

Review and practice of optimal structural design and selection of structural systems

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Abstract. The article describes the analysis of the optimal structural design and selection of structural systems and analyzes the technical and economic indicators of various design solutions. An important step in solving the design optimization problem is the correct choice of the optimality indicator. In the works included in the review, various optimality criteria are adopted. For example, the criterion for the minimum weight is justified when the structure's material is homogeneous. The issues of choosing a quality criterion when optimizing the design of a structure for minimum weight are also given a place. Comparing various recalculation methods while minimizing the weight of a structure under conditions of permissible stresses and displacements in certain load cases, the work looks at a nonlinear programming method and algorithms based on optimality criteria and a "mixed method" based on combining recalculation and nonlinear programming methods. In modern conditions, the restructuring and reorientation of the economy of the Republic, when the need arises for structures that allow placing medium and small enterprises, and in areas with the minimum level of employment, the problem arises of choosing a certain constructive solution that allows the construction of facilities with minimal labor costs, cost, the earliest possible payback and while ensuring seismic resistance. In this regard, various design solutions' technical and economic indicators are analyzed.

1 Introduction

Many teams and scientists are engaged in the optimization of building structures in our country and abroad. The works of N.V. Banichuk, E.N. Gerasimov, E.M. Jehi, V.P. Malkov, IB Lazarev, KI Mazhid, Yu.M. Pochtman, I.Pyatigorsky and others.

The most general reviews of works on the optimization of building structures are made in the works of A.I. Vinogradov, M.I. Reitman and G.S. Shapiro, L.A. Hill, M.P. Linzei, K. Zhu, V. Prager, N.D. Sergeev and A.I. Bogatyrev, N.I. Abramova, N.N. Skladneva, Lev O.E., R. Fletcher, and S. Reves, Venkayya V.B. and other scientists.

With the most advantageous use of material for designing optimal structures and frames dedicated to the research and work of S.M. Krylov, V.G. Nazarenko, A.V. Gemmerling,

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A.I. Ageeva, M.I. Reitman, M.B. Krakowski, I.B. Lazarev, S.P. Sushkova, N.D. Tuychieva, K.A. Plakhtiy, S.A. Tukaeva, and others.

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2 Method

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Analysis and selection of a constructive solution.

In modern conditions, the restructuring and reorientation of the economy of the Republic, when the need arises for structures that allow placing medium and small enterprises, and in areas with the minimum level of employment, the problem arises of choosing a certain constructive solution that allows the construction of facilities with minimal labor costs, cost, the earliest possible payback and while ensuring seismic resistance. In this regard, various design solutions' technical and economic indicators are analyzed [2-4].

In this regard, below, we analyze the technical and economic indicators of various design solutions.

Many studies have been devoted to analyzing earthquake-resistant buildings and structures' technical and economic indicators. At the same time, most of them operate with indicators of material consumption, the cost of a building, and the labor intensity of their construction. However, these indicators do not consider the specifics of the limiting states of earthquake-resistant buildings, and they are not sufficient criteria for assessing the reliability of systems [5-7].

In our opinion, such criteria are the indicator of the perfection of the design solution S_{kr} proposed by L.I. Klimnik (Moscow), which characterizes the relative costs of ensuring the bearing capacity of a structure under seismic impacts per unit of its mass. A relationship has been established between the indicators of perfection and the coefficients of the structural quality of the material of the bearing elements, as well as the indicators of the consumption of materials per unit of useful area or building volume of the building.

To assess and select an effective structural solution, the approach proposed by L.I. Klimnik, and V.T. Rasskazov is used, considering the practice of designing seismic-resistant buildings and structures, where the seismic load factor C is used. They are defined as the ratio of the seismic load at the level of the foundations of buildings S_b or at a certain level C to the mass of the floors above.

$$C_B = R_l, \quad \frac{\max}{M_{oc} * g}, \quad C_i = r_w, \quad \max(\sum * g)$$
$$C_{cr} = \left[C_B + \sum_L^{i-1} \left(1 - \frac{\sum_{hi} m}{M_{oc}} \right) C_i \right] * g$$

The ratio makes it possible to relate these coefficients. It can be used to assess the level of perfection of buildings and structures designed and built in seismic regions following the requirements of the norms of different countries, to analyze the results of studying the consequences of strong earthquakes, as well as theoretical and experimental studies of the seismic resistance of buildings and structures.

