Amirkabir Journal of Civil Engineering

Amirkabir J. Civil Eng., 53(2) (2021) 105-108
DOI: 10.22060/ceej.2018.15001.5819

Developing the plastic analysis theory for braced frames and its optimization using genetic algorithm to predict the collapse of steel braced frames

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ABSTRACT: The plastic analysis method is one of the most effective and most used methods in this field. Analysis of moment frames has been carried out with the aid of simple plastic analysis by many researchers. However, the analysis of braced frames due to the buckling of braces and the presence of axial and shear forces simultaneously in the frame members is very complex, and therefore, little research has been done in this area. In this research, a special theory based on a combination of mechanisms method for the plastic analysis of steel braced frames has been presented. Using the genetic algorithm, a program has been proposed to determine the failure mechanism and collapse load of the steel braced frames based on this methodology. The comparison of the results shows that the proposed formula is very accurate and can accurately determine the failure mode and its corresponding load. According to this, three arbitrary frames with differences in the number of stories are investigated. The collapse mechanism corresponding to the critical load factor is obtained using of the Genetic optimization algorithm and the virtual work theory. For Verification, a pushover analysis is performed for the determination of the collapse mode of each frame. In examples one and two which the frames are low-rise, the solution is the same, while in the third example, a slight difference is observed in the location of hinge formations. However, this error had been observed in moment frames due to the difference of the principals in the two applied analysis.

Review History:

Received: 9/28/2018
Revised: 11/8/2018
Accepted: 11/8/2018
Available Online: 12/15/2018

Keywords:

Plastic Analysis
Kinematic Theory
Braced Frame
Optimization
Genetic Algorithm

1. INTRODUCTION

Plastic analysis and design of frames have been investigated by various researchers since the middle of the last century. One of the latest studies is done by Greco et al., in 2017, studied the seismic collapse of moment frames, which presented a method for simulating seismic state and used SAP2000 software to validate this method [1]. Also, Saedi Daryan and Palizi in 2018 determined the failure mechanisms and collapse loads of steel moment frames using plastic analysis and using a modified dolphin metaheuristic algorithm [2].

Although numerous studies have been carried out on the determination of the collapse load and the failure mechanism of moment frames, few studies have been done to determine the failure mechanism of braced framing with the help of the plastic analysis theory.

2. THEORY

In this research, an automated method for evaluating the critical collapse loads and the collapse mechanisms has been introduced. The approach used in this method is based on the use of plastic analysis theory in constructing basic mechanisms and then combining them, which is based on the elimination of braces and the effect of this elimination on the plastic capacity of other members of the structure. Thus, with the assumption of the creation of a mechanism on each brace, there is a new plastic capacity for other members of the structure. By removing braces and knowing the new plastic capacities of the members and using the plastic analysis theory for this new frame, it is possible to find the collapse mechanism of the frame. By eliminating other braces, an operation similar to the above-mentioned one is performed to determine the most critical condition for which the minimum collapse load is obtained. For this purpose, for the frame in question, the tensile yield limit load is placed instead of the brace. Under the effect of each of these brace loads, the axial force and shear force of each member following the creation of mechanism in each of the braces are stored separately in columnar matrices in MATLAB software. The reduced capacity of the members can now be calculated. For different brace mechanisms, new structures are analyzed with the plastic method. Due to the increasing volume of computations for combining the mechanisms of larger frames, a genetic optimization algorithm is used to combine these mechanisms. Finally, the code will provide the collapse mechanism for the desired frame. For verification, after modeling the main frame in ETABS 2015 software and performing standard non-linear pushover analysis, the results are compared with the written code.

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2.1. Impact of axial and shear force

When obviating the braces, and replacing the yielding forces instead, axial and shear forces will be created in other members of the frame (beams and columns). The presence of axial and shear forces will change the properties of the cross-section of the members. In numerous studies, relationships have been presented for the reduction of the plastic capacity of members by axial forces as well as shear forces separately [3, 4].

2.2. Defining elementary mechanisms

In order to create the elementary mechanisms, a procedure is used in which the compatibility matrix is formed, and is solved by equating the equation to zero due to the assumption in plastic analysis theory that members do not elongate. Using a mathematical process, the required matrix for reaching elementary mechanisms is obtained.

