The Use of Metal Structures in the Construction of Unique Buildings and Structures

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Abstract. According to modern standards, unique buildings and structures include buildings whose spans exceed 100 meters, with successful approbation in practical application, or spans over 60 meters with new design solutions, which require the development of new special calculation methods and the creation of physical models. Unique buildings include objects with a permanent number of people of more than 500, and periodic more than 1000-10,000 people, including people who are near the structure. The reliability of design solutions is confirmed by analyzing design schemes with subsequent assessment of methods and means of performing calculations. It is also necessary to observe, in order to study, the results of calculations for the strength and stability of the spatial system of a structure, to compare the data of theoretical materials with experimental ones obtained as a result of checks.

1. Introduction

Even at the time of the creation of the project of a unique building, problems appear that do not have a standard in modern regulatory documentation. Over the past years, Russia has begun to actively create such facilities. As a result of such changes, the adoption of new norms, methods and materials for design and construction is imperative [1-2].

However, construction projects that are new in their nature also cause unprecedented, hard-to-solve problems. Due to the lack of experience in this field of construction, new solutions of a technical nature are required, which are required from the design engineer. This specialist must have knowledge of special courses and experience in designing buildings and structures of a unique type. The guarantee of quality and reliability (strength, safety and durability) is the scientific and technical support (STC) of the building at the design and construction stages. Scientific and technical support is a combined system of knowledge of an information-analytical, organizational and expert nature, to which a higher level of responsibility is applicable due to special design solutions and the use of non-standard structures. Special recommendations should be given at the stage of design and construction of metal structures for large-span unique buildings and structures. Due to the scale of the structure, safety issues are raised, namely measures to avoid progressive collapse due to collapse in accidents [3-4]. It is also worth noting the need for technical monitoring at all stages of construction, and in the future, and operation. Such a measure should exist not only to ensure the safety of the building and structure, but also to accumulate knowledge in the field of unique construction (Fig. 1).
According to modern standards, unique buildings and structures include buildings whose spans exceed 100 meters, with successful approbation in practical application, or spans over 60 meters with new design solutions that require the development of new special calculation methods, creation of physical models, etc. etc.

As noted earlier, the uniqueness of the structure increases the significance of the object. The importance of the object is also determined by the number of people permanently or temporarily located on the territory of the construction object. So, objects with a permanent number of people of more than 500, and periodic more than 1000-10,000 people, including people who are near the structure, are referred to as unique buildings [5-6].

The following goals are set for scientific and technical support: participation in the formulation of technical specifications and special technical design conditions. NTS should be carried out at all stages of design, including fabrication and study of the physical model with the study of complex assemblies. Special tasks are also posed, such as: development of recommendations for the operation of the structure and maintenance of the building in vitality in case of emergency situations (for example, progressive collapse). Ensuring the safety and reliability of structures is guaranteed through monitoring at the stage of construction and operation.

2. Terms of reference for design (STU)
This stage covers the goals and objectives of the project, its purpose, architectural and planning solutions and special construction conditions, etc. The terms of reference contains the data that are required to check the calculation of building structures.

Special technical conditions (STU). Special technical conditions are special technical standards containing increased requirements for the safety and reliability of a building or structure. Special technical conditions indicate the features of the project, at all stages, which are applied to a unique construction object. Special technical conditions are the most important part of the project documentation of the facility, which contains exceptions from regulatory documents and a detailed justification for their need [7-8].
Also, special technical conditions contain data on the level of responsibility and social significance of the structure. These indicators affect the estimated life of its operation, load and requirements for the calculation and design of the main structures.

Due to the lack of detailed standards in modern Russia, for special technical conditions, certain provisions from foreign regulatory documents can be applied.

3. Scientific and technical support during design (STC)

Scientific and technical support begins at the stage of designing sketches, which includes an analysis of world experience in the construction of such objects, as well as the development and scientific explanation of options for structures of a new, more rational type.

