EXPERIMENTAL STUDY OF PRESTRESSED REINFORCED CONCRETE ELEMENTS OF ANTISEISMIC BUILDINGS

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Abstract

Various institutions have conducted experimental research to specify characteristics of prestressed elements with different reinforcing and different levels of prestressing and to study individual structures made of such elements. Much attention has been given to changes in the natural vibration frequency and the logarithmic decrement. The energy absorbing capacity of the models has been investigated depending on cohesiveness of the stressed reinforcement with concrete. On the basis of the experimental results the frame of public buildings has been developed and recommendations on designing prestressed reinforced concrete structures for seismic regions are currently being prepared.

Paper

The prestressed concrete beams reinforced with highly strong seven-wire strands were the subjects of a series of tests conducted in the experimental department of the Central Institute of Building Structures. Application of such strands makes it possible to simplify considerably the process of production of structural elements. The models were 310 cm long and had a rectangular cross-section of 20 x 30 cm. They were made of the Grade 400 concrete and reinforced with two strands (the wire diameter being 5 mm) and three cages. At the time of the tests we studied those changes which were occurring in the dissipative and other proper-

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ties during accumulation of strains in the bending elements under the following levels of reinforcement prestressing: 6000 kgf/sq.cm,8000 kgf/sq.cm and 10000 kgf/sq.cm.Comparison tests were run for similar beams with unstressed reinforcement. The loads applied were the following: A - a step-by-step static load with relieving in each step;B - a monotonic increasing static load; C - a monotonic load of seismic deformation rates (the duration was 0.2-o.3 sec.); D - a repeated load with a level increasing in each step in the range of seismic rates;the load was relieved in each step at the same rate; E - a repeated load with a level increasing in each step in the range of seismic deformation rates and with an instant unloading of the beam in each step.

The hydropneumatic equipment which we used in our experiments allowed us to adjust the value and damping of the associated mass by changing the length and the cross-section of the inertial conduit. To simulate the effect of the interior and exterior secondary structures the associated mass was adjusted to 12 tons, so that the natural frequency of the system was 3-4 Hz,i.e. it corresponded to the most frequencies of structures.

The dynamic characteristics of the beams in the tests of the A-D modes were determined according to the character of natural vibrations,the initial amplitude of which was about 5% of the breaking strain value. The analysis of the test results showed that the small vibrations did not reflect the dynamic characteristics which the beam had under large loads. It can be assumed that the threshold of the strain lower level should be 10-20% of the breaking amplitude. The most trustworthy results can be obtained with amplitudes of natural vibrations caused by some active load of the E mode. Fig.1(a) shows changes in the natural vibration frequencies of the beam under various dynamic loads. It follows from the diagram that the natural frequency of the prestressed beams remains higher than that of the unstressed beams throughout the entire period of strain accumulation,if the dynamic load is applied in a step-by-step manner. The high frequency and therefore a higher stiffness of the prestressed beams are retained up to the predestruction stage. In the unstressed or weakly stressed beams the natural frequency drops by 25-30% of the initial frequency by the time of beam destruction. It should be noted here that the main drop of the frequency of the unstressed beams occurs in the first half of the strain accumulation process. In the subsequent period the natural vibration frequency becomes stabilized.The higher is the level of prestressing, the more pronounced becomes the tendency of the stabilized frequency to shift along the load axis towards higher values. In cases of high prestressing levels the natural frequency becomes stabilized under 40-50% of the breaking load. For these loads the natural vibration frequency of prestressed structures assumes the highest values. In contrast to the results obtained from low-intensity impact tests the logarithmic decrement of the vibrations induced by a stepped dynamic load of the E type depends on a load value. As the level of prestressing increases, the logarithmic decrement decreases (Fig.1-b).The study of the behaviour of the seven-wire strands under dynamic loads showed that there was not any noticeable difference in the extension values of individual wires of the strand. Thus,under the load corresponding to the yield limit of the strand the scattering of strain values of individual wires did not exceed 0.3-0.5%, while under the loads applied in the predestruction stage the scattering was 2.5%. The comparison of the strength and deformability of the strand-type reinforcement in the static and dynamic tests shows that the dynamic strength exceeds the static strength by 4-7%, while the limit extensions by 10-15%.

