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Fuzzy analysis for stability of steel frame with fixity factor modeled as triangular fuzzy number

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Abstract. This study presents algorithms for determining the fuzzy critical loads of planar steel frame structures with fixity factors of beam – column and column – base connections are modeled as triangular fuzzy numbers. The finite element method with linear elastic semi-rigid connection and Response Surface Method (RSM) in mathematical statistic are applied for problems with symmetric triangular fuzzy numbers. The α – level optimization using the Differential Evolution (DE) involving integrated finite element modeling is proposed to apply for problems with any triangular fuzzy numbers. The advantage of the proposed methodologies is demonstrated through some example problems relating to for the twenty – story, four – bay planar steel frames.

Keywords: steel frame; critical load; fuzzy connection; response surface method; differential evolution algorithm

1. Introduction

When we analyze the stability of semi-rigid connection steel frame structures, the fixity factor of connection has a significant influence on the buckling resistance capacity of a steel frame. In practice, however, many parameters like worker skill, quality of welds, properties of material and type of the connecting elements affect the behavior of a connection, and this fixity factor is difficult to determine exactly. Therefore, in a practical analysis of structures, a systematic approach is needed to include the uncertainty in the joints behavior and the fixity factor of a connection modeled as a fuzzy number is reasonable (Ali Keyhani et al, 2012).

In recent years, the static analysis for planar steel frame structure with the fuzzy connection has been reported (Ali Keyhani et al, 2012). However, the buckling analysis for determining the fuzzy critical load by using exact approach has been limited. For the rigid frame, Tuan et al (2015) presented an approach by using Response Surface Method (RSM) for fuzzy free vibration analysis of linear elastic structure in which response surfaces (surrogate functions) in terms of complete quadratic polynomials are presented for model quantities and all fuzzy variables are standardized. The usage of the RSM shows that this approach has effectiveness for the complex structural problems with a large number of fuzzy variables. However, the RSM is only suitable for problems which all fuzzy variables are modeled as symmetric triangular fuzzy numbers. For the problems with non-symmetric triangular fuzzy numbers, the fuzzy

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structural analysis must use another approach. Anh et al (2014) presented an optimization algorithm for fuzzy analysis by combining the Differential Evolution (DE) with the α – level optimization. DE is a global optimization technique, which combines the evolution strategy and the Monte Carlo simulation, and is simple and easy to use.

In this paper, the fuzzy critical load of planar steel frame structure with fuzzy fixity factor is determined by using two approaches for solutions. The first approach is based on the classical finite element method in combination with the response surface method for fuzzy fixity factor input and obtained fuzzy critical load output. This is implemented similarly to the approach which can be found Nguyen Hung Tuan (2015), however, the finite element is extended with the linear elastic semi-rigid connection which can be found Vu Quoc Anh (2002). The second approach is based on finite element model by combining the α – level optimization with the Differential Evolution algorithm which is a population-based optimizer. The DE is similar to the genetic algorithm (GA), but it is simple, easy for application and its global convergence and robustness are better than most other GAs (Storn et al, 1995 and Mezura-Montes, 2013). Two solution approaches are different and applied to problems with various fuzzy inputs. In the first approach, the fuzzy fixity factor modeled as the non-symmetric triangular fuzzy number has not considered yet. This is implemented in the second approach and that is the advantage of DE. A comparison of the fuzzy critical loads between the RSM and the DE is presented by considering the twenty floor, four bay planar steel frame structure subjected to concentrated loads at nodes, in which the fixity factors are modeled as symmetric triangular fuzzy numbers. The obtained results are not significantly different. Hence, the α – level optimization in combination with the Differential Evolution algorithm is applied to this analysis, in which considering the fuzzy fixity factors at the boundary constrain are modeled as non-symmetric triangular fuzzy numbers. In addition, the determinant results of the proposed algorithms are also compared with ones of the SAP2000 software. Moreover, the computational efficiency and applicability of the DE optimization in the context of fuzzy critical load analysis is demonstrated through on the example of that frame subjected to uniform loads uniformly distributed on the beams.

2. Finite element with linear semi-rigid connection

The critical load is determined by solving the Eigenvalue equation

$$Det([K]-\lambda[K_G])=0 \tag{1}$$

where $[K]$ is the assembled stiffness matrix of the frame and $[K_G]$ is the assembled geometric stiffness matrix of the frame.

The frame element with linear semi – rigid connection as shown in Fig. 1, in which E - the elastic modulus, A – the section area, I – the inertia moment, and k_i – rotation resistance stiffnesses at connections (i = 1,2).

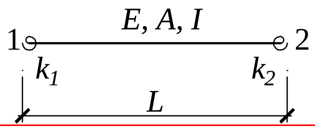

Fig. 1 Frame element with linear semi-rigid connection

The element stiffness matrix - $[K^{el}]$ and the element geometric stiffness matrix - $[K_G{}^{el}]$ of the frame are given as following (Vu Quoc Anh, 2002)