CALCULATION AND DESIGN PHILOSOPHY REGARDING THE WALLS OF MONOLITHIC EARTHQUAKE-PROOF BUILDINGS

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SUMMARY

The fact that theoretical basis and research of monolithic house building lagged behind the demands that arose in design and construction is explained by intensive development of monolithic house-building in many seismic regions of the world. The negative effect of the delay is manifested in a number of ways.

First, in some cases in designing monolithic buildings specific quantities of metal were unjustifiably increased due to application of standard reinforcement principles, which had been developed using the results of research of mainly column structures.

Second, the absence of justified principles of design of monolithic buildings, which incorporate both specifics of their construction and the work under loading, caused unsatisfactory behavior of such buildings in earthquakes. By way of an example, a number of high-rise monolithic buildings in Moldova were damaged heavily during the Carpathian earthquake of 1986.

The above facts explain the author's wish to bend every effort to filling some of the gaps in research and theoretical basis of monolithic house-building. Vast practical research and theoretical studies were made. These included testing of monolithic wall panels in composite loading; vibration and dynamic testing of full-scale monolithic buildings and their segments constructed for the purpose; a theoretical study of the state of stress and deformation of walls of monolithic buildings and their crack resistance to seismic impact (by the method of finite elements in non-linear formulation).

Essentially, the results of this research made it possible to identify the most typical destruction pattern of monolithic walls under simultaneous action of vertical and horizontal forces, and, using this pattern as a basis, to develop an appropriate analytical method for design of such structures. In addition, different reinforcement patterns based on the use of reinforcement spirals in compressed zones of the bearing cross sections, was proposed for monolithic walls.

A brief description of the main results of my research is given in the following section.

ANALYTICAL METHOD FOR DESIGN OF WALLS OF MONOLITHIC BUILDINGS

The methods is based on a design model of a multistory system with floors and ceilings separated from walls with construction joints. Vibration and dynamic tests of segments of monolithic buildings at high inertia load levels showed that disintegration of the stories with the highest load begins with an oblique crack in a lower story which continues into a horizontal crack in the construction joint and further goes on at an oblique section into the next story. Thus, is appears logical to assume that the design wall section in the destruction stage is a

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zigzag section, consisting of a connecting horizontal and two oblique sections (fig.1). The lower branch of the design section ends in a compressed zone, and the upper one crosses the tensile contour reinforcement.

In a general case the wall resistance to external impact consists of resistance of the compressed zone concrete to compression and shear (Ob), tensile stress in contour reinforcement (Ns) and in the plane bars i.e., horizontal (Qsw), vertical (Nsq) and pitch (Ts.inc.) and also of the contact forces (Qt) which arise on the sides of the design crack.

Analysis of data obtained by various researchers allowed us to disregard dowel reinforcement resistance in forming the carrying capacity of the plane structures.

