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Application of Evolutionary Techniques to Minimize Torsion for Plan Irregular Re-entrant Corner Buildings

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Abstract

Irregular structures are accounting significant presence due to varied occupational and aesthetic demands, specifically in urban infrastructure. Majority of such buildings are irregular to some extent due to the presence of asymmetry in plan, elevation, irregular vertical member distribution or floor mass distribution or combinations of these reasons. Perfectly regular buildings are an idealized concept, and in actuality, this requirement is rarely met. The effect of seismic action is due the presence of structural irregularity in buildings causes substantial displacement amplifications and stress concentrations in the members, resulting in severe damage and ultimately early collapse. According to IS-1893:2016, a building is torsionally irregular if the maximum horizontal displacement at any floor in the direction of lateral force exceeds 1.5 times the minimum horizontal displacement at the far end. Torsional irregularity, also known as in-plan irregularity, occurs when the lines of action of centers of mass and stiffness on a common vertical axis at each floor level do not coincide. During earthquakes or other lateral loads, inertia forces act through the center of mass, while resistive forces act through the center of stiffness or resistance. The relative location of a building's center of mass, strength, and stiffness influences the torsional forces operating on it. These centers of significance must be strategically placed to minimize torsional impacts on structures and provide an efficient building structure. In this paper, the impacts of Static eccentricity with regard to the building's center of mass are examined, and a non-linear dynamic analysis is performed to investigate the variation in torsional irregularity ratio and other torsional parameters. Genetic Algorithm has been adopted to minimize Static eccentricity and arrange lateral force resisting elements to achieve the lowest torsional irregularity ratio. The developed model was found to be quite productive and the torsional irregularity ratio has reduced successfully.

1. Introduction

The uneven distribution of mass, stiffness, and strength inside a structural building cause major harm to the structural systems and the recent earthquakes impacts have amply demonstrated. The damage reports from previous earthquakes have clearly shown that torsion is a significant source of distress in irregularly shaped building structures [1]. The center of mass and stiffness must be positioned optimally while retaining all functional and architectural requirements in order to avoid torsion. Therefore, it is the responsibility of the structural designer to devise a structural system that is practical, safe, elegant and also affordable. The degree of asymmetry in terms of the Static eccentricity computation is the current method used to measure vulnerability. It has been observed that this parameter is particularly useful to correlate the seismic elastic response of asymmetrical buildings. Furthermore, by taking into account a variety of criteria throughout the structural design process, Genetic Algorithm (GA) was used to optimize the design of structural components and evaluate the impact and overall response of structures under earthquake loads. In the present work torsional irregularity is utilised as the design parameter and the goal is to minimize the eccentricity between the building's center of mass (CM) and center of rigidity (CR) by minimizing storey torsional drift.

External excitation causes every structure to respond. The response is largely determined by its mass, stiffness, damping, and boundary conditions. All response elements can be represented by a single parameter, frequency 'f' or time period 'T' of vibration. A structure can be idealized as a single degree of freedom (SDOF) or a multi-degree of freedom (MDOF) system. These idealized systems can then be investigated and evaluated in relation to various excitations. Non-linear time history analysis assesses a structure's dynamic response at each time increment when its base is subjected to specific ground motion, taking into account the elastic, damping, and mass properties at that time. Nonlinear time history analysis is the most reliable method for predicting seismic demand and evaluating structural performance [40, 41, 43]. Non-linear time history analysis in real time for Earthquake Ground Acceleration Data was selected from the seismic Zone-V according to the IS 1893-2016 part-1 [2] categorization, from a location called Bhuj in the state of Gujarat, which suffered terrible consequences when the earthquake struck in 2001.

Several researchers have carried out numerous evaluations of torsional irregularity, including geometric asymmetry and reported. In compliance with TEC 2007, [3] has investigated the geometrical and structural features of the torsion irregularity. [4] proposed a synopsis of the studies on the seismic response of plan and vertically irregular buildings. According to the TEC, [5, 42] have established the requirements for an excessive torsion irregularity and examined the pertinent sections of the code. Six representative structural groups with different axis numbers, storeys, and shear wall placements were the subjects of their survey. It was observed that as the number of floors increased, the percentage of torsional abnormalities reduced. The torsional response of non-symmetric buildings to earthquake excitations was studied by [6]. This made designing non-symmetric buildings for earthquake actions significantly more difficult than designing symmetric buildings, whose reaction is just translational. [7] studied the effect of reducing the storey drift under severe earthquakes, which can cause the collapse of structures in higher seismic zones.

