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Research Article

Automatic Minimization of the Drift Performance of RC 3D Irregular Buildings Using Genetic Algorithm

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This study introduces the application of genetic algorithms for the optimal design of the seismic torsional drift performance of three-dimensional reinforced concrete buildings. Attempts have been made to achieve an optimal automatic design of the torsional drift of the storeys of reinforced concrete buildings with plan irregularities to build torsional balanced structures. The storey torsional drift response generated by static and dynamic loads can be clearly expressed in terms of vertical structure elements' sizing design variables. Two examples are provided to demonstrate the efficiency and practicability of the proposed optimum design approach. The performance of the structures was assessed as per the procedure prescribed in modern seismic code languages. Mathematical and finite element modelling were used to perform seismic analysis on buildings. MATLAB® programming was used as a solution to the sizing optimization problem. The results confirmed the proposed genetic algorithm's ability to find efficient optimum solutions to three-dimensional reinforced concrete structures through the problem of size optimization.

1. Introduction

Earthquakes are one of the most destructive and unpredictable natural hazards and cause serious problems since they affect human life in various ways. It is very important to determine the behaviour of buildings, especially torsional behaviour, during the earthquakes. Various solutions that can be applied to overcome these effects and to strengthen the structural elements are briefly explained. The real response of buildings under earthquake loads can in general be affected by applying a genetic algorithm (GA) to get the optimal design of structural members. During the design of structures, various parameters are considered. In the present research study, torsional irregularity was used as a design parameter and the eccentricity between the centre of mass (CM) and the centre of rigidity (CR) of the building was minimized by minimizing the storey torsional drift as an objective function. Goldberg is one of the first researchers to use a GA to solve engineering optimization problems [1]. Based on Goldberg's work, several researchers have successfully applied GAs to achieve optimal designs of structural elements. Many studies have been performed allotted to the subject of structural optimization of reinforced concrete structures and most of them allotted to cost. For example, Camp et al. implemented a genetic algorithm to optimum flexural design of simply supported beams, uniaxial columns, and multistorey frames by using a search for discrete-valued solutions of members in reinforced concrete frames [2, 3]. Govindaraj and Ramasamy conducted a detailed study of the optimal design of the RC continuous beams with the GA [4]. Guerra and Kiousis employed nonlinear programming (NLP) techniques for the optimal design of reinforced concrete structures [5]. Ghodrati et al. implemented GA in the optimal design of RC frames [6]. Hatindera et al, assumed that all columns are rectangular and cost optimization is carried meeting strength and serviceability requirements in accordance with IS:456-2002 [7]. Alex and Kottalil, implemented a GA for the optimal design of RC continuous beam [8]. Samruddha and Patel, examined flat slab optimization using a GA [9]. Fayaz

Basha and Madhavi Latha performed an analysis of the optimization of the RC slab design utilizing GAs [10]. Sadat and Arslan investigated the optimum eccentricity design for seismic applications utilizing a genetic algorithm. In their study, the efficiency of the GA studied and evaluated as good [11]. Sadat studied the optimization and modelling of the effect of plan irregularity on seismic behavior of buildings with artificial intelligence systems [12]. Zakia Sadat examined the approach of the genetic algorithm in the prevention of torsional irregularities in RC structures [13].

There have been several studies on torsional irregularity including geometric asymmetry such as Özmen has studied the geometrical and structural aspects of the torsion irregularity in accordance with TEC 2007 [14]. De Stefano and Pintucchi presented an overview of the progress in research regarding seismic response of plan and vertically irregular structures [15]. Özmen et al. have determined the conditions for an excessive torsion irregularity in accordance with the TEC and discussed the relevant provisions of the code. Their survey was carried out on six typical structural groups with different shear wall positions, axis numbers, and story. It was observed that the ratio of torsional irregularities increased as the number of floors decreased [16]. Anagnostopoulos et al. studied the torsional response of nonsymmetric buildings under earthquake excitations makes their design for earthquake actions substantially more complicated than the design of symmetric buildings whose response is purely translational [17]. Mishra and Dubey examined the effect of reducing storey drift in severe earthquakes, which can cause the collapse of structures in higher seismic zones [18].

In the current study, the optimization method for the design solution of the seismic torsion drift of buildings is basically based on a GA approach. Two 3D finite element models of eight stories RC buildings were considered to demonstrate the effectiveness and practicability of the proposed optimization methodology. The models were analysed with FEM Computer Programming using Equivalent Seismic Load (ESL) and Mode Superposition Methods, and MATLAB® programming was used as a solution to the sizing optimization problem. In the optimization problem, the cross-sectional dimensions of the columns and the thickness of the shear walls were regarded as design variables.

2. Plan Irregularity

The design and construction of irregular buildings should be avoided because of their unfavourable seismic behaviour and the types of irregularities in the elevation and plan. Irregularities in plan consist of four different types: torsion irregularity, A1; floor discontinuity, A2; plan projections, A3; nonparallel systems, denoted as A4 in seismic codes of practices [19].

2.1. Torsional Irregularity. Torsional irregularity is one of the most important factors as it causes severe damage to building structures. The torsional irregularity factor (η_{bi}), defined for either of the two orthogonal earthquake directions as the ratio of the maximum storey drift at any storey to the average storey drift at the same storey in the same direction, is greater than 1.20 [19]. The determination of torsional irregularity is given by equation.

$$\eta_{bi} = \frac{(\Delta_i)_{\max}}{(\Delta_i)_{\text{avg}}} > 1,2, \tag{1}$$

where $(\Delta_i)_{\max}$ is the maximum storey drift and $(\Delta_i)_{\text{avg}}$ is the mean value of storey drift for the i'th storey obtained from analysis under earthquake forces.

