes were made (100 x 100 x 400 mm) (150 x 150 x 150 mm). In order to get comparative characteristics for fibres of the accepted geometric parameters, prisms and cubes were additionally produced for dynamic studies.

Research method

As providing complete protection of buildings in the event of severe earthquakes hardly seems possible, the guidelines [24] make it possible to damage individual elements as long as people safety is guaranteed. Based on that the intensity and scheme of the experiments were chosen as follows (Figure 4).

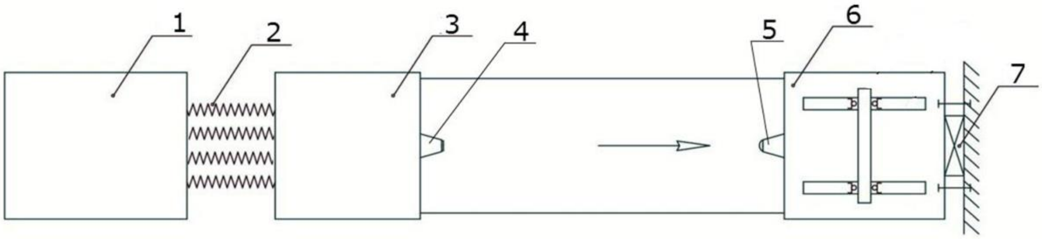

Figure 4. Scheme of dynamic studies (from the top):
1 – mechanism of trapping the shock cart and compressing the springs;
2 – springs of the stand;3 – shock cart; 4, 5 – scheme of centering the shock spot;
6 – operating cart with the tested beam; 7 – elastic filling

The tested structure was safely put on the operating cart (6) using a special structure of the beam clamping. Using the mechanism of trapping the shock cart and compression of springs (1) while using the hydraulics of the stand spring (2) was compressed down to a specified level. The shock cart (3) was set to motion due to the force of straightening of the springs. Applying some shock to the operating cart using the device for centering of the shock (4, 5), it impacted the tested beam by accelerating through the supports of a special structure. In order to obtain the second semi-wave of the acceleration of the supports of the beam between the operating cart and support, an elastic filling was provided (6).

Dynamic tests of the beam elements were conducted on a universal dynamic stand (Figure 5). The scheme of placing the beam and sensors on the operating cart is presented in Figure 6.

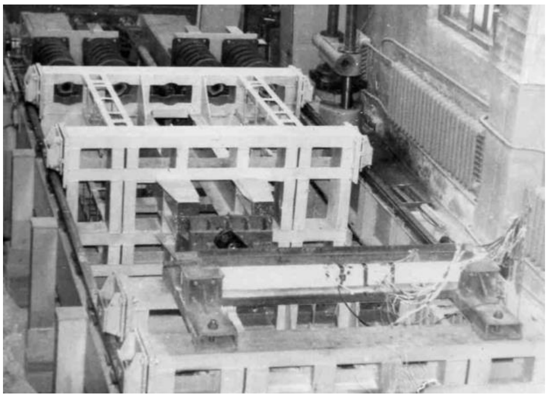

Figure 5. View of the universal dynamic stand with the tested structure

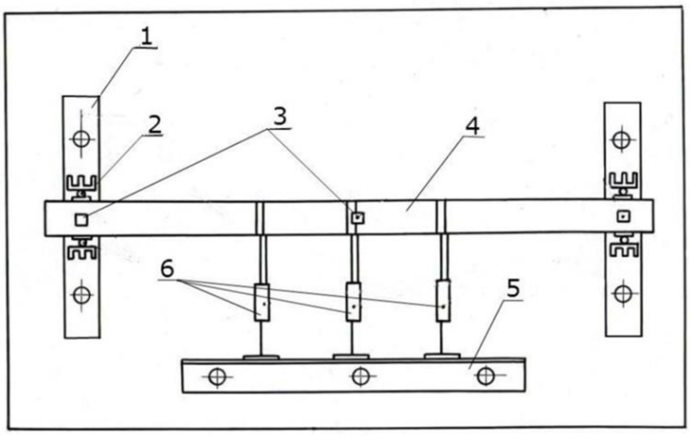

Figure 6. Scheme of placing the beam and sensors on the operating cart (from the top):
1 – the beam attached to the cart;2 – support;3 – acceleration sensors;4 – tested beam;
5 – angle for placing the displacement sensor;6 – displacement sensors

Throughout the experiment the bendings of the beam were measured at three spots in the middle of the span, accelerations on the support and the centre of the beam span, deformation of the reinforcement in the centre of the beam span.

