EFFECT OF AMOUNT AND TYPE OF REINFORCEMENT ON BEHAVIOUR OF REINFORCED CONCRETE ELEMENTS UNDER SEISMIC IMPULSE EXCITATION

by

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SYNOPSIS

Experimental data on the impulse dynamic loading behaviour of ordinary and prestressed reinforced concrete beams with different type reinforcing bars of class A-III hot-rolled steel ($R_a = 3400$ kgf/cm^2), class A-IIIB hot-rolled strengthened-by-drawing steel ($R_a = 4500$ kgf/cm^2), and class AT -VI hot-rolled thermally-strengthened steel ($R_a = 7600$ kgf/cm^2) are presented. Stiffness, dynamic behaviour, energy capacity, and vibration damping values are compared. Advantages of the use of high-strength steels in earthquake engineering are shown, and inadmissibility of the use of heavily reinforced sections is emphasized. Formulae are presented for evaluation of the limit for reinforcing, and recommendations for calculation of stiffness and crack resistance under dynamic loading are given.

Four groups of reinforced concrete beams were tested under impulsive dynamic loading. Groups I and II beams were reinforced with class A-III hot-rolled Isteg steel bars and were different in cross-section size. Groups III and IV specimens were reinforced with prestressed steel bars. Tensile reinforcement of the group III specimens of class A-IIIB hot-rolled reinforcing steel strengthened (5%) was made by drawing, and the group IV specimens used class AT-VI thermally-strengthened reinforcing steel bars.

The specimens were tested in a special stand by dropping the truck with the help of an electromagnetic tripper device. Dynamic loading was successively increased by changing brittle inserts of a specific tripper device installed between the tested specimen and the loading device. The specimens were tested by the scheme of the one-space beam loaded in one-thirds of the span by concentrated weights. As the load reached the presentvalue, the brittle insert broke, and the beam performed free damping vibrations. A number of beams were tested with an associated mass, thereat. The load application time period equalled 0.1 - 0.25 s.

A number of specimens from each group were tested under step-by-step static loading. The reinforced concrete beam strength under dynamic

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loading was higher than that under static loading on the average by 6.8%, 6.2%, 5%, and 4.5% in groups from I to IV, respectively. The increase was appreciably less than the strengthening value for the concrete and bars. Thus, the increment in the concrete strength equalled 10.6% at the given rate of load application, but the yield point increment was equal to 17% and 14% for A-II steel and A-IIIB steel, respectively, and the yield limit increment for Aт-VI steel was 10%. A lesser increase in flexural reinforced concrete beam strength in comparison with the strengthening value for bars and concrete is bound up with a close approximation of the diagram of stresses in the compression area of the dynamic-loaded flexural elements to the triaxial diagram.

The limit of ultimate reinforcing (fig.1) at static loading with the tensile reinforcement strain increment in the range of $2x10^{-3}$ to 10^{-2} is described by the formula:

$$\xi_{lim.} = \frac{2.1\xi_o^t}{3.8 \cdot \frac{\sigma_a}{1000} - \left(\frac{\sigma_a}{1000}\right)^2 + 0.1\left(\frac{\sigma_a}{1000}\right)^3 - 0.7} \qquad (1)$$

The limit of ultimate reinforcing at dynamic loading is significantly lower than that at static loading. Satisfactory agreement with the experimental data is observed when the compression area height is determined from the formula (1), with the concrete deformability specified by the formula:

$$\xi_o^t = \frac{a}{m_б^t} - 0.0008\, m_б^t R_{np}. \qquad (2)$$

For reinforcement with the yield point

$$\sigma_a = m_a^t R_a - \sigma_o. \qquad (3)$$

For reinforcement with the yield limit

$$\sigma_a = m_a^t R_a + 4000 - \sigma_o, \qquad (4)$$

where $m_б^t$, m_a^t are increments of concrete strength and reinforcement yield limit at dynamic loading in comparison with static one.

The crack resistance of reinforced concrete beams at dynamic loading is higher than that at monotonic loading. This increase is positively evaluated when the concrete strength increase is considered at dynamic loading tension.

Stiffness of beams under dynamic loading is higher than that under static loading. However, consideration of the concrete strengthening value only does not compensate this difference. Satisfactory coincidence of the design curvature with the test one is observed on increasing the coefficient characterizing the elasto-plastic state of the compression area concrete up to $\nu_t = 0.55$.

The beams of groups I and II featured the highest stiffness. After occurring of vertical cracking in the beams the curvature was nearly in linear dependence on the load up to their failure. Such a dependence is characteristic of sections heavily reinforced with longitudinal reinforcement (with an appreciable height of the concrete compression area $\xi > 0.5$), in which the ultimate strains of the tensile reinforcement before the element failure reach rather small values (strains in reinforcement before failure of groups I and II beams did not exceed $2x10^{3}$ to $2.8x10^{-3}$).

