

# Chapter 1

## Uncertain Static and Dynamic Analysis of Imprecisely Defined Structural Systems

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### ABSTRACT

*This chapter presents the static and dynamic analysis of structures with uncertain parameters using fuzzy finite element method. Uncertainties presents in the parameters are modelled through convex normalised fuzzy sets. Fuzzy finite element method converts the structures into fuzzy system of linear equations and fuzzy eigenvalue problem for static and dynamic problems respectively. As such method to solve fuzzy system of linear equations, fully fuzzy system of linear equations and fuzzy eigenvalue problems are presented. These methods are applied to various structural problems to find out the fuzzy static and dynamic responses of the structures. Also the chapter analyses the numerical solution of uncertain fractionally damped spring-mass system. Uncertainties considered in the initial condition of the system.*

### INTRODUCTION

Structural design and analysis plays a vital role for the structural safety. Most of the structures fail due to the poor design. In the design process the system parameters involved such as mass, geometry, material properties, external loads, or boundary conditions are considered as crisp or defined exactly. But, rather than the particular value we may have only the vague, imprecise and incomplete information about the variables and parameters being a result of errors in measurement, observations, experiment, applying different operating conditions or it may be maintenance induced error, etc. which are uncertain in nature. Basically these uncertainties can be modelled through probabilistic, interval and fuzzy theory.

In probabilistic practice, the variables of uncertain nature are assumed as random variables with joint probability density functions. If the structural parameters and the external load are modeled as random

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variables with known probability density functions, the response of the structure can be predicted using the theory of probability and stochastic processes are studied by Elishakoff (1983). Also the probabilistic concept is already well established for the extension of the deterministic finite element method towards uncertain assessment. This has led to a number of probabilistic and stochastic finite element procedures (Halder and Mohadevan (2000); Antonio and Hoff Bauer (2010)). Unfortunately, probabilistic methods may not be able to deliver reliable results at the required precision without sufficient experimental data. It may be due to the probability density functions involved in it. As such in the recent decades, interval analysis and fuzzy theory are becoming powerful tools for many real life applications. In these approaches, the uncertain variables and parameters are represented by interval and fuzzy numbers, vectors or matrices.

Interval computations introduced by Moore (1966) and various aspects of interval analysis along with applications are explained by Moore (1979). If only incomplete information is available, it is possible to establish the minimum and maximum favorable response of the structures using interval analysis or convex models (Ben-Haim and Elishakoff (1990); Ganzerli and Pantelides (2000)). Moreover structural analysis with interval parameters using interval based approach has been studied by various authors (Rao and Berke (1997); Muhanna and Mullen (2001); Qui et al. (2006)). Zhang (2012) used interval finite element method for uncertain reliability assessment of structures. An interesting method is proposed by Chen et al. (1995) for computing the upper and lower bounds on frequencies of structures with interval parameters. Modal analysis of structures with uncertain-but-bounded parameters via interval analysis is investigated by Sim et al. (2007). Interval analysis for vibrating systems is discussed by Dimarogonas (1995). The uncertainty behaviour in mechanics problems is explained by Muhanna and Mullen (2001) through interval –based-approach in an excellent way. Moens and Vandepitte (2004) studied an interval finite element approach for the calculation of envelope frequency response functions. Qui and Wang (2005) proposed some solution theorems for the standard eigenvalue problem of structures with interval parameters. Interval eigenvalue analysis for structures with interval parameters is studied by Chena et al. (2003). using interval finite element method. Gao (2007) analysed natural frequency and mode shape of structures for both random and interval parameter using random and interval factor method. Truss structure is used for the analysis.

Fuzzy set theoretical concept was developed by Zadeh (1965) which is further used in the uncertain analysis of structures in a wide range. As discussed above, if the structural parameters and the external loads are described in imprecise terms, then fuzzy theory can be applied. As such, Valliappan and Pham (1995) applied fuzzy logic for the numerical modelling of engineering problems. An optimization algorithm is developed by Munck et al. (2008) for fuzzy properties based on response surface for the calculation of fuzzy envelope and fuzzy response functions of models. Fuzzy structural analysis using level optimization is excellently studied by Moller et al. (2000). The transformation method has been applied for the simulation and analysis of structural systems with uncertain parameters by Hanss (2002). Also an important book is written by Hanss (2005) in which applications of fuzzy arithmetic into engineering problems are described. Fuzzy behavior of mechanical systems with uncertain boundary conditions is investigated by Chekri et al. (2000). Nonlinear membership function for fuzzy optimization of mechanical and structural systems is discussed in Dhingra et al. (1992). Reuter and Schirwitz (2011) have developed the cost-effectiveness of fuzzy analysis. Fuzzy arithmetical approach for comprehensive modelling and analysis of uncertain systems is applied to the simulation of automotive crash in structural dynamics as well as to the simulation of landslide failure in geotechnical science and engineering in Hanss and Turrin (2010). In both applications, epistemic uncertainties are considered which arise from some lack of knowledge, from simplification in modelling as well as from subjectivity in implementation. Rama

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