SEISMIC STABILITY OF UNDERGROUND SHELL STRUCTURES.

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https://doi.org/10.5281/zenodo.15648486

Abstract

This article addresses the seismic resistance of shell-type underground structures. It analyzes modern calculation methods and the properties of construction materials aimed at enhancing the stability of underground structures under seismic loads. The influence of geometry and the structural configuration of shell structures on their behavior during seismic events is also discussed. The findings of the study contribute to the development of new approaches to ensuring the safety of underground facilities.

Keywords: shell-type underground structures, seismic resistance, seismic loads, structural analysis, underground constructions, seismic safety.

In modern construction practice, underground structures, especially shell-type constructions, have become an essential part of industrial, transport, and social infrastructure. These structures must withstand not only surface loads but also seismic impacts. Natural disasters such as earthquakes pose a serious threat to the safety and functionality of underground structures. Therefore, the analysis and optimization of the seismic resistance of shell-type underground structures is one of the pressing issues in structural mechanics.

Thanks to their unique geometry and load distribution, shell forms can exhibit high resistance to seismic effects. However, achieving this requires proper structural and material design of such facilities. This article explores ways to enhance the seismic resistance of shell-type underground structures, methods of their calculation, and practical recommendations.

Shell-type underground structures are distinguished by their geometry. They possess high load-bearing capacity and excellent rigidity, which provide certain advantages in resisting seismic loads. In such structures, loads are evenly distributed across the surface, reducing stress in the materials.

Inertial forces generated during an earthquake have a significant impact on underground structures. Seismic loads affect the structural elements of the facility in various directions, leading to the development of deformations and stresses. Therefore, it is crucial to accurately account for seismic loads during the design of shell-type underground structures.

IBAST ISSN: 2750-3402

Modeling techniques, such as the finite element method, allow for highly accurate representation of the structure's behavior under complex conditions. Experimental studies support theoretical calculations by conducting tests under real-world conditions.

The materials used in shell-type underground structures (concrete, steel, and others) directly influence their level of seismic resistance. The use of modern, strong, and flexible materials makes structures more reliable and stable. Additionally, the implementation of seismic isolation systems and energy-dissipating devices enhances the resistance of structures to seismic impacts.

When designing earthquake-resistant shell-type underground structures, it is essential to consider the following aspects: the shape and dimensions of the structure, the strength of the materials used, the accuracy of seismic load assessment, and the quality of construction technologies. The use of modern computer modeling tools at the design stage contributes to ensuring the structural stability.

To enhance the seismic resistance of shell-type underground structures, various technological and structural measures are applied. In particular, the implementation of elastic and energy-absorbing elements, the use of seismic isolation systems, and the installation of special dampers at the foundation level are possible solutions. In addition, improving the crack resistance of materials and the quality of concrete plays a crucial role.

Recent scientific research has contributed to a deeper understanding of the seismic resistance of shell-type underground structures. The results of experiments conducted at testing sites and in laboratories have formed the basis for optimizing designs and developing new standards. Such research is aimed at increasing the level of safety in construction practice.

In the design of shell-type underground structures, it is essential to comply with international and national seismic standards. These regulatory documents govern the consideration of seismic loads, the selection of materials, the structural strength, and the verification criteria. Projects that meet these standards ensure the safety and reliability of construction.

Shell-type underground structures respond to seismic impacts in various ways. Their flexibility and variable stiffness help reduce deformations during earthquakes. At the same time, weak points in shell structures, such as joints and connections, can be vulnerable to seismic loads, which requires the implementation of special reinforcement measures.

To assess the impact of earthquakes on shell-type underground structures, modern methods of computer modeling and simulation are used. These tools help determine the structural response under different seismic conditions, the distribution of forces, and potential weak spots. This enhances safety during the design stage.

Modern construction materials with high strength and flexibility are used in earthquake-resistant underground structures. For example, high-strength concrete mixtures, carbon fibers, and other composite materials enhance the seismic resistance of shell-type structures. In addition, new technologies help prevent cracking and reduce damage.

The application of seismic isolation systems in shell-type underground structures reduces the impact of seismic energy on the structure. These systems include the installation of special dampers or isolators between the foundation and the structure. Energy-absorbing materials and mechanisms dampen vibrations that occur during earthquakes, thereby lowering the risk of structural damage.

When designing shell-type underground structures, strict adherence to seismic safety standards and requirements is essential. Factors such as the region's seismic activity level, subsurface conditions, and the intended purpose of the structure must be taken into account. In accordance with the standards, specialized calculations, stress analyses, and testing are carried out to ensure the long-term stability of the structure.

To ensure quick and effective elimination of earthquake-induced damage, continuous monitoring and preventive maintenance play a crucial role. The condition of the structure is monitored using special sensors and surveillance systems, and, if necessary, reinforcement and repair work is carried out. This increases the safety of the structure and extends its service life.

