Contractual and technological methods for ensuring the reliability and efficiency of seismic protection systems for the precast-monolithic civil buildings

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Abstract. The research discusses the ways to ensure the construction and operation reliability of the designed buildings and structures in earthquake-prone areas, which include the Republic of Crimea. Substantiated techniques for improving the installation structures’ technology of kinematic insulation systems developed and tested in the Krasnodar Territory of the Russian Federation are shown. The improvement consists of the innovative three-stage method of installation and alignment of concrete pipes, including successive concreting of foundations, assembly, alignment and pouring in the lower part of the column, and finally after maturing, non-alignment assembly of the middle and upper parts of the column. To reduce the intensity of inertial seismic loads, the use of precast-monolithic ceilings from hollow-core pinched reinforced concrete slabs or monolithic slabs with plastic inserts partially replacing reinforced concrete is justified. Improved designs of such plates are presented; their effectiveness and rational application are evaluated. Taking into account the preferable long periods of the insulation systems and foam glass-based finishing maintenance-free operation, their improved structural and technological solutions are presented as a part of earthquake-resistant wall filling of frame buildings.

1. Introduction
The traditional seismic protection of the civil buildings provides their frames’ reliability under the design seismic loads by increasing the strength and deformation properties of both the entire frame and its structural elements. The same building, constructed in different regions, depending on seismic zoning, will differ significantly in terms of specific consumption of steel, concrete and other resources. A quantitative assessment of this relationship is presented in many publications, for example, in the works performed under the guidance of Professor Tatyana Nikiforova [1, 2]. It states that the estimated cost of erecting the same research object is increased several times compared to its design without taking the seismicity of the construction area into account. As a result, a conclusion, supported by us, is made about the need to improve the structural systems of buildings in order to reduce the resource consumption of building in the areas with increased seismic activity.

Such already implemented projects include the kinematic seismic isolation systems developed and tested by Professor Kurzanov A.M. and engineer Semenov S.Y. [3]. The calculations of associate professor Ivanenko N.A. showed that the introduction of kinematic pipe-concrete system supports for active seismic protection of the aerial parts’ frame, as an example, on a concrete ten-storey civil
building in Sochi, provided an economic effect of 7 million roubles only due to the saving of reinforced concrete [4].

The Kurzanov-Semenov kinematic system does not conflict, but, on the contrary, is also based on a thousand-year positive experience of earthquake-resistant construction. For example, in ancient China, during the construction of religious buildings, special capitals were used on wooden columns – dougongs. They represent a self-balancing spatial system of brackets of various lengths and as a whole is a hinge through which the movements of columns to the floors are practically not transmitted [5, p. 300].

Despite the arguments presented in favour of the kinematic supports’ use for the active seismic protection, in the Russian Federation rubber-metal insulators LRB of Chinese or similar Italian origin have become more widespread nowadays. But their guaranteed service life (40-60 years) does not correspond to the solidity class of most civilian facilities currently being built, and the cost is four times higher than the cost of installing the above-mentioned kinematic supports of Kurzanom-Semenov, even without considering the costs of the inevitable replacement of alternative imported ones to continue operation object [3]. We assume that one of the reasons for this situation is, among other things, construction and technological imperfection, although fundamentally true, experimentally verified and economically justified import-substituting domestic invention of the above-mentioned authors according to the patent RU №2477353, cl. E02D27/34 (2006.01). A possible way to correct the announced status of the issue is proposed in this research.

In cases where such seismic isolation is not provided, as well as for the multi-storey civil buildings with such insulation between the foundation and the upstream frame, its seismic protection properties can be significantly improved by designing and using precast monolithic structural and technological systems of reduced own weight. The indicated decrease in the resource consumption is possible both due to the replacement of the reinforced concrete part with lighter materials of the load-bearing structures, as well as the efficient energy-saving systems of fencing and finishing coatings. In these areas, several development options have been constructed and are being tested for the technology of earthquake-resistant precast-monolithic constructions which are also annotated below.

2. Results

2.1. Improved installation technology of pipe-concrete kinematic supports for seismic isolation of the aerial part for the reinforced concrete frame

As a result of studying the kindly provided researches and design materials for the construction of a multi-storey building on the Krasnoarmeyskaya street in Sochi, as well as the photos and video materials posted on the website of the contracting research and production company, we noted the difficulty, and even the impossibility of obtaining high accuracy of the installation for the developed and more than once tested structural and technological system. So, the design recommendations for the vertical deviations when installing the pipe-concrete columns of the kinematic seismic isolation system establish their maximum permissible value of 2 cm. But practically such maximum vertical deviations can be achieved only with proper controlled accuracy of the split steel supports lower part’s installation pre-fixed on the reinforcing cage monolithic foundation of the future structure. Even if all the supports within the construction staging are installed and temporarily fixed after a high-precision geodetic calibration of their position, then in the process of subsequent concreting of the foundation it will not be possible to completely exclude their (albeit not significant) movements. And after the concrete hardening, having discovered their presence and setting the value, the resulting defect becomes practically unavoidable. And if it is not corrected, then subsequently the mounted upstream structural system will not be able to properly perceive the design seismic loads.

To avoid this likely negative events’ development, the following rather simple and low-cost refinement of the analysed technology for the active seismic protection kinematic pipe-concrete supports’ device is proposed, which received legal protection as a patent of the Russian Federation for utility model №193791 U1, SPK E02D 27/34, E04C3/34 (2019.02), Figure 1, developing the basic
invention of Prof. Kurzanov A.M. and engineer Semenov S.Y. The improvement is based on the well-known design solutions based on the technology of non-aligned mounting of steel columns on pre-installed and concreted milled plates of their lower base part, described as an example in the textbook of professors P.T. Reznichenko and G.S. Nizhnikovsky [6, p. 108].

