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Research Article

Two-Stage Optimization Method for the Bearing Layout of Isolated Structure

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Design of seismic isolated building is often a highly iterative and tedious process due to the nonlinear behavior of the system, a large range of design parameters, and uncertainty of ground motions. It is needed to consider a comprehensive optimization procedure in the design of isolated buildings with optimized performances. This can be accomplished by applying a rigorous optimization technique. However, due to many factors affecting the performance of isolated buildings, possible solutions are abundant, and the optimal solution is difficult to obtain. In order to simplify the optimization process, an isolated building is always modeled as a shear-type structure supported on the isolated layer, and the optimal results are the parameters of the isolated layer which could not be used as a practical design of the isolated structure. A two-stage optimization method for designing isolated buildings as a practical and efficient guide is developed. In the first stage, a 3D isolated building model is adopted that takes into account of nonlinear behavior in building and isolation devices. The isolation devices are simplified as a kind of lead-rubber bearing. The genetic algorithm is used to find the optimal parameters of the isolated layer. In the second stage, the location parameters of isolation bearing layout are optimized. Moreover, the cost of the isolation bearing layout should be as low as possible. An integer programming method is adopted to optimize the number of each type of isolator. Considering vertical bearing capacity of isolators and the minimum eccentricity ratio of the isolated layer, the optimal bearing layout of the isolated building can be obtained. The proposed method is demonstrated in a typical isolated building in China. The optimum bearing layout of the isolated building effectively suppresses the structural seismic responses, but the cost of the isolated layer might slightly increase.

1. Introduction

The trial method, which achieves a predetermined design goal by continuously adjusting the mechanical parameters of the superstructure and the isolated layer, is a commonly adopted design method for isolated structures. Due to many factors affecting the performance of isolated buildings, such as the type and the parameters as well as layout of isolators, possible solutions are abundant, and the optimal solution is difficult to select on the basis of the decision maker's choice of trade-off. For example, an isolated building has 20 isolation bearings. Considering the requirements for vertical bearing capacity, each isolator is limited to 2 types, and each type is either natural rubber bearing (LNR) or lead-rubber bearing (LRB); thus, each isolation bearing has 4 possible choices, and the bearing layout of the building has 4^{20} possible choices, i.e., 1.1×10^{12}. Hence, a successful design of an isolated building requires simplifying the optimization process and implementing the optimized selection.

The optimal design of isolation bearings for buildings has been studied in the past decades. Pourzeynali and Zarif [1] found that the optimal values of the parameters of a base isolation system obtained using genetic algorithms simultaneously minimized the displacement of a building's top story and that of the base isolation system. Fallah and Zamiri [2] used a genetic algorithm to achieve the optimal design of sliding isolation systems for suppressing the seismic responses of buildings. Fan et al. [3] adopted a sequential quadratic programming algorithm for optimizing an LRB system by considering the uncertainties of structural and seismic ground motion input parameters. Nigdeli et al. [4] proposed a harmony search (HS) optimization method for seismically isolated buildings subjected to near-fault and far-fault earthquakes. They developed an optimization program in MATLAB/Simulink using the HS algorithm to optimize the stiffness and damping ratio of isolation system parameters. Xu et al. [5] determined the optimal design parameters of triple friction pendulum bearings for high-rise buildings by applying a genetic algorithm. The optimization results showed that the optimal triple friction pendulum bearing is more effective and reliable in reducing base shear, floor acceleration, and story drift. Li et al. [6] identified the optimal design parameters of isolated equipment using a penalty function method. The ratio of the standard deviation of the first-order modal displacement of the superstructure for the isolated structure to the fixed-base structure was used as the optimal objective. The dynamic reliability of isolated equipment was used as the constraint condition. Shoaei and Mahsuli [7] presented a reliability-based approach for the seismic design of steel moment frame structures isolated with LRB devices. To predict the parameters of the base isolation system, they proposed a regression equation that was calibrated against a set of optimally designed base-isolated systems using a genetic algorithm. Jiang et al. [8] proposed an optimal design method based on an analytical solution for a storage tank with an inerter isolation system. Nevertheless, the aforementioned studies modeled a building as a shear-type structure with one lateral degree of freedom at each story. Bearings exhibited linear and nonlinear behavior such that only the optimal values of the parameters of the base isolation system were obtained; however, the optimal results could not be used as a practical design of the isolated structure. Zhou et al. [9] proposed five base-isolated schemes for District E of the Guangdong Science Center. The optimal isolated scheme was identified after comparing those five schemes with each other. In their study, the model of an isolated building was a 3D finite element model, and the optimal isolated scheme could be used in practical design. However, the optimal solution was based only on engineering experiences. Accordingly, a two-stage optimization method for an isolation bearing layout is proposed in the current study to achieve a practical optimization design of an isolated structure. Modal and time history analyses for isolated structures are completed with finite element analysis, and the optimization procedure is applied to the optimal algorithm. The optimization solution is the layout of isolation bearings that can function as a practical design for isolated buildings.

