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Application Status and Development Trend of Performance-Based Seismic Design Methods

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Abstract

Performance based seismic design (PBSD) method is a frontier subject in the field of seismic engineering in recent years. Compared with the traditional code based design method, PBSD pays more attention to the actual performance of the structure under earthquake action. By discussing the application status and development trend of PBSD method, this paper summarizes its advantages in seismic engineering, and analyzes the comparison with traditional design methods. The results show that PBSD has significant advantages in improving the seismic performance of structures and reducing economic losses, but it also faces the challenges of technical complexity and practical application.

Keywords

Seismic Design; PBSD; Application Status; Development Trend.

1. Introduction

In recent years, frequent earthquakes have brought huge casualties and economic losses to many cities around the world. The traditional seismic design method is mainly based on the minimum requirements of the code, which is usually difficult to fully guarantee the performance of the structure in the earthquake [1]. The performance-based seismic design method came into being. The performance-based seismic design method focuses on the actual performance of the building structure in the earthquake, rather than just meeting the requirements of the code. By considering the reliability, toughness and durability of the structure and other factors, it can ensure that the building has a better seismic capacity in the event of an earthquake. This design method first needs to carry out seismic risk assessment to determine the damage degree that may be caused by the earthquake. Then, according to the use and importance of the building, determine the required performance objectives. Next, the designer will consider the structural material [2], structural form and connection mode of the building to ensure the required seismic performance in the earthquake. In addition, advanced numerical simulation technology can be used to comprehensively evaluate the performance and optimize the design of building structures. The performance-based seismic design method can not only improve the safety of buildings, but also reduce the impact of earthquake disasters on people and property. Through reasonable design and construction, buildings can be controlled to damage in the earthquake, so as to ensure the safety of personnel and reduce the cost of repair and reconstruction.

In short, with the threat of frequent earthquakes, the development of performance-based seismic design methods has become particularly important. By fully considering the performance of the structure and seismic risk, we can improve the seismic resistance of buildings and infrastructure in the earthquake, and reduce casualties and economic losses. This is an area of continuous development and improvement. We hope that more science and technology can be invested in seismic design in the future to ensure that our city is safer and more sustainable.

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2. Application Status and Development Trend of Performance-Based Seismic Design Method

2.1. Performance Oriented Vs. Specification Oriented

Performance based seismic design (PBSD) pays attention to the actual performance of the structure, and aims to achieve the expected performance goal by predicting and controlling the performance of the structure in the earthquake. This method not only considers the seismic capacity of the structure, but also evaluates its function, damage and recovery time under different earthquake intensities. In contrast, the traditional seismic design method focuses on meeting the requirements of the code, mainly relying on the predetermined design criteria and safety factors to ensure the seismic performance of the structure. Performance based seismic design (PBSD) pays attention to the actual performance of the structure [3], and aims to achieve the expected performance goal by predicting and controlling the performance of the structure in the earthquake. This method not only considers the seismic capacity of the structure, but also evaluates its function, damage and recovery time under different earthquake intensities. In contrast, the traditional seismic design method focuses on meeting the requirements of the code, mainly relying on the predetermined design criteria and safety factors to ensure the seismic performance of the structure.

In [4] the performance-based design method, the designer needs to clarify the performance objectives that the building needs to achieve, such as no damage, repairable damage or life safety. These goals will dominate the design decisions, including the selection of structural materials, the design of component sizes and connection methods. Designers can predict the response of buildings in earthquake events through performance evaluation and simulation analysis, and adjust and optimize according to the expected performance objectives. This method can provide more flexible design space, allow designers to carry out customized design according to specific needs, and effectively balance the economy and seismic performance of the structure. In contrast, the traditional code oriented design method mainly relies on specific seismic design codes and safety factors, such as ensuring that the structure does not collapse in the event of an earthquake. This method assumes that there is a definite relationship between the response of the structure and the seismic load, and realizes the safety of the structure through the given design criteria. However, this method can lead to differences between the design results and the actual seismic performance, because the design requirements in the code may not meet the actual needs in all cases.