The measurements were performed using acceleration and displacement sensors and the deformation of reinforcement using strain gauges. The resulting values were fixed by means of intensifiers and oscillographs. In order to observe cracks and their development, the surface of the beams was wetted with acetone.

Results and Discussion

The prisms and cubes were tested [25] under a static and dynamic load one by one. The test results for the cubes are in Table 2. The cubes were made without reinforcement (series 1), with disperse reinforcement with the fibre content of 1 % (series 2) and 2 % (series 3). The average cubic strength of concrete at the time of the tests was 31.4 MPa. The average cubic strength of concrete for the dynamic tests was 32.7 MPa. The strength of concrete during the dynamic tests was 4.2 % higher than that during the static tests. The average cubic strength of fibrecocnrete for beams with a combined reinforcement and those with a disperse one with 1.0 % of fibre reinforcement at the time of the tests was 32.6 MPa. The average strength of such cubes of fibreconcrete during the dynamic tests was 34.4 MPa.

The strength of cubes of fibreconcrete for the dynamic tests was 5.5% higher than that for the static ones.

Table 2. Results of the compression tests of cubes

№ of the series	Static		Dynamics	
	Sample labelling	Failure load, kN	Sample labelling	Failure load, kN
1	K-B-S-1	702	K-B-D-1	735
	K-B-S-2	709	K-B-D-2	739
	K-B-S-3	710	K-B-D-3	738
2	K-FB-S-1(1.0)	739	K-FB-D-1 (1.0)	776
	K-FB-S-2(1.0)	736	K-FB-D-2(1.0)	774
	K-FB-S-3(1.0)	730	K-FB-D-3 (1.0)	771
3	K-FB-S-1(2.0)	742	K-FB-D-1 (2.0)	780
	K-FB-S-2(2.0)	748	K-FB-D-2 (2.0)	785
	K-FB-S-3(2.0)	746	K-FB-D-3 (2.0)	778

In Table 2 there are the following denotations: K is a cube; B is concrete; FB is fibreconcrete; S is static;

D is dynamic; 1, 2, 3 is the number of a sample; (1.0), (2.0) is a percentage of a volumetric fibre reinforcement.

The average cubic strength of fibreconcrete for beams with combined reinforcement and those with a disperse one with 2.0 % of fibre reinforcement was 33.15 MPa. The average strength of such cubes of fibreconcrete during the dynamic tests was 34.7 MPa. The strength of cubes of fibreconcrete during the dynamic tests was 4.8 % higher than that during the static tests.

The compression strength of fibreconcrete was 4–6 % higher than that of standardized concrete depending on the percentage of fibre reinforcement.

The results of the tests of prisms are presented in Table 3. The prisms were made in series 1 with no reinforcement, in series 2 with a disperse reinforcement with 1 % of fibre and in series 3 with 2 % of fibre.

Table 3. Results of the compression tests of prisms

№ of the series	Static		Dynamics	
	Sample labelling	Failure load, kN	Sample labelling	Failure load, kN
1	P-B-S-1	258	P-B-D-1	285
	P-B-S-2	266	P-B-D-2	281
	P-B-S-3	262	P-B-D-3	280
2	P-FB-S-1(1.0)	280	P-FB-D-1(1.0)	299
	P-FB-S-2(1.0)	283	P-FB-D-2(1.0)	301
	P-FB-S-3(1.0)	276	P-FB-D-3(1.0)	308
3	P-FB-S-1(2.0)	290	P-FB-D-1(2.0)	315
	P-FB-S-2(2.0)	292	P-FB-D-2(2.0)	309
	P-FB-S-3(2.0)	286	P-FB-D-3(2.0)	313

In Table 2 there are the following denotations: P is a prisms; B is concrete; FB is fibreconcrete; S is static; D is dynamic; 1, 2, 3 is the number of a sample; (1.0), (2.0) is a percentage of a volumetric fibre reinforcement.