Torsion is generated when the centre of rigidity (CR) and centre of mass (CM) in the building are not coincident; the distance between these two centres is called *eccentricity* [20]. The centre of mass is generally the geometrical centre of the floor (in plan). The position of the CR depends on the characteristics of the lateral load-resisting system components (shear walls, moment frames, braced frames, etc.). Torsional effects can only occur in buildings with rigid diaphragms. While the structural CM is impacted by seismic loads, the structural CR responds to these loads. If the eccentricity between these two centres is large, a moment of torsion occurs around the CR and the structure starts to rotate around the axis of rigidity. This moment of torsion generates extra shear forces [20]. The response and behaviour of such a structural system under seismic load conditions is largely dependent on its overall shape, size, and geometrical arrangement of the vertical members (shear walls and columns).

2.2. Storey Drift. The storey drift ratio, which is the maximum relative displacement of each floor divided by the height of the same floor, is a significant parameter to evaluate. The lateral drift performance of a building, which is obtained by combining the peak modal response using Square Root of the Sum of Squares (SRSS) and Complete Quadratic Combination (CQC) rules, shall not exceed 0.02 h [19].

2.2.1. Limitation of Relative Storey Drifts. In earthquake resistant design, it is necessary to limit lateral storey drifts of a building. Extreme drifts may cause structural and nonstructural damage to buildings. Reduced relative storey drift, Δ_i, of any column or structural wall shall be determined by equation (2) as the difference of displacements between the two consecutive stories [19].

$$\Delta_i = d_i - d_{i-1}, \tag{2}$$

$$\delta_i = R\Delta_i, \tag{3}$$

where, d_i and d_{i-1}, represent lateral displacements obtained from the analysis according to reduced seismic loads at the ends of any column or structural wall at storeys i and $(i-1)$. Effective relative storey drift, Δ_i, for columns and shear walls of the i'th storey of a building for each earthquake direction is obtained from (3). The maximum value of effective relative storey drifts, Δ_i, within a storey, $\Delta_{i,\max}$, calculated by (4) for columns and shear walls of the

i'th storey of a building for each earthquake direction shall satisfy the condition given by

$$\frac{(\Delta_i)_{\max}}{h_i} \leq 0,02. \quad (4)$$

If the condition specified by (4) is not satisfied at any storey, the earthquake analysis shall be repeated by increasing the stiffness of the structural system [19].

3. Genetic Algorithm

The genetic algorithm (GA), the most famous evolutionary algorithm (EA) so far, is an approach to modelling genetic evolutionary mechanisms based on the principles of survival and adaptability of the fittest [21]. The purpose of the GA is to meet a better functional operation process that includes reproduction, crossover, and mutation. GAs only use function values in the search process to progress towards a solution regardless of how functions are assessed. Continuity or differentiation of the functions of the problem is neither necessary nor used in algorithmic computations. Thus, the algorithms are very general and applicable to all types of problems such as discrete, continuous, and no differentiable. The central principle of a GA is to generate a new set of designs (population) from the existing set to improve the average fitness of the population. The operation continues until a stop criterion is met or the number of iterations reaches a specific limit.

3.1. Algorithm for Optimal Drift. In this section, the proposed algorithm is described.

3.1.1. Initial Population. The initial population is constructed. At this stage, before the population is initialized, the designer must select the number of individuals (set of solutions) in each population.

3.1.2. Evaluation. After creating the initial population, fitness is evaluated for each design variable, $f(x)$, in the population. Fitness is specified by the outcome of the objective function. The evaluation function to be used in the search or the required solution must be specified in advance.

3.1.3. Fitness Assignment. Several options exist to assign fitness. In a rank-based fitness assignment, the design variable is ranked based on its objective values.

3.1.4. Reproduction. In GA, a new generation is generated via reproduction from the previous generation. In this case, the three mechanisms (selection, crossover, and mutation), discussed below, are used to create the next generation.

3.1.5. Crossover. Crossover options describe how the genetic algorithm combines two strings of design variables (parents) to form a crossover child for the following generation.

3.1.6. Selection. The selection options specify how the GA selects the best design variables for the following generation. The problem is how to select these design variables, based on Darwin's theory of evolution, the best ones should survive and generate a new design variable.

3.1.7. Elite Count. Elite count specifies how many design variables with the greatest fitness values in the present generation are guaranteed for survival in the following generation.

3.1.8. Crossover Fraction. Crossover fraction specifies the fraction of the next generation, other than elite design variables that are produced by crossover. "The crossover fraction value is set to a fraction between 0 and 1, and the default value is 0.8" [22].

3.1.9. Mutation. Each species is "mutated" at a random location. The basic idea of using this operator is to introduce some diversity into the population. Mutation forms a new design variable by making (with small probability) by randomly reversing some bits from 0 to 1, or vice versa to the values of the genes in a copy of a single parent design variables. By default, for bounded or linearly constrained problems, the design variables remain feasible [22].

3.1.10. Optimization Criteria. The algorithm terminates criteria include generation number, computational time limit, and functional tolerance. The algorithm stops once either of these conditions is fulfilled. When optional generations are increased, the ending result is often improved.

