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# Optimal Design of Special truss Moment Frame using Genetic Algorithm with MIDA Analysis

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*Genetic algorithm,*
*Seismic optimal design,*
*Modal incremental dynamic analysis.*

## Abstract

Optimization of structures in civil engineering means designing structures in such a way that both technical issues are observed and have the lowest execution cost. Today, due to the limitations of urban lands and the type of use of some structures, special truss moment frames (STMF) have become more important due to their use in large openings. In this paper, the optimization of special truss moment frame by genetic algorithm under modal incremental dynamic analysis (MIDA) has been considered. For this purpose, the optimal design of two three-story frames with one and two openings with the aim of simultaneously optimizing the weight of the structure and its seismic performance is presented. Problem design restrictions are in accordance with AISC341-16. The optimization code is written in MATLAB software environment and OPENSEES software is used for structural analysis. The results show the high capability of this method for optimal seismic design of this type of structures.

## 1.Introduction

By using modern computer methods in recent decades, the analysis of structures can be done with great accuracy and speed. However, in the field of design, this is often done by trial and error with user intervention. Considering that, the purpose of designing structures is to find the best section among the sections available for each member so that it meets the needs of resistance and service [1]. In order to find the best design due to a large number of possible design modes, the search operation cannot be done by controlling all designs. Therefore, considering the discrete nature of the problem, this work is done using numerical methods. So far, many methods have been proposed to optimize discrete problems, which can be referred to as the genetic algorithm method. There are several applications of this type of algorithm in various fields of engineering, including discrete structural optimization, which shows the insight of the resulting answers [2].

The use of special truss moment frames in multi-story industrial and commercial buildings with long spans is one of the main design considerations for designers. These beams have more stiffness and strength than columns due to their construction method and high height [3]. In such structures, seismic energy is lost through special ductile pieces located in the middle of the truss beams and the place of formation of the plastic joint is the middle area of the truss [4-5]. Some studies show that special trusses, in addition to having a suitable breakdown mechanism for seismic areas, also seek to save some steel consumption [6-7]. Special trusses can be designed in the form of x-diagonals, vierendeel and multiple vierendeel panels. (Fig. 1)

So far, a lot of research has been done on the performance as well as the design criteria and limitations of these structures. In the meantime, less attention has been paid to the response modification factor of these frames. Therefore, in this paper, the optimization of a special truss moment frame with the aim of simultaneously optimizing weight and response modification factor by genetic algorithm under MIDA analysis has been considered.

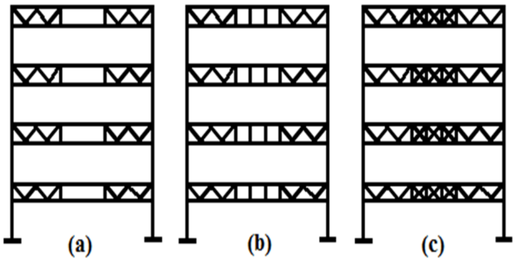

Figure 1. Frame with special truss beam
(a) Vierendeel, (b) multiple vierendeel panels, and (c) x-diagonals

## 2. Modal Incremental Dynamic Analysis(MIDA)

A new technique for the dynamic response of structures is investigated. This applied procedure can predict the approximate seismic performance of the structures and it is fast, inexpensive and results are reasonably acceptable. In fact, this novel method logically combines two different techniques, 'incremental dynamic analysis (IDA)' and 'modal pushover analysis (MPA)', presented by Mofid at el. This method will take advantage of both methodical ideas such as equivalent single degree of freedom of multi-degree structures and the implementation of the different scaled levels of an earthquake record to the provided equivalent SDF structure. Using this procedure, simple approximate curves that present a realistic linear and non-linear seismic behavior of the structure due to the applied scaled level of earthquakes can easily be extracted. Fig. 2 shows the steps of the MIDA method [8-9].