One among the pioneers to demonstrate the application of a genetic algorithm to solve engineering optimization problems [8]. The research indicates that a number of authors have effectively used genetic algorithms to create structural element designs that are ideal. The majority of the evaluations that have been done have considered cost as the objective function for the structural optimization of reinforced concrete structures.

The application of genetic algorithm for achieving optimum design of various engineering problems that includes flexural design of simply supported beams, uniaxial columns and multi-storey frames by using a search for discrete-valued solutions of members in reinforced concrete frames was studied by [9,10]. [11] presented a detailed study report on the optimal design of the RC continuous beams with the use genetic algorithm. [12] demonstrated the application of nonlinear programming (NLP) techniques for the optimal design of reinforced concrete structures. [13] presented a genetic algorithm model for the optimal design of RC frames. According to [14], cost minimization is done while following the IS:456-2002[15] standard for the structure's strength and serviceability. It was observed that in their study all of the columns are assumed to be rectangular.

In [16] authors utilized a genetic algorithm for the optimal design of an RC continuous beam. The topology optimization was demonstrated by [17] the work was concentrated on solving the topology optimization problem for cantilever and simply supported beams MATLAB and built-in optimization tools. [18], studied RC flat slab optimization using a GA. [19] conducted a detailed analysis on the optimization of the RC slab design employing a genetic algorithm. [20] examined the optimum eccentricity design for seismic applications using a genetic algorithm. In their study, the effectiveness of the genetic algorithm was examined and reported to give good solution. In [21] the author assessed the optimization and finite element modelling of the effect of plan irregularity on the seismic behavior of buildings with artificial intelligence systems. [22] also assessed the approach of the genetic algorithm in the prevention of torsional irregularities in RC buildings.

In [23] the authors applied a genetic algorithm for the optimal orientation of lateral force resisting elements (LFREs) for low to medium rise RC vertical asymmetrical buildings. In their study, the effectiveness of GA was demonstrated and reported to give minimum static eccentricity for low to medium rise vertical asymmetrical models. Authors were able to successfully tune the GA parameters for the said models for minimization of torsion.

Based on the literature review, it was noted that few researchers tried to examine the performance of low- to medium-rise buildings with shear walls positioned at various points. Instead, most previous studies were more concerned with the study of torsional responses for low-rise buildings and limited to simple plan irregularity [24, 25, 26]. Researchers that looked into the dynamic features of low to medium-rise buildings with asymmetric plans and static eccentricity was reported. Therefore, it can be inferred that research on the seismic response of critical plan irregular structures utilizing the Non-Linear dynamic analysis approach by the organization of the structure's lateral force resisting elements which are vital and efforts have been made to address the same.

2. Methodology

The optimization method was used in the present study to solve the seismic torsional drift design problem for asymmetrical buildings using a G.A. methodology in order to investigate the stated target. 3 D finite element models of five- and ten-story RC buildings were taken into consideration to demonstrate the proposed optimization methodology's efficacy and viability. The models were investigated utilizing mode superposition and equivalent seismic load (ESL) techniques in FEM computer programming. The orientation optimization problem was solved via the Genetic Algorithm (GA). The column's orientation angles were taken into account as design variables in the optimization problem.

2.1. Stiffness eccentricity

A structural system considered with a rigid floor diaphragm comprising of 'i' resisting elements, if 'W_i' is the weight, K_{xi} & K_{yi} are the elastic lateral stiffness in 'X' and 'Y' directions respectively, then the center of mass, which is defined as the point where entire mass of the system is concentrated, can be located as follows.

The location of center of mass (X_{cm}, Y_{cm}) in plan can be obtained using the Eqns. 1 and 2.

$$X_{cm} = \Sigma W_i \times X_i / \Sigma W_i \quad ......(1)$$

$$Y_{cm} = \Sigma W_i \times Y_i / \Sigma W_i \quad ......(2)$$

The coordinates of center of stiffness (X_{cs}, Y_{cs}) are given using Equations 3 and 4;

$$X_{cs} = \Sigma K_{yi} \times X_i / \Sigma K_{yi} \quad ......(3)$$

$$Y_{cs} = \Sigma K_{xi} \times Y_i / \Sigma K_{xi} \quad ......(4)$$

where, (X_i, Y_i) are the geometric coordinates of the i^{th} resisting element.