3.1.11. Multiple Runs for a Problem. Since genetic algorithms make decisions in multiple locations depending on the generation of random numbers, when the same problem is executed at different times, it can give different end designs. It is recommended to run the problem several times to make sure that the best possible solution has been achieved [21, 23].

4. Optimization Problems

4.1. Formulation of Optimum Design. In formulating the optimal design problem, it is necessary to identify the design variables of the structural system, the objective function must be reduced to a minimum, and the design constraints must be applied to the system. The problem of optimizing the structural and mechanical system is to find the vector (x) of the design variable, representing the size/shape/topology and other properties of the system to minimize the main function $f(X)$. A discrete structural optimization problem can be indicated as follows (5) [21, 23]:

$$\text{find} X = [x_1 x_2, \ldots, x_n] \text{Which minimize} f(X). \quad (5)$$

Subject to the constraints

$$g_j(X) \leq 0;\ j = 1, 2, \ldots, m,$$
$$x^{iL} \leq x_i \leq x^{iU};\ i = 1, 2, \ldots, n. \quad (6)$$

Design variable x indicates section sizes of columns and walls, $f(X)$ is termed the objective function, and $g_j(X)$ is the inequality constraint. There is no need to relate the number of variables n and the number of constraints m. x^{iL}, x^{iU} are both n-length vectors containing the lower and upper limits of the computational variables, respectively.

If only one variable is present, optimization is unidimensional. A problem with multiple variables needs multi-dimensional optimization. Optimization is increasingly difficult with the increase in the number of dimensions. Numerous multi-dimensional optimization approaches generalize to a range of unidimensional approaches [21, 23].

4.2. Sizing Optimization. The aim of structural sizing optimization is generally to provide optimum cross sections for the individual structural elements. In the problem of size optimization, the design variables are usually geometrical parameters such as the length, width or thickness of the part being optimized. Given that the geometry and boundary conditions are already known, these may be used to define the column and shear wall constraints in terms of geometry, resistance, strain, etc. [1, 24].

4.3. Size Limitation Constraints. These are the lower and upper limits applied to the dimensions of the column and the shear wall, according to architectural and/or geometric requirements. These constraints have several dissimilar names in the literature, including technological constraints, side constraints, and simple bounds. Note that all the previous constraints have been used as constraints for the model to obtain the optimal cross-sectional dimensions of the column and thickness of shear wall.

5. Optimal Drift Performance Design of 3D Buildings with Irregular Plan

5.1. Objective Function. The mathematical formulation of the discrete problem with the real value of the variables can be represented by

$$\min \text{drift} = \left(\text{Drift}(X)^2 + \text{Drift}(Y)^2\right)^{0,5}. \quad (7)$$

Subject to $g_j(x) \leq 0;\ j = 1, 2, \ldots, m$ (behavioral)

$$x^{iL} \leq x_i \leq x^{iU};\ i = 1, 2, \ldots, n, \quad (8)$$

where Drift(X), Drift(Y) are the storey drift in X and Y direction, respectively; drift represents the objective function. The vector function $g(x)$ returns a vector of length m are the behavioral constraints imposed by the seismic and reinforced concrete structure design codes, x^L and x^u are the lower and upper bounds, respectively.

5.2. Design Variables. In the present study, individuals are defined as the thickness of the shear walls and the cross-sectional dimensions of the columns. The columns' section is square and rectangular with dimensions $b_c \times h_c$. The number of variables is the same as the number of vertical structural elements, including the thickness of the shear walls and the depth and width of the columns.

5.3. Design Constraints. Two main types of constraints are taken into consideration in relation to structural design elements. First-type of structural constraints on cross-section load capacities are considered. The second type is the compatibility constraint, which includes constraints to define architectural requirements. These constraints comprise the minimum and maximum cross-sectional dimensions of the vertical structural elements required by the seismic design codes [21].

5.4. Column Constraints

5.4.1. Capacity Constraint. For the purpose of the cross-sectional dimension of the column to be the largest calculated axial compressive resistance under the combined action of vertical loads $N_{d\max}$ and seismic loads, the cross-sectional dimension of the column shall fulfil circumstance of (9) [19].

$$A_{\text{ci}} \geq \sum \frac{N_{d\max}}{0,5\, x\, F_{\text{ck}}};\ \text{for}\ i = 1, 2, \ldots, nm. \quad (9)$$

Here, A_{ci} is the area of the column and F_{ck} is the characteristic compressive resistance of concrete.

5.4.2. Geometric constraint. For the current formula, columns can be square or rectangle. The width h_c and depth b_c of a column cross-section shall not be smaller than the minimum size limit value indicated for the columns. The smaller dimensions of the rectangular columns section shall not be less than $25 \times 30\,\text{cm}^2$ and the cross-section dimensions shall not be less than $750\,\text{cm}^2$. Equations (10) and (11) demonstrate that column dimensions are limited to

$$\frac{b_{\min,i}}{b_i} - 1 \leq 0;\ i = 1, 2, \ldots, n_{\text{column}}, \quad (10)$$

$$\frac{h_{\min,i}}{h_i} - 1 \leq 0;\ i = 1, 2, \ldots, n_{\text{column}}. \quad (11)$$

In which i is an index denoting the number of columns, while n_{column} is the total number of columns. The minimum $b_{\min}$ depth and $h_{\min}$ width shall be determined separately for each problem based on its architectural circumstance.