As the analysis of the results showed, the most preferable according to this criterion for constructing structures with 12 floors are reinforced concrete frame buildings with flexible reinforcement.

The applied wireframe schemes can be divided into several varieties according to the static scheme of work and the material of the frame, according to the static scheme - frame, frame-lattice, and tie. The material of the frame is steel and reinforced concrete. Reinforced concrete frames are made in monolithic and prefabricated versions.

In the frames of the frame system, all vertical and horizontal loads are taken up by the frames. In frame-braced frames, in the perception of horizontal loads, they participate like frames, and the degree of their participation in the work is determined by the ratio of the stiffness of one and the other system.

3 Results and discussion

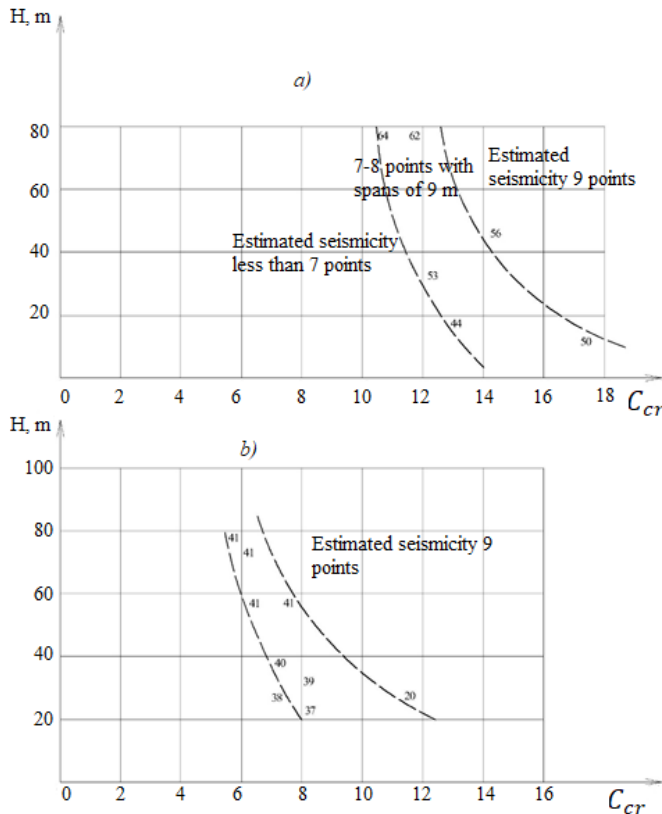


Fig. 1. Areas of rational use of reinforced concrete frame buildings with various design solutions: a - steel rebar; b - with steel encased profile.

In a tie system, the ties fully absorb the wind load, and the frames, "freed" from horizontal forces, work only for the vertical load.

In the republic, the following types of buildings are most widespread in the construction of residential buildings: frame (frame and frame-tie) and large-panel; in recent years, a certain interest has been shown in monolithic housing construction. A comparison of technical and economic indicators, in particular especially expensive metal and cement at the moment, for various structural systems, showed that for frame systems, the consumption of cement is minimal (15% less than in panel systems), and the consumption of the metal is 10% less than in panel systems with a narrow pitch. At the same time, it should be noted that there is a well-functioning industrial base for frame systems. It can meet various architectural and planning requirements, which is important in conditions requiring the construction of many processing and trading enterprises [8-10].

Frame systems allow the use of all sorts of local materials for interior and exterior walls, which to some extent, meet local customs and conditions. The review below will pay attention to various negative properties of frame systems. Still, the main thing in our studies is that the system's reliability is constantly monitored, which is important for the seismic conditions of the Republic.

Currently, in all regions of the republic, frame buildings made in prefabricated reinforced concrete have been used in public buildings. The most widely used reinforced concrete structures of the IIS-04 series. Technical and economic indicators of various design solutions for the construction of civil buildings.

Steel consumption A - panel with a flexible frame of the first floor: B - panel at a narrow step: C - frame: D - large-block: D - panel at a wide step.

