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Developments of modern science and technology have greatly enhanced the ability of engineering community in understanding the phenomena, mechanism and performance of engineering structures and systems. Meanwhile, the defect and inadequate of deterministic methodologies in modeling and analysis of engineering systems also exposed the importance of uncertainty analysis. As a matter of fact, it is recognized more and more clearly that the randomness propagation in a physical system plays an important role in understanding and controlling many phenomena and behaviors of engineering structures and systems, particularly those emerging in nonlinear mechanics and systems.

To capture the rule of randomness propagation in a physical system, including the propagation mechanism, multi-scale random fluctuations and coupling effects in complex engineering systems, two methodologies exist: moment evolution and probability density evolution. This lecture would stress on the later. On the basis of the principle of probability preservation and its random event description, a new kind of general probability density evolution equation (GPDEE) is introduced which could capture the randomness propagation in a dynamical system. Then this kind of equation is extended to general physical systems and therefore reveals the secret of randomness propagation in a physical system. Some recent developments using GPDEE are summarized, including: (1) the physical random models for dynamic excitations, especially taking seismic ground motion as an example; (2) the multi-scale stochastic damage model for concrete materials and structures; and (3) a physical approach to the global reliability of structures, respectively. Besides, some typical engineering applications are illustrated as well.