5.4.3. Compatibility Constraint. Compatibility constraint is applied to allow the beam reinforcing steel bars to continue along the columns so that the depth of the columns (b_c) at a given story is not less than the corresponding beam depth (b_w). In the standardized form, the compatibility constraint may be written as

$$1 - \frac{b_c}{b_w} \leq 0. \tag{12}$$

6. Numerical Analysis

To illustrate the effectiveness and efficiency of the design of RC structures through a GA two 3D multistorey examples are provided. In the first example, the structural system consists of RC frames, whereas, in the second example, the system consists of RC frames interacting with reinforced concrete shear walls (dual systems). In these examples, first of all, for irregular L-shaped buildings, mathematical modelling and finite element analysis were developed to examine the seismic performance of buildings. After the analyses some outputs were taken and processed using MATLAB®. The slab and shear walls were modelled with shell elements. The slabs were modelled as a rigid diaphragm to restrict all the nodes in each floor and to facilitate the equal plan displacement. For simplicity fixed supports were used in all directions. With the objective of achieving realistic outcomes, the dimensions of the structural members were calculated through a primary design procedure. Automatic generation of meshes enabling efficient meshing of all elements was used, and the meshes were sufficiently thin to satisfy the model's accuracy. The dynamic response of an asymmetrical plan having various eccentricities was first compared to assess the effects of the torsion response. After the analysis is done, we obtain the structural response such as torsion ratio, displacement, drifts, and we use optimization algorithms to find good parameters. The structural optimization method for the 3D RC building structure is proposed, and the problem of optimizing the drift of the floors is formulated and applied utilizing MATLAB® using a GA. Member sizes, including section sizes for column and thickness sizes for shear walls, are considered as the design variables. The lateral storey drift of the structure is regarded as an objective function to satisfy the seismic code provisions. GA repeatedly changes a set of solutions throughout its entire run. Until a violation is detected, the objective function $f(x)$ will not be subject to penalties. The algorithm was terminated when the number of generations reached the maximum number of generations to be utilized. To terminate the return operations, the generating variables should be a minimum of 90–95% similar. The buildings were resolved three times, and among the optimal solutions achieved for each set, the best solution was regarded as the optimal design. As for the final design application, the most suitable sections are selected to satisfy TEC-2007 and TS 500–2000 code provision based on static and dynamic linear analysis. In all test cases the project parameters of the models and seismic details of the structure's models are tabulated in Table 1 and in Table 2 shows various GA parameters used for the optimization of process controllers. All models have eight stories with total height of 24 m.

6.1. Loads of the Structure and Load Combinations. The structures are subjected to horizontal loads obtained from the superposition of the seismic design mode according to [19] approach. The storey weight consists of the dead load and 30% of the live load (for residential buildings according to TEC-2007 at the time of the earthquake). The assumed dead and live loads on the slab for each floor are 1.56 kN/m^2 and 2 kN/m^2, respectively. The following load combinations (13) are considered, and the model is analysed for the critical load condition [19].

$$F_d = 1,4\,\text{Dead} + 1,6\,\text{Live};\ F_d = \text{Dead} + \text{Live} \mp E;\ F_d = 0,9\,\text{Dead} \mp E, \tag{13}$$

where Fd is the required strength of a member for resisting factored loads based on load combination. A total of sixty-five types of load combinations are considered in the analysis.

The algorithm is applied in MATLAB® (R2018b Student Version) running an Intel® Core™ i5-8250U 1.90 GHz processor with 8 GB of Random-Access Memory (RAM). Each solution case of the example problems was run several times and passed different CPU times.

Table 1: The TEC-2007 parameters.

Parameters for the model design	Seismic details of the structures
Storey number: 8	Earthquake zone: 1; soil class: Z2
Storey height: 3.0 m	Spectrum characteristic periods T
Columns sections:	$T_A = 0.15$; $T_B = 0.4$
(1) Model: 25/55, 55/25 cm	Earthquake zone factor: $A_0 = 0.4$
(2) Model: 50/50 cm	Importance factor: $I = 1$
Shear wall: 25/200 cm	Reduction factor: R
Slab thickness: 15 cm	(1) Model $R = 8$
Concrete class: C25	(2) Model $R = 7$
Density of concrete: $F_c = 25$ kN/m^3	Damping ratio = 5%
Modulus of elasticity: $E_c = 30000$ MPa	Ductility level: high
Steel class: S420: $E_s = 200000$ MPa	Live load factor: 0.3

Table 2: A set of solver parameters selected to resolve the case study.

Population type	Double vector
Migration direction	Forward
Population size	200
Fitness scaling function	Rank scaling
Selection function	Tournament
Elite count	10
Crossover fraction	0.8
Crossover function	Crossover scattered
Mutation function	Adaptive feasible
Hybrid function	None

6.1.1. Example 1. Design optimization of the eight-storey building with two spans in each horizontal direction comprised 64 column elements. There is only a single group of storeys as the plan layout of the columns is the same for all storeys, and the vertical structural elements are divided into 8 groups of columns, thus each population has a total of 16 variables. Consequently, there are 128 design variables present in the optimization problem. In this implementation, the lower limits of the width and height of the columns are taken as 35 cm, and the upper limits of the width and height of the columns are taken as 55 cm. The current model's plan geometry has the same 10 m projecting dimensions on the X and Y-directional axes. The A3 ratio in the irregular L-shaped model was computed as 50% in both directions, exceeding the 20% limit ratio. In this example the contribution of the infill wall loads on beams is neglected. All the beam cross sections are 25 cm × 50 cm.

