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Research Article

Application of Evolutionary Algorithm Technique to Minimize Torsion for Plan and Vertical Asymmetrical RC Buildings

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ABSTRACT

Plan and vertical irregularities in reinforced concrete (RC) medium-rise buildings pose significant challenges in seismic analysis due to their susceptibility to torsional effects. Irregularities such as mass, stiffness, and geometric discontinuities cause eccentricities between the building's centers (i.e.; mass and rigidity centers), inducing lateral and rotational responses that compromise structural safety. This work presents the use of evolutionary algorithms to minimize the stiffness eccentricity and thereby optimize the seismic torsional behavior for three-dimensional asymmetrical RC buildings. In order to achieve the torsional stiff structures, efforts are being made to attain an ideal preprogrammed design of the rotational deformation of the diaphragms of the proposed RC structures with asymmetries (in-plan and vertical). Both static as well as dynamic forces cause the torsional drift of floor diaphragms and they can be precisely described with regard to the design variables for the orientation of vertical structure elements. To illustrate the effectiveness and viability of the suggested optimization strategy, two examples were attempted successfully. The procedures outlined in the current seismic standards were followed to evaluate these structures' performance. Finite element mathematical models were employed to perform seismic assessments of said asymmetrical buildings. The Genetic Algorithm model was used to address the orientation optimization problem. Outcomes of the proposed study confirmed that the proposed Genetic Algorithm (GA) can solve the orientation optimization problem for three-dimensional reinforced concrete asymmetrical buildings in an efficient and optimal manner. Linear static analysis method, though easy and computationally efficient, fail to capture the torsional responses accurately. Linear dynamic analysis method, incorporating modal contributions, provide better accuracy but are limited in addressing inelastic behavior of the structural elements. Nonlinear dynamic analysis method emerges as the most reliable technique, offering precise modeling of torsional amplification under real earthquake records. The study is found to be very productive and useful as the stiffness eccentricity and torsional irregularity ratio get reduced significantly by adopting this method.

Keywords: Stiffness eccentricity, Asymmetric structure, Non-linear Time History analysis, Torsional drift, Torsional Irregularity Ratio, Evolutionary Algorithm.

1. INTRODUCTION

Earthquakes pose significant dangers and challenges to society due to their destructive and unforeseeable nature, impacting human life in diverse and grave ways. Seismic forces impose complex demands on buildings, especially those with plan and vertical irregularities. These irregularities result from discontinuities in stiffness, mass, or geometry across the plan and along height of the buildings, leading to lateral and rotational responses during seismic events. Medium-rise RC buildings, typically 5–10 stories tall that are commonly used in urban areas, are particularly prone to these effects due to their intermediate stiffness and mass distribution. The seismic response of reinforced concrete (RC) buildings is significantly influenced by structural irregularities. It's crucial to analyze how buildings, especially their torsional behaviour, behave during earthquakes and there are different solutions available to mitigate these impacts and strengthen the structural elements, which are summarised; moreover, the application of evolutionary algorithm which optimizes the structural design of lateral force resisting elements and to determine the impact and the overall response of buildings under earthquake loads by taking into account various parameters during the structural design process. In the present study, the design parameter utilized is a torsional irregularity ratio with the objective of minimizing the difference between the building's centers (i.e.; mass and rigidity centers), of the models considered by reducing the story torsional drift. Torsional moments arise when the mass and rigidity centers do not align, causing eccentricity. Medium-rise buildings are especially vulnerable due to their intermediate height, which balances flexibility and stiffness.

Humar and Kumar (1998) [1] Influence of torsional coupling effects on multistory RC structures was investigated using linear static and linear dynamic approaches. The authors demonstrated that linear static methods significantly underestimate torsional response, especially in soft-story buildings. Highlighted the necessity of dynamic methods for torsion-sensitive structures.

Chopra and Goel (2002) [2] Studied and explored the influence of higher-mode contribution on the seismic response of vertically asymmetrical structures. Modal analysis captures significant torsional contributions in irregular buildings includes the key findings by the authors. Linear dynamic analysis was recommended for preliminary design of irregular RC structures.

Rutenberg et al. (2004) [3]Analyzed the stiffness irregularities in RC buildings using response spectrum methods and found that stiffness irregularity leads to concentrated inter-story drifts, increasing vulnerability to seismic torsion. The authors stressed the importance of adequate stiffness distribution to mitigate torsional effects.

The next two publications by Stathopoulos and Anagnostopoulos (2000 and 2003) [4, 5]are particularly intriguing since they compare the overused one-story, three-dimensional shear beam building model to a detailed plastic hinge model of the same building. To the best of our knowledge, this is the first recorded comparison. A real one-story concrete structure was designed, and member-by-member plastic hinges were modelled very precisely. The corresponding simplified model's characteristics were estimated as previously done, with element strengths based exclusively on seismic activity as stated in Eurocode 8. Initially only single story was used in order to avoid multistory-multi mode effects as a source of differentiation between the two basic and detailed models (plastic hinge). The two models were evaluated on three (two historical and one artificial) distinct sets of ten ground motion pairs with different characteristics. Significant qualitative differences between the two models' results were found during the investigation. The most notable of these was that, in relation to the ongoing debate over whether the flexible or stiff side portion is more important (i.e., has higher ductility demands due to torsion), the simplified structure supported the conventional wisdom that the stiff edges have higher ductility demands, while the full plastic hinge structure indicated that the flexible side portion was the critical one.

Numerous studies have been conducted on torsional asymmetry, including geometric irregularity. Özmen (2004)[6] examined the geometrical and structural phases of the torsion asymmetry according to TEC 2007. Basu and Jain (2007) [7] A simple approach for determining the building centers has been created and may be used with any basic building analysis program. The approach applies to both orthogonal and non-orthogonal RC buildings, taking into consideration all potential definitions of static eccentricity to calculate design responses. An asymmetrical RC building is analyzed to demonstrate the suggested technique. Static eccentricity causes significant variance in member force resultants. A mathematical argument is provided to support the suggested technique for non-orthogonal buildings.

De Stefano and Pintucchi (2008)[8] they provided an overview of the progress made in studying how plans and vertically asymmetrical RC buildings react to seismic actions. Özmen et al. (2014)[9] they have investigated the code's permissible provisions and determined the circumstances for an extreme torsional asymmetry in accordance with TEC. They have investigated the code's permissible provisions and determined the circumstances for an extreme torsional asymmetry in accordance with TEC. A group consisting of 6- typical RC buildings with different shear wall locations, axis numbers along both orthogonal directions, and storey counts were the subjects of their investigation. It was observed that as the number of floors increases, the torsional irregularity ratio increases. Anagnostopoulos et al. (2015)[10] In contrast to regular structures, whose behavior is only translational, the authors' analysis of the torsional behavior of non-symmetrical RC buildings under seismic forces makes their design for seismic actions far more difficult. Mishra and Dubey (2017)[11] examined how reducing storey drift during extreme seismic conditions might lead to the collapse of buildings in higher seismic zones.