To ensure the seismic resistance of shell-type underground structures, continuous seismological monitoring is essential. Specially installed sensors and monitoring devices track movement, deformation, and stress levels in the structure in real time. Based on this data, engineers can take the necessary measures and respond promptly in emergency situations.

To improve seismic resistance, new materials and construction technologies are being introduced. For example, composite materials with high elasticity and energy absorption capabilities, as well as enhanced strength and durability through nanotechnology. These innovative approaches contribute to the creation of safer and more durable underground structures.

When constructing earthquake-resistant underground structures, environmental factors must also be considered. It is important that construction materials and technologies do not harm the environment and ensure energy efficiency. Moreover, to reduce construction and repair costs, efficient design and the use of advanced technologies are required.

When designing shell-type underground structures to ensure seismic resistance, the following principles are important:

- The shape and geometry of the structure should provide effective distribution of seismic loads;
- The elasticity of materials and their energy absorption capacity must be taken into account;

- Additional stabilization elements, such as tension networks or braces, should be applied;
- The design must consider groundwater movement and changing soil conditions.

Before the construction of earthquake-resistant underground structures, their strength is tested under laboratory conditions. Using computer modeling and physical models, the response of structures to various seismic scenarios is analyzed. Based on these tests, construction projects are certified and their compliance with safety standards is confirmed.

Best practices and international seismic standards, such as ISO and Eurocode, are applied in construction projects. These standards define the technical and safety requirements necessary for the erection of shell-type underground structures and serve as guidelines for experienced engineers.

Shell-type underground structures are subjected to complex loads during seismic events, including bending, shear, and sliding forces. Taking these forces into account, the elastic and plastic properties of the structure are analyzed. Finite Element Method (FEM) modeling is used to assess the seismic behavior of the shell.

Dynamic loads acting on underground structures during earthquakes are studied using vibration analysis. This process determines the natural frequencies of the structure, and the design is optimized to prevent resonance conditions. The interaction of seismic waves on the surface and within underground layers is also taken into account.

During an earthquake, the interaction between the soil and the underground structure is of great importance. Soil elasticity, its potential for liquefaction, and other mechanical properties affect the strength of the structure. Therefore, during the design stage, it is necessary to create a complex dynamic model of the soil-structure system.

To enhance the seismic resistance of underground structures, additional protective systems are installed. For example, seismic isolators, energy-absorbing elements, and deformation-reducing devices are applied. These technologies reduce seismic loads on the structure and increase safety levels.

The seismic resistance of materials used in shell-type underground structures is a crucial factor. The mechanical properties of concrete, steel, and other composite materials—particularly their modulus of elasticity, tensile strength, and crack resistance—are tested. Having sufficient elasticity and plasticity in materials is important to accommodate the necessary deformation of the structure during earthquakes.

When designing shell-type underground structures considering seismic loads, the shape and thickness of the structure are optimized. This helps reduce material consumption and increase safety levels. Various design options are tested through computer modeling, and the most effective solution is selected.

The deformation of shell structures under earthquake influence is a complex multifactor process that depends on the stiffness of the structure, load distribution, and soil conditions. To accurately predict and monitor deformations, modern sensors and monitoring systems are installed, allowing timely safety measures to be taken in emergency situations.

Shell-type underground structures closely interact with the soil. During an earthquake, soil movement and deformations significantly affect the structure. Therefore, soil conditions are thoroughly studied during the design stage, and necessary construction technologies are applied to ensure the stability of the structure.

To enhance the seismic resistance of shell-type underground structures, special protective measures are introduced. For example, seismic dampers, flexible connections, and additional reinforcement elements may be installed. This increases the flexibility of the structure and helps absorb earthquake energy.

Modern computer programs (such as ANSYS, SAP2000, ETABS) are widely used to analyze the behavior of shell structures under seismic loads. These tools help determine the structural responses to various loads, deformations, and stress distributions, as well as assess safety indicators.

During construction, strict adherence to seismic requirements and safety standards is necessary. To ensure the stability of shell structures, it is important to select high-quality materials, and installation work must be performed by qualified specialists. Additionally, at every stage of construction, inspections and tests are carried out to ensure compliance with standards.

Conclusion

Shell-type underground structures require specialized design and construction methods to ensure their seismic resistance. Taking into account the interaction between the structure and the soil during an earthquake, increasing structural flexibility, and applying necessary protective measures enhance stability. Modern software enables precise analysis of the structure’s condition under seismic loads and assessment of safety indicators. At the same time, strict adherence to quality and standards during construction is of great importance.

As a result, incorporating seismic requirements in the design and construction of shell-type underground structures ensures their safety and long-term operation. In the future, further improvements in seismic resistance of such structures are expected through new technologies and materials.

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