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Published by Elsevier Science Ltd 1996
Paper No. 1372. (quote when citing this article)
Eleventh World Conference on Earthquake Engineering
ISBN: 0 08 042822 3

VIBRATIONAL TESTS ON SECTIONS OF MONOLITHIC BUILDING AT HIGH LEVELS OF LOADING

A.S. Zolotcov and Yu.V. Izmailov

National Center for Research and Standardization "CERCON"
N. Milescu Spataru 9, apt. 168, Kishinev, 277042, Republic of Moldova

ABSTRACT

In the majority of cases full-scale dynamic testing of buildings is characterized by relatively low inertial load factors, in consequence of which one can not afford studying the performance of such systems at the stage of plastic deformations development, as well as when the systems suffer damages and, finally, at the stage of destruction. Meanwhile, comprehension of monolithic buildings performance in these circumstances is the obligatory condition for their design modification as regards "earthquake-resistance", i.e. exposure to the consequences of earthquakes.

Carrying out of vibration-survival tests on two sections of a monolithic building up to the total collapse of the latter, followed by reinforcement of the sections and repeated tests, made it possible to suggest some new proposals concerning designing and stress analysis of such buildings at high levels of loading.

KEYWORDS

DAMAGE DYNAMICS UP TO THE TOTAL COLLAPSE AS CONCERNS MONOLITHIC BUILDINGS. WALLS REINFORCEMENT SYSTEMS. DYNAMIC CHARACTERISTICS. STRESS (SHEAR STRENGTH) ANALYSIS. REINFORCEMENT TECHNIQUE.

Objectives of the Experiment

The given experiment pursued a number of objectives, the main ones being as follows:

1. Besides vertical marginal reinforcement (contour reinforcement) ordinary wall slabs of the buildings are usually reinforced along the whole surface of the slabs planes. It is done by using welded fabrics of flat reinforcing frames spaced at 80-100 cm. Study of the load stressed state of the walls on the basis of finite elements method indicates low effectiveness of such a traditional reinforcement systems.

On this account one of the purposes of the given experiment was to test the effectiveness of different systems of wall slabs plane reinforcement.

2. It is known that different structural damages inflicted on the building affect its bearing capacity in different ways. Therefore, the study of monolithic buildings damage dynamics up to the buildings failure at high levels of loading, like seismic ones, is of great interest. It is only natural that one had to organize

instrumental observation of dynamic characteristics of the buildings in order to reveal their contribution to the earthquake damage to the latter.

3. At present there exist rather a lot of suggestions concerning analytical assessment of the reinforced concrete buildings walls bearing capacity at high levels of loading. Some of suggestions are being recommended by Building Codes standards of various countries. As all the methods proposed are approximate, ones evaluation of the design predictions credibility on the basis of actual experimental data is a matter of special interest.

This problem had been solved in the progress of the experiments described.

4. During the earthquake in the Carpathians area (1986) a lot of buildings in Moldova were damaged one way or another, severe damaging included. In view of that fact further maintenance of the damaged buildings became impossible without basic reinforcement. That is why one of the tasks of the given experiment was a full-scale testing of monolithic buildings' damaged walls reinforcement method developed under laboratory conditions.

One can see that the investigators faced a lot of problems. Within the scope of the present report it seems difficult to cover in detail all the results obtained. Thus the authors had to abandon publishing the majority of intermediate data and to touch upon only final results.

Subject of Inquiry and Experimental Procedure

The experiment was carried out on two 6-storeyed monolithic building sections erected on the basis of progressive shuttering method of construction (Fig. 1). Foundation of each building section was done in the form of a 9840 x 14600 x 400 mm plate of Brand 200 cast-in-situ concrete. The plates were placed at a distance of 1000 mm from each other. Between the foundation plate and the upper floors there was built technical basement with blank walls of M 200 heavy-weight concrete, wall thickness being 400 mm. The walls of upper floors (200 mm thick) were made of haydite concrete with a cube strength between 14.8 and 26.1 MPa. Floor slabs, 160 mm in thickness, were made of heavy-weight concrete with a cube strength from 14.8 to 32.1 MPa. Contour reinforcement was identical for all the walls (10 18 A-III), plane reinforcement being different (cf. Fig. 1). One of the walls had no plane reinforcement at all.

