STRENGTHENING OF MONOLITHIC BUILDINGS DAMAGED BY SEVERE EARTHQUAKES

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SUMMARY

Monolithic house-building is a relatively young type of residential and civil engineering in the Republic of Moldova and FSU countries. Large-scale construction of such buildings started in the early 1970's. The accepted structural concept of applied design philosophy allows us to consider this type of buildings to be the most earthquake-resistant.

The Carpathians earthquakes of 1977, 1986 and 1990 happened to be virtually the first field testing of the named buildings' performance under extreme conditions. It has been reported that the majority of buildings failed to stand the proof and resist in a fitting manner the disastrous effects of the natural calamity.

To the moment of the earthquake which occurred in 1986 in Kishinev there have been constructed more than 100 monolithic buildings, generally 8 to 24 storeys high. After the earthquake in question more than 90 of them were inspected. The majority of inspected buildings (about 65%) revealed I-II-degree structural damages that needed no rehabilitation.

21% of buildings showed III-degree damages. The extent of damages in each building varied (from separate structures up to whole sections or even storeys. Eight 9- to 16-storey buildings proved unsafe and needed global reinforcement, their occupants having to move away. On the whole, 36 buildings of this type needed local reinforcement of unsafe structures.

Amid the structural elements of the buildings the most affected turned to be the walling systems. Among severe damages suffered by the walls the specialists name the following: crushing of loose concrete and buckling of vertical reinforcing bars, falling of walls over horizontal sections, destruction of lintels, appearance of wide cracks in the wall-floor junction areas, development of cross-shaped cracks in the walls, interfenestrations, partitions and lintels.

Monolithic buildings having been in service not very long, there emerged no necessity in the large-scale reinforcement of their structures, and hence - lack of experience as to carrying out of such works. That is why on mitigating the damages caused by the Carpathians earthquakes mostly traditional ways of reinforcement were used for strengthening large-panel buildings. However, because of variance of structural patterns in this type of buildings the applied methods of monolithic buildings reinforcement proved to be too labour-consuming and not very effective.

INTRODUCTION

A). Practical methods

Today in the Republic of Moldova the activities on reinforcement, retrofitting and rehabilitation of reinforced concrete buildings can be subdivided into two categories: those allowing for the possibility of structural restoration without changing the building's static structural model and those implying the above changes.

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The ways of reconstruction of RC members without changing their initial design diagram (ideal RC member) imply in the majority of cases enlargement of cross-section of structures due to arrangement of one- or two-sided coverings, casings, fittings, etc.

The demerits of the named techniques are: firstly, the difficulties arise regarding joint performance of the main structure and reinforcing components. Overcoming of the above entails considerable labour requirements and substantial consumption of steel and concrete. Secondly, rehabilitation or strengthening of structures by using the named recovery techniques results in appreciable growth of their mass, which is not desirable for the purposes of seismic resistance.

The above shortcomings can be more or less successfully avoided when using structural reinforcement techniques implying alteration of the initial structural model.

Studies on the problems of rehabilitation and retrofitting of monolithic buildings that started after severe strikes of the Carpathians earthquake of 1986 revealed the fact that repair of most characteristic defects in monolithic walls (cavities and caverns due to stoppages in the process of concrete casting) by applying ordinary techniques can not ensure complete recovery of solidity and, hence, the strength of the walls. The least effective way among those mentioned above is manual filling of cavities with concrete or finishing of cavities with concrete solution.

Subject to thorough pointing of cavities resulted from using of loose concrete in the process of construction, pointing being followed by spraying of concrete in the cavities or placement of concrete with vibration, it is possible to eliminate 60-80% decreasing in the structures' bearing capacity, the potential decrease being caused by local weakening of the structure. Local effect (80-90%) can be reached by injecting cement solution into the loose concrete cavities.

Proceeding from the developed pattern of damages suffered by the buildings there have been worked out two packages of measures on buildings reinforcement.

The first one provided for local strengthening of separate structural components by way of using customary means in the form of steel casings or one- or two-sided reinforced concrete jackets. To the end of the 90's such rehabilitation works have been effected on 24 projects. At present similar works are carried out on two 16-storey blocks of flats.

The second package of measures regarding reinforcement of monolithic buildings is designated for the cases of large-scale damages in the walls. This package provides for reinforcement of monolithic walls by two-sided RC jackets. Each wall under reinforcement shall be pre-cleaned from plaster and loose concrete. After water flushing on both sides two fabric reinforcements are installed, connected in between by cross bars passing through the halls drilled in the wall. After setting the forms there is effected two-sided concreting of the wall being strengthened with flowing concrete. Quantity of metal consumption on application of this variant of reinforcement makes about 100 kg/m^2 of total area, which almost two times surpasses the initial specific quantity of metal (per structure).

