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A Succinct Review Of The Analysis Of Various Types Of Structures Subjected To Random

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Abstract. *The pseudo excitation method (PEM) of random vibration analysis (RVA) is an efficient way of evaluating the seismic response of structures. Because of the cross-correlation terms between different participating modes and between the excitations, this method is an accurate, complete quadratic combination (CQC) method. The Response Spectrum Method (RSM), often used in earthquake engineering, ignores the importance of randomness of structural parameters, i.e., randomness emerging from geometric or material characteristic variability. These parameters, when neglected, would cause a severe problem for seismic evaluation. The spatial effects of ground motion, the wave passage and incoherence effects are essential in determining the safety of long-span space lattices; when not considered, they make the results unreliable for such structures.The RVA and Time History Method can sufficiently accurately incorporate ground the ground motion's spatial effects. The proposed pseudo-excitation method is quite effective in generating seismic design parameters. It also incorporates the randomness introduced by the various elements and avoids difficulties related to the time history method. The random vibration method provides a modest and competent solution for multiple seismic excitations. Fatigue failure can also be conveniently evaluated using the pseudo-excitation method of random vibration analysis. This research aims to investigate the seismic response of structures utilising a PEM of random vibration technique.*
Keywords: *pseudo excitation method (PEM), complete quadratic combination (CQC), response spectrum method (RSM), random vibration analysis (RVA), spatial effect, wave passage effect*

INTRODUCTION

Random vibration analysis plays a crucial role in assessing the dynamic behaviour of civil engineering structures subjected to stochastic loads such as wind, earthquake, traffic, and ocean waves. Unlike deterministic loads, which their magnitude and direction can precisely characterise, random loads exhibit statistical variability, making their analysis more challenging. A thorough dynamic analysis method is required to calculate response quantities for moderately or substantially time-dependent loads, presuming that the structure is deterministic and the loading history is thoroughly described or comprehended, i.e., it follows a specific rule or a precise time function, such as a constant, linear, harmonic, or other recognised time function. The dynamic analysis is apposite since all necessary parameters may be uniquely determined or known in such a structural and loading condition.[1]
In practice, the major challenge in dynamic structural analysis is correctly evaluating the loading functions and their properties, such as frequencies, durations, amplitudes, and phases. But we have little information on loading parameters due to a lack of understanding of complex excitations in nature, which are generally derived from historical data or observations of phenomena that occur randomly, such as earthquakes and sea waves. Wind loading on high-rise buildings and towers and traffic loading on bridges are also examples of random vibrations. The only information available comes from past occurrences, and a probabilistic technique can be utilised to characterise the structural responses. If the excitation loading varies arbitrarily over time, the subsequent answer will be random. Random vibration is the subject of such a response mechanism, and its characteristic properties can be calculated using statistical and probabilistic methods. Earthquakes are the most destructive random vibrations to people's

lives and property [2]–[4], so the random seismic response of different types of structures should be comprehensively studied. Not only can the displacements and internal forces, commonly required in structural designs, be computed using the random vibration analysis method, but it also has advantages over the traditional dynamic approach of seismic analysis. For example, the fatigue damage to life at some high-stress points can be evaluated using the power spectrum density (PSD) functions of some exciting responses and their moments, and the spatial effects of seismic action can be incorporated into the evaluation.Due to the complexity of calculating the role of cross-correlation in determining the structural response of a system under random vibration, it is frequently overlooked if cross-correlations are ignored, natural frequencies in beams on elastic foundations and cylindrical or spherical shells cluster together, resulting in significant inaccuracy [5].

The response spectrum approach fails to consider spatial effects, such as wave passage and incoherence, which are crucial in long-span space lattices. Random vibration and time history methods can accurately handle wave passage effects. However, they require a suitable set of ground motions and scaling or modification of the chosen time history, resulting in inconvenient implementation, excessive computation time, and doubt about sufficient input curves for a reliable statistical average. The pseudo-excitation approach avoids the challenges of creating numerous spectrum-matching input time histories and generates seismic design parameters quickly. The random vibration method [6]–[9] is a simple and efficient way to deal with multiple excitation seismic analyses, making it suitable for dealing with spatial effects issues like time history analysis. Yet, many engineers still find it challenging to apply the random vibration method to complex structural seismic analysis, and this could be because the traditional random vibration techniques are computationally inefficient and complex.Lin proposed the pseudo-excitation technique (PEM) [8], a very efficient and accurate random vibration analysis method. The computational efficiency of the PEM was found to be significantly higher than that of traditional random vibration methods [10], [11]. The PEM can efficiently and accurately analyse the random vibration responses of complex structures subjected to stationary or non-stationary random excitations [12]. PEM provides accurate structural reaction data without relying on a specific ground motion input curve. It includes cross-correlation terms between participant modes and excitations, ensuring accuracy. Stationary random analyses are transformed into harmonic ones, while non-stationary analyses are transformed into deterministic transient ones, making them easy to solve.Random Vibration Analysis Considering Uncertainty of Structural Parameter. Seismic analysis of engineering structures often relies on deterministic models, neglecting the randomness arising from construction and material variations. In reality, most structures are irregular due to construction imprecisions. Discrepancies in dimensions and material understanding can lead to uncertainty in mass and stiffness.