The IIS-04 frame is distinguished by high factory readiness, a large degree of unification, and good technical and economic indicators. For example, per 1 square meter of flooring, the cement consumption for the IIS-04 frame is 49.1 kg, for the frame with prestressing 51 kg, and for the frame 1.020. 1 -2s -77 kg. At the same time, a negative feature is that in the IIS-04 frame, cutting into linear elements is adopted when almost all frame struts are located in the zones of maximum effort. Of the frame systems with a transom solution, it is necessary to note structures with H-shaped elements (Republic of Kazakhstan, Alma-Ata), the so-called flat "Cross", and volumetric "Cross" (Republic of Uzbekistan, Tashkent). In these systems, the connection of columns and girders is made at the so-called points of zero moments, which favorably affects the behavior of frame systems under seismic impacts. Negative factors in the massive use of these systems are the complexity of the implementation of tooling, and reinforcement products, the complexity of transportation of prefabricated products, and a significant decrease in the level of unification [12].

Many frame systems are erected with monolithic flat slabs erected by raising floors. In this system, continuous reinforced concrete slabs with holes for the passage of columns are made in a ground-level package. After the concrete has gained the required strength, they are raised to the design marks along pre-installed columns using special hoists.

The positive qualities of this system are the ability to widely change the configurations, sizes, and grid of supports to improve the volumetric planning solutions. The negative side of this system is the need to attract specialized construction organizations equipped with the necessary equipment and auxiliary production.

At SNIIEP dwelling (Moscow), a system of prefabricated monolithic structures of the KUB-1 frameless frame has been developed. In this system, the columns are non-cantilevered with cutouts at the level of each floor with exposure of the longitudinal working reinforcement for welding the collars of the knee plates and embedding the nodes. Floor slabs for installation from flat reinforced concrete slabs of three types: knee-type, framing the hole for the passage and connection with the column; intercolumnar resting on the patella; flyby - medium. The disadvantages of the system under consideration include the requirements for high-quality production of prefabricated elements in the factory. The system's reliability is determined by: the quality of welded joints, which requires highly qualified personnel, and the quality of the embedment of nodal joints [8].

In foreign construction, the most widespread (Yugoslavia, Austria, Hungary, Italy) are prefabricated monolithic bezel-less frames of the Yugoslav IMS system.

The considered bezel-less frame with reinforcement tension under construction conditions consists of multi-story columns, ribbed or complex slabs, and stiffening diaphragms. The connection of the slabs to the columns is carried out with the help of prestressing rope fittings laid in the intervals between adjacent slabs and stretched over the columns; the intervals between the slabs are monolithic. The positive qualities of the system include a significant reduction in the number of embedded parts and the amount of welding during installation. The disadvantage is the wide range of prefabricated elements. During installation, special equipment is required at the construction site - jacks with dynamometric devices and clamps for tensioning the reinforcement, scaffolds, and inventory formwork for the embedding areas [2].

For earthquake-prone regions, Tobisima KENSETSU (Japan) has developed a PREBIC system assembled from thin-walled reinforced concrete elements. In the hollow elements of columns and beams, additional working reinforcement and connecting elements in the joint area are laid, then ceilings from hollow slabs are mounted, and the structures are monolithic. The positive qualities of the system include ease of transportation and installation without the use of powerful cranes; lack of welded joints and embedded parts.

4 Conclusions

Considering structural systems, the greatest preference for technology-economic indicators should be given to the IIS-04 series because concrete consumption for this system is the smallest compared to all considered. However, for systems of 7-16 floors, preference can be given to IMS systems, where there is a decrease in steel consumption due to the use of high-strength rope fittings of the K-7 class and the absence of embedded parts. For example, steel consumption per 1 square meter of flooring for the IMS system is 16.1 kg, for the IIS series - 04 is 24.3 kg, and for the frame 1.020.1-2S is 17.2 kg.

Prospective, apparently, will be the use of a prefabricated, developed in JSC "ToshuizhoyLITTI" - a monolithic frame with an abandoned formwork "Tashkent", in its characteristics and positive properties close to the Japanese system PREBIC. So for the construction of public buildings in earthquake-prone regions of the Republic, the construction of frame systems is promising, which will be the object of our research.

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