In the practice of in-situ house-building there gained grounds construction of 12-24 storeyed high-rise buildings. Carrying out of full-scale testing of building sections having such a height entails significant technical difficulties. That is why experimental building sections were designed as 6-storeyed structures, but the stress level at their lower floors was brought to that of 16-storeyed buildings. To this effect each section before vibration-survival testing underwent vertical prestressing around the walls' edges using cable-block systems and 100 tons power hydraulic jacks. Additional loading for each wall made up 2400 kN. Building sections were tested by using B-2 vibration machine with 6 vibrators having changeable unbalanced mass. Each vibrator's momentum could have been varied within the range of 31-390 kgm, frequency band being 0.7-6.0 Hz.

The vibration machine was rigidly connected to a steel frame, set up solidly on the section covering. Inertial loading was developing towards blank walls; momentum on the shaft of vibration machine grew stepwise. Maximum level of enertial loading reached approached that of a 10 grade seismic scale, being calculated according to the former USSR Building Code standards - SNiP II-7-81 "Construction in the seismic regions".

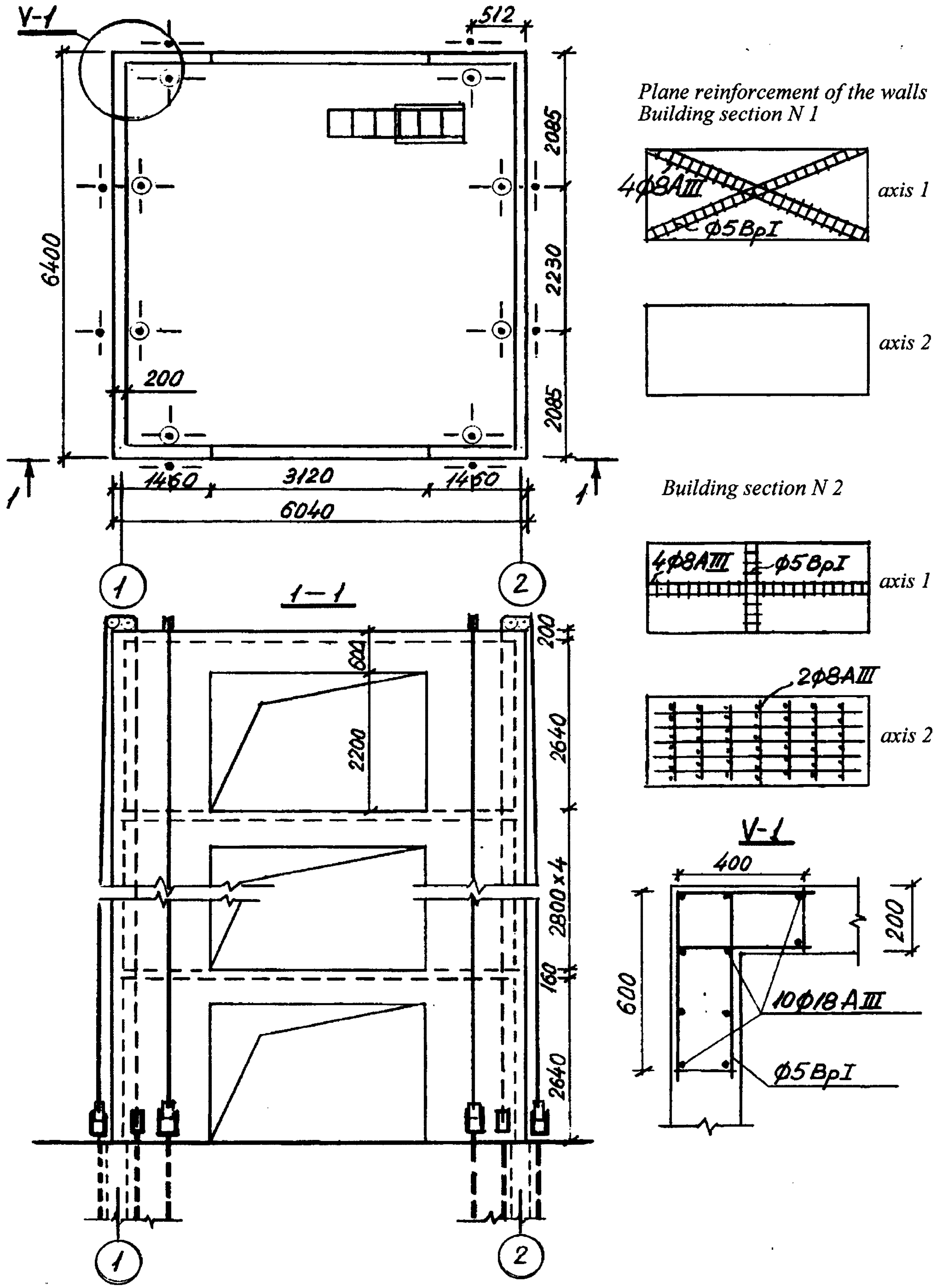


Fig.1. **Test building sections design**

To observe sections displacement and deformation of their walls there were used vibration transducers of various types as well as strain-measuring devices. Indications were recorded by oscillographs.

MAIN TESTING RESULTS

On testing the sections there were revealed both general and specific mechanisms of damages development, the latter being conditioned by the differences in walls plane reinforcement.

Generality of crack formation was as follows (cf. Fig.2).

First there appeared inclined cracks in the walls of the ground floor. As far as inertial load grew, the amount and width of crack openings grew as well. Then there appeared similar cracks in the walls of the first floor; after that there appeared a shear along the structural joint at the level of the floor slab above the ground floor. Inclined cracks in the walls of the ground and first floor joined together in the shear plane middle portion. There took place a kind of division of walls into