Static eccentricity (es): It is the offset of center of mass from center of stiffness. The coordinates of Static eccentricity are

$$e_{sx} = X_{cm} - X_{cs} \quad ......(5)$$

$$e_{sy} = Y_{cm} - Y_{cs} \quad ......(6)$$

2.2. Torsion in Irregular Buildings

Numerous researches have considered investigating the effect of coupling between lateral and torsional vibrations caused by earthquake response in irregular buildings. Initially, most of these studies were focused on the elastic response of buildings. The consequences of lateral-torsional coupling in such systems are now well understood. In recent years, the focus has switched over to inelastic systems in order to gain conclusions that can be used to building design [27, 28]. In the recent two decades, there has been renewed interest in evaluating the torsional effect in earthquake-prone buildings, owing to the necessity to review and strengthen torsional provisions [29, 30]. In [31, 32, 33] the author demonstrated that the old criterion is inadequate since building structures in seismic locations rely on inelastic responses when subjected to significant earthquakes. The authors [34] carried out a large parametric study in which basic asymmetric buildings were examined using static linear analysis and the standard torsional provisions found in seismic codes. The findings verified [33] observations, indicating that the implementation of these provisions causes an increase in the structure's necessary lateral resistance, with uncertain effectiveness in controlling the torsional problem in the inelastic region. Furthermore, an increase in the final strength eccentricity was seen in some situations, which is clearly an undesirable condition.

According to IS-1893 (Part 1): 2016 [2] a building is torsional irregular if the maximum horizontal displacement of any floor in the direction of the lateral force at one end of the floor is greater than 1.5 times the minimum horizontal displacement at the other end of that same floor in that direction.

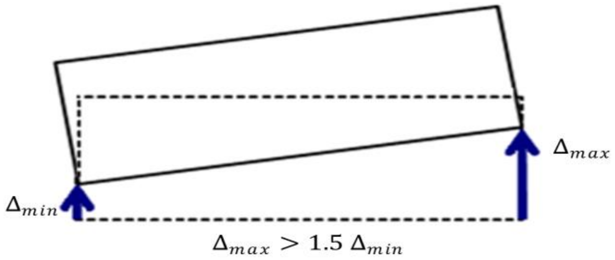

Figure 1. Torsional Irregularity as per IS: 1893 [2].

2.3. Genetic Algorithm

Genetic algorithms (G.A.) are search techniques used in computing to solve optimization and search problems. G.A. is a type of evolutionary algorithm that use processes inspired by evolutionary biology, such as inheritance, mutation, selection and crossover [35]. Evolution normally begins with a population of randomly created individuals and occurs across generations. In each generation, the fitness of each person in the population is assessed, and several individuals will be selected from the current population (depending on their fitness) and altered (recombined and maybe mutated) to create a new 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. Mutation options specify how the genetic algorithm makes small random changes in the individuals in the population to create mutation children. The basic idea of using this operator is to introduce some diversity into the population. In the present work two mutation operators were studied, mutation gaussian and mutation power. Mutation gaussian adds a random number taken from a Gaussian distribution with a mean of 0 to each entry of the parent vector. Mutation power influences the magnitude of the mutation and for integer-constrained problems, the default mutation function is mutation power, which mutates a parent by raising a random number to a power [35]. The algorithm's following iteration incorporates the new population. The method typically halts after either the maximum numbers of generations have been created or the population has attained an acceptable fitness level. The Genetic Algorithm Toolkit in MATLAB [35] is to create a collection of adaptable tools for the implementation of a wide range of genetic algorithm techniques. The genetic algorithms make decisions in many locations based on the creation of random numbers, running the same problem at different times can result in different final designs. According to [36, 37], it is advisable to run the problem multiple times to ensure that the best possible solution is obtained.

2.4. Description of the Proposed Method

To assess the effects of Static eccentricity on the torsional irregularity ratio, eccentricity is reduced by defining objective function in GA model. The orientation angles of columns serve as variables. This objective function is optimised using GA technique. Using these optimal orientations, the asymmetrical buildings are reanalysed, and the torsional irregularity ratio is recalculated and compared to the original model.

The objective function for minimizing Static eccentricity is

$$F_s = (e_{sx}^2 + e_{sy}^2)^{0.5} \quad (7)$$

For 5-Storey and 10-Storey buildings, two models in each case are generated including basic model. RC5SB (Re-entrant Corner 5 Story Basic Model); RC10SB (Re-entrant Corner 10 Story Basic Model); RC5SP (Re-entrant Corner 5 Story Proposed Model); and RC10SP (Re-entrant Corner 5 Story Proposed Model).