Figure 1 shows the typical floor plan and 3D view of the asymmetric structures that are taken into consideration for the torsional analysis. The dimensions of the columns marked as C1, C3, C5, C6, C8 in Figure 1 are 25 × 55 cm, the dimensions of the remaining columns marked as C2, C4, C7 are 55 × 25 cm. The results of the example are listed and compared.

The results of the optimisations are presented in the following:

The GA convergence graph is illustrated in Figure 2, where the optimum design is reached in 20 generations. After 20 iterations, which were identified as termination criteria, and at a CPU time of about 20 hours the optimum solution with the number of function evaluations 4000 was obtained.

Tables 3–5 show the cross-section sizes of columns and comparison of initial and optimal solutions of eccentricity and torsional irregularity ratio for response spectrum analysis, respectively. Tables 4 and 5 show the eccentricity between CM and CR and the maximum values of the torsional irregularity ratio at the critical loading condition for each storey in the optimal solutions achieved by GA. As a result, in all the storeys the eccentricity and torsional irregularity of the optimum design were significantly decreased using the introduced optimization process.

6.1.2. Example 2. A shear wall-frame structure was selected as the second application example. Since the plan design of the structure model is the same for all storeys, thus there is only a single group of storeys, in this case there are 16 design variables for column sections and 2 design variables for wall thickness. Consequently, there are a total of 144 design variables exist in the optimization problem, including 16 design variables for shear wall and 128 design variables for columns. Moreover, in the case of the shear wall, the lengths are set to 200 cm and only the thicknesses are design variables. The section sizes for column and thickness sizes for shear walls are predetermined. The A3 ratio in the irregular L-shaped model was computed as 67% on the X-axis and 50% on the Y-directional axis, exceeding the 20% limit ratio. The assumed wall load on each frame of the floor is 12 kN/m. All the beam cross sections are 30 cm × 50 cm. In this implementation, the lower limits of the height and width of the columns are taken as 30 cm and 20 cm for shear wall thickness. Likewise, the upper limits of height and width are taken as 60 cm for columns and 30 cm for shear wall thicknesses. By assuming that the site class of the structure is Z2, response modification factor $R = 7$. Figure 3 shows the typical floor plan and 3D view of the asymmetric structures that are taken into consideration for the torsional analysis.

The results of the optimisations are presented in the following. The GA convergence graph is illustrated in Figure 4, where the optimum design is reached in 20 generations. After 20 iterations, which were identified as termination criteria, and at a CPU time of about 25 hours the optimum solution with the number of function evaluations 4000 was obtained.

Tables 6–8 show the cross-section sizes of columns and thickness of shear walls and a comparison of applied and optimal solution of eccentricity and torsional irregularity ratio for response spectrum analysis, respectively. Through these comparisons in tables and figures, we find that the eccentricity and the torsional irregularity of the optimized design is much lower than that achieved during the original design. The results show that in terms of torsion irregularity, the distribution of structural rigidity is more efficient than geometric asymmetry. It should be noted that the maximum irregularity ratio for all storeys takes place at the lowest storeys.

7. Results and Discussion

When the program was started during the optimization process; the selected design variable values were assigned to the dimensions of the column section in the preprepared system, the system was solved, and the objective function was calculated, thus the torsional drift was minimized. Evolution will continue until the predetermined generation number is completed. At each generation, the fitness value decreases from the first generation to the next generation as the objective function is minimized and the number of generations reaches a specified limit (Figures 2 and 4). As each generation progresses, population variables become more successful. Column dimensions and torsional drift values were printed onto an output file as each generation progresses. As for final design application, the members of this generation (cross section of column and thickness of shear wall) with better fitness value were taken as the optimum point.

Tables 3 and 6 show the applied and optimal solution of the cross-section sizes of columns and thickness of shear walls. The results show that the sizes and directions for the optimized solution are different than those of the applied ones. In these tables the dimensions of the columns are denoted as depth and width corresponding to the x and y-axis, respectively.

To compare the initial and optimal design, after the implementation of the optimization process on 3D eight-story RC buildings, the optimum design was obtained. The optimum results reveal that by using the automated design process, a design candidate can be achieved associated with the minimum eccentricity and torsional irregularity ratio that conforms to the standard code's provisions (Figures 5 and 6) and Tables 4, 5, 7 and 8). As seen from the figures and