blocks that moved past each other during vibration-survival test. There appeared cracks in the floor slabs and walls of the upper floors of the building sections. The most affected happened to be the walls of the ground floor. At the stage of destruction there took place spalling of concrete out of compressed zones and buckling of contour reinforcement which intensified this way destruction of the zones in compression. There occurred compression fracture of contour reinforcing rods. Not any damage to flanges of wall sections was discovered (longitudinal slacking, punching, etc.), though according to the readings of strainmeters the flanges were actively involved into the performance of the walls.

One should point out the following distinctive features of the damage pattern as concerns building sections:

- the wall without plane reinforcement has suffered relatively great damage, i.e. wider opening of cracks, number of cracks being smaller, and significant transverse displacement (up to 10 mm) of the wall blocks formed. In the same wall there occurred rupture of contour reinforcement. One could see spalling of concrete fractions from the places where inclined cracks crossed;

- as far as spacing of plane reinforcing rods got narrower, the number of inclined cracks in the walls grew, and the width of their openings became smaller;

- plane reinforcement rods being spaced widely, there took place buckling of the latter;

- the wall with diagonal plane reinforcement happened to be the least affected one. This type of reinforcement proved to be the most efficient as well, which allows us to recommend this method to be favored for strengthening the walls of reinforced concrete buildings;

- in the floor slabs there were formed multiple through cracks that made it possible for diagonal cracks in the walls of the first floor to extend to the walls of the ground floor through the horizontal portion of the structural joint.

Extensive bench tests of reinforced wall panels [1, 2] showed that contour reinforcement exerts substantial and often decisive influence upon the performance of the walls. This influence is non-uniform. Its main aspects verified during vibration-survival testing described are as follows:

- contour reinforcement cross-section enlargement leads to expansion of the compressed zone and in-