2.2. Detailed Analysis vs. General Analysis

PBSD uses refined nonlinear analysis to deeply study the response of the structure under earthquake action, considering various nonlinear behaviors and failure modes. [5] This method can provide more accurate performance evaluation, help designers optimize structural design and improve seismic performance. However, the traditional method mostly uses linear static analysis, mainly through the linear elastic theory, ignoring many nonlinear effects and potential failure mechanisms, which may underestimate or overestimate the actual seismic capacity of the structure in some cases. Detailed analysis and general analysis are two common analysis methods in structural engineering. They evaluate the response of structures under earthquake action. The following is a detailed explanation of these two methods:

1. detail analysis: detail analysis is a refined nonlinear analysis method, which deeply studies the response of the structure under earthquake action and considers various nonlinear behaviors and failure modes. This method evaluates the performance of the structure by simulating the nonlinear behavior of the structure, such as plastic deformation, buckling and failure. Detailed analysis can more accurately predict the behavior of the structure under

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earthquake, and help designers optimize the structural design and improve the seismic performance.

2. general analysis: general analysis is a commonly used traditional method, which mostly uses linear static analysis, mainly through the linear elastic theory. The general analysis is mainly used for the preliminary evaluation of the structure to determine the overall performance of the structure. This analysis method only considers the linear behavior of the structure and ignores many nonlinear effects and potential failure mechanisms. Therefore, in some cases, the general analysis may underestimate or overestimate the actual seismic capacity of the structure.

In general, detailed analysis and general analysis are two different methods for seismic response evaluation. Detailed analysis can provide more accurate performance evaluation by considering the nonlinear behavior and failure mode of the structure. The general analysis is mainly calculated by the linear elastic theory for the preliminary evaluation of the structure. According to the specific situation, the designer can choose to use appropriate analysis methods to evaluate the seismic performance of the structure.

3. Application Status

3.1. Domestic Application Status

In China, performance-based seismic design method (PBSD) is gradually being paid attention to and applied. In recent years, with the improvement of seismic fortification standards and the increase of large and complex engineering projects, PBSD has been widely used in high-rise buildings, long-span bridges, nuclear power plants and other important projects. The introduction of various codes and guidelines, such as code for seismic design of buildings (GB 50011) and code for seismic design of bridges (jtg/t B02), has provided strong technical support for the promotion of PBSD. At the same time, scientific research institutions and universities also actively carry out relevant research, promoting the development of PBSD theory and practice. Domestic scientific research institutions and universities are actively studying and practicing performance-based seismic design methods. They have continuously improved the application level of PBSD in engineering design through the combination of theoretical research, simulation experiment and engineering practice.

In the field of high-rise buildings, PBSD has been widely used. The number of super high-rise buildings in China is increasing, and the earthquake risk faced by these buildings is also more severe. By using the PBSD method, engineers can better analyze and evaluate the seismic performance of the structure, formulate the corresponding design scheme, and improve the seismic capacity of the building.

In the aspect of long-span bridges, the application of PBSD has also been promoted. Long span bridges have the characteristics of complex structure and load, and have high requirements for seismic performance. PBSD method can help engineers consider the response of bridges under earthquake, reasonably determine structural parameters, and improve the seismic performance and safety of bridges.

In addition [6], as an important infrastructure equipment, the seismic performance of nuclear power plant also needs to be considered in the design. PBSD method can help engineers evaluate the overall performance of nuclear power plant structure under earthquake, and formulate corresponding design and improvement schemes to ensure its seismic capacity and safe and stable operation.

In general, the performance-based seismic design method has been widely used in China. With the improvement of seismic fortification standards, the improvement of specifications and guidelines, and the efforts of scientific research institutions and universities, the popularization and application of PBSD in various important engineering projects will be further expanded,

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which will play an important role in improving the seismic capacity and safety of engineering structures in China.

3.2. International Application Status

Internationally [7], PBSD has been widely used in many countries. The United States, Japan and Europe are in a leading position in the field of seismic design, and the application of PBSD in these areas is relatively mature. For example, many technical reports issued by the international building code (IBC) and the Federal Emergency Management Agency (FEMA) of the United States have detailed provisions and guidance on the PBSD method. Japan has accumulated rich experience in the application of PBSD in practical engineering projects and continuously improved relevant technical specifications and standards. European countries are also promoting the research and application of PBSD, focusing on transnational cooperation and experience sharing.