The average prism strength of concrete at the time of the tests was 26.2 MPa. The average strength of prisms of concrete during the dynamic tests was 28.2 MPa. The prism strength of concrete during the dynamic tests was 7.6 % higher than that during the static tests.

The average prism strength of fibreconcrete for beams with a combined reinforcement and those with a disperse one with 1.0 % of fibre reinforcement at the time of the tests was 27.9 MPa. The average strength of such prisms of fibreconcrete during the dynamic tests was 30.3 MPa. The strength of prisms of fibreconcrete during the dynamic tests was 8.6% higher than that during the static tests. The average prism strength of fibreconcrete for beams with a combined reinforcement and those with a disperse one with 2.0 % of fibre reinforcement at the time of the tests was 28.9 MPa. The average strength of such prisms of fibreconcrete during the dynamic tests was 31.2 MPa. The strenght of prisms of fibreconcrete during the dynamic tests was 8 % higher than that during the static tests.

The prism strength of fibreconcrete was 6.5–10 % higher than that of standardized concrete depending on the percentage of fibre reinforcement. The tests of prisms showed that the failure of prisms of fibreconcrete was viscous unlike fragile failure of concrete prisms. It should be noted that the distribution of fibre has a great influence on the nature of failure of prisms [26]. It is particularly the case for the percentage of volumetric reinforcement of 1 %.

Non-reinforced prisms were originally deformed elastically. Then microcracks occurred and transformed into localized microcracks that came together under a load and as a result, the prism lost its strength. During the dynamic tests concrete prisms were almost torn into pieces. In order to take a photograph of the samples, they had to be put together using a wire. In disperse reinforced prisms the failure was more viscous with its nature having to do with the amount of fibre in concrete. The comparison of the type of a failure of prisms during the dynamic tests is in Figure 7.

Figure 7. Typical view of failures of prisms following a dynamic impact: on the left are concrete prisms, on the right are fibreconcrete prisms

The impact on the tested beams was an impulse by applying a dynamic load to the operating cart. As a result of the impact, the resulting acceleration by using the supports of the tested structure was 18-22 g. The time of impact of each of the semiwaves of acceleration was 9-10 msec. The difference between the readings of the sensors of acceleration on different supports was 0.8-1.2%. The centre of the span of the tested beam started displacement following 2.5-3.5 msec after the supports started displacement. As a result, there was alternating loading and unloading occurring in the beams, which caused a change in their stress-strain state. These led to the accumulation of residual deformations and damages. The results of the tests of the experimental beams are presented in Table 4.

Table 4. Results of the tests of the beams using impacts such as “seismic” ones (the mean values in the series)

№ of the series	Sample labelling	Maximum displacement of the centre of the span, mm	Time of oscillations of the beam, msec	Maximum acceleration of the centre of the span, g	Notes
1	B-ZHB-D	9	210	48	
2	B-FZHB-D(1.0)	6	120	45	
3	B-FB-D(2.0)	12	60	12	Failure of the beam
4	B-FZHB-D(2.0)	5	105	40	
5	B-FB-D(1.0)	-	-	8	Failure of the beam

In Table 4 there are the following denotations: B is a beam; ZHB is ferroconcrete; FZHB is fibreferroconcrete; D is dynamic; (1.0), (2.0) is a percentage of the volumetric fibre reinforcement.

The ratio of the maximum acceleration on the support and in the centre of the span of the beam was 0.6–0.7. In Figure 8 there are graphs of the oscillations of the centre of the span of the beam under an alternating dynamic highly intensive impact.

