The Application of Computer Simulation Technology in Seismic Reliability Random Vibration Analysis of Shear Wall Structures

Rong Tang\(^1\), Yinli Guo\(^2\)

\(^1,2\)Wuchang University of Technology, Wuhan, Hubei, China, 430223

*E-mail: 834034693@qq.com

Abstract. In recent years, the computer simulation technology has been widely studied, among which the seismic reliability theory of the structure and the seismic performance evaluation of the structure is widely concerned. The seismic reliability analysis of structures is of great significance to the seismic performance evaluation, design and decision of structures. Taking earthquake action as a random process and using random vibration theory to study the probabilistic characteristics is an important development of structural seismic theory. In the more than half a century since Housner first used stochastic processes in 1947, the random vibration theory has been applied and developed rapidly in engineering seismic analysis, and has increasingly become a more advanced and reasonable seismic analysis tool.

Keywords: Computer Simulation, Shear Wall, Seismic Structure, Reliability Analysis

1. Introduction

Related research work in China began in the early 1960s, and gradually became active in the 1980s. However, the research and analysis of seismic response of engineering structures by using the random seismic theory is far from enough at home and abroad, which is not commensurate with the advanced nature of this theory. Although the random vibration theory has been studied in many aspects in the seismic field of bridge engineering, underground engineering, derrick structure, large-span structure and so on, and some research results have been obtained, due to the complexity of the random vibration theory, it is seldom applied in the seismic design of practical engineering.

2. Research status of random vibration of structure

2.1. Nonlinear random vibrations
In the early 1960s, the diffusion process and stochastic differential equation were introduced into the random vibration, and the nonlinear random vibration received great attention. The FPK method for solving nonlinear random vibration was proposed by Fokker, Plank, Kolmogorov, etc. Subsequently, the rigorous mathematical foundation of FPK method was established\textsuperscript{[1-2]}. However, for the FPK method of nonlinear system, only the exact stationary solution of the single-degree-of-freedom system excited by white noise can be obtained. Therefore, the approximate methods (random mean method, moment method, statistical linearization method, etc.) are proposed to solve the nonlinear random vibration problem.

2.2. Solutions of non-stationary random vibration

For random loads, such as wind load and wave force, which obviously does not conform to the assumption of stationary, the vibration of the structure under such loads is non-stationary random vibration. Priestleym. B proposed a special kind of non-stationary process-modulation random process-and Hammond JK proposed a frequency-domain method of evolution response spectrum under such non-stationary excitation\textsuperscript{[3-4]}. In general, the state space dynamic equation and the complex modal analysis are more effective in the non-stationary response.

2.3. Random vibrations of large structures

The multi-point excitation with a certain time and space correlation between each point excitation generally appears in the multi-degree of freedom system. Many scholars in the world pay attention to the study of random vibration with multi-point excitation. When Liu Yuntian et al. studied the spatial-temporal correlation characteristics of seismic excitation, they used two-step correlation spectrum expansion, and obtained the random response of structure directly by means of structural mode decomposition.

3. Seismic response analysis method based on computer simulation technique

3.1. Mode decomposition reaction spectrum method

In 1959, Housner gave the first design spectrum based on the response spectrum theory. Since then, the method of mode superposition response spectrum has become the leading method for structural seismic analysis. Two key problems in the application of mode decomposition response spectrum method are the combination mode of maximum reaction and the mode selection method of participating in the combination. The commonly used modes of reaction combination include the CQC method considering the mode correlation and the SRSS method without considering the mode correlation.

In the seismic analysis, the calculation diagram of the high-rise frame structure is simplified to the shear layer model, in which the vertical load-bearing members of the whole structure are combined into a total vertical bar, and the mass is concentrated on each floor, thus forming a series mass system model of the cantilever beam.

The calculation diagram of shear layer model of high-rise frame structure is shown in figure 1 below.
The time history of the differential equations of structural motion at the ground acceleration is \( x \). The excitation is expressed in matrix form as

\[
M \ddot{x} + C \dot{x} + Kx = -MEg(t)
\]

(1)

Where: 
- \( M \) - \( n \times n \) order mass matrix
- \( K \) - \( n \times n \) stiffness matrix
- \( C \) - \( n \times n \) damping matrix
- \( X \) - \( n \times 1 \) times the unit vector of order 1

![Figure 1](image1.png)

**Figure 1.** Schematic diagram of shear layer model calculation of high-rise frame structure

In one case, the cast-in-place reinforced concrete frame structure has 12 floors, each with a height of 3.3m. The concrete grade of the column is C30, and the concrete grade of the beam is C20. The span of the beam is 4.5m, the section size is, the section size of the column. The plane figure is shown in figure 2:

![Figure 2](image2.png)