2.3. Determination of collapse loads and combination of basic mechanisms

Collapse loads in a specified mechanism are obtained using Eq. 1. Displacements and rotations of mechanisms are considered virtually, and the internal and external virtual work equations are written.

$$\lambda_c = \frac{internal\,virtual\,work}{external\,virtual\,work} \tag{1}$$

The external virtual work is obtained by multiplying the forces applied to the nodes P in the corresponding displacement of those nodes for each specific mechanism.

$$external\,virtual\,work = P^T d \tag{2}$$

The internal virtual work is also achieved for each mechanism by multiplying the rotations in the plastic hinge r in the plastic moment of the members in which the hinges are formed.

$$internal\,virtual\,work = M_p^T |r| \tag{3}$$

2.4. Combination of basic mechanisms using the genetic algorithm

The Genetic algorithm is used to select the appropriate basic mechanisms for the combination process. Chromosomes are strings of binary bits whose number of bits is considered to be the number of independent mechanisms. Number 1 for each bit indicates that its corresponding mechanism is involved in the combination of mechanisms, and 0 means that it is not involved. Mutation and crossover is also applied are this process.

3. VERIFICATION OF THE INNOVATIVE FORMULA AND THE PRESENTED CODE IN MATLAB

3.1. Example one: a one-span and five-floor frame

The frame and its characteristics is shown in Fig. 1. The

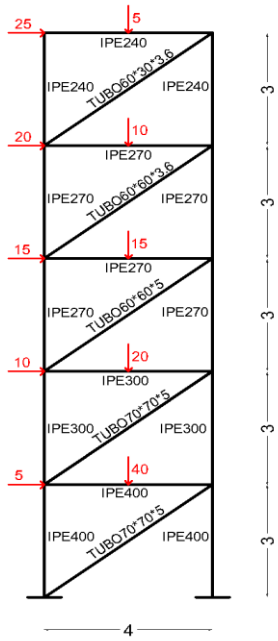


Fig. 1. Example 1

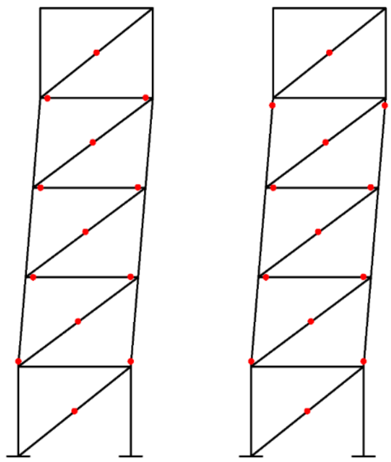
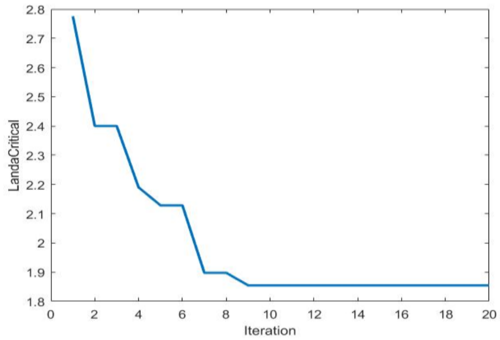


Fig. 2. Right: Collapse mechanism obtained from the code, and Left: Collapse mechanism obtained from static nonlinear analysis in ETABS2015

proposed method showed the failure mechanism in Fig. 2-right, while the pushover result are shown in Fig. 2-left. The only minor difference is observed in the location of a hinge in a column on the fourth floor, which in the model made in ETABS was formed in the fifth-floor beam. It became notable especially with the increase in the number of floors in the structure. The genetic algorithm converged to the minimum load factor of 1.85 after 9 repetitions whose diagram is given in Fig. 3.

4. CONCLUSIONS

In this study, a new formula is presented to evaluate the failure modes of planar frames. This formula, which is presented for the first time for braced frames, is based on



the removal of braces and applying the effects of removing them on the frame then producing the basic mechanisms and combining them. The code written for this approach can automatically calculate the critical collapse mechanism using optimization tools with appropriate accuracy. The efficiency of this method is compared with that of standard nonlinear static analysis. The collapse mechanism matches the results of the written code. At the same time, the computational effort, the accuracy and speed of the innovative formula, the degree of convergence, and its combination with the genetic algorithm are highly satisfactory.

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HOW TO CITE THIS ARTICLE

A. Saedi Daryan, S. Palizi, Developing the plastic analysis theory for braced frames and its optimization using genetic algorithm to predict the collapse of steel braced frames, Amirkabir J. Civil Eng., 53(2) (2021) 105-108.

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