Goldberg (1989)[12] was among the pioneers in employing a genetic algorithm to address engineering optimization problems. According to Goldberg's investigation, a number of authors have successfully introduced genetic algorithms to attain the optimal design of RC structural members. The cost of structurally optimizing RC structures has been the subject of several evaluations, the majority of which have been devoted to cost. Chou, J., & Ghaboussi, J. (2001)[13] Applied GA for structural damage detection as an inverse issue, with an emphasis on the presence, location, and extent of damage. It defines the problem as an optimization challenge that is solved using a genetic algorithm (GA). Static displacement measurements at selected degrees of freedom (DOFs) detect changes in structural parameters such as Young's modulus and cross-sectional area. Unlike previous approaches, GA searches the issue space using objective function values and can find damage locations even with a small number of measurements.

Camp et al. (2003) [2, 3]applied GA for optimum bending design of multi-story frames, simply supported RC beams, and columns employing a search for discrete-valued solutions. Govindaraj and Ramasamy (2005)[16] presented a thorough study on the optimal design of RC continuous beams using a GA. Guerra and Kiousis (2006)[17] applied non-linear analysis (NLA) procedures for the ideal design of RC buildings. Ghodrati et al. (2008)[18] introduced a GA model for RC buildings for achieving the optimal design. Hatindera et al. (2014)[19] made the assumption that all vertical elements are rectangular in shape and cost optimization is calculated while adhering to IS:456-2002[20] standard for strength and serviceability of the structure. Alex and Kottalil (2015)[21], applied a GA for RC continuous beam models for achieving the optimal designs. Samruddha and Patel (2017)[22], studied the optimization of the RC flat slab buildings using a GA. Fayaz Basha and Madhavi Latha (2018)[23] assessed the usage of GA by studying the design RC slab. Sadat and Arslan (2021)[24] studied the design for optimum eccentricity for seismic behaviour using GA. In their research, the effectiveness of the GA was studied and reported to give a good solution. Mei, L., & Wang, Q. (2021) [25]Presented a critical review on the rising concern about sustainability and efficiency in the architecture, engineering, and construction (AEC) business, with an emphasis on structural optimization in civil engineering. With advances in computational tools and information technology, structural optimization has become a popular approach to sustainable design. The report evaluates previous research, examining optimization targets, procedures, and trends, and identifies present constraints and future research prospects. It covers the four main aspects of structural optimization: analysis, formulation, methodologies, and computational tools. The study emphasizes successes and limitations, as well as recommendations for future structural optimization research. Sadat (2021)[26] assessed the effect of GA optimization in-plan asymmetry on the seismic behaviour of RC structures using artificial intelligence (AI) enabled systems. Sadat (2022)[27] also assessed the proposal of the GA to avoid torsional asymmetries in RC structures for low to medium rise RC vertical asymmetrical structures, the authors used a GA to determine the best orientation for lateral force resisting elements (LFREs). According to their investigation, GA is successful in providing the least amount of static eccentricity for vertical asymmetrical models that are low to medium in height. The GA parameters for the aforementioned models were successfully adjusted by the authors[28] to minimize torsion.

It was observed based on the literature review carried out, that the earlier studies were more concentrated on the study of torsional responses for low- rise buildings and are limited to plan irregularity only and few researchers attempted to study the seismic performance of low to medium-rise buildings with shear walls placed at different locations. It was also reported by researchers studying the dynamic characteristics effect of the low to medium-rise buildings having asymmetric plans with stiffness eccentricity. The reviewed papers consistently highlight the limitations of linear static and linear dynamic methods in accurately predicting torsional responses in vertically irregular RC buildings. While linear methods are computationally efficient, they fail to account for inelastic and higher-mode effects. Nonlinear dynamic time history analysis, despite being resource-intensive, is indispensable for capturing the true torsional behavior, especially under severe seismic excitations. Accordingly, it was inferred that the importance of studies on the seismic response of vertical asymmetrical RC buildings using the Non-Linear dynamic analysis method through the arrangement of lateral load-resisting elements in the structure is important and an attempt has been made in that direction.

Advances in computational tools and IT have popularized structural optimization for sustainable design. The report evaluates previous research, examining optimization targets, procedures, trends, current constraints, and future research prospects. It covers four main aspects: analysis, formulation, methodologies, and computational tools. Despite not being thoroughly discussed in the majority of the gathered papers, computational tools and design platforms are crucial as they have a big impact on optimization efficiency. The computational and design criteria can undoubtedly be met by the current tools. To further enhance the optimization capabilities, computational efficiency, and data interoperability, new tools or integrated platforms are still required as discussed by Mei, L., & Wang, Q. (2021) [25].

An optimization approach was used in this work to design seismically generated torsional drift for irregular buildings based on a G.A. in order to investigate the given goal. Three three-dimensional finite element models of five and ten-story reinforced concrete structures were used for evaluating the effectiveness and viability of the GA approach under consideration. The Proposed models were explored with a finite element model using the mode superposition and Equivalent static Load (ESL) methods. The Genetic Algorithm (GA) was used as a model tool for the column orientation optimization problem. The orientation angles of the columns were taken into consideration as design factors in this study.

2. ASYMMETRICAL RC BUILDINGS

The construction and design of asymmetrical buildings are generally ignored due to their adverse seismic performance and various irregularities in both elevation and plan. However, based on practical considerations and aesthetic constraints, irregular structures cannot be avoided. Irregularities in the plan includes five different types i.e.; Torsion irregularity, Floor discontinuity, Re-entrant corners, Out-of-plane offsets in vertical elements and Nonparallel systems. Irregularities in elevation consist of seven types: Stiffness irregularity, Vertical geometric irregularity, Mass irregularity, In-plane discontinuity in vertical elements resisting lateral forces, Floating columns, Strength irregularity, and Irregular modes of oscillations in two orthogonal axes as per seismic codes of practice i.e.; IS: 1893-2016[29].

2.1 *Torsional Irregularity:* It significantly weakens building structures. According to IS: 1893-2016 [29], the torsional irregularity ratio (η_{bi}), which, for either of the two orthogonal seismic directions, should not be more than 1.5. It is the ratio of maximum to minimum floor drift at any given level in the same direction. The torsional irregularity is determined from the following equation.

$$\eta_{bi} = (\Delta_i)_{max}/(\Delta_i)_{min} > 1.5 \tag{1}$$

where: $(\Delta_i)_{max}$ = maximum floor drift for the ith floor;

$(\Delta_i)_{min}$ = minimum value of floor drift for the ith floor.

When the building centers (i.e.; mass and rigidity centers) in the building are non-concurrent then torsion is generated as reported by Duggal (2013)[30] static eccentricity is the term used to describe the distance between these two centers. While the location of the center of rigidity changes depending upon the material and geometrical properties of the lateral force-resisting system components, such as moment frames, bracing system, shear walls, etc., the center of mass is often the geometric center of the structural plan. Torsion is only possible in structures with stiff diaphragms. In structural systems, the mass center is affected by seismic forces, hence the structural rigidity center responds to these forces. According to Duggal (2013)[30] if the distance between these two centers is greater, a torsional moment generates about the rigidity center and the building rotates around the vertical axis which usually the axis of rigidity. More shear is produced by the torsional moment. The response of such a RC building under seismic forces mainly depends on the shape, angle, and geometric placement of the lateral force resisting elements such as columns and piers.

