Journal of Constructional Steel Research 130 (2017) 79–87

Contents lists available at ScienceDirect

Journal of Constructional Steel Research

Optimum seismic design of steel frames considering the connection types

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ARTICLE INFO

Article history:
Received 13 March 2016
Received in revised form 5 November 2016
Accepted 8 December 2016
Available online xxxx

Keywords:
Structural optimization
Steel moment frame
Frame connection topology
Structural seismic design
Meta-heuristics algorithms

ABSTRACT

In this paper seismic design optimization of steel moment frames is studied. In addition to element sections, the connection types (simple or rigid) are considered as design variables. Element stresses and story drifts are limited according to the AISC-LRFD design criteria. The heights of the bottom and top columns, heights of the two intersecting beams and the flange widths of beams and columns are compared at each joint in order to control the constructional requirements. Compactness and slenderness for sections and column to beam plastic moment capacity ratio for joints are checked according to seismic provisions of AISC. Optimum results of three examples are obtained utilizing the enhanced colliding bodies optimization and particle swarm optimization and the performance of these algorithms for the present optimization problem are compared.

1. Introduction

Structural designers are interested in selecting variables of a structure in an efficient manner. However, the complex nature of the design criteria is the main obstacle for finding the best solution. One of the major challenges in structural design optimization is to introduce new methods to overcome this problem by the existing computational power. Meta-heuristic algorithms are the best way to solve this kind of problems. The first, oldest, and most popular one is genetic algorithm (GA) [1]. Particle swarm optimization (PSO) [2], ant colony optimization [3] and harmony search [4] are other ones.

Many researchers tried to optimize the weight of steel moment frames with elastic material using static analysis by early meta-heuristic algorithms as well as the recent ones. Talatahari et al. [5] used eagle strategy based on differential method. First, they found some appropriate region and then achieved near optimum results with some mathematic approaches. Kaveh et al. [6] utilized big-bang big-crunch algorithm to optimize trusses and frames. This algorithm was based on weight averaging on choices and the weight of each choice was related to desirability of its objective function. Kaveh and Talatahari [7] extend ant colony optimization (ACO) to improved ACO for decreasing the size of the trail matrix and to increase the speed of the algorithm. They also optimized structures by imperialist competitive algorithm [8]. In this algorithm, agents were considered as countries and they organized colonies. Best agent of each colony was identified as empire and other agents of the corresponding colony tried to get collected near the empire. Aydoğdu et al. [9] optimized real world steel space frames using artificial bee colony algorithm with Levy flight distribution. They considered constructional dimensional constraints and P-Δ effect and optimized 3D steel frame structures. Murren and Khandelwal [10] used the design-driven harmony search in steel frame optimization. This kind of algorithms utilize constrains conditions and demand capacity ratio to produce the next generation. Decreasing the number of iterations was the main advantage of these algorithms. Carbas [11] optimized 3D steel frame structures using enhanced firefly algorithm. In this method some algorithm parameters were changed during the design iteration altering the attractiveness and randomness properties of the algorithm.

In some of these articles, researchers compared their algorithm with their own previous research results. But some research works focused on comparing their algorithm at different conditions to find their abilities. Hasançebi et al. [12] compared seven non-deterministic search techniques in the optimum design of real size steel frames and concluded that the simulated annealing and evaluation strategy are the best ones based on convergence power and robustness. Hare et al. [13] surveyed twelve non-gradient optimization methods in structural engineering. Saka and Geem [14] made an extensive review on mathematical and meta-heuristic applications in design optimization of the steel frame structures. Alberdi and Khandelwal [15] compared the robustness of meta-heuristic algorithms for steel frame optimization under gravity and wind forces. They found out that design driven harmony Search and tabu search are better than other famous

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http://dx.doi.org/10.1016/j.jcsr.2016.12.002
0143-974X/

algorithms. Kaveh and Ilchi Ghazaan [16] compared colliding bodies optimization (CBO) and enhanced colliding bodies optimization (ECBO) for optimizing steel frame structures. They found that the ECBO is better in terms of convergence and robustness power.