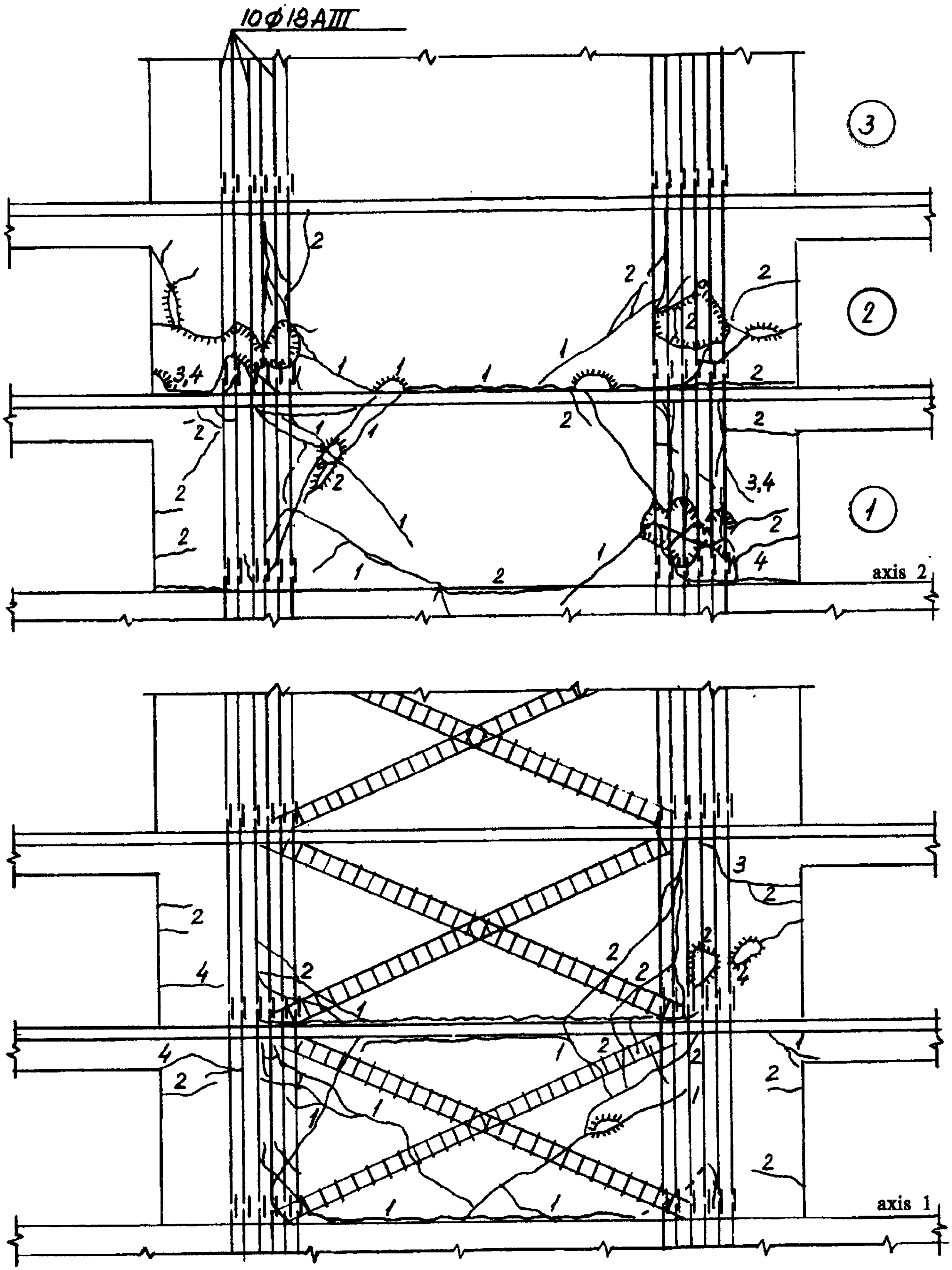


Fig. 2. **Patterns of cracking in the walls of the building section N1 (ground floor, first and second storeys)**

creasing of load-carrying capacity of the walls along oblique and supporting cross-sections under the action of lateral force;

- contour reinforcement depth becoming more substantial, there increases stiffness of the walls. Consequently, there grow seismic loads, while deformation plasticity of the building decreases.

- contour reinforcing rods buckling "in compression" results in intensive destruction of the zones of concrete being compressed. The time of this undesirable phenomenon onset is a function of contour rods diameter, thickness of protective concrete layer and depth of the transverse reinforcement. The authors have developed principally new systems of contour reinforcement, which are under experimental testing at present.

In the course of vibration-survival tests the authors obtained a lot of experimental data. Some of them are shown in Fig. 3.

To calculate the strength of monolithic building walls one can use rather a great variety of methods proposed by various authors (G. Ashkinadze, F. Barda, O. Ernandes, F. Tassios, V. Imas and some others). As a rule, all these methods are based on rather a strong idealization of calculated design of the walls, as well as on a number of assumptions. Design testing showed that prediction based on these techniques (including procedures officially recommended in the former USSR Building Code) gives 2-3 times higher results than the experiment.

In this connection there was developed the method of reinforced concrete walls designing on a horizontal and diagonal cross-sections basis. This method depends on solving of the set of 3 simultaneous equations, the equations taking into account external load stresses M, Q, N, as well as ultimate stresses in the compressed zones as regards concrete and reinforcing roads (contour and plane reinforcement) crossed by the design diagonal section; it also considers cohesive forces along the path of a critical crack [2].