2.2 *Storey Drift:* It is the ratio of the maximum relative displacement of a storey to the height of the same storey, this is a crucial parameter for measuring torsion. Translational drift behaviour of a RC structure is achieved by combining the modal peak responses by using the Complete Quadratic Combination (CQC) and Square Root of the Sum of Squares (SRSS) rules, and not to exceed 0.02 h as per IS: 1893-2016[29]. Limiting a building's lateral storey drifts is essential when designing earthquake-resistant constructions. Buildings may sustain structural and non-structural damage as a result of extreme drifts. According to IS: 1893-2016 [29], the difference of lateral displacements between any two subsequent floors shall be used to calculate reduced relative storey drift, Δ_i, of any vertical element, such as columns or piers (structural walls), using equation (2).

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

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

The translational displacements resulting from calculations based on decreased seismic activities at the ends of any column or pier at floor levels i and (i−1) are represented by d_i and d_{i-1}. For each earthquake direction, equation (3) yields the effective relative storey lateral drift, Δ_i, for the columns and piers of a structure's i^{th} storey. Maximum value of effective relative storey lateral drifts, Δ_i, within a storey, $\Delta_{i,max}$, calculated by equation (4).

$$(\Delta_i)_{max}/h_i \leq 0.02 \quad (4)$$

Equation 4 requires that the piers and columns of a building's i^{th} story meet the requirements for each earthquake direction. In accordance with IS: 1893-2016 [29], the seismic analysis shall be revised by making the lateral force resisting system more rigid if the requirement specified by equation (4) is not satisfied at any given floor.

3. GENETIC ALGORITHM

Genetic algorithm (GA) is one of the most popular transformative algorithms (TA), according to Rao (2009)[31]. It is an approach to model genetic transformative mechanisms in view of standards of both viability and versatility of the fittest. The GA's goal is to improve the functional operation process by including crossover, mutation, and reproduction. Regardless of the method used to derive functions, the GA employs function values to move closer to a solution. When calculating algorithms, neither the continuity nor the differentiation of the problem's functions is utilized. As a result, the techniques are incredibly versatile and may be used for discrete, continuous, and non-differentiable issues. The fundamental idea behind a GA is to increase the population's average fitness by creating a new population set from the existing one. Until a certain number of iterations is reached, the process keeps going.

The important steps associated with the GA model are described briefly here.

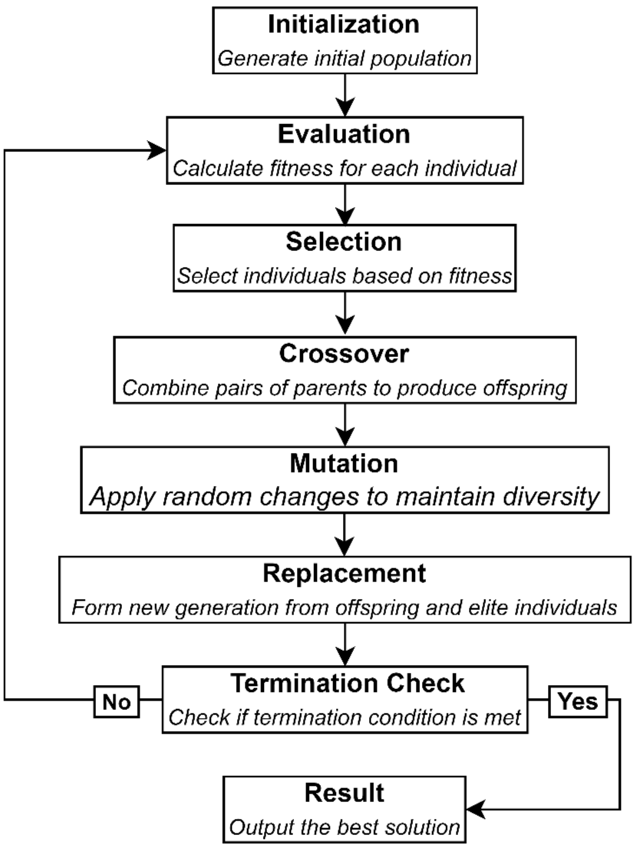

Fig 1: Typical Flowchart of Genetic Algorithm for Minimization Function

Figure 1 shows a detailed flowchart that illustrates a complete methodology that is involved in a typical GA for minimization function. The important steps associated with the GA model are described briefly here.

Initialization typically involves the generation of initial population of potential solutions randomly. Each individual in the generated population represents a potential solution and is typically represented as a binary string or vector.

Evaluation, in this step the evaluation of the fitness of each individual in the already defined population is carried out with the chosen fitness function. It evaluates how better each solution is in terms of minimizing the given function.

Selection generally involves picking up individuals to be parents based on their fitness values (i.e., the higher the fitness value higher the probability of being selected). Various techniques are involved in this process that include but are not limited to tournament selection, rank selection, or roulette wheel selection.

Crossover, also known as recombination, combines the pairs of selected parents to produce the offspring. One-point crossover function, two-point crossover function, and uniform crossover function etc., are some of the common methods involved in this process.

Mutation typically involves the application of random changes to genes of selected individual offspring to maintain genetic diversity in the population. This process helps to prevent the GA from getting stuck up in local minima solutions.

Replacement, in this step the replacement of the current population with the new generation of offspring is carried out. In addition to this, a typical form of elitism is also applied to the offspring to ensure that the best solutions are carried forward to the next generation.

Termination Check, here the algorithm checks if the chosen termination criterion (i.e., maximum number of generations, stall limit of generations, time limit or a satisfactory level of fitness is achieved) is met. If the chosen termination criterion is not met then the function returns to the evaluation stage.

Result, in this step the best individuals in the selected population is considered the optimal solution to the given minimization problem.

Several Runs for a Problem: Several Runs for a Problem, When the same issue is run at various times, genetic algorithms can provide distinct final designs because they make judgments in several regions based on the creation of random numbers. According to Rao (2009) [26] and Arora (2012) [17] to ensure that the optimal solution has been found, it is advised to run the problem many times.