Seismic design optimization of steel frames has been studied by some researchers. Xu et al. [17] presented the performance-based seismic design under the equivalent static seismic load for minimizing structural cost and earthquake damage. Gong et al. [18] used nonlinear response history analysis and multi-objective genetic algorithm. Minimum weight, minimum seismic input energy and maximum hysteretic energy of fuse members were their objective functions. Kaveh and Zakian [19] used time history and simultaneous dynamic-static analysis. They employed Charged System Search and improved harmony search as optimization algorithms and the elements cross-sections were considered as variables. Tehranizadeh and Moshref [20] utilized pushover and incremental dynamic analysis. A generalized optimization criteria algorithm that performed sensitivity analysis, so-called “dual method”, was employed to solve a multi-objective optimization problem. Lagaros et al. [21] used linear and nonlinear time-history analysis with natural and artificial ground motion records. They used an evolutionary algorithm for optimization and considered the entire suggestion of the EuroCode3 about development of full plastic moment of displacement-based elements. Gholizadeh and Salajegheh [22] used a combination of the genetic algorithm and simulated annealing to solve the optimization problem. In their paper neural networks were used to reduce the calculation cost of the optimization algorithm and the time history analysis. Kaveh et al. [23] optimized 3D steel structures under the seismic load based on response spectral and equivalent static analysis by cuckoo search algorithm. They found that using spectral and equivalent static analyses lead to nearly identical optimum results.

Steel moment frames that are discussed above have rigid beam to column connections. Semi-rigid connection optimization of frames was performed by many researchers. Simoes [24] was one of the first researchers that optimized frames with semi-rigid connections subjected to stress and displacement constraints using linear programming method. Kameshki and saka [25] used GA for non-linear steel moment frames. Nizar et al. [26] considered costs more carefully by multi-stage production costs. They also considered five types of semi-rigid connections and two types of base plate connections. However, rigid connections have been more popular than semi-rigid connections and their optimization has been studied more extensively. Rigid connections are very expensive compared to the simple ones, but they increase stiffness of the frames and help to satisfy drift and stress constraints. Kripakaran et al. [27] used genetic algorithm for design of moment-resisting steel frames by considering steel and connection costs. First, they found optimum element sections, and then optimized the type of each connection by the GA. Also, they presented a set of optimum results instead of a single one. Alberdi et al. [28] considered simultaneous connection topology optimization and section optimization using the GA, ACO, tabu search and harmony search. Their frames were designed for the wind and gravity loads.

There are some studies on rigid connection type optimization and these do not focus on seismic design. The results of these studies are not fully practical because the constructional criteria are not fully included. The main objective of the present study is the cost optimization of 2D steel moment frames by changing element sections and connection types under the earthquake lateral loads and gravity loads. In addition to stress and drift, constructional and seismic design criteria, form the constraints of the problem. This paper is organized as follows: In the next section, the design criteria of steel structural elements and frames are provided. Section 3, defines the problem and identifies the variables, constraints and objective function of the optimization problem. Optimization algorithms are discussed in Section 4. Some numerical examples are introduced in Section 5. Finally, some concluding remarks are presented in Section 6.

2. Structural design

2.1. Loading

In this study, structural elements are designed according to AISC-LRFD [29] and the load combination for stress and stability check is defined as follow [30]:

$$W = 1.2DL + 1.6LL + EL$$

For modeling earthquake load, some methods are introduced by ASCE [30]. Equivalent lateral force procedure is the simplest and most conservative one and according to this code the base shear is defined as a portion of effective weight. Lateral resisting system type, importance factor, peak ground acceleration, soil condition, structure geometry etc. must be considered for calculating the base shear. The lateral force at each story is a portion of the base shear and its value can be calculated according to the structure's first period and the effective weight of the story.

2.2. Analysis

Displacement-based finite element method which is one of most popular methods to analyze the structures is used in the present work. Also, the second order effects are considered by amplified first order analysis method.

2.3. Strength, stiffness, seismic design and construction criteria

According to AISC-LRFD [29] and seismic provisions of AISC [31], the following conditions must be checked:

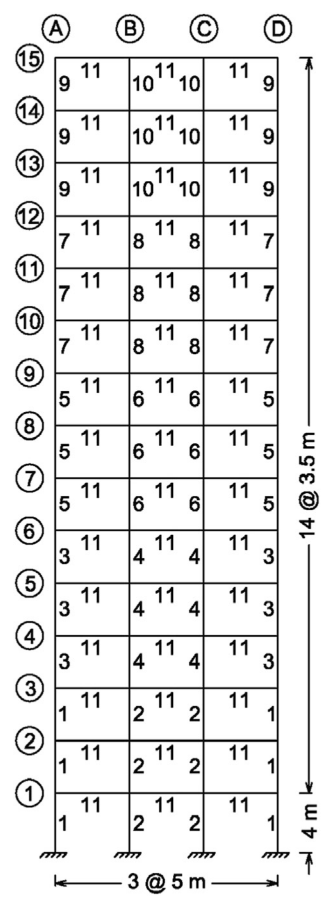

Fig. 1. Schematic of the 15-story frame (Example 1).