**Figure 2.** The plan of the high-level frame
The natural vibration frequency of the structure calculated by SAP modeling is compared with the calculated value by virtual excitation method. The results are as table 1:

| Order number | SAP  | The absolute value | The virtual excitation | The relative error |
|--------------|------|--------------------|------------------------|--------------------|
| 1            | 1.1614 | 1.0502 | 0.1112 | 9.57% |
| 2            | 2.2112 | 2.1909 | 0.0203 | 0.92% |
| 3            | 2.2864 | 2.209  | 2.209  | 3.39% |
| 4            | 2.8913 | 2.803  | 2.803  | 3.05% |
| 5            | 2.9679 | -      | -      | - |
| 6            | 3.5458 | -      | -      | - |
| 7            | 3.719  | -      | -      | - |
| 8            | 4.267  | -      | -      | - |
| 9            | 4.5209 | -      | -      | - |

The comparison results show that the virtual excitation method is feasible to calculate the natural frequencies of structures. Since it is impossible to combine all modes in structural analysis, the natural frequencies and modes are rarely solved by direct analytical methods. Instead, numerical methods such as rayleigh-ritz method, Lanczos coordinate method and subspace iteration method is used to obtain the first several modes starting from the lowest mode. Because the high-frequency vibration energy of the excitation structure with high order mode is rapidly attenuated in the process of propagation, the low-order mode with a certain order is generally combined in the seismic response calculation of the structure. For multi-high-rise buildings, the mass participation coefficient accumulator is generally used to judge whether the number of modes considered meets the requirements. How to choose the main mode of structural seismic response to effectively reduce the number of modes has become an important link in the application of mode decomposition method to spatial structures. At the same time, complex problems such as multi-point input effect and the applicability of design response spectrum should be considered when the response spectrum method of mode decomposition is used to analyze the seismic response of large-span spatial structures.

3.2. Dynamic time-history analysis method

Due to the vibration mode decomposition method in the calculation using the superposition principle, applies only to calculate the earthquake response of structure of linear phase, when the span increases, the geometric nonlinear effect, or the ground motion intensity level is higher, structure in elastic-plastic stage, use this method to solve the structure earthquake effect, theory is no longer valid. The time history analysis method developed in the 1950s is a numerical method directly based on the structural dynamic equation. This method USES the direct integral technique to solve the dynamic equation. According to the need to solve the coupled equations, it is divided into two types: explicit
method and implicit method (such as the central difference method).

The dynamic time-history analysis method has been widely used to calculate the seismic response of long-span spatial structures. However, due to the large amount of time history analysis, the correct analysis and judgment of the calculated results depend on the high quality of the structure analysis of the engineers. Most importantly, the calculation results of the time-history analysis method depend on the selected ground motion input, and different ground motion records of the same site may lead to very different results. In order to reduce the uncertainty of the analysis results and to reliably grasp the whole process of the structure's catastrophic failure under earthquake, the engineering designers used a series of ground motion inputs with increasing intensity to analyze the structural dynamic time history one by one.

4. Conclusion

In recent 10 years, some influential people in the field of earthquake resistance at home and abroad are seeking a more reasonable solution to this challenging problem. As a modern emerging discipline, random vibration has attracted a large number of scientists and engineers to conduct in-depth research since its establishment in the 1950s due to its extensive engineering background, and its basic theoretical framework should be said to have been established long ago. But applications in engineering have so far been limited to simpler models. The main reason is that the calculation method has not been a big breakthrough. Next, the more important problem is how to maintain and expand the advantages, develop the theoretical achievements, and turn them into the advantages of engineering.

References

[1] Dai J, Gao W, Zhang N, et al. Seismic random vibration analysis of shear beams with random structural parameters[J]. Journal of Mechanical Science & Technology, 2010, 24(2):497-504.

[2] Jun, Dai, Wei. Seismic random vibration analysis of shear beams with random structural parameters[J]. Journal of Mechanical Science & Technology, 2010.

[3] Tung A T Y, Kiremidjian A S. Application of System Reliability Theory in the Seismic Analysis of Structures[J]. Earthquake Spectra, 1992, 8(3):471-494.

[4] Daneshjou K, Fakoor M. Efficient Algorithm for Reliability Analysis of Structures under Random Vibration[J]. Journal of Solid Mechanics & Materials Engineering, 2007, 1(11):1293-1304.

[5] Wen Y K. Application of Random Vibration Method to Safety and Damage Analysis of Buildings and Structures[J]. Studies in Applied Mechanics, 1986, 14:511-523.

[6] Yuanqiang T, Dawen S, Xinghua L. The Application of ANSYS on the Random Vibration Analysis of Beam-shell Structure[J]. new technology & new process, 2009, 17(5):568-72.

[7] S, D, Xue. Random Vibration Study of Structures under Multi-Component Seismic Excitations[J]. Advances in Structural Engineering, 2016.