4. STRUCTURAL MODELS

Two multi-story irregular buildings are taken into consideration in order to use a GA to explain the torsional behavior in RC constructions. Five story model for the first structural system, while ten floors model for the second structural system. Finite element analysis and mathematical modeling were used to evaluate the seismic response of RC buildings. Following the analysis, the GA technique was used to compute and further process the results. To limit all of the nodal points on each level and to speed up uniform plan lateral displacement, the slabs were modeled using shell elements and as a stiff diaphragm. For convenience, columns were typically supported by fixed supports in all directions. A primary design process was used to establish the size of the structural components with the primary goal of achieving realistic results. Automatic mesh generation was employed. The dynamic response of a vertically asymmetrical structure with different eccentricities was initially evaluated in order to assess the consequences of the torsional response of the said RC structures. The structural results and responses, including displacement and torsion ratio, will be obtained upon the completion of the study. Optimization methods were employed to find better settings for drifts. In accordance with this, the structural optimization approach for the three-dimensional RC construction is suggested. The current work uses a GA to create and apply a method for optimizing the drift of the floors. The design variables in this case were the member angles. In order to meet the seismic codal criteria, the lateral storey drift of the building is taken into consideration as an objective function. Since the evolutionary algorithm continuously alters a set of solutions while it operates until an infringement is found, objective function f(x) will not be fined. The process was stopped for the chosen value when the number of defined generations reached the already defined limit for generation. The producing variables must be at least 90 to 95 percent similar in order to end the return operation procedure. After the buildings were resolved three times, the best design which is regarded as the best solution among the optimal solutions attained for each set was produced. Based on static and dynamic linear analysis, the best cross sections are selected for the final design application in order to meet the criteria of IS 456-2000[20] and IS 1893-2016[29] codal regulations. Tables 1 and 2 provide the different GA parameters used for process optimization in each test instance, together with the seismic details of the models under consideration. Two models of five and ten stories with total heights of 15 and 30 m are considered.

Table 1: Presumed Initial Information Needed for the Analysis

S.No.	Variable	Data
1	Frame Type	SMRF
2	Number of levels/ Stories	5 Storey & 10 Storey
3	Typical Storey Height	3 m (Bottom Story Height = 3.6 m)
4	Materials	M30 & Fe550
5	Slab	127 mm
6	Beams	300 mm x 500 mm
7	Columns (Basic model)	5 Storey: 300mm x 450mm; 10 Storey: 300mm x 600mm
8	Dead Load	Self-weight of members; Super Dead Load = 1 kN/m²
9	Live Load	Live Load = 3 kN/m²; Roof Live Load = 2 kN/m²
10	Earthquake Data (Linear Static Analysis)	Zone Factor: 0.36 (Zone V) Importance factor: 1.5; Response reduction factor: 5 Site type: II

Table 2: Solver parameters chosen to for the analysis

Number of Stories	5-Storey & 10-Storey
Number of Variables	8
Population Size	500, 3500
Mutation Function	Mutation Power
Crossover Function	Crossover Two Point
Crossover Fraction	0.8, 0.75
Number of Elite Members	25, 175
Max Generations	800
Stall Generation Limit	100, 800

4.1 Structural Loads and their Combinations: According to the [20] method, the RC structures are exposed to lateral forces that are derived from the superposition of the seismic design modes. The weight of the storey has been converted to mass that comprises dead load (full) and live load (25% for residential buildings confirming IS 1893 (Part 1): 2016[29] during an earthquake). For every storey, the super imposed dead loads and live loads on the floor slabs are 1 kN/m² & 3 kN/m², respectively, and for the roof, 2kN/m² of roof live load is assumed. The model is examined under the worst-case load scenario after taking into account the load combinations (25) [20]. Every problem's solution scenario was run many times to achieve the best solution.

Example 1. Buildings (5 and 10 Storey) with 6 spans along the X-axis and 4 spans along the Y-axis comprising 29 vertical (column) elements at each storey level were considered. In this execution process, the size of the columns is taken as 300 mm x 450 mm for a 5-storey building and 300 mm x 600 mm for a 10-storey building. The considered model's plan geometry has 5 m spans and 4 m spans respectively in the X and Y axes. The cross section for all the RC beams is 300 mm × 500 mm.

Figure 2 describes the typical floor plan, and figures 3 and 4 show the elevation and 3-dimensional view of the non-symmetric RC buildings that are considered in the present study for the stiffness and torsional analysis. In these models to induce vertical stiffness irregularity (Soft story) the bottom story height is taken as 3.6 m instead of default 3 m as assumed. A total of 29 columns were taken as variables marked as C1, C2, ... and C29 are taken into consideration and the example's outcomes are listed and examined and the optimizations' outcomes were tabulated.

Figure 6 shows the GA convergence graph, where 700 generations are needed to attain the optimal design. The optimal solution with 1000 function evaluations was found after 20 iterations, which were determined to be the termination criterion.

The orientation of columns in degrees and a comparison of initial and optimal solutions, its objective uses Gaussian and Power functions for variation in population, generation and crossover, whereas Table 4 shows a comparison of initial and optimal member angles for the best penalty value of all considered parameters relating to stiffness and torsional irregularity for non-linear time history analysis, respectively.

Subsequently, the torsional irregularity ratio of the optimal design is then significantly decreased in all storeys by employing the newly presented optimization technique.

5. OPTIMIZATION

5.1 *Developing the Ideal Design:* To formulate the optimum design issue, the structural system's variable set must be identified, the system must be subjected to the selected constraints, and the objective function must be minimized. Here is an example of a discrete structure optimization problem (6)[7, 18]:

$$\text{Find } x = [x_1, x_2, \ldots, x_n] \text{ which minimize } f(x) \tag{6}$$

$$\text{Subject to the constraints } g_j(x) \leq 0;\ j = 1, 2, \ldots, m,$$

$x^{iL} \leq x_i \leq x^{iU}$; i = 1, 2, ... , n.

The design variable x in this work signifies the angles of the column section. We refer to f(x) as the objective function. The lower limit and upper limit of the chosen variables are contained in the n-length vectors x^{iL} and x^{iU}, which represent the inequality constraint gj(x).

5.2 *Orientation Optimization:* Goal of RC structural orientation optimization is typically to offer optimal cross-section angles for the specified vertical elements.

6. OPTIMAL ECCENTRICITY FOR RC BUILDINGS WITH IRREGULARITIES

6.1 Objective Function: In the present study, in order to decrease eccentricity, the objective function is:

$$Min\ Eccentricity = \sqrt{(ecc(X)^2 + ecc(Y)^2)} \tag{7}$$

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

$$x_i^L \leq x_i \leq x_i^U; i = 1, 2, \ldots n \tag{8}$$

Here the eccentricities between the building centers in orthogonal directions are denoted by ecc(X) and ecc(Y), respectively. A vector of column orientations "m," which represent the behavioural restrictions imposed by seismic action and reinforced concrete building design standards, is returned by the vector function $g_j(x)$; the lower and upper boundaries of the angles in degrees are denoted by x^L and x^U, respectively.

7. RESULTS AND DISCUSSIONS

The system was solved and the objective function was minimized as the chosen design variable values were allotted to the chosen column section in the system that had already been constructed, the torsional eccentricity was reduced when the program nears the completion of optimization process. Evolution will continue until the specified number of generations is attained. When the number of generations exceeds a certain threshold and the goal function is reduced, from the first generation to the next, the fitness value falls.

With every generation, population factors become more effective. As each generation progressed, column orientation values (angles) were written onto an output file. The members of this generation (column angles) with higher fitness values were considered the ideal point for the final design application. The output demonstrates that the angles utilized in the basic model and the optimized solution differ. These tables display the column angles in degrees, with positive and negative signs corresponding to clockwise and counterclockwise directions.