In the production and experimental department of the Tbilisi Zonal Research Institute of Experimental Design we studied the energy absorbing capacity of the bending prestressed structures with the reinforcement of various cohesiveness with concrete. We tested the following three types of models: a model with the reinforcement having cohesion along the entire length of the beam, a model with the ungrouted reinforcement and a model with the reinforcement placed into the open channels and grouted with cement mortar. The models were the concrete beams with a cross-section of 22x22 cm and a span of 4.0 m. The stressed reinforcement was of 2 Ø 10 and of the A-Y class. In addition to the stressed reinforcement some additional A-I class reinforcement of 2 Ø 5 was used in the stretched zone of the beam concrete. The tests of the models were run under step-by-step increasing repeated loads. Fig.2 shows a general view of the beam tested. The results of the tests showed that the energy absorbing capacity of the structures with the reinforcement laid in the open channels exceeded by 30-40% the capacity of the beams with the reinforcement cohered with concrete (Fig.3). Under the rated loads the energy absorbing capacity of the beams with the reinforcement grouted with cement mortar corresponded to the energy absorbing capacity of the beams with the reinforcement cohered with concrete. Under the loads making up 0.8-0.9 of the breaking load the energy absorbing capacity of the models approached the capacity of the models with the reinforcement having no cohesion with concrete. The difference in the energy absorbing capacity of the models is mainly due to various lengths of those areas in the stressed reinforcement where plastic deformations developed (the pure zone bending was 50% of the beam span). When the open channels were grouted with cement mortar,the same effect was observed only after the deformation and peeling of the grouting. A favourable effect (even distribution of cracks,lower concentration of stresses in the compressed zone of concrete) on the behaviour of the structures with the ungrouted stressed reinforcement was produced by the additional reinforcement of the stretched concrete zone. It follows from the above-said that structures with the stressed reinforcement laid in open channels and grouted with cement mortar are more suitable for seismic regions as the reliability of such structures is higher than that of structures with the ungrouted stressed reinforcement, while the energy absorbing capacity differs but slightly.

In another series of experiments we tested a fragment of the frame of a public building which is supposed to be built with experimental purposes in seismic regions. The design loads on the floor were 800 and 1250 kgf/sq.cm; the storey height was 4.2 m; the column grid was 6x9,6x12 and 9x9 m. The columns had a cross-section of 40x40 cm and a height for 1,2,3 and 4 storeys; the cross-bars with a trough-shaped cross-section were 546,846 and 1146 cm long, 65 cm high and had shelves in the lower part;the cross-bars were connected with the columns by means of the so-called "friction joints" created by tightening the reinforcement laid in the open channels. Two full-scale models of the frame fragment were tested. Each model consisted of a column of a two-storey height and four cross-bar arms. The tests were run under a permanent load on the column and step-by-step increasing loads on the cross-bars. The loading schemes are shown in Fig.4. The tests showed that the relatively small prestresses in the bar reinforcement of the A-III class (2000 kgf/sq.cm including losses) made it possible to bear the cutting forces in the conjugations owing to the friction in the joints. When the relation of the design normal force to the design bending moment is m=10 and the relation of the opposite sign loads is ρ=-0.5 (Model No.2),also when m=5 and ρ=0 (Model No.1), the cross-bar edges are destroyed in the compressed concrete zone, while no destruction is observed in the central zone of the unit. Under the same loading scheme II (Fig.4) the sagging of the end of the П-4 arm of Model No.2 with the reinforcement laid and grouted in the open channels appeared to be somewhat less than the similar sagging of Model No.1 with the open reinforcement even in the initial loading stages. The visible cracks in the model with the ungrouted stressed reinforcement appeared earlier. The first cracks in the upper channel grouting were formed under the forces exceeding the design values. Subsequently,after the development of plastic deformations,there occurred a sudden separation of the grouting accompanied by formation of longitudinal cracks along the entire cross-bar length (loading scheme IV). Thus, the experimental results of the frame fragment tests show that it is possible to realize the effect of additional energy absorbtion when loading the structures with reinforcement grouted in open channels.

