Application of the Performance- Based Seismic Design in urban rail transit

Lihui YANG

School of Civil Engineering, Beijing Jiaotong University ,Beijing, China
Email: lhyang@bjtu.edu.cn

ABSTRACT :

The current seismic design codes aim to ensure people's safety．However，the cost and time expended on repair or restoration of the damaged structures according to the requirements of these codes will be unexpectedly high．The extensive damage of the recent earthquakes have led to significant advance in bridge seismic design and retrofitting. The performance-based seismic design (PBSD)will develop future seismic codes which should be based on the theory of satisfying different performance targets at different hazard levels，not on the purpose of ensuring people's life safety as suggested by the traditional theory. In China, urban rail transit is playing more and more important roles in modern urban transportation, Compared with those employed in railway and highway, bridges in urban rail transit have their own characteristics. This article attempts to shed some light on several critical problems for the seismic analysis of bridges in urban rail transit. It is proposed that the design of bridges of urban rail transit be dependent on the requirements of its performance and appropriate principles of multi-level defenses.

KEYWORDS: urban rail transit; bridges; Performance- Based seismic design (PBSD)

1.INTRODUCTION

It has been demonstrated that dependence merely on land transportation is not quite satisfying. It is now a common practice for solving the traffic problem of big cities to exploit urban rail transit by utilizing the underground and overground space. With the rapid development of economy in China, more and more urban rail transit is constructing in big cities like Beijing, Shanghai, Chongqing and Guangzhou. Most bridge of urban rail transit lie in the dense transportation region, demanding the higher safety and reliability which is closely related with the life and property of people. China is liable to suffer earthquake and the influence area of earthquake ranges extensively. The resistant intensity of seismic design is generally beyond 7 degree for more than 70 percent of capital cities of province in China. Apparently, construction of urban rail transit always involves seismic design. Reasonable methods of seismic design are, however, still lacking for the corresponding national criteria of China. This article is intended to analyze the key issues of seismic design of bridges of urban rail transit and present potential schemes for solving these problems.

The primary goal of traditional code provisions is to ensure life safety and prevent structural collapse. Recent earthquakes, however, reveal that economic losses caused by less drastic structural damages as well as by functional disruptions can be enormous and comparable to the structure's initial cost. Therefore, the issue of damage control needs to be addressed adequately in the design stage in order to reduce future economic losses. By use of appropriate cost functions associated with varied damage states, designers have an opportunity to consider earthquake-related economic losses in a direct and explicit manner; seismic structural design based on life cycle cost analysis then becomes a tractable approach. Minimization of the expected life cycle cost, which is a direct sum of the initial cost and the expected lifetime seismic damage cost, has received much attention for seismic design optimization.

2.PERFORMANCE BASED SEISMIC DESIGN

Performance-based earthquake engineering (PBEE) implies design, evaluation, and construction of engineered facilities whose performance under common and extreme loads responds to the diverse needs and objectives of owners-users and society. It is based on the premise that performance can be predicted and evaluated with quantifiable confidence in order to make, together with the client, intelligent and informed trade-offs based on life-cycle considerations rather than construction costs alone.

PBEE is a desirable concept whose implementation has a long way to go. There are legal and professional barriers, but there are also many questions whether PBEE will be able to deliver its promises. It appears to promise engineered structures whose performance can be quantified and conforms to the owner's desires. If rigorously held to this promise, performance-based engineering will be a losing cause. We all know that we cannot predict all important seismic demands and capacities with perfect confidence, even in a probabilistic format. There are, nevertheless, compelling reasons to advocate PBEE as a critical area for research and implementation. The objective of seismic engineering should be to design and build better and more economical facilities. Both terms are relative to the status quo. In the writer's opinion, significant improvements beyond the status quo will not be achieved without a new and idealistic target to shoot for. We need to set this target high and strive to come close to its accomplishment. We may never fully reach it, but we will make significant progress if we have a well defined target. PBEE is the best target available, and we need to focus on it. Table 1 shows the different between traditional design and performance-based design.

Table 1 Comparison between traditional design and performance-based design

	Objective performance	Design and inspection methods	Structural performance
Traditional design	Qualified by codes	Qualified by codes	Meet the codes demand performance is inexplicit
performance-based design	Qualified by owner	Select proper method by designer	Satisfied the objective performance performance is explicit

2.1 A global framework

In the USA, several conceptual frameworks for PBEE have been developed in recent professional efforts (SEAOC Vision 2000, FEMA 273, ATC-40). They differ in details but not in concepts. Figure 1 illustrates a global framework, which identifies processes, concepts, and major issues that need to be addressed. The issues encompass seismological, geotechnical, structural, architectural and MEP (nonstructural), and socio-economic considerations.