After the optimization procedure was applied to 3-dimensional five- and ten-story RC structures, the best design was produced, allowing for a comparison between the initial and ideal designs. The best results demonstrate that using the automated design technique can result in a design candidate that satisfies the conventional codal limitations and has a minimal eccentricity and torsional irregularity ratio. In both the x and y axes, torsional irregularity ratios were determined to be less than 1.5 for all levels, as can be seen from the figures in both solutions.

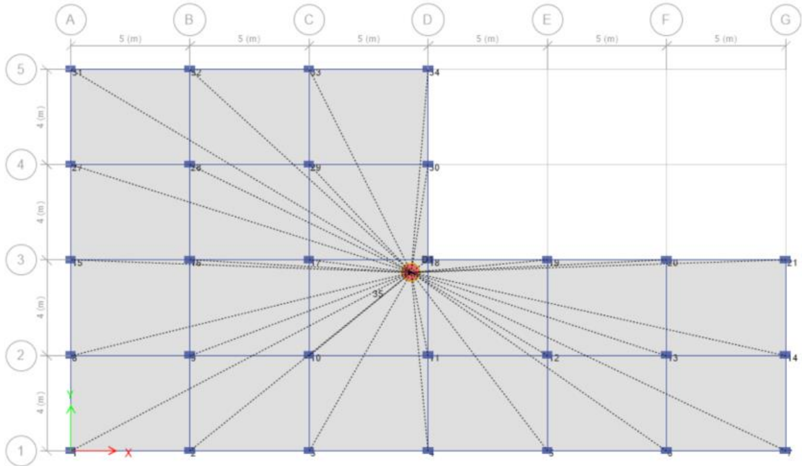

Fig 2: Typical Floor Plan of 5 &10 Storey Models

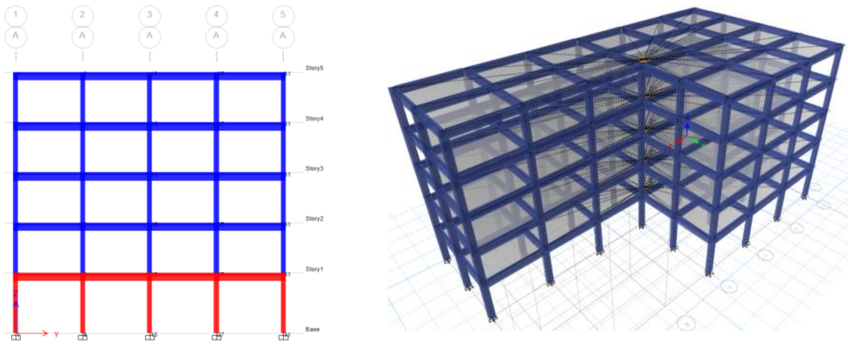

Fig 3: Elevation and 3D View of 5-Storey Model

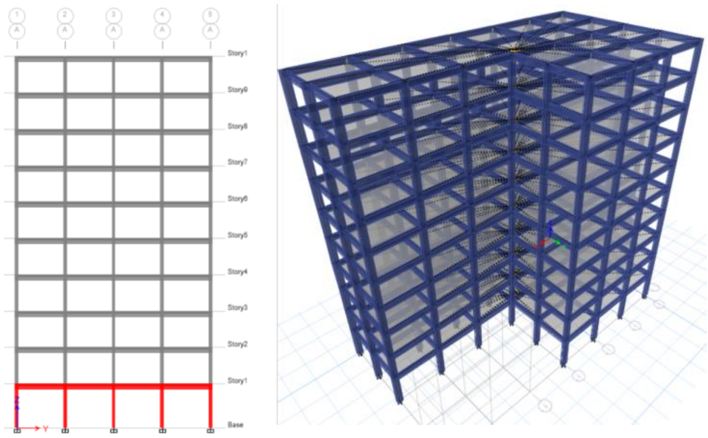

Fig 4: Elevation and 3D View of 10-Storey Model

7.1 Variation in Population (5-Storey):

The variation in population was carried out from 200 to 1000 with two varying mutation functions (Gaussian & Power). The results of the outcome are shown in the below graph.

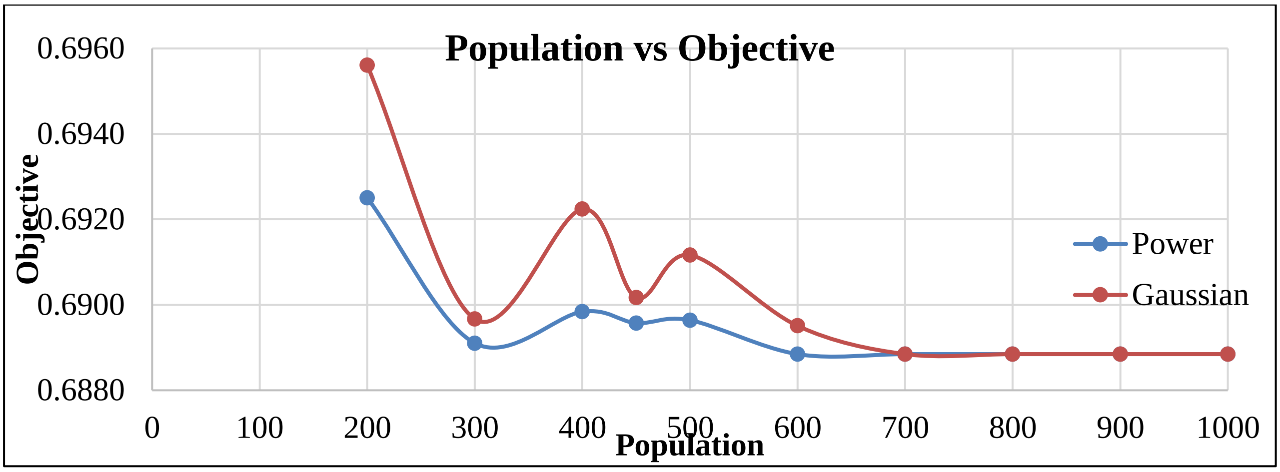

Fig. 5: Variation of Population and Objective

It can be observed from the graph that the power function achieves the objective at 600 populations whereas the Gaussian function achieves the same objective at 700 populations.

7.2 Variation in Generations (5-Storey):

The variation in a generation was carried out from 60 to 800 with two varying mutation functions (Gaussian & Power). The results of the outcome are shown in the below graph.