In addition to the United States, Japan and Europe, the application of PBSD has also been promoted and applied in other countries. Some countries with frequent earthquakes, such as Turkey, New Zealand and Chile, have also begun to use PBSD method to improve the seismic capacity of buildings, bridges and other projects. In Turkey, because the country is located on the seismic belt, the seismic risk is high. Therefore, the construction and bridge engineering field in Turkey has paid extensive attention to the PBSD method. The Turkish government and relevant research institutions have attached great importance to the practical application of PBSD and formulated corresponding seismic design criteria and specifications. New Zealand is also a country with frequent earthquakes, and its engineering industry attaches great importance to seismic design. The PBSD method has been widely used in engineering projects in New Zealand, including residential, commercial buildings and public facilities. The New Zealand government advocates the use of PBSD method to ensure that buildings can maintain structural integrity and safety in the event of an earthquake. As a seismically active country, Chile has been actively promoting the application of PBSD method in the field of seismic design for a long time. Seismic engineers in Chile have made great achievements in the research and practice of PBSD method, and relevant achievements have been reflected in the seismic code and guidelines of that country.

In general, the application of PBSD has been widely promoted and applied internationally. Governments, scientific research institutions and engineering industries around the world have recognized the importance of PBSD method in improving the seismic capacity of engineering, and continue to strengthen research and practice to meet the challenges brought by natural disasters such as earthquakes.

4. Development Trend

In the future, with the gradual promotion of PBSD in engineering practice, relevant standards and specifications will be continuously improved and refined. The new design criteria and evaluation methods will further clarify the specific requirements of various performance objectives and improve the scientificity and operability of the design. At the same time, the technical exchange and standard unification between different countries and regions will be further strengthened to promote the overall improvement of the global seismic design level. Secondly, with the development of computer technology and numerical simulation methods, the analysis tools and technologies of PBSD will also continue to progress. Efficient and accurate nonlinear analysis software and calculation platform will further improve the design efficiency and analysis accuracy, and provide more reliable technical support for seismic performance evaluation of complex structures. In addition, the application of artificial intelligence and big data technology will also bring new development opportunities for PBSD. Through intelligent design and optimization methods, the seismic performance and design efficiency of structures will be further improved, and more engineering projects will begin to use PBSD method [8]. The continuous accumulation of practical application experience will provide valuable data and case support for the development of PBSD. These experiences will help to improve the design process, optimize the analysis method, and provide reference for future engineering design. In addition, through the long-term monitoring and performance evaluation of the built structure, the effectiveness and reliability of the PBSD method are further verified, and its application in a wider range of engineering fields is promoted. The development of PBSD will pay more and more attention to multidisciplinary integration and comprehensive application. Technologies and methods in structural engineering, seismic engineering, materials science, building information modeling (BIM) and other fields will continue to be cross integrated to jointly promote the innovation and progress of PBSD. For example, BIM Technology can realize the information integration and collaboration in the PBSD design process, and improve the design efficiency and accuracy; The application of new materials can improve the seismic performance and durability of the structure; The progress of earthquake early warning and monitoring technology can provide real-time data support for PBSD and improve the dynamic response ability of the design.

5. Conclusion

With the continuous development and improvement of the application of PBSD, the future trend shows that it will play a more important role in the field of seismic engineering. The further improvement of standards and specifications will be an important development direction. As the application of PBSD method expands, countries will continue to carry out research and practice to update and improve the existing guidelines, and develop more specific guidelines for different types of structures and earthquake risk situations. At the same time, with the continuous progress of computer technology, PBSD analysis tools and software will become more powerful and efficient, which will enable engineers to more accurately evaluate the performance of the structure under seismic load and optimize the design scheme. In addition, more practical experience and data will be accumulated, which will help to verify and improve the PBSD method, and provide more accurate design parameters and suggestions. The PBSD method needs the cooperation of structural engineers, seismic engineers, civil engineers and other disciplines. The future development will emphasize the integration and cooperation between different disciplines to promote the realization of comprehensive performance-based seismic design. In addition, the promotion and application of PBSD need to cultivate professionals with relevant knowledge and skills. Educational institutions and training institutions will focus on cultivating students' and engineers' PBSD theoretical and practical abilities to meet the growing demand. In general, with the continuous development and application of PBSD method, we can expect it to play a more important role in the field of seismic engineering in the future. Through continuous research and innovation, we will be able to design safer, more reliable and better anti-seismic structures to provide better anti-seismic protection for the society.

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