The unpredictability of dynamic response in such engineering structures with unknown parameters should not be overlooked, as it might have severe consequences in engineering practice. As a result, in real engineering applications, investigating the problem of random structures susceptible to random seismic excitation is critical. Among various methods available to incorporate structural randomness, the pseudo excitation method (PEM) [13]–[19] is a modest and mighty tool for random vibration analysis.

A new hybrid PDD-PEM method for analyzing stationary random vibration of structures outperforms standard MCS, providing more computationally efficient design solutions and sensitivity estimates for RDO and RBDO problems [20].

Random Vibration Analysis to Evaluate the Seismic Response of multi-story frames

Traditional building seismic response assessments use the response spectrum method, which is computationally inefficient due to ground motion. A pseudo excitation method (PEM) [21], [22] was proposed for three-dimensional tall buildings, including foundation interaction, to obtain seismic response more computationally simply than the traditional method. This method offers additional benefits over the response spectrum approach.

Symmetric structures must withstand random vibrations during earthquakes, making the implication of random vibration analysis for eccentric structures much more significant. The power spectral density analysis [23] has been used to test the issue of setback buildings with different area setback ratios and height setback ratios subjected to random earthquake excitations. The pseudo-excitation method [24] has also been applied to the study of towers, proving to be an effective method for analysing random vibrations. The pseudo-excitation method is ideal for random vibration analysis in multi-story structures subjected to wind loads, but more effective methods are needed for seismic loading. Other approaches, such as the Probability Density Functions of linear structural responses and the Probability Transformation approach [25], are more suitable for seismic loads. The Direct Probability Integration Method (PTM) [26] was proposed to solve non-Gaussian excitation and random parameters problems, but it relies on the relationship between the characteristic function and the PDF of a linear system.

Random Vibration Analysis to Evaluate the Seismic Response of Bridges and Long Span Structures Subjected to Multi Support Excitations

Uniform excitation is suitable for high-rise buildings but insufficient for long-spanned structures like bridges, stadiums, nuclear power plants, and dams. Multiple excitations with spatial variability are preferred for long-span bridge [27] dynamic analysis.

The pseudo-excitation method has been extended to multi-point excitation conditions, using MIMO random differential equations [10] of motion for seismic analysis. This method is computationally convenient and efficient for multiple excitation problems.

While investigating multiple and single support excitations, it was deduced that multi-support excitation is recommended for long-span space lattice and cable structures. This pseudo-excitation method [28], a Complete Quadratic Combination method, provides accurate results comparable to time history analysis. In 2008, the pseudo-excitation method [29] was recommended as the fundamental tool in the Chinese building code titled "Guidelines for seismic designs of highway bridges." It has been recognised as a highly efficient and precise approach for random vibration analysis of structures in stationary and non-stationary conditions. PEM is also making significant progress in the area of high-speed trains. Zhang et al. suggested an optimised methodology [30] to explore the seismic analysis of multi-supported structures subjected to spatially changing ground motions based on the theory of the PEM.

Two improved pseudo-excitation methods [31] have been developed to evaluate the seismic response of cable-stayed bridges. The direct displacement approach and colossal mass method show that fundamental frequencies significantly influence structural seismic response.

The pseudo-excitation method, combined with accurate modal integration, has been demonstrated to calculate footbridge [32]– [34] reaction when people are present. With the natural walking variability in mind, a simple spectral model is proposed to account for intra- and inter-pedestrian variability.

Using a simplified multi-span structure model, Zhao investigated multi-support excitation effects [35] on structural response parameters. The study finds that wave-passage frequency affects the function's period, and the coherence function affects amplitude attenuation.

The study on the Bosporus Suspension Bridge [36] emphasised the importance of considering seismic spatial variability for a realistic response of structures subjected to multi-support excitation.