The comparisons are made between basic and proposed buildings and conclusions are drawn.

2.5. Structural Models

To investigate the impacts of the center of stiffness, a two-way asymmetric R.C.C building with re-entrant corners was analysed using Non-linear Time History Analysis (FNA) in the most recent version of ETABS software. The entire span length is 30 metres in the X direction and 20 metres in the Y direction. The layout is the same for all buildings, however columns serve as the lateral load resisting parts. The fundamental architecture for RC5SB and RC10SB models is made out of columns of uniform size.

To illustrate the torsional behaviour in RC structures through GA, two multi-storey examples are provided. In the first example, the structural system consists of 5 floors (RC5SB), whereas, in the second example, the system consists of 10 floors (RC10SB). In these examples, first of all, for irregular 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 GA approach. The slabs were modelled with shell elements as a rigid diaphragm to restrict all the nodes on each floor and to facilitate equal plan displacement. Accidental eccentricity is incorporated into the design to adjust for actual distributions of both self-weights, super imposed dead and live load during earthquakes, distributions of stiffness and strength in the building, and torsional components of the ground motion. Generally fixed supports were used for columns in all directions to make simple model. The main objective of achieving realistic outcomes, the dimensions of the structural members was 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 a plan asymmetrical re-entrant corner building having various eccentricities was first compared to assess the effects of the torsion response. After the analysis was carried out the structural will be obtained and responses such as torsion ratio, diaphragm centre of mass displacement and angular acceleration; optimization algorithms were used to determine good parameters. The structural optimization method for the 3D RC building structure accordingly is proposed.

In the present study, optimizing the torsional drift of the floors is formulated and applied by utilizing GA. The member angles were considered as the design variables. In present work the models are having 29 columns which will serve as 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 subjected to penalties. The algorithm was terminated when the number of generations reached the maximum number of generations as per the selected value. 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. The final design application is selected such that the most suitable sections need to satisfy IS 456-2000 [15] and IS 1893-2016 [2] code provisions based on static and dynamic linear analysis.

In all the test cases of the models type of structure used is SMRF (Special Moment Resisting Frame) with typical storey height of 3 m. For all the models a beam size of 300 mm x 500 mm was used. Column sizes for 5 story model are 300 mm x 450 mm whereas for 10 story model are 300 mm x 600 mm. Slab is modelled as shell element with a thickness of 125 mm. The linear static analysis was performed by adopting Seismic zone V, Importance factor 1.5 and Response reduction factor of 5 were taken as earthquake data with type of soil as medium. To perform non-linear time history analysis in real time, Earthquake Ground Acceleration Data was selected from the seismic Zone-V according to the IS 1893-2016 part-1 [2] categorization, from a location called Bhuj in the state of Gujarat. Various models of five and ten stories with total heights of 15 and 30 m are considered. For all the structural elements M30 grade concrete and Fe550 grade rebars were used.

Figure 2 shows the time history data of Bhuj earthquake scaled to target response spectrum of I.S 1893-2016 [2] and SeismoMatch software [38] was used for matching the earthquake accelerograms to target response spectrum.

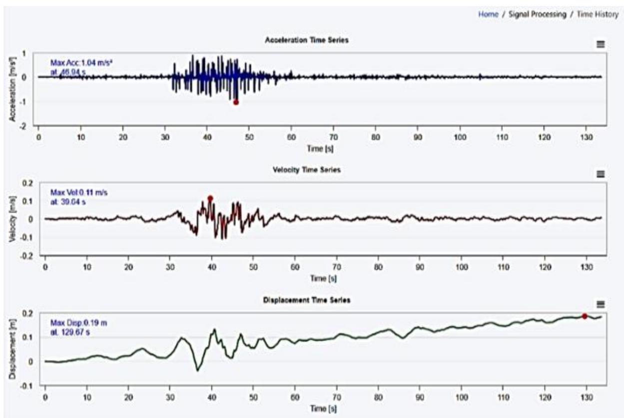

Figure 2. Matched Bhuj TH Data to Target Response Spectrum

Table 1 shows various GA parameters used for the optimization of process controllers.