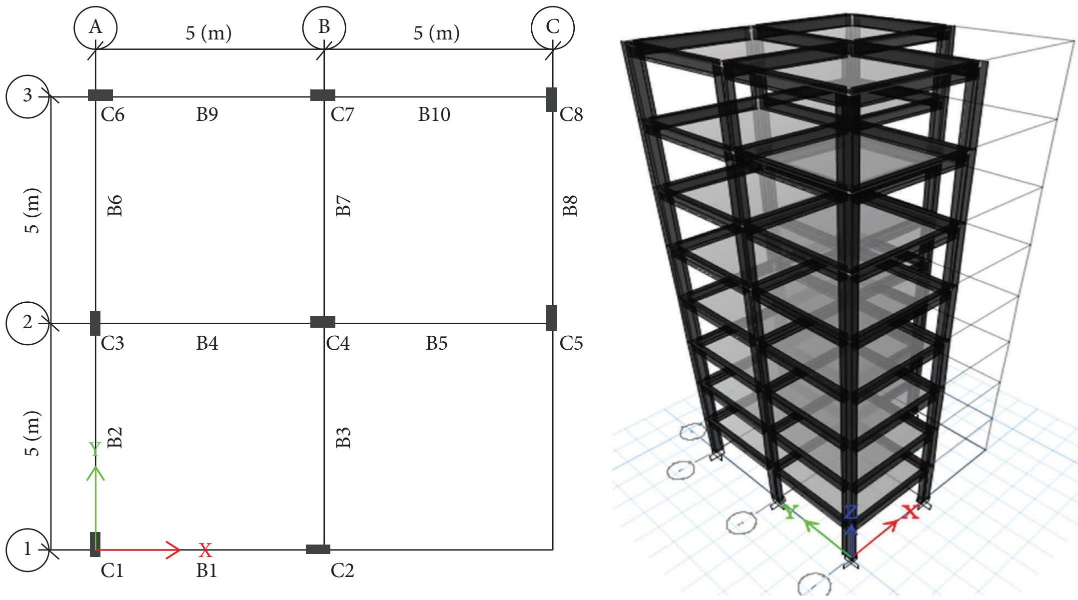


Figure 1: Example 1, (a) Typical floor plan view. (b) 3D view.

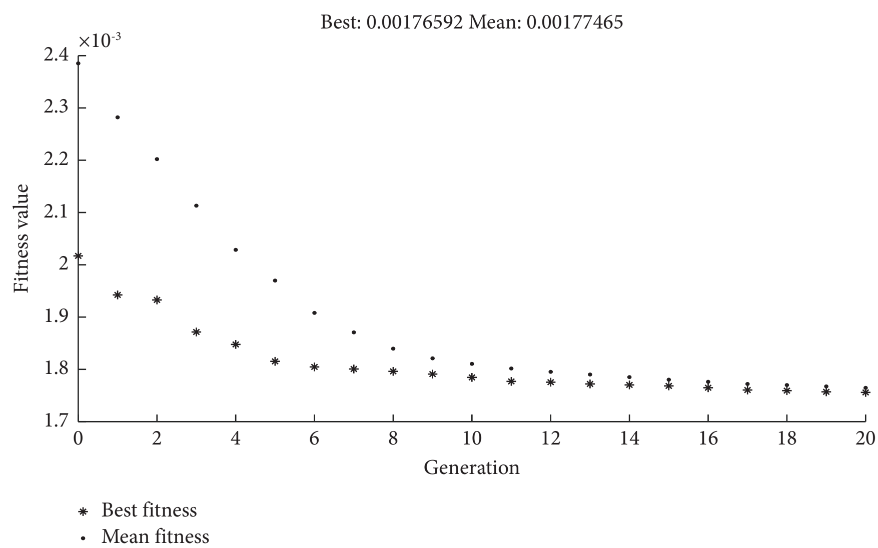


Figure 2: Example 1, Convergence graph of the genetic algorithm.

Table 3: Example 1, Comparison of initial and optimal member sizes.

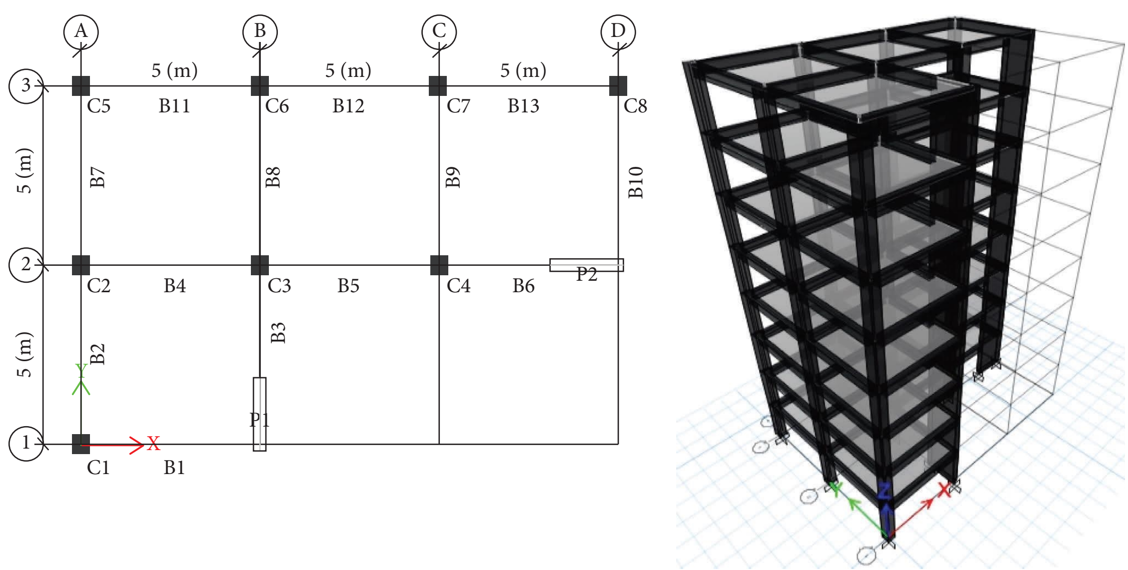
Column no.	Initial solution (cm)		Optimum solution (cm)	
	Depth (b_c)	Width (h_c)	Depth (b_c)	Width (h_c)
C1	25.0	55.0	41.91	48.20
C2	55.0	25.0	39.39	43.74
C3	25.0	55.0	49.09	38.35
C4	55.0	25.0	51.54	50.16
C5	25.0	55.0	51.80	40.09
C6	55.0	25.0	51.23	41.26
C7	25.0	55.0	38.89	46.64
C8	55.0	25.0	39.26	48.25

Table 4: Example 1, Comparison of initial and optimal solution of torsional irregularity ratio.