B). Experimental research

The National Centre for Research and Standardization of Construction "CERCON" (former Laboratory of Seismic Stability under the Kishinev Polytechnic Institute) deals with the development and perfecting of new methods of monolithic buildings reinforcement. These methods are based on the principle of recovery of bearing capacity of the joints over the "wall - floor's rigid body" intersection by way of arranging reinforced channels, as well as strengthening of structure in itself by injecting wide spectrum of polymer-cement compositions.

Initially vibration-survival tests of fragments of monolithic buildings were carried out in order to study the effectiveness of various wall slabs plane reinforcement systems under dynamic loading. Shock-resistance dynamic tests were performed at the Central Research Institute "TsNIIEPzhilishcha" and the Laboratory of Seismic Stability under the Kishinev Polytechnic Institute. The tests were performed on the modified vibration-testing machine B-2 shaker unit (VID-80).

In order to create at the compressed bearing zones of the walls of lower storeys of the building's fragments the stress levels corresponding to those exerted by similar loads in a 16-storey monolithic building some additional loading was applied to the walls of the fragments, the load being transferred with the help of a cable-block system and DG-100 hydraulic jacks.

Each fragment was made in the form of a 6-storey compartment (module) having two mirror-picture arranged C-walls (plan view). Foundation of each building compartment represented a solid plate 9840 x 14600 x 400 mm of B15 grade monolithic concrete. Plates of the fragments were spaced at a distance of 1000 mm from each other.

On each plate up to the ground level there was erected a technical basement 1600 mm high with the walls 400 mm in thickness made of B15 grade heavy-weight concrete. The walls of six upper floors, 2800 mm high each, were made of B15 grade claydite-concrete, 200 mm thick. Along lateral axes the walls of the fragments underwent continuous concreting, while along longitudinal axes the walls had openings 3120 x 2200 mm. The floors underwent concreting with B15 grade monolithic heavy-weight concrete 160 mm thick.

Contour reinforcement of both fragments was effected by using G-formed space frames (10 D18 A-III). Types of plane reinforcement of all four walls of the fragments varied.

Fragment N1: wall along axis 1 - without plane reinforcement; wall along axis 2 - reinforced with skewed space frames (cages). Fragment N2: the wall along axis 1 - reinforced with vertical bar mats; the wall along axis 2 - reinforced with cross-shaped space frames (cages). Detailed information on characteristics of applied materials, fragments erection technology as well as the process of carrying out vibration-survival tests and the analysis of data obtained therewith is kept at the National Centre “CERCON”.

As a result of vibration-survival tests the walls of the fragments showed class III-IV damages: developed inclined cracks with the width of crack opening up to 5.0 mm; destruction and spalling of concrete in compressed zones near bearing cross-sections, horizontal cracks over the conjunctions where the floors’ rigid bodies met the walls, bars buckling and fracture of contour reinforcing bars.

To carry out repair and reconstruction works some applicable procedures and techniques had been worked out by the Laboratory of Seismic Stability in co-ordination with the Central Research Institute “TsNIIEPzhilishcha”. To put the above methods into practice there were used construction polymeric materials based on epoxy resins. On local additional concreting of the walls the expanding cement M500 was applied. Restoration of damaged reinforcement in contour frames was effected by using hot-rolled class A-II D 18 reinforcement. Internal (deep-seated) polymeric reinforced channels were reinforced with A-III bars (D18 and D20). To effect application reinforcement there was used T-10 glass cloth. Specially developed methods were adopted to recover the structure of the fragments in question. Injecting of polymeric adhesive cement into cracks was effected by using injection device designed by V.Burovenco (c. Kishinev).

As the recovery works advanced, natural period of vibrations was being determined in monolithic fragments of the buildings on the basis of microseisms and by inducing oscillations in the buildings by way of applying horizontal load to the floors of the 6-th storey level, such load being consequently relieved. The investigations pursued showed that each stage of recovery works exerted influence on behaviour of dynamic parameters of the fragments, and hence affected their stiffness. Thus, clearing and removing of damaged concrete from the portions of compressed zones near bearing cross-sections resulted in the increase of natural frequency of the fragments, while further stages of rehabilitation works, restoration of damaged contour reinforcement included, additional placing of concrete locally in the areas from which the damaged concrete had been removed, as well as recovery of the walls continuity by application of polymeric materials caused decrease in the natural frequency of the fragments. Analysis of collected data on variation of dynamic characteristics of the fragments convincingly proved that the effected rehabilitation and recovery measures increased the rigidity of buildings and, consequently, were to improve their bearing capacity. The above conclusions have to be verified in the course of repeated vibration-survival tests which are expected to demonstrate the effectiveness of techniques on recovery of the buildings walls’ continuity expressed not only in quality terms but also quantitatively.