Table 1. A set of solver parameters selected to resolve the case study

Number of Stories	5-Storey & 10-Storey
Number of Variables	29
Population Size	600, 800
Mutation Function	Mutation Power
Crossover Function	Crossover Two Point
Crossover Fraction	0.7, 0.85
Number of Elite Members	30, 40
Max Generations	2900
Stall Generation Limit	200, 250

In [23] the authors carried out a large parametric study in which vertical asymmetric buildings were examined using static linear and non-linear analysis and the standard torsional provisions found in I.S 1893-2016 [2]. Table 1 represents the GA parameters for plan irregular re-entrant corners buildings which were obtained on the similar lines as demonstrated by [23]. The findings verified the authors observations, indicating that the tuning of GA parameters is an essential part in the application of evolutionary optimization technique for minimization of torsion in asymmetrical buildings.

The centers of mass and stiffness are estimated for both basic models (RC5SB and RC10SB), and eccentricity is determined using equations 5 and 6. Figure 3 depicts the plan of the structural models, whereas Figures 4 depict the isometric perspectives.

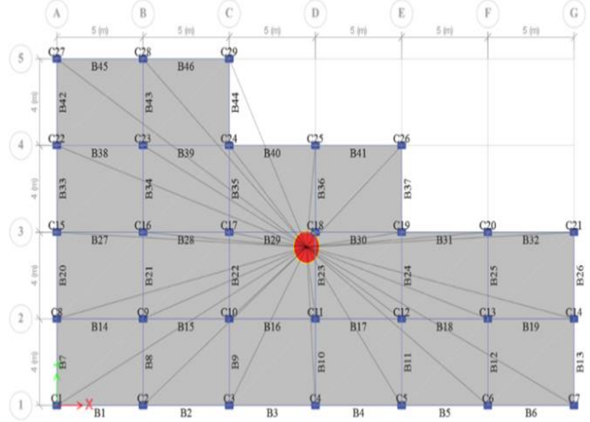

Figure 3. Plan of RC5SB and RC10SB Models

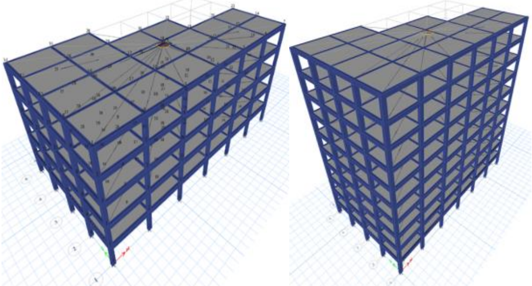

Figure 4. Isometric Views of RC5SB and RC10SB Models

After analysing the buildings for linear load cases and performing design check of all the concrete members, nonlinear hinges are assigned to beams and columns as per [39].

Typically, the first nonlinear time history load was utilized to provide gravity stress, followed by following lateral nonlinear time history load instances that began with the gravity time history case's terminal condition. The basic models underwent nonlinear time history analysis in both the 'X' and 'Y' directions. The displacements shown below were obtained after analysing both linear and non-linear scenarios. Table 2 and 3 represents torsional irregularity ratio of RC5SB and RC10SB models

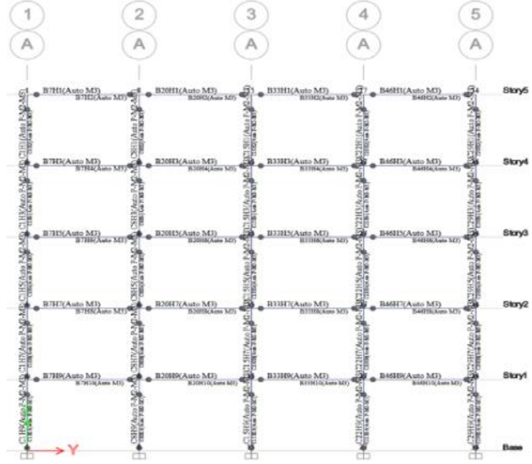

Figure 5. Hinge assignments at the ends of the beams and columns.

Table 2. Torsional Irregularity Ratio of RC5SB Model

Max. Displacement, Δ_{max} (mm)	Min. Displacement, Δ_{min} (mm)	Torsional Irregularity Ratio, $\Delta_{max} / \Delta_{min}$
37.959	23.061	1.65

Table 3. Torsional Irregularity Ratio of RC10SB Model

Max. Displacement, Δ_{max} (mm)	Min. Displacement, Δ_{min} (mm)	Torsional Irregularity Ratio, $\Delta_{max} / \Delta_{min}$
78.572	45.061	1.74

Using the equations 7, as the objective function, the orientation of Columns was obtained for minimum Static eccentricity (Proposed Models), for RC5SP and RC10SP models by Genetic Algorithms Technique. Fig 6 represents the Column orientations for RC5SP and RC10SP models.