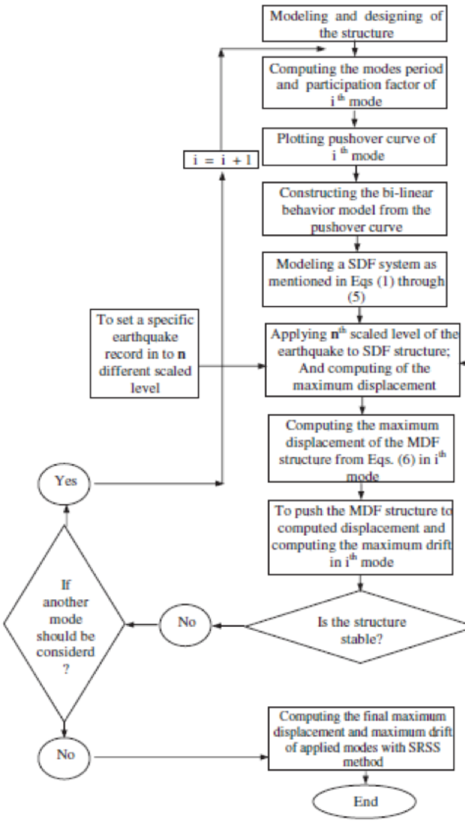

Figure 2. MIDA working flowchart[8]

## 3. Genetic algorithm (GA)

Genetic methods are among the methods developed in the field of artificial intelligence and are one of the most evolved optimization methods inspired by living nature. These algorithms are based on the principles of natural evolution. Genetics is the science that talks about how biological plates are inherited and passed down from generation to generation. Chromosomes and genes are the main transmitters of biological plates in living organisms. They work in such a way that eventually the superior and stronger genes and chromosomes remain and the weaker genes are destroyed. In other words, the result of the interaction of genes and chromosomes is the survival of the fittest. In simple genetic algorithms, the response space (design space) is examined point by point[10-11]. Genetic algorithms begin with the production of selectively or randomly determined primary population members (Courses). Courses are chosen according to their competence to become parents and produce children. After the genetic disciplines, a new combination of them is found using the graft operator, so that the new designs (children) have parts of the two previous designs (parents). The new population then replaces the previous population, and this cycle continues. New populations are usually more qualified. In other words, the population improves from one generation to the next when the algorithm stops when it reaches convergence, or the criterion of cessation is met, or it reaches the maximum of the desired generation[12-13].

## 4. Problem formulation

The design principles of various structural systems are always based on safety and economics, which are the basic concepts of optimization. In this paper, the objective function is to minimize the weight of the structure and maximize the coefficient of behavior simultaneously. The geometric arrangement of the truss, the sections of the members, the height of the truss, and the length of the special area are considered as design variables. This objective function can be represented as follows [14]:

$$Minimize\ f = W + \frac{70.W}{R^{1.4}} + WK_gC_g \tag{1}$$

Where $C_g$ is the sum of the constraints of the problem, $K_g$ is the penalty coefficient-penalty coefficient which is considered equal to 10, R is the response modification factor which is calculated in this study using MIDA analysis. And W is the weight of the structure, which is obtained from the following equation:

$$W = \rho AL \tag{2}$$

Where:

ρ, A and L indicate weight density, cross-section, and member length, respectively.

The applicable restrictions are derived from the rules and restrictions of AISC341-16[4], which are:

Limiting the axial force of the X-shaped members of the special zone

$$C_1 = f_{xaxial}/F_{xaxial} \geq 1 \tag{3}$$

Where:

$$= 0.03F_yA_g/\alpha_sF_{xaxial} \tag{4}$$

Limitation of axial force of special zone beam

$$C_2 = 2.2F_{Baxial}/F_{Baxial} \geq 1 \tag{5}$$

Where,

$$F_{Baxial} = \phi F_n = 0.9F_yA_g \tag{6}$$

Shear force limit in the middle of the beam of the special zone

$$C_3 = V/0.25V_{ne} \geq 1 \tag{7}$$

Where:

$$V_{ne} = \frac{3.6R_yM_{nc}}{L_s} + 0.036EI\frac{L}{L_s^3} + R_y(P_{nt} + 0.3P_{nc})\sin\alpha \tag{8}$$

Limitation of the combination of axial and flexural force in columns

$$C_4 = Comb_{(axial-Moment)} \geq 1 \tag{9}$$

Where:

For $\frac{P_u}{\varphi P_n} \geq 0.2$

$$Comb_{(axial-Moment)} = \frac{P_u}{\varphi P_n} + \frac{8}{9}(\frac{M_{ux}}{M_{cx}} + \frac{M_{uy}}{M_{cy}}) \tag{10}$$

For $\frac{P_u}{P_n} < 0.2$

$$Comb_{(axial-Moment)} = \frac{P_u}{\varphi P_n} + \left(\frac{M_{ux}}{M_{cx}} + \frac{M_{uy}}{M_{cy}}\right) \tag{11}$$

Stability index constraints

$$C_5 = \phi_i/0.25 \geq 1 \tag{12}$$

$$\theta_i = \left[\frac{P_u\Delta_{eu}}{V_uh}\right]_i \tag{13}$$

Where,

$$\theta_{max} = \frac{0.65}{C_d} \leq 0.25 \tag{14}$$

Finally, $C_g$ is defined as follows:

$$C_g = C_1 + C_2 + C_3 + C_4 + C_5 \tag{15}$$

The following Figure 3 flowchart shows the process of optimizing the truss flexural frame using the island genetic algorithm .

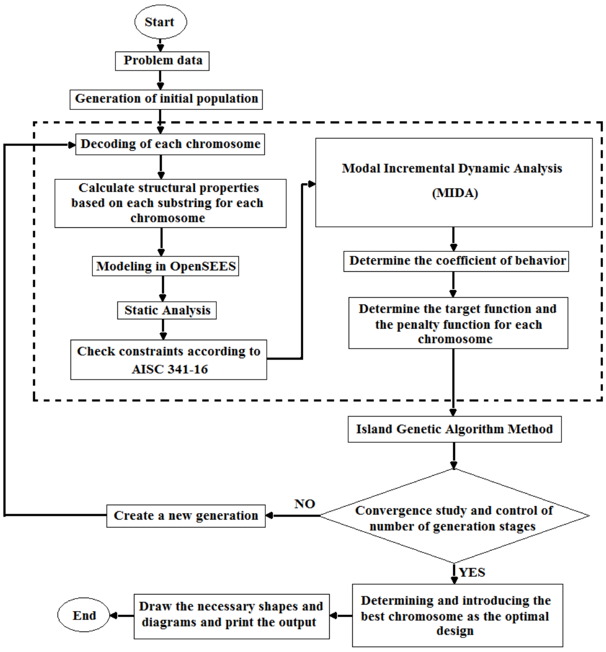

Figure 3. flowchart the process of optimizing

## 5. Numerical examples

In this section, two special truss bending frames with three floors or one and two 18-meter openings have been optimized. The elements are typed to simplify (Fig.4). Structural analysis used using OPENSEES software[15] and MATLAB programming environment[16] was used for the necessary computer programs. The dead and live loads are 500 $kg/cm^2$ and 200 $kg/cm^2$ for all floors and 500 $kg/cm^2$ and 150 $kg/cm^2$ for the roof, respectively. The steel used is St37 with Young modulus equal to the nominal yield strength Fy = 2400 $kg/cm^2$ and the final strength Fu = 3700 $kg/cm^2$ Has been.

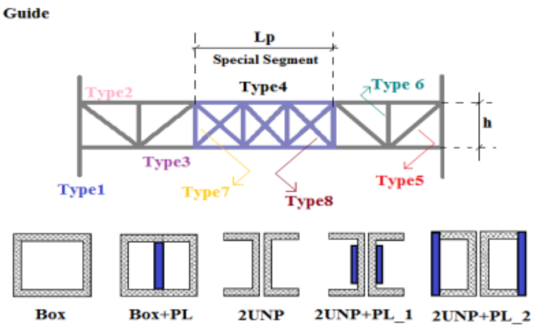

Figure 4. Cross sections

### 5.1. Three-story frame with one-bay

optimal design of the three-story frame with one- bay, shown in Fig. 5, is performed as the first example. Fig. 6 shows the convergence curve during the optimization process. The optimized sections are given in Table 1. Table 2 includes the results of the optimum design for the present algorithm. Fig. 7 shows the optimal arrangement of trusses for the optimization process.