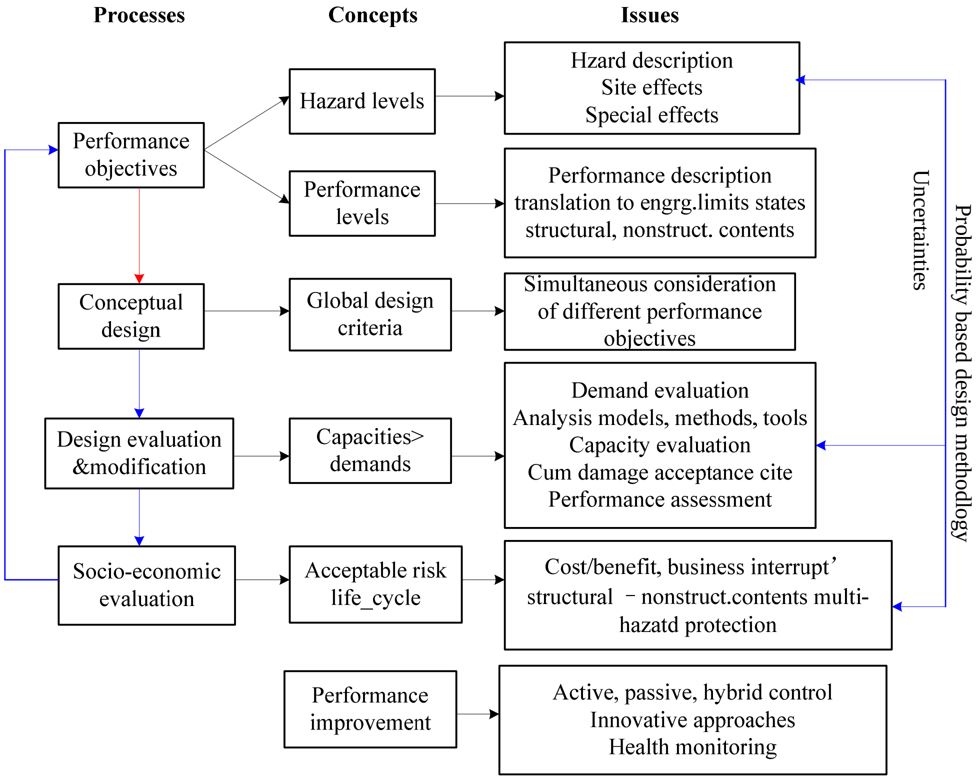

Fig. 1 A global framework for performance-based earthquake engineering

Although the concept of probability-based extreme state is adopted in the criteria of most countries, the index of structure reliability is only applied at the level of structure component due to the specificity and complexity of civil structure. The partial coefficient determined from verification and design-based methods is used to consider the extent of uncertainty. Although it is readily accepted by engineers, the index of structure reliability spans a wide range, leading to a vague risk level. As a result this calls for the direct application of the formulation of the index of structure reliability to the performance-based seismic design in future.

2.2Performance Based Seismic Design

Performance Based Seismic Design(PBSD) is one part of the PBEE, involving the following aspects: determination of earthquake risk, selection of performance level, target performance and appropriate site, concept design, initial design, final design, feasibility test for design process, design examination, and quality control during structure construction, as well as the detailed work of maintenance during service.

Genarlly, Performance Based Seismic Design include four steps. Fig 2 shows the process of the PBSD