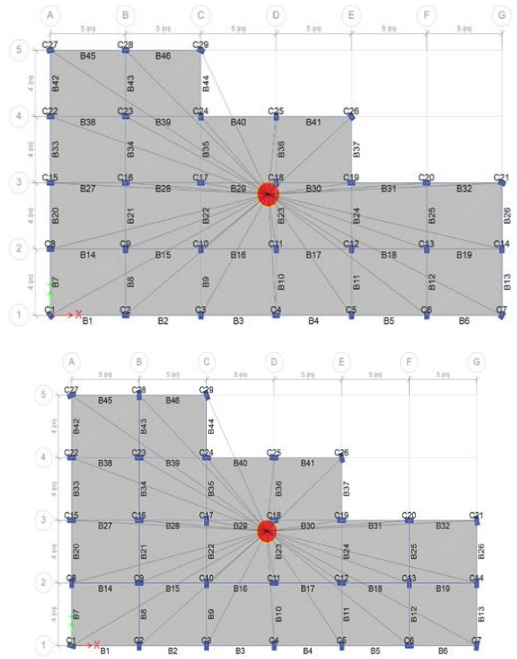

Figure 6. Plan of RC5SP and RC10SP Models

Nonlinear Time History analysis was performed for these models and the torsional irregularity ratios were evaluated and compared.

3. Results and Discussion

The present work evaluates the effectiveness of varying location of centres of stiffness in the plan irregular re-entrant corner buildings. The effectiveness is evaluated with various torsional parameters such as Torsional Irregularity Ratio, Rotation of Diaphragm and Diaphragm's acceleration in both the directions of excitation.

When the program commenced during the optimization process, the selected design variable values were assigned to the selected lateral load resisting elements in the pre-prepared system, the system was solved, and the objective function was calculated, resulting in the torsional eccentricity being minimized. Evolution will continue until the predetermined generation number is reached. The fitness value drops from one generation to the next as the objective function is minimized and the number of generations approaches a predetermined limit. Population variables improve with each successive generation.

3.1. Variation in Population (5-Story):

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.

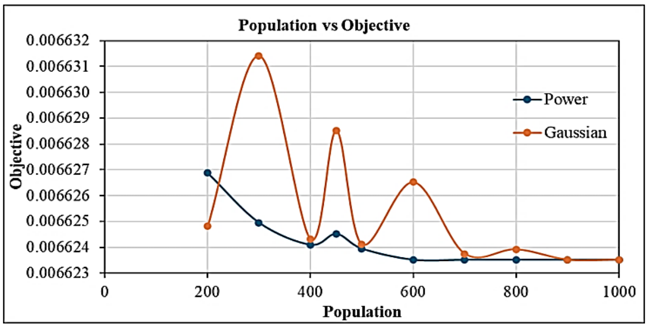

Figure 7. Variation in Population and Objective-5-story

It can be observed from the graph shown in figure 7 that the power function achieves the objective at 600 populations whereas the Gaussian function achieves the same objective at 900 populations.

3.2. Variation in Generations (5-Story):

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.

It can be observed from the graph shown in figure 8 that the power function achieves the objective at 200 generation whereas the Gaussian function achieves the same objective at 700 generation.

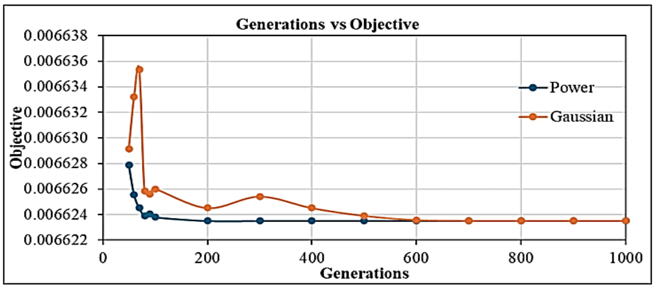

Figure 8. Variation in Generations and Objective-5-story

3.3. 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.