Storey	Initial solution Torsional irregularity ratio (ηbi)		Optimum solution Torsional irregularity ratio (ηbi)	
No.	Dir. X	Dir. Y	Dir. X	Dir. Y
8	1.15	1.09	1.05	1.04
7	1.14	1.06	1.05	1.04
6	1.13	1.05	1.05	1.03
5	1.13	1.05	1.05	1.03
4	1.13	1.05	1.05	1.03
3	1.13	1.05	1.05	1.04
2	1.13	1.04	1.04	1.04
1	1.12	1.03	1.04	1.05

Table 5: Example 1, Comparison of initial and optimal solution of eccentricity.

Storey no.	Initial solution Eccentricity (cm)	Optimum solution Eccentricity (cm)	Reduced eccentricity (%)
8	42.70	4.51	89.4
7	40.97	4.68	88.6
6	38.45	4.64	87.9
5	36.44	5.52	84.8
4	34.96	7.12	79.6
3	34.33	9.52	72.2
2	36.02	13.58	62.3
1	46.26	20.83	55.0



(a) (b)

Figure 3: Example 2, (a) Typical floor plan view. (b) 3D view.

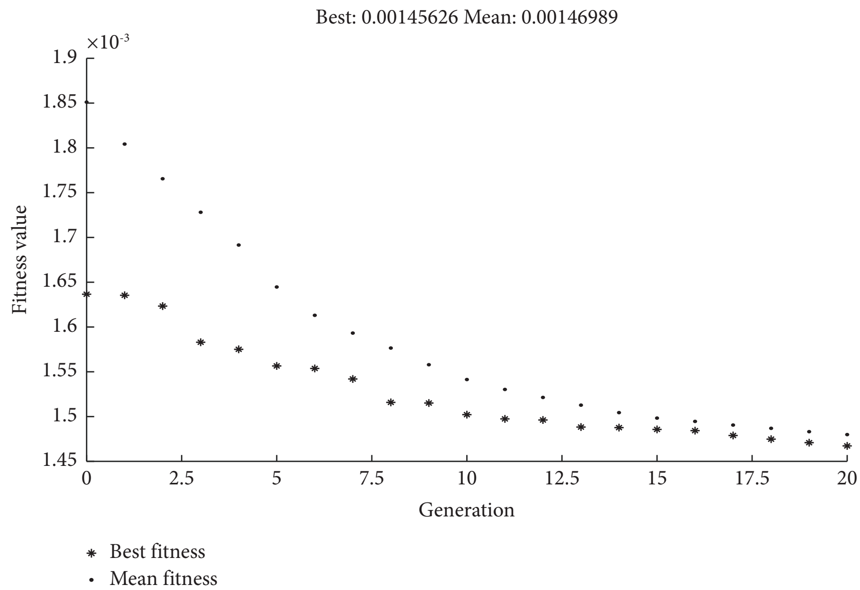


FIGURE 4: Example 2, Convergence graph of the genetic algorithm.

TABLE 6: Example 2, Comparison of initial and optimal member sizes.

Column no.	Initial solution (cm)		Optimum solution (cm)	
	Depth (b_c)	Width (h_c)	Depth (b_c)	Width (h_c)
C1	50.0	50.0	54.90	35.19
P1	30.0	200.0	23.99	200.0
C2	50.0	50.0	56.06	33.98
C3	50.0	50.0	41.27	58.8
C4	50.0	50.0	35.44	59.46
P2	200.0	30.0	200.0	24.86
C5	50.0	50.0	59.44	31.99
C6	50.0	50.0	59.24	35.77
C7	50.0	50.0	34.28	60.00
C8	50.0	50.0	33.69	59.92

TABLE 7: Example 2, Comparison of initial and optimal solution of torsional irregularity ratio.

Storey no.	Initial solution Torsional irregularity ratio (ηbi)		Optimum solution Torsional irregularity ratio (ηbi)	
	Dir. X	Dir. Y	Dir. X	Dir. Y
8	1.13	1.08	1.14	1.12
7	1.11	1.09	1.13	1.09
6	1.10	1.12	1.12	1.09
5	1.09	1.14	1.11	1.09
4	1.09	1.16	1.10	1.09
3	1.08	1.18	1.09	1.09
2	1.07	1.23	1.08	1.09
1	1.07	1.33	1.08	1.12

Table 8: Example 2, Comparison of initial and optimal solution of eccentricity.

Storey no	Initial solution Eccentricity (cm)	Optimum solution Eccentricity (cm)	Reduced eccentricity (%)
8	63.2	23.4	63.01
7	70.4	33.1	52.96
6	74.3	38.9	47.59
5	79.1	45.5	42.48
4	85.6	53.9	37.00
3	95.2	65.5	31.19
2	108.9	81.8	24.90
1	128.7	105.9	17.70

