Seismic Performance and Performance Standard of Bridge

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Abstract: The performance-based seismic design of bridge structure enables people to estimate the seismic performance of the bridge under various possible future earthquake actions in advance. However, "seismic performance" itself is a very broad, complex and fuzzy concept, which can be understood and described from multiple perspectives. For example, from the designer's point of view, the understanding of seismic performance is the magnitude of various mechanical responses of the structure under the action of earthquake, such as strain, displacement, speed, acceleration, etc.; from the user's point of view, the most intuitive feeling of seismic performance is the magnitude of loss under the action of earthquake, etc. Therefore, it is necessary to define the seismic performance clearly, and put forward the corresponding evaluation index system and design evaluation method. In this paper, firstly, the concept of performance-based seismic fortification standard is introduced, and its particularity and manifestation in bridge structure are pointed out. On this basis, suggestions on performance-based seismic fortification standard of bridge structure are put forward.

Relevant Concepts of Performance-Based Seismic Fortification Standards

Seismic Fortification Principle. The seismic fortification principle of structure refers to the general principle and purpose of seismic fortification of engineering structure [165], which is generally listed in the general rules or instructions of seismic design code. According to the code for seismic design of buildings (GB50011-2001) [15], the fortification principle of the code is to "reduce the earthquake damage of buildings, avoid casualties and reduce economic losses"; according to the detailed rules for seismic design of highway bridges (JTG / tb02-01-2008) [17] (hereinafter referred to as the detailed rules), the seismic fortification principle of the code is to "reduce the earthquake damage of highway bridges and guarantee Safety of people's lives and properties, reduction of economic losses, better exertion of the function of highway traffic network and its role in earthquake relief: the seismic fortification principle of AASHTO (2002) [167] bridge seismic code of the United States is "reducing the seismic damage of bridges"; Eurocode 8, the European standard on seismic design, in its general principles (EN 1998-1:2004) [168], states that its seismic fortification principle is "Protect people's lives, reduce damage and keep important civil buildings in normal operation." It can be seen that although the description of seismic fortification principles in various codes is more general, the general principles are no more than three aspects: reducing structural earthquake damage, protecting life safety and reducing economic loss. Although these three are related to each other, they are not the same. When formulating norms, we can focus on one of them or take them into account. For example, the traditional code takes the safety of human life as the first goal, often only focuses on the seismic performance of the main structure, and ignores the seismic performance of auxiliary facilities and secondary components, sometimes it may cause significant loss of life and property. The new performance-based seismic design idea pays more attention to the overall seismic performance of the structure, and is committed to the control of economic loss within the expected range while protecting life safety.

Seismic Performance and Performance Level. Seismic performance refers to the general term of all kinds of responses of engineering structures or components under the action of earthquake [166]. The seismic performance can be described from different perspectives. From the perspective of engineering earthquake resistance, various mechanical response quantities of structure or component under earthquake action can be used to describe, such as stress, stress, strain, displacement, speed, acceleration, etc., or the damage degree of structure and component under earthquake action can be used to describe, such as qualitative description of intact, slight damage, medium damage, serious damage, collapse, etc., or The magnitude of the consequences (casualties, direct economic loss, indirect economic loss) caused by structural damage under earthquake is described. All kinds of description methods reflect only one aspect of seismic performance, but they are always related to each other. At the same time, considering the huge uncertainty of earthquake action and the uncertainty of structural response and people's social and economic activities, all the above description methods can be based on the probability, so they can also be described according to the magnitude of the probability of occurrence of various response quantities or damage degrees. For example, it can be considered that the probability of "collapse" in the same earthquake environment is small Structure is better than structure with high probability of collapse.

Fortification performance objectives. The goal of fortification performance is the sum of performance level or grade required by each fortification level [166], which reflects the maximum degree of expected damage of the structure under each fortification level. Structural, non structural components and the consequences of their failure are considered to be structural performance level problems. The establishment of performance objectives needs to consider many factors such as the characteristics of the building site, the function and importance of the structure, the investment and benefit, the loss and restoration after the earthquake, the potential historical or cultural value, the social benefit and the bearing capacity of the owner.

Performance Based Seismic Design Code. Performance based seismic design code is a normative document embodying the idea of performance-based seismic design. It mainly stipulates the seismic fortification principle, seismic fortification level, seismic performance level, seismic fortification performance target, control index of performance level at all levels of various structures and non structures, design analysis method, seismic measures, quality assurance measures, etc. The performance-based seismic design code should reflect the following characteristics [148150]:

(1) The unification of multi-level performance level, multi-performance target and multi seismic level. That is, on the basis of a full study of the seismic risk level, social and economic level, and the development level of engineering seismic science and technology, appropriate seismic fortification principles and standards shall be stipulated;

(2) The unity of investment and benefit. That is to say, based on the principle of "investment benefit", the work of each link of seismic fortification (including the formulation of fortification standards and the design of specific projects) is carried out;

(3) The unity of generality and individuality. That is, on the basis of meeting the relevant minimum standards for use and safety specified in the specification, the owner shall be allowed to flexibly select different performance objectives according to the actual situation and risk tolerance, so as to maximize the economic benefits.