Design calculation of bearing capacity of the walls in building sections NN 1 and 2 in accordance with the above mentioned method fell out from experimental data to the value of 9-10% and 0-3% respectively. When verifying this method on a great number of wall panels tested on a shaker unit (up to destruction), deviation of theoretical Q-values from experimental data varied within the limits + 15%.

Both building sections being destructed, the authors strengthened them using polymer compositions. Reinforcement procedures included:

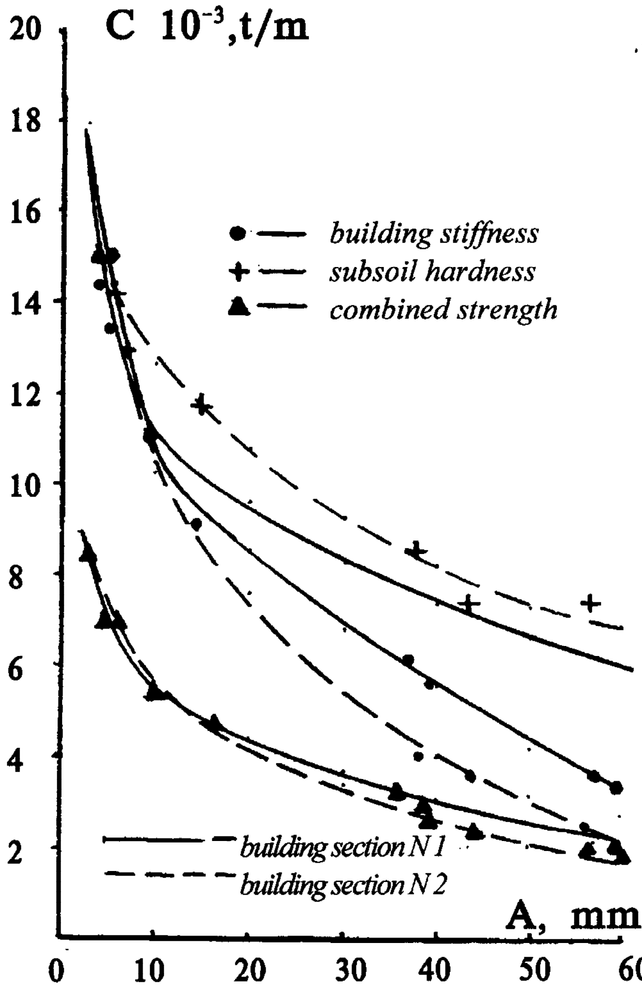
- clearing of the zones in compression from spalled concrete, the latter being subsequently substituted for polymeric concrete;

- replacement of ruptured or buckled contour rods with reinforcing insertions of the same diameter by way of welding;

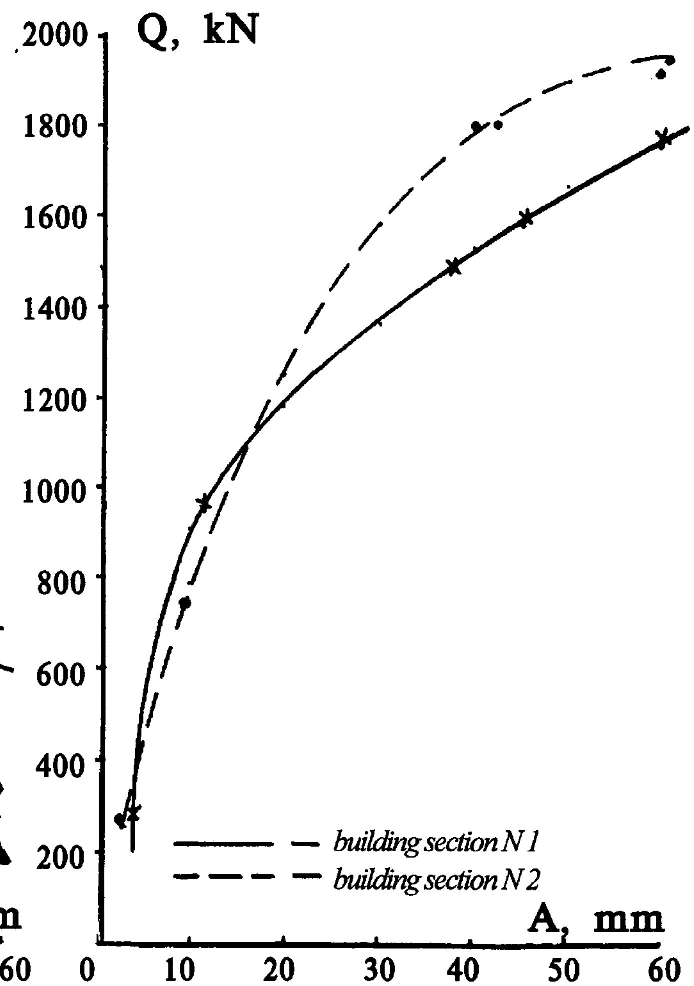
- arranging of round reinforced pins made of polymeric concrete in the floor-and-wall connection area over the ground floor;