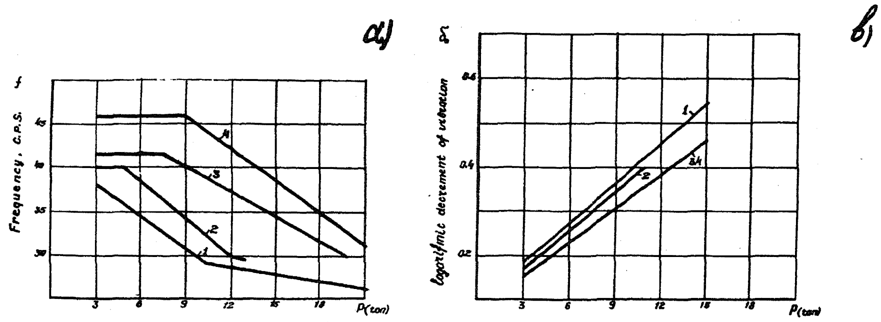

Fig.1. Changes in the natural frequency(a) and relative decrement(b) of beam vibrations depending on the limit load levels in the tests of the E mode for beams with: 1-σ_H=0; 2-σ_H=6000 kgf/sq.cm; 3-σ_H=8000 kgf/sq.cm; 4-σ_H=10000 kgf/sq.cm

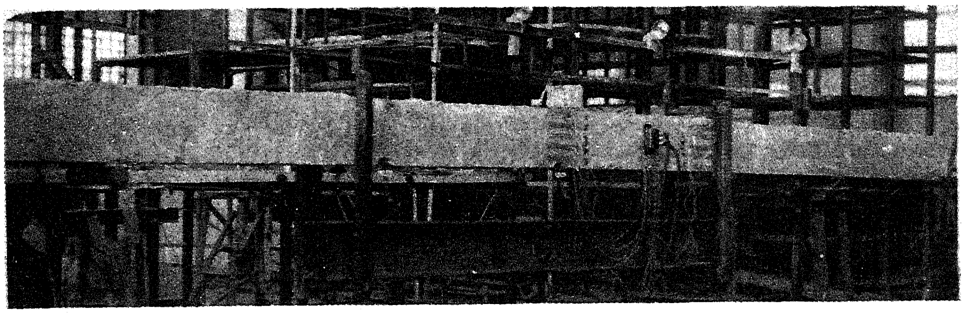

Fig.2. A general view of the beam being tested

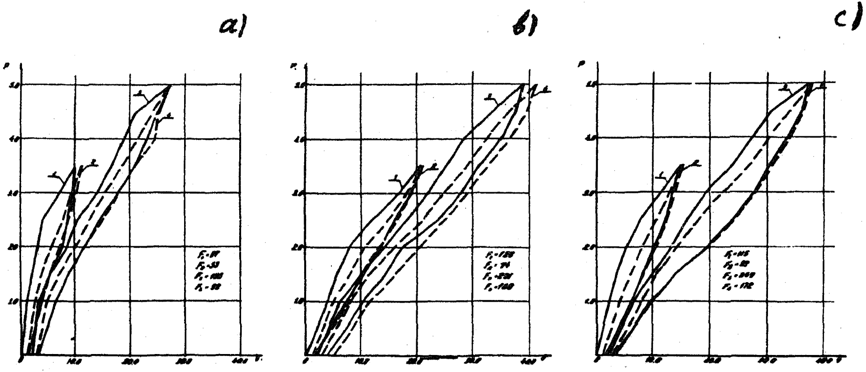

Fig.3. "Force-Displacement" diagrams showing dependence on a loading level

a)for beams with reinforcement having cohesion with concrete,
b)for beams with reinforcement having no cohesion with concrete,
c)for beams with reinforcement placed in open channels and grouted with cement mortar