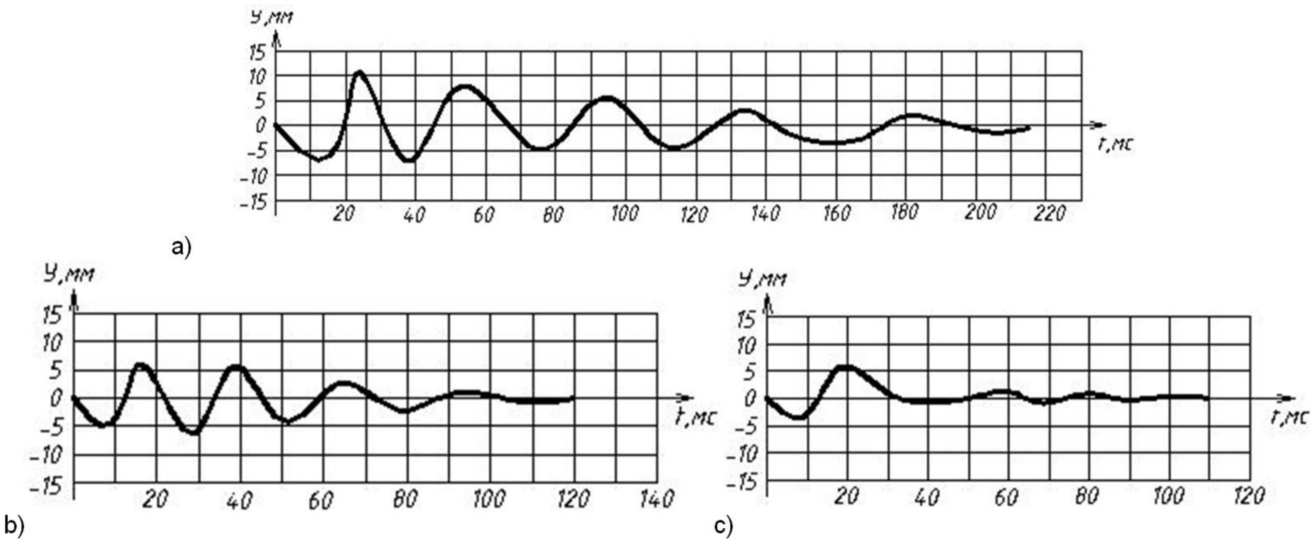

Figure 8. Graphs of the oscillations of the centre of the span of the beams under an alternating dynamic impact with the intensity 20 gbeams of series 1 (a), of series 2 (b), of series 4 (c)

The tests of the beams with a combined reinforcement (series 2 and series 4) showed that the amplitude of the oscillations in the centre of the span of such beams is almost two times less than in ferroconcrete ones (series 1). It can be accounted for with the fact that fibres additionally perceive some of compression forces and curb a bending increase. Damping of the oscillations of fibreferroconcrete beams was more rapid than in ferroconcrete ones and as the percentage of fibre reinforcement went up, it grew even more so. Rapid damping of the oscillations of the structure has a positive effect on the human behavior during earthquakes contributing to low levels of panic.

There were visible cracks all through the ferroconcrete beams and plastic deformations in the longitudinal rod reinforcement in the centre of the span. Under an identical impact in the beams of series 2 there were visible cracks with less opening but not all through them. In the beams of series 4 there were no visible cracks and in the longitudinal rod reinforcement in the centre of the beams there were no plastic deformations. This is due to a great influence of the dynamic strength of concrete of initial defects in the structure of concrete (e.g., microcracks). The use of a disperse reinforcement reduces this influence to a maximum.

The tests of fibreconcrete beams showed the following. In the beams of series 3 the total time of the oscillations was on average 60 msec, maximum bending of the beam was 12 mm with enough cracks in the beams but they retained their integrity as a self-sustaining element. However, it was not able to perceive the external impacts that followed. The beams of series 5 almost failed with a crack all through them. The fibreswere largely stretched from the matrix. Due to a constant stretching of the fibres, the failure was viscous.

Numerical Calculation of the Oscillations of the Beam

Numerical modelling of the oscillations of the beam under an impulse load was performed using the finite element method by means of a computational tool Structure CAD (SCAD). In the software in order to solve a dynamic task, an absolutely stablevatriant of the Newmark method was implemented in the form of the “predictor-corrector” algorithm [27].

The sizes, mass of the beam, type of an impulse and parameters of the damping of the oscillations were accepted according to the results of the experiment. A preliminary modal analysis of the dynamic model of the beam (Figure 9.) showed that the first frequency of the oscillations was f = 26.74 Hz (T_1 = 0.0374 sec). The time of the shock impulse obtained during the experiment was t_u = 0.018 sec. With a relative time of the impulse t_u/ T_1 = 0.05 its time has no great influence on free oscillations of the beam [28] as shown in Figure 10.