- injecting of critical inclined cracks in the wall with polymer solution (all other cracks in the wall planes and floor slabs were not strengthened in the course of repair.

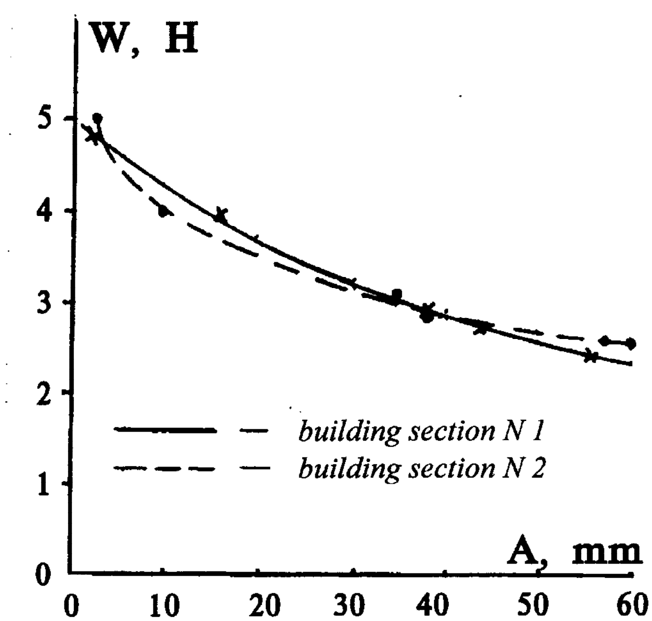
Repeated tests of one of the building sections showed [3] that the method of wall reinforcement described affords the opportunity to fully restore the initial values of strength and stiffness of monolithic buildings.



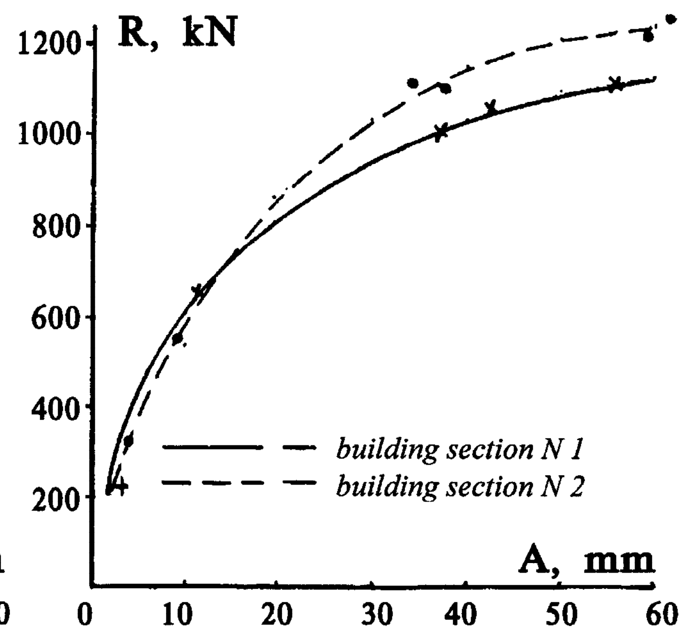
Graphs of building stiffness and subsoil hardness changing



Graphs of lateral force changing



Graphs of resonance frequency changing



Graphs of restoring force changing

Fig 3.

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