Seismic Fortification Standards of Domestic Commonly Used Seismic Design Codes

Cecs160:2004 (hereinafter referred to as "the general rules") issued by China Engineering Construction Standardization Association in 2004 is the first recommended code based on the performance-based seismic design idea, which is mainly applicable to the seismic design of construction projects. Based on the current seismic zoning in China, the code adopts the design of "three links, two levels" to achieve the expected performance goals. "Three ring section" refers to the determination of the fortification standard through three links: the determination of the seismic design category of the structure, the determination of the design intensity or the design ground motion parameters, and the determination of the importance level of the building. "Two levels" refers to two levels of design to achieve the predetermined performance objectives: the first level design is designed according to the earthquake fortification ground motion with 10% exceedance probability given on the TMJ within the specified life of the building importance category; for most building structures, the design objectives can be met through the basic requirements of the seismic design and the seismic structural measures; the second level design is the seismic design In addition to meeting the requirements of the first level design, the buildings with higher categories shall be tested for elastic-plastic deformation according to the rare earthquake to meet the corresponding fortification requirements. See table 2-8 for the requirements of seismic fortification level and the minimum fortification performance of each functional category specified in the general principles. In order to make the building structures of each functional category meet the specified performance requirements under the earthquake action, the general principles divides the seismic design of each functional category structure into five categories: A, B, C, D and e according to different seismic acceleration. Different categories have different design requirements. For the importance of the structure, the general principles follows the division method of the current standard for classification of seismic protection of buildings (gb50223) [171], but reflects the importance of different building structures by changing the design reference period.

Table 1 Minimum Performance Requirements under Different Vibration Levels Specified in General Rules

Ground motion level	Function of earthquake resistant building			
	Ⅰ	Ⅱ	Ⅲ	Ⅳ
Frequent earthquakes (annual exceedance probability of TMJ is 63%)	Basic operation	Full operation	Full operation	Full operation
Seismic fortification (TMJ annual exceedance probability is 10%)	life safety	Basic operation	Function	Full operation
Frequent earthquakes (TMJ annual exceedance probability is 5%)	Approaching collapse	life safety	Basic operation	Function

Suggestions on Performance-Based Seismic Fortification Standards for Bridge Structures

Although there are some studies on the relevant issues in the seismic performance design standard of bridges [75172-175], there are few discussions on this from the perspective of performance-based seismic design, and no broad consensus has been formed at present.

As mentioned before, the formulation of seismic fortification standards includes the determination of seismic fortification principles, fortification objectives of different types of projects, fortification ground motion level and classification of structural importance. The last three tasks are the embodiment of seismic fortification principles and the specific contents of the fortification standards. From the point of view of performance-based seismic engineering, the fortification standard should be able to embody several principles, such as the unity of multi-performance level, multi-performance target, multi seismic level, the unity of investment and benefit, the unity of commonness and individuality. Therefore, the determination of the best seismic fortification standard is essentially a multi-objective and multi constraint dynamic optimal decision-making problem with the main purpose of reducing the loss of earthquake disaster (casualties and economic loss). It is necessary to predict the earthquake risk (seismic risk analysis) and the earthquake loss (economic loss, casualties, social politics, economy, psychology, etc.) As the basis, it involves seismology, geology, engineering, economics, sociology and many other fields. It can be seen that the formulation of seismic fortification standards is an extremely complex problem.

On the other hand, the seismic fortification standards determined by various codes are the results of many studies. The seismic fortification standards of bridge structures can also be determined by referring to the provisions of existing codes at home and abroad. Therefore, according to the above-mentioned domestic and foreign performance-based seismic design codes and the provisions of relevant seismic fortification standards in the current detailed rules of our country, this paper puts forward suggestions on the formulation of performance-based seismic fortification standards for bridge structures in our country.

According to the current seismic zoning map and the seismic fortification level adopted by various codes in China, the following three magnitude earthquake level is recommended:

Frequent Earthquake: it is defined as the earthquake with a large probability of occurrence during the design and use of the bridge. The earthquake with a probability of exceeding 63.2% in 50 years can be used, and its recurrence period is about 50 years;

Occasional earthquake: it is defined as an earthquake with a moderate probability of occurrence during the design and use of the bridge. The earthquake specified in the current seismic zoning map can be used, that is, an earthquake with a probability of exceedance of 10% in 50 years, with a return period of about 475 years;

Rare earthquake: it is defined as an earthquake with a small probability of occurrence during the design and use of the bridge. An earthquake with a probability of exceedance of 2% in 50 years can be used, with a return period of about 2475 years.