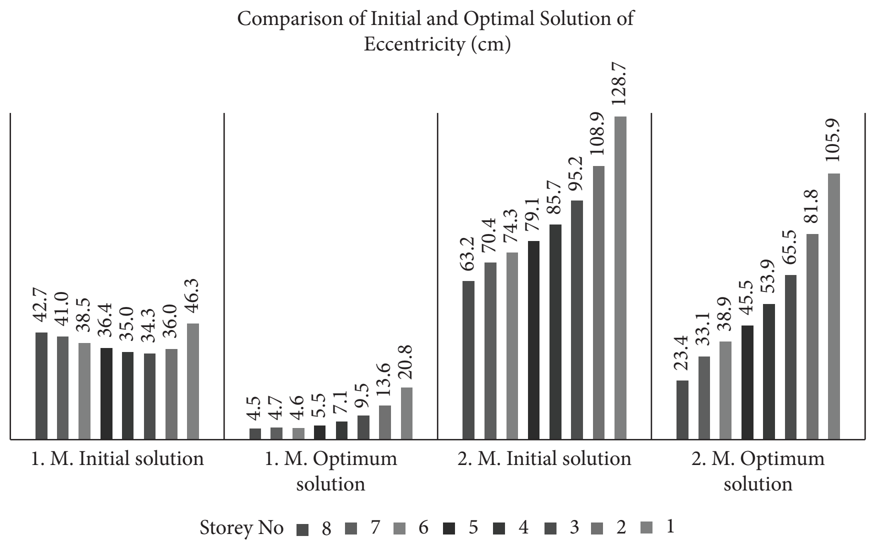


Figure 5: Comparison of initial and optimal solution graph of eccentricity of both Examples.

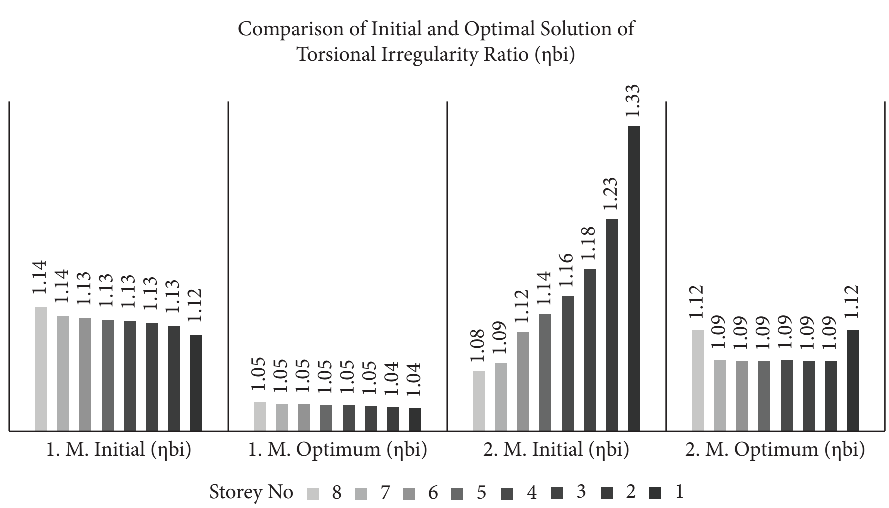


Figure 6: Comparison of initial and optimal solution graph of torsional irregularity ratio (ηbi) of both Examples.

tables, in both solutions, it was observed that the torsional irregularity ratios for all storeys were less than 1, 2 in the x and y direction.

8. Conclusion

This paper develops a genetic algorithm for designing RC buildings with plan irregularities to produce torsionally balanced structures. The structural optimization method for 3D RC frame system and shear wall-frame system is proposed, and prepared programming optimizer is utilized as optimization solution. For this purpose, two 3D finite element models of eight stories RC buildings were presented to illustrate the efficiency and practicality of the proposed optimization method. The story drift response generated by static and dynamic analysis is explicitly expressed in terms of vertical structural elements' sizing design variables. The conclusions can be summarized as follows:

(1) In the design optimization problem, the optimum size of the sections of the vertical elements of the structures were generated considering the initial sizes, consequently, at all steps of optimization, the minimum storey torsional irregularity of the structures was achieved. In all of storeys the eccentricity between the CM and the CR decreases with a decrease in design storey torsional drift ratio. The torsional drift ratio for different eccentricity between the CM and the CR gives an indication of the enhanced seismic requirement on the structure while satisfying TEC-2007 design code provision.

(2) Design variable size has a significant impact on optimum objective function values. An increase in design variable size causes a large increase in computation time but a small decrease in the objective function values.

(3) To achieve a more precise solution, we have increased the population size and maximum generation options from their default values and decreased the elite count and operating tolerance options. Moreover, increasing the initial population size will lead to a better convergence graph and a better optimum solution.

(4) It is important to note that the best objective function value may improve, or it may get worse by selecting different operators. Selecting a good set of operators for a problem is often best done by engineer experimentation.

(5) The combining solution procedure of MATLAB® and ETABS® by using the CSI Application Programming Interface (API) requires a high-speed digital computer to saving computer time because this method is difficult from the procedural point of view and requires a lot of computer time.

(6) The GA optimization technique can automatically and progressively improve a performance-based torsional drift design to achieve optimum performance and generate minimum torsion response. Moreover, we concluded that GA optimization can be an effective and powerful tool for structural optimization of reinforced concrete structures.

(7) Finally, however, the calculations and optimisations are mainly done by the computer, the method still required a skilled engineer to design a structure with a good quality result.

9. Future Research

For future research, more critical design constraints associated with width, depth and longitudinal reinforcement can be included as well as constraints on cross-sectional dimensions of structural members to meet global solutions for the optimization problem.

Data Availability

Data supporting the results of this study have been carefully reviewed and can be found in the text and in Tables 1 and 2 above.

Conflicts of Interest

The author declares that they have no conflicts of interest.

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