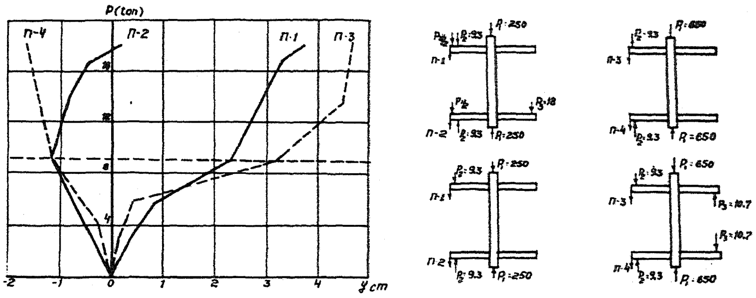

Fig.4. Diagram of arm end sagging and loading schemes of Models Nos.1 and 2

———————— Model No.1 with ungrouted reinforcement

---------- Model No.2 with reinforcement grouted with cement mortar

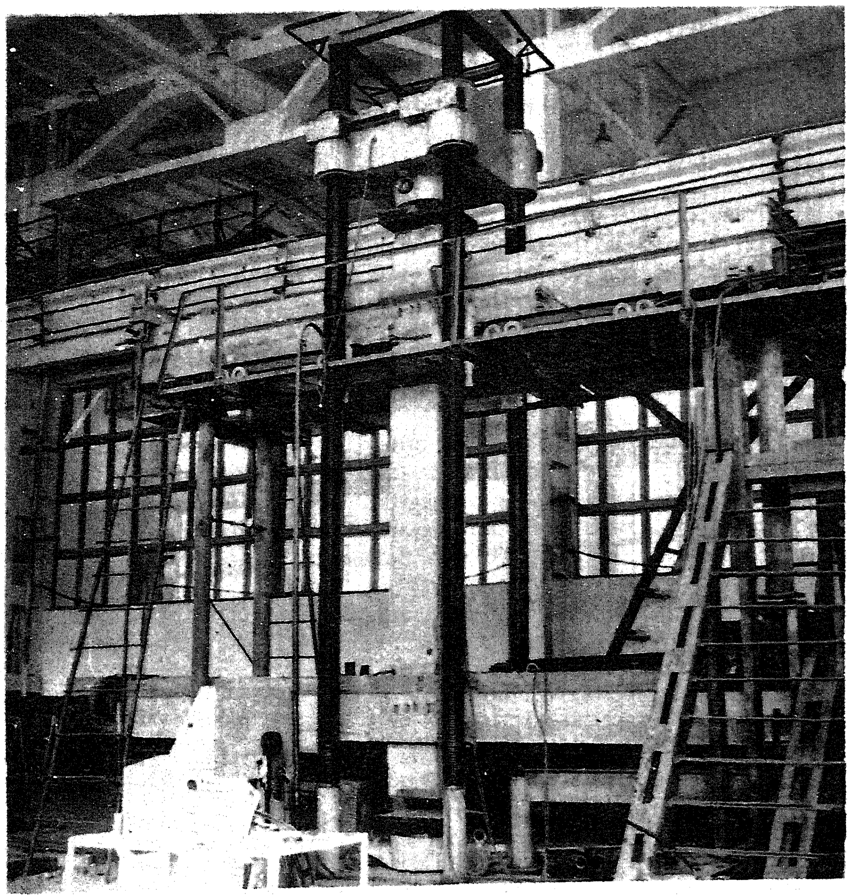

Fig.5. A general view of the fragment being tested