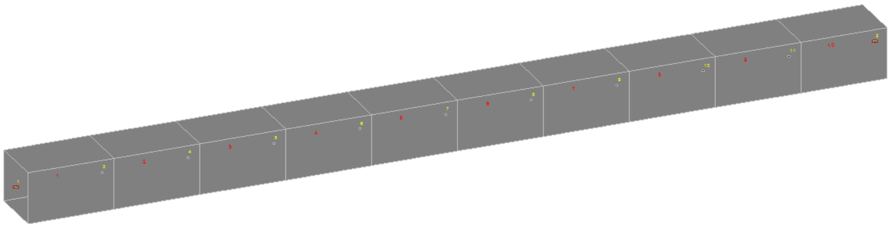

Figure 9. Finite-element model of the beam of a rectangular section

While comparing the calculated linear elastic operation of the material obtained in the assumption and experimental vibrorecord, it can be concluded that the nature of oscillations of the beam during the experiment was non-linear due to damages of the concrete and reinforcement. Cracks and plastic deformations in the reinforcement also contribute greatly to the saturation of the oscillation energy as shown in the experimental vibrorecord.

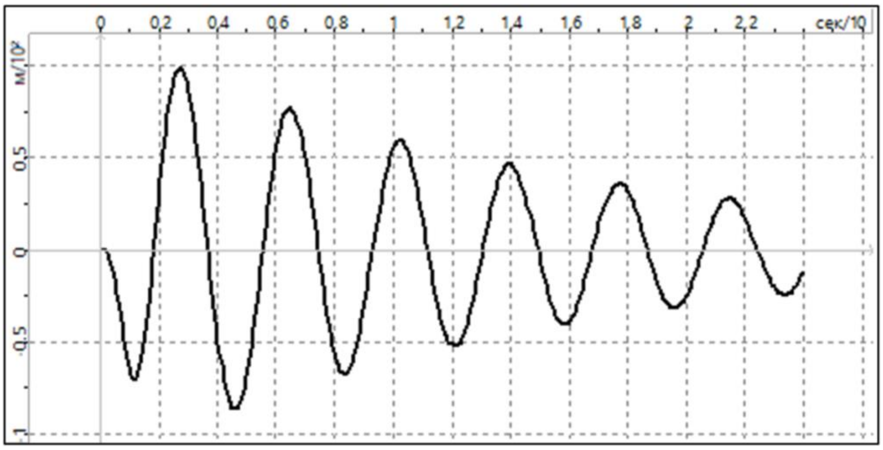

Figure 10. Calculationalvibrorecord of displacements in the middle of the span of the beam

The results of the studie sareinagreement withthoseobtained by otherre searchers [6, 8, 9, 10, 11, 12, 13, 14, 17, 18] and compliment them in terms of the use of disperse reinforcement with steel fibre with a small l/d ratio in structures under an alternating highly intensive dynamic load.

Conclusions

1. The use of a disperse reinforcement with the use of fibres with a small l/d ratio has a significant impact on the behaviour of structures with a combined reinforcement under an alternating dynamic highly intensive load thus resulting in an increase in the crack resistance as well as a decrease in the amplitude and time of oscillations of structures with a combined reinforcement.

2. Under alternating dynamic highly intensive loads it is reasonable to make use of a combined reinforcement since structures with only one fibre reinforcement are not capable of perceiving such loads.

3. During an alternating deformationfibre shows extra resistance to the opening of cracks not only due to cohesion with concrete but also thanks to the resistance in the transverse direction. If the resistance of fibres is in the axial direction, after being stretched out of the matrix they continue to resist due to the friction force along the surface of a resulting channel in the concrete.

4. Cubes and prisms with a disperse reinforcement has a higher compression strength compared to a non-reinforced concrete under a static and dynamic impact for the employed geometric parameters of fibres. An increase in the strength is due to “the ring effect” created by a disperse reinforcement that prevents transverse expansion.

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