Kang et al. found that PEM [37] is essential for seismic analysis of structures under 3D stochastic excitation, but finite element software lacks calculation templates. The following steps will be conducted to obtain the stochastic response of structures using the pseudo-excitation method [37].

1) Select the power spectral density (PSD) and coherency model; 2) decompose the cross-PSD matrix; 3) compose pseudo excitations; 4) modify FEM boundary conditions; 5) apply pseudo excitations; 6) perform harmonic analysis; 7) extract pseudo response; 8) calculate PSD, RMS, and variance.

The non-stationary random vibration of railway bridges under heavy-haul trains using a pseudo-excitation method [38], [39] that considers train-track-bridge coupling dynamics was also studied, recommending the PEM [40] as an efficient method.

The PEM technique, which transforms random rail irregularities into pseudo-harmonic excitation, is crucial for analyzing vehicle-bridge systems under random excitation. Ma and Choi's study found that wave propagation velocities significantly impact the system's random vibration performances and running safety, emphasizing the importance of considering these velocities in calculations.[41].

Zhu and Li improved the pseudo excitation method by incorporating self-adaptive Gauss integration (SGI) technology, reducing computational effort for stochastic response analysis. They also demonstrated system power spectral density charts and used Poisson's crossing assumption for response determination[42].

The pseudo-excitation technique (PEM) was used to determine the unpredictability of excitations and the statistical effects of random responses. Combining conventional integration methods with PEM is crucial for large-scale structures with a broad frequency range. Gauss numerical integration [43]–[45] is commonly used for numerical calculations due to its fewer integral numbers and enhanced accuracy. In this circumstance, self-adaptive technology [46] is induced to participate with the PEM, resulting in an effective method for resolving random vibrations. This method can evaluate the adaptation of random excitation to actual structural responses while measuring, automatically determine critical frequency intervals of random excitation, and intelligently process the defined critical and noncritical frequency intervals. By incorporating self-adaptive Gauss integration (SGI) technology as a unique combining integration, Zhu et al. [47] sought to improve the efficiency of the PEM.

Random Vibration Analysis to Study Characteristics of the Dynamic Behaviour of Earth Dams

Random vibration techniques are valuable for predicting earthquake response statistics in earth dams due to the unpredictable nature of ground motions and the sensitivity of dams to excitation details. Gazetas et al. [48] developed a methodology to investigate the dynamic behaviour of inhomogeneous shear beams excited by strong vertical shear waves, avoiding unrealistic simplifying assumptions in standard random vibration theories. Engineers face uncertainty in evaluating the dynamic performance of earth dams, and various analytical approaches, soil attributes, and accelerograms can result in a wide range of stresses, displacements, and response values. Inhomogeneity caused by the dependence of soil modulus on adequate confining pressure has been discovered to be an essential factor in the dynamic analysis of earth dams and should be considered.

Random Vibration Analysis for Equivalent Linear Site Response Analysis.

Deng et al. introduced an alternative Soil-Structure Interaction [49] analysis using acceleration response spectrum instead of acceleration time history, transforming input into PSD function, and calculating response PSDs. This method derives design parameters and provides stable mean response. Random vibration theory [50] site-response analysis predicts site amplification without input-time histories, enabling seismic-hazard studies for nuclear power plants. It uses Fourier amplitude spectra or power spectral densities for input motion.

RVT [50] over-predictions are more common for moderately soft soil deposits with high impedance contrast at the soil/rock contact, and they occur primarily at site fundamental frequencies. The amount of the overprediction in the soft site tested was relatively insensitive to the increase in inelastic demand; on the other hand, the overprediction in the stiffer site rose as the site softened due to rising inelastic demand. Compared to many analyses [51] in the time series approach [52], RVT would only require one study to determine the mean amplification function for a site and input spectrum, resulting in significant computational savings.

CONCLUSION

Civil engineering structures often have randomness due to material, geometric, or construction factors. The response spectrum method does not consider this randomness, but the pseudo-excitation method incorporates it. However, the conventional response spectrum method cannot account for wave passage effects, making its results less reliable. Random vibration and time history methods can accurately handle wave passage effects, but time history analysis requires selecting ground motions, scaling, and simulations. The proposed pseudo excitation method eliminates these challenges and is efficient at generating seismic design parameters. It also guards against un-conservatism by providing a stable mean response directly with design response spectra. Random vibration analysis is indeterministic and can predict safety probability, making it convenient for evaluating fatigue failure.

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