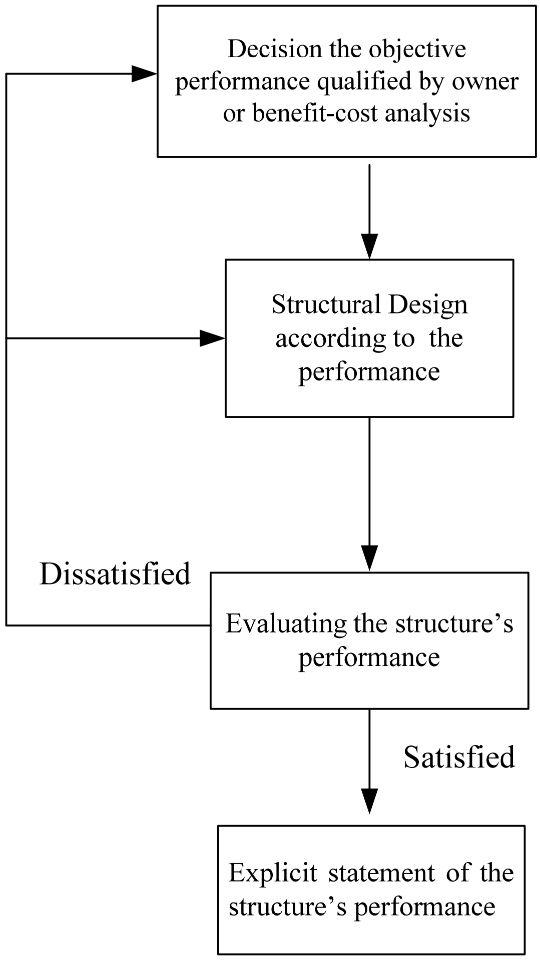

Fig. 2 Process of PBSD

2.3 Optimization seismic model

The index of structure reliability reflects the safety performance of the system. Based on the concept of structure reliability, the optimization seismic model with consideration of the relationship between investment and benefit can be expressed as

$$\left.\begin{array}{c} \text{find x} \\ \min W(\mathrm{x}) = C_0(\mathrm{x}) + P_{fs}(\mathrm{x})C_{fs} \\ \text{s.t.} \quad P_{fs}(\mathrm{x}) \le \left[P_{fs}\right] \\ \mathrm{g}_{\mathrm{j}}(\mathrm{x}) \le 0 \end{array}\right\}$$

where the object function W stands for the total cost of structure in the life cycle; x is the vector of design variable; C0(x) is the initial cost; Pfs (x)is the probability of failure，[Pfs]is the objective value; gj(x) is limited items.

In this optimization mode, the expectation is the product of the probability of structure failure and the corresponding loss. The method, though easy to use, is difficult to find practical application in engineering. The design concept based on above Equation over-emphasizes lowering the cost of structure, losing sight of the long-term benefit of economics and society. This method may give rise to some critical damage due to the fact that it aims at a lower-level design meeting the basic requirements of standard criteria. The poor quality increases the maintenance cost for daily running and reduces the life period. Human life and property may suffer great loss from the disaster in nature which cannot be predicted in advance.

3. THE MODE OF STRUCTURE FAILURE AND DAMAGE CRITERIA

Methods of evaluation on the cost are dependent on the mode of structure failure, and can fall into the following three categories according to the various results due to structure failure:
(1) Failure mode of human sensitivity: the structure librations arising from the dynamic load leads to the uncomforting feeling or lower working efficiency or harms the health of people.
(2) Failure mode under common usage: the structure may lose its normal performance due to its large deformation or librations under the influence of load.
(3) Failure modes of structure safety: In the first case, structure deformation or strength reaches its maximum under the extreme load, and thus structure suffers the largest damage or collapses. Fatigue damage of structure occurs under common load in the second case.

At present, there are five criteria for judging structure failure:
a. Criterion of strength damage
b. Criterion of deformation damage
c. Criterion of energy damage
d. Dual-criteria of deformation and energy damage
e. Criterion of oscillation damage.

4. CONCLUDING REMARKS

The study on urban rail transit is still under development, and hence the theory of seismic design for existing bridges in urban rail transit is far from being well established during their construction. The possible defects with different extents existing in these bridges calls for specific methods and techniques based on new concepts to retrofit there structures.

For the practical application of the performance-based seismic design method, the damage index has to be defined to quantify the performance of rail transit. Moreover, designers should perform multiple disaster analysis based on lifetime design method in parallel with the establishment of national and trade specifications and laws along with corresponding insurance system.

REFERENCES

FAN lichu.(1997). Some Problems in Seismic Design for Modern Urban Bridges.Journal of Tongji University, 25(2):147-154.
ZHONG Wan-xie , LIN Jiahao , WU Zhigang ,et al.(2000) Development of Analytical Method for Long-span Bridges[J] Journal of Dal ian University of Technology, 40(2):127-134.
YU Jitao.(2005). Model Selection of Straddle Monorail Station. Symposium of Design for Chongqing Straddle Monorail System. China communications Press.
FAN lichu, LI jianzhong, Wang junjie. (2001).Seismic Design of Viaduct. China communications Press.
M. J. N. P riestly, F. Seible, G. M. Calvi. (1997).Seismic Design and Reinforce of Bridge. China communications Press
Wang Guangyuan, Cheng Shuxun.(1997) .The Theory and Apply of Soft Design for Structure Systems. National Defense Press.
Helmut Krawinkler.(1999)challenges and progress in performance-based earthquake engineering, *International Seminar on Seismic Engineering for Tomorrow – In Honor of Professor Hiroshi AkiyamaTokyo, Japan, November 26.*

Vision 2000 Committee.(1995). Performance-based engineering of building. Miranda E. Seismology Committee of the Structure Engineer Association of California Oakland：Wiley Inc．

NCHRP report 472.(2002) Comprehensive Specification for the Seismic Design of Bridges. Transportation Research Board National Research Council.