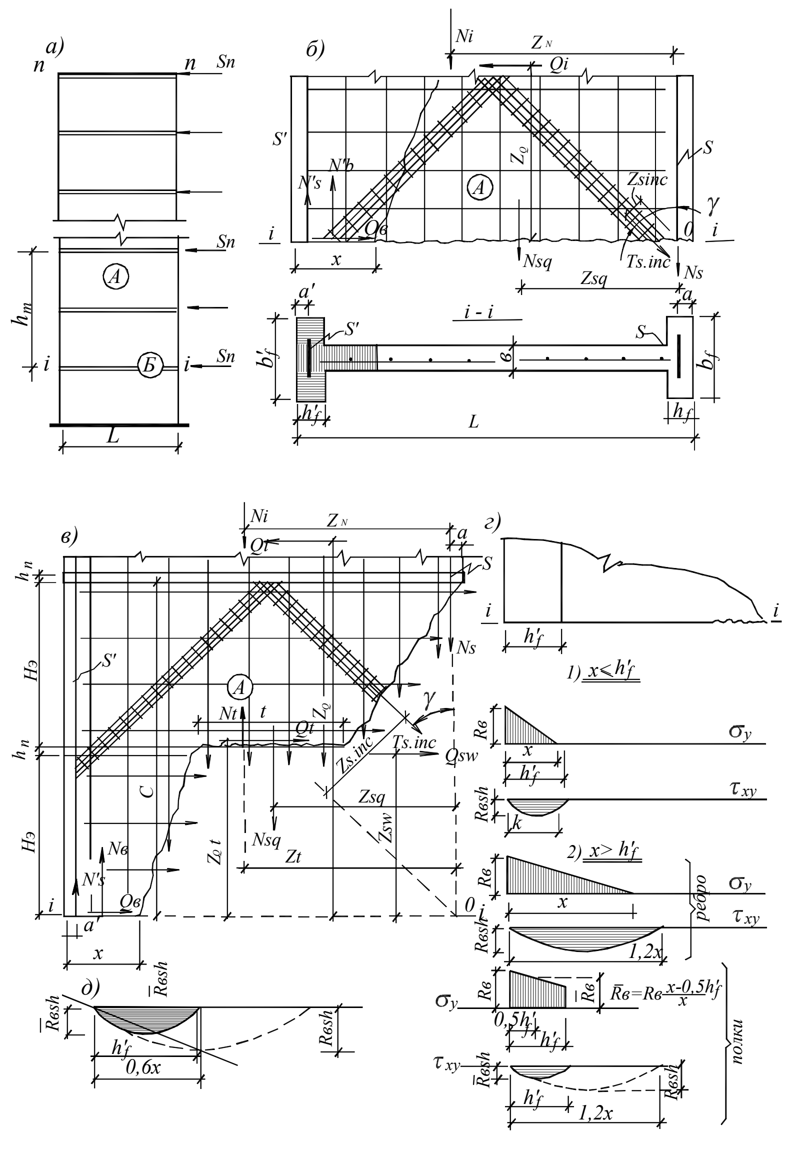

Fig.1

Given the equilibrium condition of the wall dissected by the design zigzag section (fig.1) obtain a system of equations for the calculation of the wall strength:

$$N_i = N_b + N_s^{'} - N_t - N_{sq} - T_{s.inc} \cdot \cos\gamma;$$

$$Q_i = Q_b + Q_t + Q_{sw} + T_{s.inc} \cdot \sin\gamma;$$

$$M_{i(0)} = Q_i Z_Q = N_b Z_b + N_s^{'} Z_s^{'} + N_t Z_t + Q_t Z_{Qt} - N_{sq} Z_{sq} + Q_{sw} Z_{zw} + T_{s.inc} Z_{s.inc} - N_i Z_N \, .$$

By disclosing the contents of the components of these levels the author obtained the required design formulae [1]. They were used for making design forecast of the carrying capacity (S) of two 6-story segments of buildings brought to disintegration in vibration tests. Deviation of the computed values (S) from the experimental ones was within a margin of 8 percent while other design methods used in various countries such deviation varied from 60 to 280 percent.

DESIGN PHILOSOPHY FOR WALLS OF MONOLITHIC BUILDINGS

As is known, ensuring stability of compressing reinforcement bars poses a serious problem for designers of RC structures. The problem becomes all the more complex when the structure works in loading with alternating sign.

In order to solve this problem the author tested a number of RC panels with various reinforcement (fig.2). The tests were made on a testing bed of a special design on which constant vertical loading was applied alongside with the stepwise increase in horizontal loading of alternating sign.