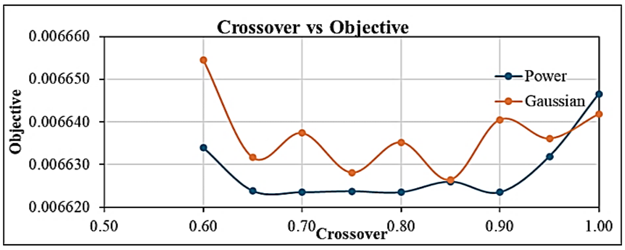

Figure 9. Variation in Cross-over and Objective-5-story

It can be observed from the graph shown in figure 9 that the power function achieves the objective at 0.7 crossover whereas the Gaussian function achieves the same objective at 0.85 crossover.

Similarly, the same variation in population, generation and cross-over operators were performed for the 10-story models and the respective values are tabulated in Table 1.

Column orientation values (angles) were printed to an output file as each iteration progressed. In terms of the final design implementation, the members of this generation (column angles) with the highest fitness values were chosen as the optimal point.

The results demonstrate that the angles for the optimum solution differ from those of the utilized ones. For RC5SP model orientation angles for critical columns C1, C7, C21, C26 and C29 are -52, 57, -19, -54 and -26. Whereas for RC10SP model the orientation angles are -15, 80, -78, -75 and -67 respectively. The columns' angles are represented in degrees clockwise and anticlockwise, with positive and negative signs, respectively.

The ideal design was obtained after implementing the optimization procedure on 3D five and ten-story RC buildings. The most favourable outcomes indicate that by using the automated design method, a design candidate may be obtained with the lowest eccentricity and torsional irregularity ratio that complies with the standard code's provisions [2]. The tables in both solutions show that the torsional irregularity ratios for all Stories are less than 1.5 in the x and y directions.

The following tables contain the results of the analysis carried out for the basic and proposed models as discussed earlier. Table 4 and Table 5 represent the values of Torsional Irregularity ratio of different proposed models of 5-Storey and 10-Storey plan irregular re-entrant corner buildings.

Table 4. Torsional Irregularity Ratio of RC5SP Model

Max. Displacement, Δ_{max} (mm)	Min. Displacement, Δ_{min} (mm)	Torsional Irregularity Ratio, Δ_{max} / Δ_{min}
30.271	23.041	1.31

Table 5. Torsional Irregularity Ratio of RC10SP Model

Max. Displacement, Δ_{max} (mm)	Min. Displacement, Δ_{min} (mm)	Torsional Irregularity Ratio, Δ_{max} / Δ_{min}
64.346	43.603	1.475

It can be observed from the Table 4 and Table 5 that the torsional irregularity ratio for RC5SP and RC10SP models is 1.31 and 1.475 respectively which is less than 1.5 as stipulated by the standard code's provisions [2].

Table 6 and Table 7 represent the values of Torsional Irregularity ratio of basic and proposed models of 5-Storey and 10-Storey plan irregular re-entrant corner buildings.

Table 6. Comparison of Torsional Irregularity Ratio of RC5SB and RC5SP Models

Description	Max. Displacement, Δ_{max} (mm)	Min. Displacement, Δ_{min} (mm)	TIR, Δ_{max} / Δ_{min}
Basic	37.959	23.061	1.65
Proposed	30.271	23.041	1.31
Percentage Reduction	20.18 % Decrease		

It can be observed from the Table 6 that the torsional irregularity ratio for RC5SB model is 1.65 which is greater than 1.5. Whereas for RC5SP model the value is 1.31 which is less than 1.5. There is a decrease of 20.18% in torsional irregularity ratio for 5 story proposed model.

Table 7. Comparison of Torsional Irregularity Ratio of RC10SB and RC10SP Models

Description	Max. Displacement, Δ_{max} (mm)	Min. Displacement, Δ_{min} (mm)	TIR, Δ_{max} / Δ_{min}
Basic	78.572	45.061	1.74
Proposed	64.346	43.603	1.475
Percentage Reduction	15.22 % Decrease		

It can be observed from the Table 7 that the torsional irregularity ratio for RC10SB model is greater than 1.5. Whereas for RC10SP model the value is less than 1.5. There is a decrease of 15.22%.