CONCLUSIONS

Experimental research carried out on small specimens, large-scale fragments of the walls, as well as on two 6-storey (full-size) fragments of monolithic buildings during shock-resistance dynamic tests up to failure showed that on carrying out rehabilitation works taking account of behaviour of buildings’ walls under extreme loading global repair of damages is not always required. In most cases recovery of bearing capacity can be achieved through applying local reinforcement.

By now 6 monolithic buildings have already been rehabilitated in Moldova by using the above technique. Experiences gained in the course of executed works has shown that the developed procedures proved to be rather cost-effective and made it possible to reduce both specific consumption of materials and labour input on performing repair and rehabilitation of buildings damaged by earthquakes, not changing thereby the overall plan dimensions and proper weight of structures.

The conducted tests showed that on choosing the measures to reinforce the walls of monolithic buildings one shall first of all pay attention to such factors as the walls' contour reinforcement, which is to be strengthened in case of necessity, and the state of compressed zones near bearing cross-sections.

Generally, as one can judge from assessing the nature of damages suffered by monolithic buildings in Kishinev, reinforcement of the latter shall be both complex and individual in its character, i.e. on the one hand one shall take account of specific features of damages, their extent and location in the building but, at the same time, rehabilitation shall be based on application of various most simple though efficient techniques. Many of the above techniques proved practicability of using the method of injecting separate cracks located in the damaged portions of the walls and confinement of reinforcing bars bundles with the help of reinforcing rods.

Choosing of methods to strengthen the buildings suffering damages caused by the earthquakes shall be made on the basis of thorough examination of stock-taking forms for buildings (maps or charts of damages) completed during detailed inspection of the building stock. Analysis of the named documents shall result in making the summary table of damages including their classification by types, as is stipulated by applicable codes. To repair each type of damages there is to be applied the most suitable and effective rehabilitation technique. Such an approach allows to abandon development of building reinforcement projects and thus makes the recovery process more operative and efficient.

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Abstract

Monolithic housing is relatively young type of residential and civil engineering in the Republic of Moldova and FSU countries. Mass construction of such buildings refers to early 70th. Thereby accepted engineering solution tended to consider this type of buildings as the most seismic resistant ones.

Carpathian earthquakes of 1977, 1986, 1990 have actually served as the first test for such buildings behavior under extreme conditions. As it has been reported, the majority of these buildings have failed to pass the exam set by the natural calamity. As a result of the above mentioned earthquakes eight 9 to 16-storey buildings proved emergency condition and required global reinforcement and vacation of residents. Another 36 building of that type required local reinforcement on faulty structures.

Taking into account insignificant term of monolithic buildings operation there was no need for mass reinforcement of their structures, and hence, no experience in carrying out such work. Therefore in clearing consequences of Carpathian earthquakes use has been made of traditional methods of reinforcement, used for reinforcement of large-panel buildings. However, accounting for constructional differences in these building the applied methods of monolithic buildings reinforcement proved labour consuming and low efficient.

In view of the above the National Center for Research and Standardization of Construction “CERCON” (former Laboratory of Seismic Resistance at the Chisinau Polytechnical Institute) deals with development and improvement of new methods of monolithic buildings reinforcement. These methods are based on recovery of bearing capacity of joints at the intersection “wall-to-ceiling beam” by means of reinforced channels and by reinforcement of faulty structures by injecting a wide spectrum of polymer-cement compositions.

Experimental researches carried out on small specimens and large-scale wall fragments, as well as on two 6-storey (natural size) fragments of monolithic buildings under vibro-dynamical tests up to failure showed that in recovery works (with due account for nature of these buildings walls action under extreme strain) global liquidation of damages is not always required. In the majority of cases recovery of bearing capacity can be achieved by local reinforcement.

By use of these methods 6 monolithic buildings were recovered in Moldova recently. Experience showed that the developed methods are economically efficient and allow to decrease material and labor consumption without change of overall dimensions and own mass of structures.

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STRUCTURAL MATERIALS, ELEMENTS AND SYSTEMS, Monolith, Strengthening, CERCON, Moldova, Vibro-dynamical tests,