Reinforcement amount in groups III and IV beams was in the range of mean percentage ($\xi = 0.2 \div 0.4$). Diagrams of beams deflections were similar to diagrams of tensile reinforcement strains. In group III beams the stiffness was not practically changing from the cracking moment to reaching 75-80% of their load capacity. With a further increase in the load, a speeded-up drop in stiffness was observed. A gradual decrease in stiffness took place in the beams with the class AT-VI high-strength tensile reinforcement (Group IV) after cracking. Comparing the deformability of the groups III and IV beams that differ insignificantly in their strength, considerably greater deflections in the specimens reinforced with high-strength steel should be noted. Gradual stiffness reduction of concrete sections with high-strength reinforcement and constantly less value of its stiffness as compared to those of sections with medium-strength reinforcement, are indicative of the expediency of using high-strength reinforcing steel for structures subjected to significant dynamic loading. However, when relatively low residual strains after reinforcement fracture are considered, any possibility should be excluded for reinforced concrete elements with high-strength reinforcement to be destructed due to the reinforcement fracture. For steels with uniform elongation of no less than 2%, the possibility of reinforced concrete elements failure due to the reinforcement fracture is practically excluded on condition that $\xi \geqslant 0.05$.

Comparison of dynamic behaviour of the test specimens was performed by dynamic coefficients (fig.2) representing the ratio of the beam support reaction at a sudden application of weight P to its reaction at static application of the same weight $(\frac{P}{2})$. The group I beams were characterized by the highest dynamic coefficients. If after cracking the dynamic coefficient decreased from 2.0 to 1.75, then a stage before failure it was equal to 1.87 - 1.90, i.e. a suddenly applied load in heavily reinforced concrete beams (with compression area height $\xi \geqslant 0.5$) induced nearly the same reaction as in the elastic element.

In prestressed beams the dynamic coefficient began decreasing before visible cracking. After cracking it decreased to 1.75 in group III, and to 1.73 in group IV. Then its values increased a little, reaching 1.82 and 1.8 at 60 and 70% of the load capacity, respectively. With a further increase in the load, a speeded-up decrease of dynamic coefficient was observed. On the whole, the dynamic coefficients of the group IV beams were lower than those in group III, though a sharp decrease was observed in the dynamic coefficients of the latter group beams at loads higher than 90% of their load capacity (at the beginning of the reinforcement yielding).

The lowest energy capacity was observed in beams with a large height of the compression area (groups I and II). The specific energy capacity for groups III and IV specimens (columns 2,3 of Table 3) was higher than for group I by 64% and 124%, respectively, and the yield energy value (column 4 of Table 3) was 2 and 2.3 times higher, respectively. This fact confirms the conclusion on inadmissibility of providing a great amount of longitudinal reinforcement in sections used in earthquake engineering.

On the whole, the energy capacity of the beams with the Aт-VI high-strength reinforcement (group IV) proved to be higher than that of similar specimens with the A-IIIB medium-strength reinforcement (group III).

Comparatively small values of the group III and IV yield coefficients were accounted for by the fact that the elastic energy value was determined from the cracking load, and the cracking resistance of prestressed sections was appreciably higher.

Vibration damping values for every group beams were practically in one and the same range, though the vibration damping coefficients were in the ranges of $\varepsilon = 0.16 \div 0.3$ for groups I and II, $\varepsilon = 0.22 \div 0.46$ for group III, and $\varepsilon = 0.17 \div 0.4$ for group IV.

Table 3

Energy Capacity of Beams Groups

Group	A	$\frac{A}{A_I}$	$F_{пл}$	$\frac{F_{пл}}{F_{плI}}$	F_y	$\frac{F_{пл}}{F_y}$
1	2	3	4	5	6	7
I	10,1	1,00	7,58	1,00	0,04	200
II	7,12	–	53,32	–	0,18	300
III	16,52	1,64	15,0	2,00	0,32	48
IV	22,61	2,24	17,4	2,30	0,33	52

Table 1

Characteristics of Test Beams Groups

Group	Cross-section, cm, b x h	Longitudinal tensile reinforcement	Longitudinal compressive reinforcement	Prestressing in tensile reinforcement, kgf/cm^2	Quantity of specimens	Concrete strength, kgf/cm^2	
						Rпр	Rp
1	2	3	4	5	6	7	8
I	12x16	2ϕ 25 A-III	-	-	8	366	27
II	12x20	2ϕ 25 A-III	-	-	4		
III	12x16	2ϕ 18 A-IIIB	2ϕ 14 A-III	3830	12		
IV	12x16	2ϕ 12Aт-VI	2ϕ 14 A-III	7465	12		