Table 8 and Table 9 represent the values of Rotation 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 Rotation of RC5SB and RC5SP Models

S.No	Load Case	Rotation of Diaphragm (in radians) x 10^{-4}		Percentage Reduction
		Basic Model	Proposed Model	
1	EQX	3.44	1.58	54.07 % Decrease
2	EQY	4.97	2.41	51.51 % Decrease
3	NLTH_X	1.40	0.35	75.00 % Decrease
4	NLTH_Y	2.27	0.19	91.63 % Decrease

Table 9. Comparison of Diaphragm's Rotation of RC10SB and RC10SP Models

S.No	Load Case	Rotation of Diaphragm (in radians) x 10^{-4}		Percentage Reduction
		Basic Model	Proposed Model	
1	EQX	8.32	3.53	57.57 % Decrease
2	EQY	11.17	7.91	29.19 % Decrease
3	NLTH_X	3.16	0.80	74.68 % Decrease
4	NLTH_Y	4.01	1.76	56.11 % Decrease

It can be observed from the Table 8 Table 9 that the diaphragm rotation of RC5SP and RC10SP models has improved i.e.; there is a reduction of about 50% for linear elastic case and 75% for non-linear dynamic case for RC5SP model when compared to RC5SB model. Whereas for RC10SP model there is reduction of about 30% for linear static case and 56% for non-linear dynamic case when compared to RC10SB 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 10. Comparison of Diaphragm's Angular Accelerations of RC5SB and RC5SP Models

S.No	Load Case	Angular Accelerations in rad/sec²		Percentage Reduction
		Basic Model	Proposed Model	
1	NLTH_X	0.014	0.002	85.71 % Decrease
2	NLTH_Y	0.014	0.006	57.14 % Decrease

Table 11. Comparison of Diaphragm's Angular Accelerations of RC10SB and RC10SP Models

S.No	Load Case	Angular Accelerations in rad/sec²		Percentage Reduction
		Basic Model	Proposed Model	
1	NLTH_X	0.012	0.003	75.00 % Decrease
2	NLTH_Y	0.021	0.010	52.38 % Decrease

It can be observed from the Table 10 Table 11 that the diaphragm angular acceleration of RC5SP and RC10SP models has improved i.e.; there is a reduction of about 57% for non-linear dynamic case for RC5SP model when compared to RC5SB model. Whereas for RC10SP model there is reduction of about 52% for non-linear dynamic case when compared to RC10SB model.

4. Conclusion

Based on the results obtained for the RC5SB, RC10SB, RC5SP and RC10SP models, following conclusions are drawn:

- Torsional irregularity ratio decreased by a maximum of 20.18% for RC5SP model whereas for RC10SP model it decreased by 15.22%.
- After proper orientation of LFRE's, the diaphragm center of mass displacement reduced by 91.63% for RC5SP model whereas for RC10SP model it reduced by 74.68% at the top storey of the respective models.
- Diaphragm's angular accelerations due to NLTH using Bhuj earthquake data reduced by a maximum of 85.71% along x-direction for RC5SP model whereas for RC10SP model it reduced by a maximum of 75% along x-direction at the top storey of the respective models.
- Optimum population sizes for RC5SP and RC10SP models with Gaussian function are 900 and 3000 respectively. Whereas with power function values are 600 and 800 for RC5SP and RC10SP models respectively. This indicates that the power functions achieve the same objective with lesser population size thus saving the time required by algorithm to achieve the optimal solution.
- Optimum generation values for RC5SP and RC10SP models with Gaussian function are 700 and 1000 respectively. Whereas with power function values are 200 and 250 for RC5SP and RC10SP models. Using power function objective value stabilized after 200 generations for RC5SP model and 250 generations for RC10SP model. For RC5SP and RC10SP models objective value stabilized after 1000 generations with Gaussian function. This indicates that the power functions achieve the same objective with lesser generation size thus saving the time required by algorithm to achieve the optimal solution.
- Optimum cross over values RC5SP and RC10SP models using gaussian function are 0.85 and 0.75 respectively. Whereas with power function values are 0.70 and 0.85 respectively.
- Proper structural layout improves the building's torsional stability.

Furthermore, it can be concluded that the torsional parameters in irregular buildings can be reduced by using evolutionary algorithm techniques to generate optimum column orientations with power function as mutation operator.

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Author contributions

Mohd Abdul Hafeez: Conceptualization, Proposed Methodology, Software, Writing-Original draft preparation. **Dr. M. Anjaneya Prasad:** Methodology, Validation, Writing-reviewing and Editing. **Dr. N. R. Dakshina Murthy:** Validation, Writing-reviewing and Editing.

Conflicts of interest

The authors declare no conflicts of interest.

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