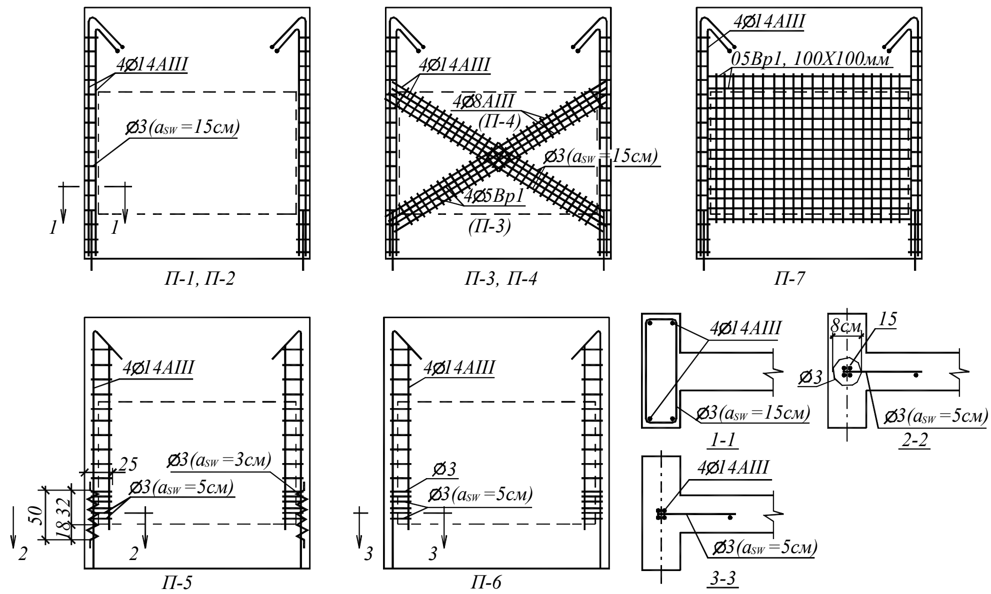

Fig.2

In this test the compressed zones of the bearing cross-sections of all the panels with classical reinforcement patterns were disintegrated because of the buckling of vertical structural columns, the latter caused the exhaustion of the carrying capacity of the structures. This phenomenon, however, was not present in the panels in which contour reinforcement near the bearing cross-sections was twined with reinforcement spirals of rather low power. As a rule, the latter panels disintegrated due to the breakage of structural columns in the work in tension stage.

The results of the above tests allow us to recommend indirect reinforcement of the bearing cross-section zones of the contour reinforcement in the walls of monolithic buildings. Note that disintegration of such zones was observed both during vibration tests of segments of monolithic buildings and upon examination of monolithic buildings after the Carpathian earthquake of 1986.

Experts in earthquake-resistant monolithic house-building are not yet in agreement on what plane reinforcement of walls of monolithic buildings should be like. Sometimes completely opposite opinions are voiced. Some support the idea that plane reinforcement is not required at all. Others state that contour reinforcement in monolithic buildings should not exist and should be completely replaced with plane reinforcement.

CONCLUSIONS

The author's research alongside with the research of [2] provide enough data to support the following conclusions i.e.,

1. During earthquakes walls of monolithic buildings undergo flexural and shearing strain. Contour reinforcement is highly efficient for the former component of the strain. Both theoretical studies and tests (bench tests and full-scale vibrodynamic tests) clearly prove it.

2. In the complete absence of plane reinforcement a few oblique cracks appear in the walls, though the width of opening is significant. This fact, in addition to others, results further in complete elimination of contact forces on the sides of the cracks Whereas with plane reinforcement the number of cracks in the wall plane increases while the width of opening decreases.

3. The design analysis shows that plane reinforcement has undoubtedly a role to play in the formation of the carrying capacity of walls of monolithic buildings though its role is less important than that of the contour reinforcement.

Reinforcement of continuous wall panels with two meshes is a classical pattern. Later reinforcement of panels with flat frames, which were connected into three-dimensional blocks by means of horizontal columns, was proposed.

Theoretical analysis of the state of stress and strain of monolithic walls in composite loading showed that the pattern of major tension stresses on the plane, which cause cracks in panels, was far from uniform. In some areas reinforcement was not necessary at all.

The same research showed that concentrated plane reinforcement of wall panels rather than uniform reinforcement is efficient. This was confirmed experimentally. Panels with plane reinforcement by means of diagonal reinforcement cage showed the best results in bench tests of variously reinforced panels. Steel consumption for plane reinforcement of such panels was 2.0 to 3.0 times less than in panels with traditional reinforcement.

The tests of disintegration by vibration of specially constructed segments of monolithic buildings confirmed high efficiency of diagonal plane reinforcement. The walls in the segments had different reinforcement pattern, and one wall had no reinforcement at all.

In the closing paragraphs of this report is should be noted that considerable amount of scientific and research data on monolithic buildings has been accumulated over the recent years. Unfortunately, the data are scattered and more often than not the form in which they come to the knowledge of designers is not right.

It is high time, I am convinced, to carefully analyze the information and use the results as a foundation for establishing international earthquake-resistant monolithic building code.

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