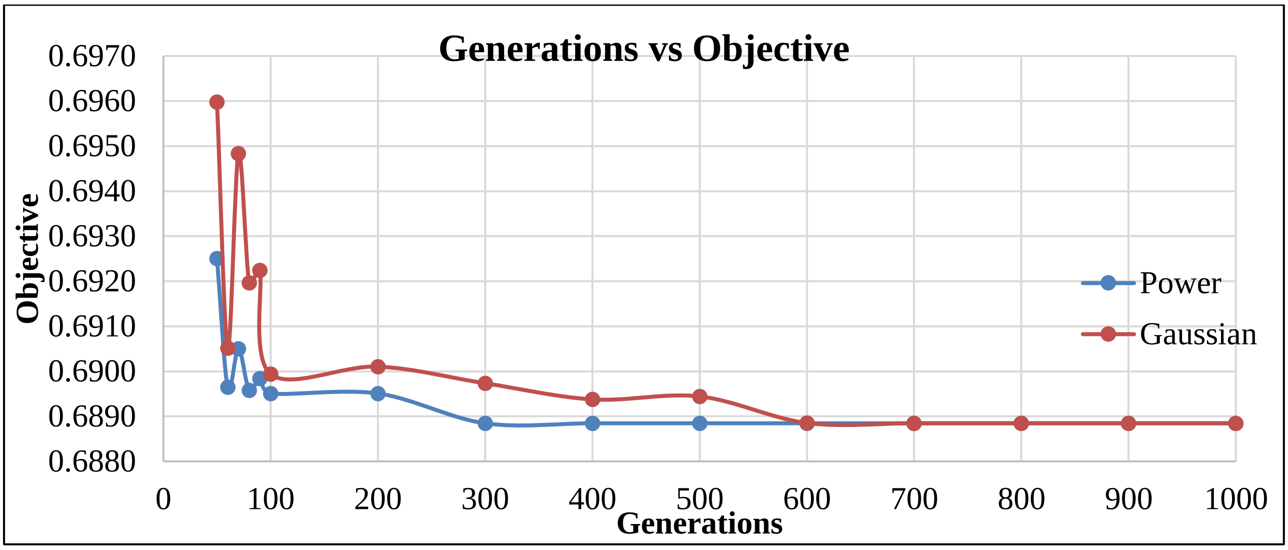

Fig. 6: Variation of Generation and Objective

It can be observed from the graph that the power function achieves the objective at 300 generation whereas the Gaussian function achieves the same objective at 700 generation.

7.3 Variation with Crossover (5-Storey):

The variation in the crossover was carried out from 0.6 to 1.0 with two varying mutation functions (Gaussian & Power). The results of the outcome are shown in the below graph.

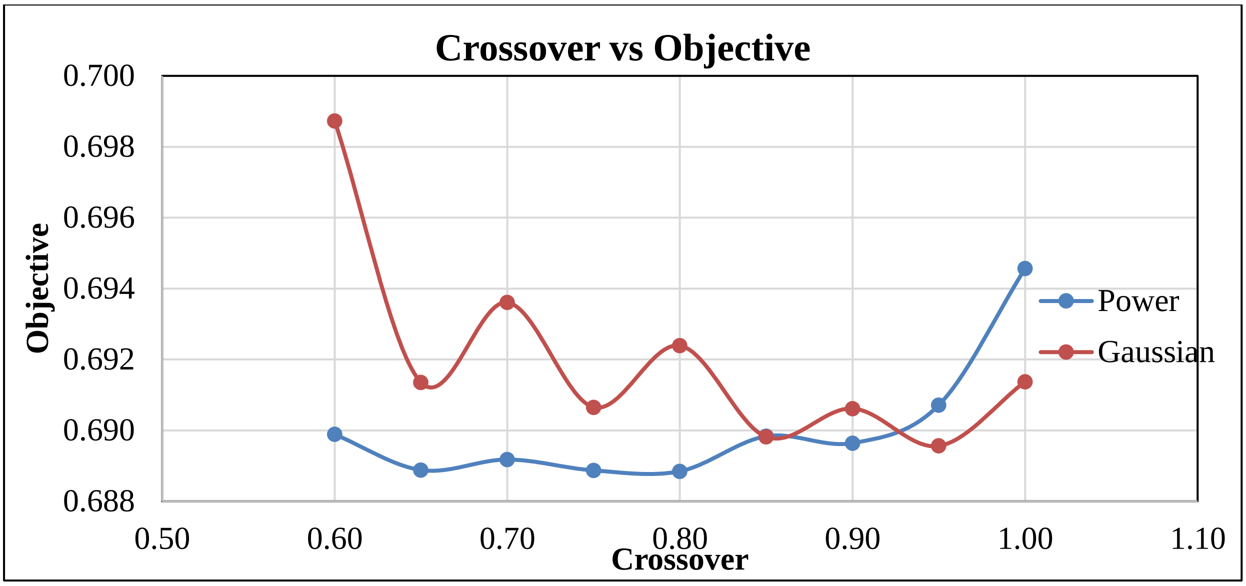

Fig. 7: Variation of Crossover and Objective

It can be observed from the graph that the power function achieves the objective at 0.80 crossover whereas the Gaussian function achieves the same objective at 0.95 crossover.

7.4 Variation in Population (10-Storey):

The variation in population was carried out from 200 to 20,000 with two varying mutation functions (Gaussian & Power). The results of the outcome are shown in the below graph.

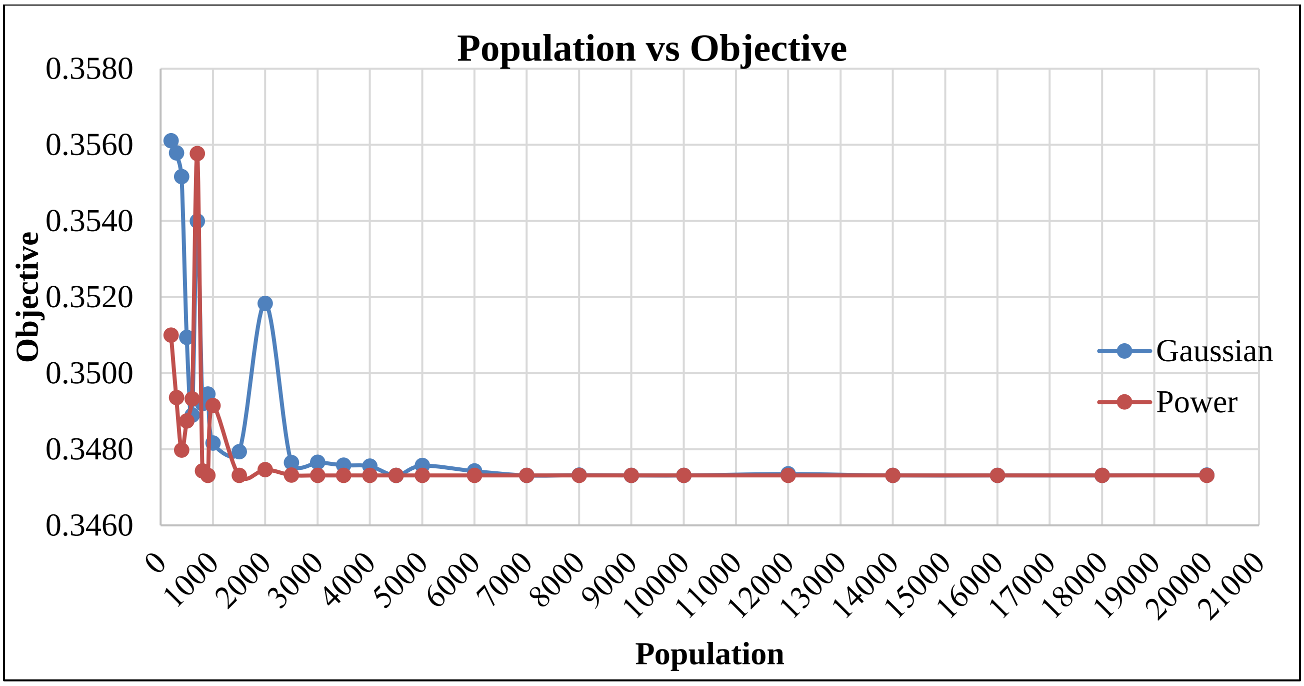

Fig. 8: Variation of Population and Objective

It can be observed from the graph that the power function achieves the objective at 900 population whereas the Gaussian function achieves the same objective at 4500 population.