Table 2

Characteristics of Tensile Reinforcement

Reinforcement diameter and class	At static loading				At dynamic loading			
	$\sigma_T(\sigma_{0,2})$ kgf/cm^2	σ_B kgf/cm^2	δ_p %	δ_5 %	$\sigma_T(\sigma_{0,2})$ kgf/cm^2	σ_B kgf/cm^2	δ_p %	δ_5 %
1	2	3	4	5	6	7	8	9
ϕ25 A-III	3895	6391	14,1	24,7	4547 / 1,17	6878 / 1,08	16 / 1,13	26,3 / 1,06 *
ϕ18 A-IIIB	5700	6540	9,1	17,2	6500 / 1,14	7060 / 1,07	11,7 / 1,29	19 / 1,10
ϕ12 Aт-VI	10000	13350	4,3	12	11000 / 1.10	15200 / 1.14	4.7 / 1.09	14.3 / 1.19

*The numerator refers to absolute values, the denominator to dynamic-static behaviour ratio.

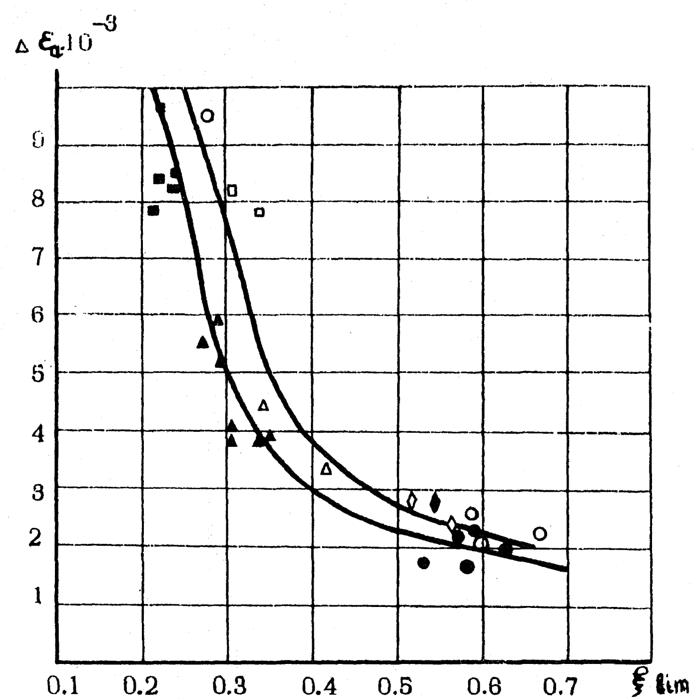

Fig.1. Bending Concrete Members Reinforcing Bound

Group I Group II Group III Group IV

Static Loading ○ ◇ △ □

Dynamic Loading ● ◆ ▲ ■

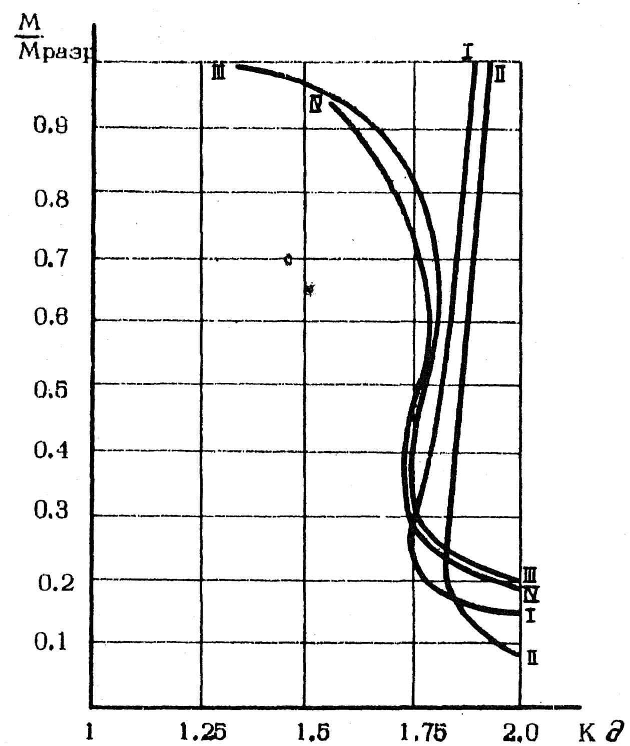

Fig.2. Reinforced Concrete Beams Dynamic Koefficient