Figure 5. Three-story frame with one-bay used in the problem

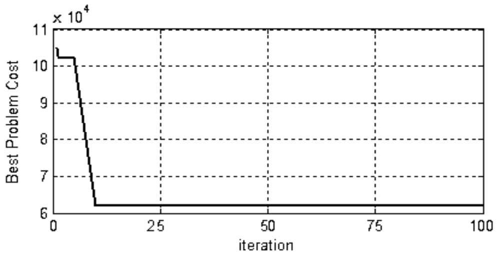

Figure 6. the changes in the value of the objective function to converge to the optimal Three-story frame with one bay during the optimization process

Table 1. Optimized structural sections for Three-story frame with one-bay

| Story | Type 1 | Type2 | Type3 | Type4 | Type5 | Type6 | Type7 | Type 8 |
|---|---|---|---|---|---|---|---|---|
| Mida 1-3 | Box240*20 | 2unp80+Pl5_2 | 2unp80 | 2unp80 | 2unp80 | 2unp80 | 2unp80 | - |

Table 2. the optimal design results of the Three-story frame with one-bay

| Weight | h | Lp | R | T |
|---|---|---|---|---|
| 6827.174 (kg) | 1 | 4.5 | 4.6 | 2.04 (sec) |

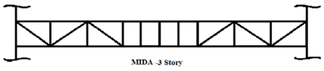

Figure 7. the optimal truss arrangement of the Three-story frame with one-bay

### 5.2. Three-story frame with two-bay

In this example, the optimal design of the three-story frame with two-bay, shown in Fig. 8, is performed. Fig. 9 shows the convergence process in the design of this frame. The design results of the models including the final sections for each type and the geometric specifications of the truss are reported in Tables 3-4, respectively. Fig. 10 shows the optimal arrangement of the truss of this frame.

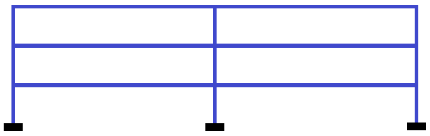

Figure 8. Three-story frame with two-bay used in the problem

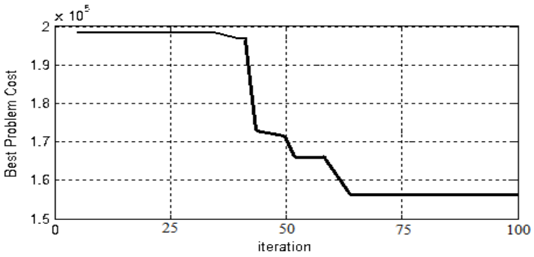

Figure 9. the changes in the value of the objective function to converge to the optimal Three-story frame with two bay during the optimization process

Tabale 3. Optimized structural sections for Three-story frame with two-bay

| Story | Type1 | Type2 | Type3 | Type4 | Type5 | Type6 | Type7 | Type8 |
|---|---|---|---|---|---|---|---|---|
| MIDA 1-3 | Box280*20 | 2UNP100+PL5_2 | 2UNP100 | 2UNP100 | 2UNP80 | 2UNP80 | 2UNP80 | - |

Table 4. the optimal design results of the Three-story frame with two-bay

| Weight | h | Lp | R | T |
|---|---|---|---|---|
| 11326.26 (kg) | 1.4 | 7.659 | 3.37 | 2.49 (sec) |

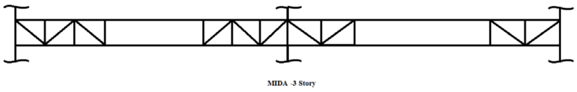

Figure 10. the optimal truss arrangement of the Three-story frame with two-bay

### 6. Conclusion

A Genetic algorithm is an optimization method inspired by living nature, which in this article has been tried to use to design the optimal structure of a special truss flexural frame. Due to the importance of considering earthquakes in today's designs, in this research, the seismic force was also considered. In order to seismically analyze the structure, MIDA analysis was used, which has good accuracy and speed. The results of the algorithm show the efficiency of the above algorithm in solving optimization problems. In this way, it can design a structure with reasonable weight and very good seismic performance in an acceptable time, and at the same time meet all the constraints governing the problem.

## Declaration of Conflict of Interests

The authors declare that there is no conflict of interest. They have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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