The technology refinement provides the consistent implementation of the following operations. At first, the designed reinforced concrete foundations of the building are reinforced and concreted in such a way that their upper surface is not consciously brought to the design elevations of 2-3 cm. Even before concreting, in the places of the future installation for the lower supports of the steel-concrete kinematic columns, design releases of reinforcement and places of installation of anchor bolts for future installation, alignment and temporary fixing of the mentioned supports. After the strength of the monolithic reinforced concrete foundation thus prepared, the future embedded parts — prefabricated steel cylindrical supports by the means of eyelets with nuts radial placement on them — are threaded onto the threaded anchors arranged in it. It is with the help of the latter that the lower parts of all future pipe-concrete kinematic columns are supposed to be installed, adjusted and precisely fixed in the position.

After reconciling the lower part of the supports with towards elevations, as well as their horizontal position with high-precision geodetic instruments and tools, it is possible to start pouring high-strength non-shrink fibrous concrete into the space between the foundation and the lower support through the upper hole in it. Approximately this method is traditionally used in the installation of technological equipment on its previously concreted foundations [7]. Thus, using the proposed technology it is possible to achieve high machine-building accuracy in installing the kinematic pipe-concrete supports under the conditions of significantly lower traditional construction accuracy in concreting blocks under the frame of a multi-storey earthquake-resistant building. In turn, the presented technique increases the reliability of the proposed system in terms of the estimated seismic impact.
2.2. Technology development for lightweight precast-monolithic floors

The use of multi-hollow floor slabs of multi-storey civil buildings used to be considered universally widespread in the USSR and certainly as an effective technological solution of the past. Their use is justified and recommended by the set of rules 14.13330.2014 “Construction in seismic areas”. In full accordance with the set of rules, by changing the articulated-movable work pattern for pinching in the monolithic support zone while maintaining the reverse bending, some more resource saving can be achieved (our patent RU No. 2617813 C2) presented in [8]. In addition, in order to reduce the resource consumption of the inter floor ceilings’ production, many innovative developments have recently been performed, for example, partially replacing monolithic reinforced concrete with the inserts from the blocks of natural and artificial origin [9–10] or plastic [11–12]. Analysing the well-known foreign systems Porotherm, Teriva, Ytong, Rectolight, as well as the domestic prefabricated monolithic MARKO precast monolithic floors (PMF) system created in their development, it was found that the latter is more adapted (technologically) for use in seismically active Crimea. Although by slightly increasing the own weight of the floor, it is possible to achieve a certain decrease in labour intensity and cost by replacing the factory-made loose-leaf blocks with limestone (a local building material) [13].

Since during calculation of the buildings’ frames in seismically active zones, their own weight is of the utmost importance, we should strive to reduce it everywhere, including the construction of precast-monolithic ceilings. For this, it is already universally accepted that plastic liners that replace reinforced concrete in those parts of the structure where the calculated stresses are minimal or eliminated are used. An example of such a system was presented by us at the last CATPID-2019 conference and published in the Conference Proceedings [14]. It also shows the feasibility of developing the VELOX technology with the support of ceilings on all four sides. The system will work like a slab, providing a comprehensive synergistic effect of reducing the resource consumption while increasing reliability and earthquake resistance. Over the past period, the patent for a utility model RU No. 190006 U1 that implements the formed principles, was obtained.

2.3. The device Technologies for filling reinforced concrete frames of cellular concrete blocks with insulation and finishing with foam glass products

A comprehensive improvement of the multi-story frame buildings’ designs for construction in seismically active zones should also include the development of structural and technological systems for wall filling of frames, their insulation and decoration. The conditions using masonry from small wall blocks to fill a monolithic reinforced concrete frame fully correspond to these conditions. The conditions of durability, fire resistance and environmental cleanliness correspond to the insulation systems and finishing foam glass blocks fixed to the masonry wall filling. Reliability of the device with ensuring the required compliance with respect to the reinforced concrete supporting frame under the influence of seismic loading can be achieved due to the original system of fastening the insulation and the finishing layer with plastic or carbon-fiber brackets, shown in Figure 2.
Figure 2. Insulating and finishing systems for filling the outer walls of the reinforced concrete frame: a) - fixing the heat-insulating layer using plastic brackets (Pat. RU No. 162256 U1): 1 - insulation, 2 - wall filling, 3 - plastic bracket, 4 - dowel, 5 - reinforcing mesh, 6 - protective and finishing layer; b) - the same, with detachable brackets (Pat. RU No. 184426 U1): 1 - brick wall, 2 - foam glass blocks, 3 - reinforcing cell in the layer of plaster, 4 - putty-painting layer, 5 - dowel, 6 - bracket, 7 - its corner part, 8 - washer

3. Summary
The technology of the civil buildings’ earthquake-resistant construction requires further improvement in terms of structural solutions of elements and assemblies of their precast-monolithic frames. When designing such frames with Kurzanov-Semenov kinematic supports, it should be possible to reconcile and temporarily fix the lower part of these supports on a monolithic reinforced concrete foundation, by the analogy with the industrial buildings steel columns’ non-calibrated installation technology. To reduce the dead weight of inter-floor ceilings, it is recommended to use structures made of monolithic reinforced concrete with replacing part of it with inserts made of lightweight filling materials, and wall barrier should be made of small wall blocks with lining and insulation by laminated structures based on foam glass products. The examples of innovative design solutions that implement the above-mentioned principles and provide an economic effect both at the stage of construction and operation of buildings in the areas of increased seismic activity are shown.

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