It should be pointed out that at present, the same design ground motion parameters are generally used for the above-mentioned ground motion levels in various codes of our country. However, due to the different levels of seismicity in different places, the size of the ground motion parameters with the same probability of occurrence is not necessarily the same, and some of them are quite different [64177]. Therefore, it is advisable to consider the differences of seismicity in different regions in the code and give the method of determining the ground motion levels at all levels.

Seismic Performance Level of Bridge Structure

Generally speaking, the seismic performance of bridge structure mainly refers to the damage condition in the earthquake. However, in order to more effectively control the seismic performance of the structure in the earthquake and carry out the seismic design based on the structural performance, the division of the seismic performance level of the bridge structure should be included in the description of its performance level. These two aspects are closely related. Therefore, in accordance with the provisions of various codes at home and abroad, the seismic performance of bridge structure is divided into five grades, corresponding to different levels of damage and performance of functions. The degree of damage can be divided into five levels: basically intact, slightly damaged, moderately damaged, severely damaged, and nearly collapsed. The corresponding performance level can be divided into five levels: full operation, operation, limited operation, life safety, and collapse prevention. The classification standard and comprehensive description of each performance level are shown in table 2.

Table 2 Seismic performance level division of bridge structure

Performance grade	Damage degree of structure	Performance of functions	Structure state description
I	intact	Normal operation	The structure is generally undamaged and can be put into use without repair
II	Slight damage	Operate	The structure is slightly damaged, and the normal function can be restored after general renovation

Performance grade	Damage degree of structure	Performance of functions	Structure state description
Ⅲ	Moderate damage	Restricted operation	In case of limited damage to the structure, emergency use can be provided after emergency repair or temporary reinforcement, and normal use function can be fully restored after permanent repair
Ⅳ	Serious damage	life safety	The structure is seriously damaged, but the structure will not collapse and endanger life safety, and the repair is not feasible or has no long-term repair value
Ⅴ	Approaching collapse	Prevent collapse	In case of catastrophic damage, the structure is about to collapse, completely losing the use function and unable to be repaired

Obviously, the above division of performance level is only a broad description. In order to achieve the various performance levels listed in the table, it is still necessary to put forward quantitative evaluation indexes for performance levels at all levels according to the characteristics of different types of structures, and stipulate the bending strength, shear strength, deformation capacity (or energy consumption capacity) of structures and components, respectively, from the structure level to the main structure, auxiliary structure and from the component level to the main and secondary components The feasible performance control index is given. All of these need a lot of theoretical analysis and experimental research, especially on the basis of probability to grasp the performance indicators of various components. In the third chapter, the ductility indexes of the above performance levels are studied and some suggestions are put forward.

Seismic Performance Target of Bridge Structure

The seismic performance target of bridge structure refers to the sum of the performance level required to be achieved by the bridge structure under each seismic level, reflecting the maximum damage degree expected to be achieved and the level expected to perform the function of the bridge structure under each seismic level. Because the performance ability of use function is closely related to the damage degree of structure, the damage degree of structure can also be used to describe the performance level, but the damage degree of structure and non structure components closely related to the performance function should be completely described. Obviously, what kind of performance level the bridge structure is required to achieve in the earthquake, or what kind of damage degree it is allowed to achieve, requires comprehensive consideration of many factors such as the characteristics of the project site, the importance of the bridge structure, investment and benefit, the difficulty of post earthquake loss and reconstruction, social benefit and economic bearing capacity to optimize and determine. Here, refer to the above domestic and foreign specifications and the current detailed rules

According to the provisions of table 3, the recommendations for the minimum seismic performance objectives of bridge structures under different vibration levels are shown in table 3.

Each column in table 3 corresponds to the minimum seismic performance target of this type of bridge. According to different seismic requirements, the performance objectives of concrete bridges can also be improved. In the seismic design of bridge structure, it is necessary to design and test the performance objectives under different seismic levels. Of course, in many cases, it is usually controlled by the performance target at one of the seismic levels. For example, for the key bridge, if the performance target under the fortification earthquake is met, the performance target under the frequent earthquake will be met naturally.

Table 3 Minimum seismic performance target of bridge structure under different vibration levels

Ground motion level	Seismic performance of bridge structure			
	General bridge	Ordinary bridge	Important bridge	Key bridge
Frequent earthquakes (the probability of exceeding in 50 years is 63%)	I	I	I	I
Seismic fortification (exceeding probability of 50 years is 10%)	Ⅳ	III	II	I
Rare earthquake (the probability of exceeding 50 years is 2%)	V	Ⅳ	III	II

Conclusion

The research of performance-based seismic protection standards involves many contents, and a complete set of performance-based seismic protection standards needs extensive investigation and research. In this chapter, combined with various existing codes at home and abroad, suggestions are put forward for the formulation of performance-based seismic protection standards in China. This paper first introduces the basic concepts involved in performance-based seismic design standards, then introduces the seismic design standards of various codes at home and abroad, and finally refers to the relevant provisions of various codes at home and abroad on the seismic design standards, the seismic dynamic level, seismic importance classification standards, seismic performance level, and the seismic performance objectives of various bridges 。

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