7.5 Variation in Generations (10-Storey):

The variation in a generation was carried out from 100 to 1000 with two varying mutation functions (Gaussian & Power). The results of the outcome are shown in the below graph.

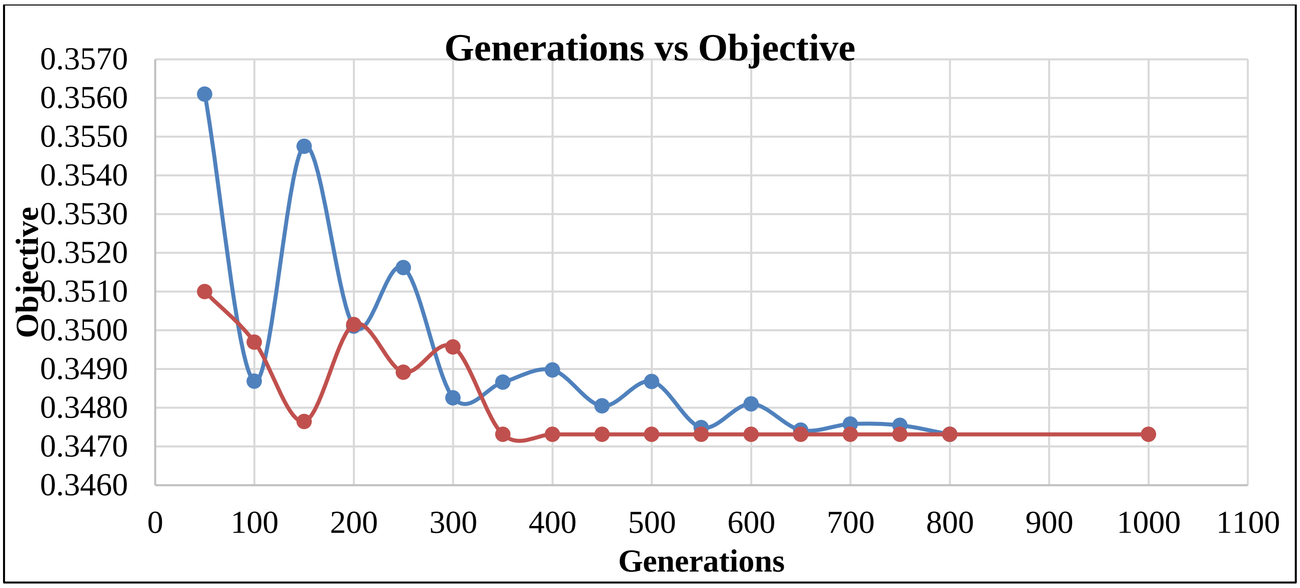

Fig. 9: Variation of Generation and Objective

It can be observed from the graph that the power function achieves the objective at 350 generations whereas the Gaussian function achieves the same objective at 1000 generations.

7.6 Variation with Crossover (10-Storey):

The variation in the crossover was carried out from 0.6 to 1.0 with two varying mutation functions (Gaussian & Power). The results of the outcome are shown in the below graph.

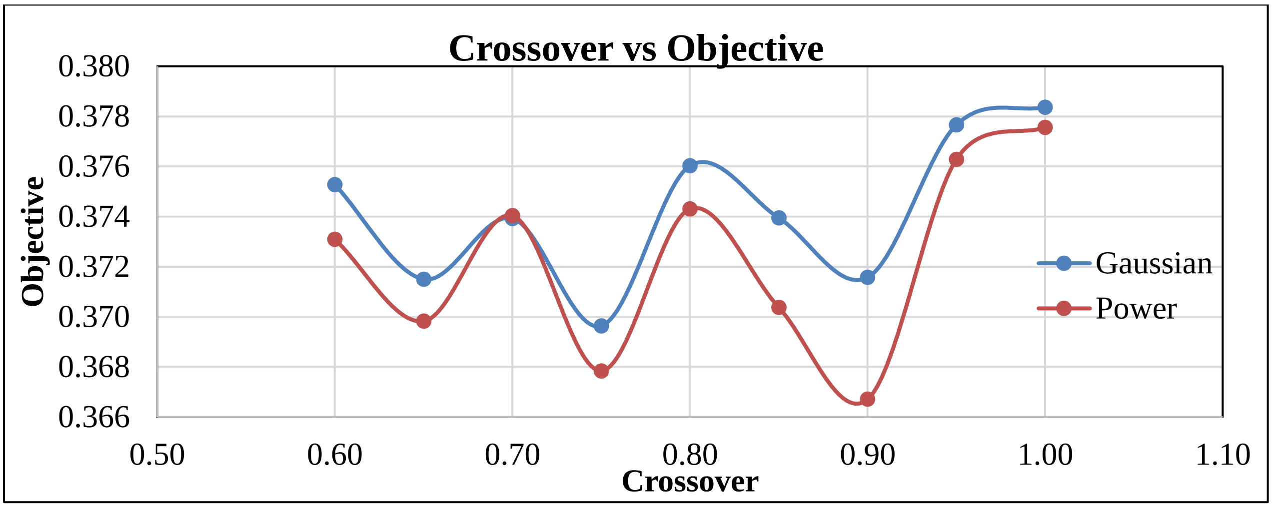

Fig. 10: Variation of Crossover and Objective

It can be observed from the graph that the power function achieves the objective at 0.90 crossover whereas the Gaussian function achieves the same objective at 0.75 crossover.

7.7 Final GA Parameters (10-Storey):

Table 3: Solver parameters selected for study

Number of Stories	5-Storey & 10-Storey
Number of Variables	8
Type of Optimization Technique	Genetic Algorithm
Population Size	600, 900

Mutation Function	Mutation Power
Crossover Function	Crossover Two Point
Crossover Fraction	0.80, 0.90
Number of Elite Members	20, 155
Max Generations	300, 350
Stall Generation Limit	1000, 1000
Function Tolerance	0.1

Table 4: Orientation angles of Basic and Proposed Models

Column ID. No.	Basic Model Storey 5 & 10	Proposed Model Storey 5	Proposed Model Storey 10
1	0°	-45°	-54°
2	0°	0°	90°
3	0°	90°	90°
4	0°	0°	90°
5	0°	90°	90°
6	0°	90°	0°
7	0°	40°	29°
8	0°	0°	90°
9	0°	90°	90°
10	0°	90°	90°
11	0°	90°	0°
12	0°	90°	0°
13	0°	90°	90°
14	0°	90°	90°
15	0°	0°	0°
16	0°	0°	0°
17	0°	0°	90°
18	0°	90°	0°
19	0°	0°	0°
20	0°	0°	0°
21	0°	-70°	-25°
22	0°	0°	0°
23	0°	0°	0°
24	0°	90°	0°
25	0°	90°	0°
26	0°	-45°	-37°
27	0°	65°	53°
28	0°	0°	90°
29	0°	-50°	-45°