In the design process, for the adopted scientific and technical solutions, schemes with various options for the layout and location of the supporting structures can be adopted. After that, their work is analyzed as part of an integral system, with various options for stiffness and geometric parameters [9-10].

It is at this stage of development that recommendations are made on the appointment of the missing normative loads. For large-span pavements, recommendations are developed for determining snow and wind loads by blowing a physical model of a structure in a special wind tunnel that simulates wind effects. The calculated values of the weight of the snow load of possible precipitation exceeded once every quarter of a century are taken according to SP 20.13330.2016. To improve reliability, the reliability factor is taken as \( \gamma_n = 1.2 \).

At the stage of detailed design, temperature effects, ice loads and effects caused by the deformation of the base of the structure, as well as seismic loads are investigated for those areas in which it is required to be taken into account.

At the stage of development of working documentation, new non-standard design solutions are investigated and recommendations for their design, as well as the parameters of the main elements, are introduced. In parallel with this, a certain calculation method is established, which until this point in time had not been applied in the current regulatory and technical documents. The methodology includes the current operating conditions of the structure and a step-by-step calculation method with the previously introduced actual loads and physical and mechanical properties of materials.

The design scheme of a large-span object is accepted, presented in the form of a model as a generalized spatial system. The composition of the design scheme should include both the base and foundations, as well as the structure frame and spatial coverage (Fig. 2).

![Figure 2. Example of a large span coverage.](image)
Further, verification static and dynamic calculations are performed, such as the calculation of a structure in a geometrically nonlinear formulation using computer systems and numerical modeling of the operation of individual parts and assemblies. In the calculations of some objects, physical and structural nonlinearity is also subject to consideration. For structures that perceive vibration and other repetitive loads, a special study is carried out on the endurance of the structure. If, during the inspection, knots with emerging plastic deformation are found, then such knots are subject to additional fatigue check [11-12].

The reliability of design solutions is confirmed by analyzing design schemes with subsequent assessment of methods and means of performing calculations. It is also necessary to observe, in order to study, the results of calculations for the strength and stability of the spatial system of a structure, to compare the data of theoretical materials with experimental ones obtained as a result of checks.

4. Scientific and technical support for the manufacture and installation of structures

This section is responsible for the development of "technical conditions for the manufacture, installation and acceptance of steel structures", which contain requirements not previously described in the normative and technical documentation. In the project for the production of works (PPR), the issues of the accuracy of manufacturing and assembly of metal elements, acceptance (technical quality control) of used materials and rolled products, technical control, quality control of metal structures at the stage of their manufacture, control of installation work for compliance with the design production of works in parts of the preparation of the structure for installation, pre-assembly, sequential installation, alignment and fastening, etc.

It is also worth noting the need for scientific support of the project for the production of work and their implementation includes carrying out numerical calculations that simulate all stages of the installation of the system, determining the control geometric parameters and design loads, temporary supports, etc.

In order to determine the actual quality of rolled products, a multilevel scheme of incoming metal inspection is used. Samples are tested at a metallurgical plant, a metal structure manufacturer, as well as in specialized laboratories (sampling). In addition, scientific and technical control of compliance with the project, regulatory documents and "Technical conditions" of the quality and grades of materials is carried out by analyzing the certificates and passports of the quality of rolled products provided by the manufacturers. Research is carried out on the chemical composition, content of harmful impurities, microstructure, strength, ductility and toughness of the metal, and the resistance of the metal to brittle fracture [13-14].

Selective technical control and acceptance of mounting connections on high-strength bolts include: visual inspection of the preparation of the contact surfaces of the elements; control of compliance with technological requirements for fire treatment of surfaces and subsequent manual cleaning with metal brushes; acceptance control of hardware based on the manufacturer's certificates; checking the preparation of hardware in accordance with technological requirements; control of assembly and control of sealing of joints by visual inspection of mating elements [15-16].