Table 5: Torsional Irregularity Ratio

Story	TIR-Basic Model	TIR-Proposed Model	Percentage Reduction	
5-Story	1.63	1.44	11.66%	Decrease
10-Story	1.68	1.48	11.90%	Decrease

It can be observed from the Table 5 that the torsional irregularity ratio for 5 story and 10 story basic model is greater than 1.5. Whereas for proposed 5 story and 10 story model the value is less than 1.5. There is a decrease of 15.22%

Table 6: Comparison of Diaphragm's Rotation for 5 story model

S.No.	**Load Case**	**Rotation of Diaphragm (in radians) x 10-4**		**Percentage Reduction**
		Basic Model	**Proposed Model**	
1	EQ-X	5.08	2.66	47.64% Decrease
2	EQ-Y	5.78	3.1	46.37% Decrease
3	NLTH-X	2.65	0.78	70.57% Decrease
4	NLTH-Y	3.58	0.39	89.11% Decrease

Table 7: Comparison of Diaphragm's Rotation for 10 story model

S.No.	**Load Case**	**Rotation of Diaphragm (in radians) x 10-4**		**Percentage Reduction**
		Basic Model	**Proposed Model**	
1	EQ-X	9.67	4.71	51.29% Decrease
2	EQ-Y	12.98	8.89	31.51% Decrease
3	NLTH-X	4.45	1.51	66.07% Decrease
4	NLTH-Y	5.26	2.65	49.62% Decrease

It can be observed from the Table 6 Table 7 that the diaphragm rotation of proposed 5 and 10 story models has improved i.e.; there is a reduction of about 46% for linear elastic case and 89% for non-linear dynamic case for 5 story proposed model when compared to basic model. Whereas for 10 story proposed model there is reduction of about 31% for linear static case and 51% for non-linear dynamic case when compared to basic model.

Table 11 and Table 12 represents the values of Angular Acceleration of Diaphragm at the top storey of different models of 5-Storey and 10-Storey plan irregular re-entrant corner buildings.

Table 8: Comparison of Diaphragm's Angular Accelerations of 5 story model

S.No.	Load Case	Angular Accelerations (rad/ sec2)		Percentage Reduction
		Basic Model	Proposed Model	
1	NLTH-X	0.022	0.0046	79.09% Decrease
2	NLTH-Y	0.024	0.0098	59.17% Decrease

Table 9: Comparison of Diaphragm's Angular Accelerations of 10 story model

S.No.	Load Case	Angular Accelerations (rad/ sec2)		Percentage Reduction
		Basic Model	Proposed Model	
1	NLTH-X	0.018	0.0051	71.67% Decrease
2	NLTH-Y	0.027	0.014	48.15% Decrease

It can be observed from the Table 8 Table 9 that the diaphragm angular acceleration of 5 story and 10story models has improved i.e.; there is a reduction of about 79% for non-linear dynamic case for proposed 5 story model when compared to basic model. Whereas for proposed 10 story model there is reduction of about 48% for non-linear dynamic case when compared to basic model.

8. CONCLUSIONS

Selecting appropriate computational tools and design platforms is crucial for both performing optimization algorithms and achieving the best possible structure design, in addition to modelling and structural analysis, optimization methodology and optimization problem formulation. Structural design and analysis were formerly done by trial-and-error method to minimize the torsion, which was labour-intensive and prone to mistakes. As information technology has advanced, several design platforms and computational tools have been created to offer a setting for finite element modelling, structural analysis, and design. Latest well-known software programs, such SAP2000 and ETABS, greatly increase computation speed and produce superior outcomes.

In order to create torsionally balanced structures and design RC buildings for both plan and vertical abnormalities, this research explores a GA. For a three-dimensional RC frame system, the structural optimization method is recommended, and an optimization solution is implemented using a prepared programmed optimizer. Two three-dimensional finite element models of five- and ten-story reinforced concrete buildings were created in order to accomplish this goal and show the effectiveness and usefulness of the suggested optimization method. Angle (design variables) is a concise way to explain the storeys eccentricity response brought on by non-linear dynamic analysis in terms of vertical structural components. The following is an outline of the conclusions.

(1) By treating the starting angles in the design optimization issue as zero, the vertical elements of the structures were oriented. As a result, the structures' lowest storey torsional irregularity was reached during different optimization stages. As the design storey torsional eccentricity ratio is reduced, the eccentricity between the CM and the CR reduces in all storeys. The increased seismic need for the structure in accordance with the IS 1893 (Part 1): 2016 codal provision is suggested by the torsional eccentricity ratio for various eccentricities between the different building centres.

(2) The ideal objective function values are significantly influenced by the design variable (angle). The goal function values somewhat drop as the design variable (angle) increases, but the calculation time increases significantly.

(3) To achieve optimal performance and minimize torsion response, a performance-based torsional eccentricity design may be gradually and spontaneously improved using the GA optimization approach. In addition, we came to the conclusion that the structural optimization of RC structures can benefit greatly from the use of GA optimization.

(4) It is important to remember that using alternative operators may cause the optimal objective function value to increase or become critical. Engineer efforts are frequently the most effective way to choose a decent collection of operators for a problem.

(5) Using the Gaussian function, the ideal population sizes for the five-story and ten-story models are 700 and 4500, respectively.

(6) The optimum sizes of the population for 5 and 10-storey models using the power function are 600 and 900 for 5 and 10-storey models respectively.

(7) Optimum generation values for 5 and 10-story models with Gaussian function are 700 and 1000 respectively. Whereas power function values are 300 and 350 for 5 and 10-story models. Using the power function objective value stabilized after 300 generations for 5-story models and 350 generations for 10-story models. For 5 and 10-story models objective value stabilized after 700 and 1000 generations respectively with Gaussian function.

(8) Optimum cross-over values for 5 and 10-story models using the Gaussian function are 0.95 and 0.75 respectively. Whereas power function values are 0.80 and 0.90 respectively.

(9) Torsional irregularity ratio decreased by a maximum of 11.90% for 5 story proposed model whereas for 10 story proposed model it decreased by 11.66%.

(10) The diaphragm rotations decreased by 89.11% for the 5-story proposed model and 66.07% for the 10-story proposed model at the top storey of the corresponding models following the correct alignment of LFREs.

(11) Using the Bhuj earthquake data, the diaphragm's angular accelerations due to NLTH decreased by up to 79.09% in the x-direction for the 5-story proposed model and up to 71.67% along the x-direction for the 10-story proposed

model at the top storey of each model.

(12) Additionally, by employing evolutionary algorithm approaches to develop optimal column orientations with power function as mutation operator, it is possible to lower the torsional parameters in irregular structures.

Data Availability

The information pertaining to the study's findings has been thoroughly reviewed and is included in the text as well as in the above Tables.

Conflicts of interest

The author acknowledged that they have no conflict of interest.

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