Acceptance control of high-strength bolts, nuts and washers is carried out on the basis of the manufacturer's certificates. Taking into account the uniqueness of the object, additional selective tensile tests are carried out from 3 to 6 bolts from each batch to determine their actual bearing capacity. When testing bolts, the technology of recording a machine strain diagram is used. These tests are preceded by control mechanical tests of the bolt material with the determination of the plastic characteristics. Impact tests are carried out, the hardness of the bolt material is determined.

To ensure the quality of welded assembly joints, a system of scientific and technical measures is carried out, including: examination of the project for the production of welding works (PPSR); systematic operational control of compliance with the requirements for the implementation of basic technological operations; acceptance control to confirm the absence of dangerous defects in welded joints, which is carried out by visual inspection and ultrasonic flaw detection, in accordance with the set of rules.
5. Results and discussion

Development of recommendations for ensuring the safety of the structure from progressive collapse during emergency impacts. The safety of a large-span structure from an avalanche-like collapse of structures must be ensured, in case of emergency impacts, by the correct choice and application of one or more of the measures listed below, in some cases corresponding to a certain emergency impact.

Assignment of the necessary reserves of the bearing capacity of the main ("key") structural elements, primarily ensuring the overall stability of the structure to minimize the impact of possible design, manufacturing, installation, or improper operation of the structure [17-18].

Elimination or prevention of the danger of emergency impacts to which a structure or object may be exposed.

The choice of rational design solutions and materials that ensure the bearing capacity of the structure even in the presence of local (within one structural element) damage.

Design of "key" elements, taking into account the possible emergency impact, not excluding the standard design loads and impacts, but complementing them.

Monitoring the condition of supporting structures and organizing the proper operation of the structure.

The listed activities should be ensured by the qualified execution of design and construction work, as well as using materials of appropriate quality, the choice of control and acceptance methods and their mandatory implementation at all stages of design, construction and operation of the structure.

At the design stage of large-span structures, it is recommended to consider several interrelated approaches to ensure the safety of structures from avalanche-like (progressive) collapse under emergency impacts, namely: the systemic principle - assessment of the vulnerability of the applied structural schemes in case of emergency impacts and avalanche-like collapse, development of solutions that are effective to mitigate the consequences under various threat scenarios; preventive safety measures; reducing the degree of hazard of emergency impacts; slowing down the collapse - to ensure sufficient time and paths for evacuation from the building after the start of local damage to the structure.

It is worth paying special attention when making decisions on the possible causes and type of impacts of an emergency nature, the possible consequences of a progressive collapse, especially focusing on the possible danger to life and health of people, economic losses.

With regard to the same level of ensuring the safety of structures from an avalanche (progressive) collapse during various emergency situations, they can differ from each other and be interchangeable. Tightening of one type of measure can compensate for the weakening of another type of measure. Different solutions may correspond to a specific type of threat. For example, in the event of a fire, it is more rational to use a fire retardant coating to maintain the bearing capacity. However, in most cases, a rational combination of several methods should be adopted. Such a combined approach minimizes the cost of funds while significantly improving the ability of structures to resist avalanche collapse during emergency impacts [19-20].

6. Conclusions

Monitoring at the stage of construction and operation of the structure. Increased requirements for the reliability of unique large-span structures determine the need for their technical condition control, with the organization of a monitoring system, which includes: assessment of loads, impacts and factors that are the causes of the occurrence and development of defects; assessment of types of defects, their location, nature of development; non-destructive testing methods to obtain reliable and reliable information about the object; calculation for actual (actual) loads, as well as analysis of the compliance of monitoring results with reality; development of criteria for assessing the danger of detected defects and recommendations for the safe operation of the structure. The result of field surveys is an assessment and forecast of the actual bearing capacity of structures, forecasting on this basis the residual life of the structure, making informed decisions on extending the period of trouble-free operation of facilities.
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