2. Ideas and Flow of the Two-Stage Optimization Method for Isolation Bearing Layout

The optimization method for the two-stage isolator layout is presented as follows:

> Stage 1: the optimum mechanical parameters of the isolated layer are identified through a multiobjective genetic optimization procedure. Time history analysis of isolated structures with finite element analysis using SAP2000 software is completed, and optimization is performed in MATLAB. The simultaneous minimization of the earthquake reduction coefficient and isolator displacement, as well as the interstory displacement ratio, is considered as the objective function. The multipopulation genetic algorithm (MPGA) is used to find the optimal parameters of the isolated layer, including horizontal equivalent stiffness, yield displacement, and ultimate displacement.
>
> Stage 2. The optimal layout of isolation bearings can be determined on the basis of the optimal parameters of the isolated layer. Integer programming is performed to determine the optimal layout of isolation bearings to minimize the error between the parameters of the actual isolator layout scheme and the optimum parameters of the isolated layer and the cost of the isolation bearing layout scheme.

Through the two stages, a complex optimization problem can be transformed into two relatively simple optimization problems. In the first stage, a 3D finite element model is adopted for the isolated structure to ensure the accuracy of the dynamic analysis results. Three parameters of the isolated layer are selected to immediately obtain the optimization results. In the second stage, the optimum parameters are used to determine the layout of the isolation bearings. The proposed method can serve as a practical and efficient guide for isolated building designs.

Figure 1 presents the flowchart of the two-stage optimization method for the isolation bearing layout.

3. Realization of the Two-Stage Optimization Method for Isolation Bearing Layout

3.1. Stage 1: Optimum Parameters for the Isolated Layer. Two of the most common types of isolation bearings, namely, LNR and LRB, have been frequently used in isolated buildings. Since the isolated layer is composed of LNR and LRB, one can use a bilinear model to represent the mechanical behavior of the isolated layer, as shown in Figure 2. Q_d is the yield force, K_1 is the elastic stiffness, K_2 is the postyielding stiffness, K_{eq} is the equivalent stiffness, X_y is the yield displacement, and X_m is the ultimate displacement.

The isolated layer is supposed to be installed with one type of isolated bearing; therefore, three parameters are sufficient to describe the behavior of the isolated layer, i.e.,

$$X = \left[K_{eq} \;\; X_y \;\; X_m \right]^T, \tag{1}$$

where K_{eq} is the horizontal equivalent stiffness of the isolated layer, and $K_{eq} = N \times k_{eq}$; N is the total number of isolation bearings, k_{eq} is the horizontal equivalent stiffness of the type of isolated bearing; X_y is the yield displacement of the isolated layer; and X_m is the ultimate displacement of the isolated layer. X_y, X_m are also equal to the parameters of the type of isolated bearing.

The optimum mechanical parameters of the isolated layer are identified through a multiobjective optimization problem. First, the earthquake reduction coefficient of the

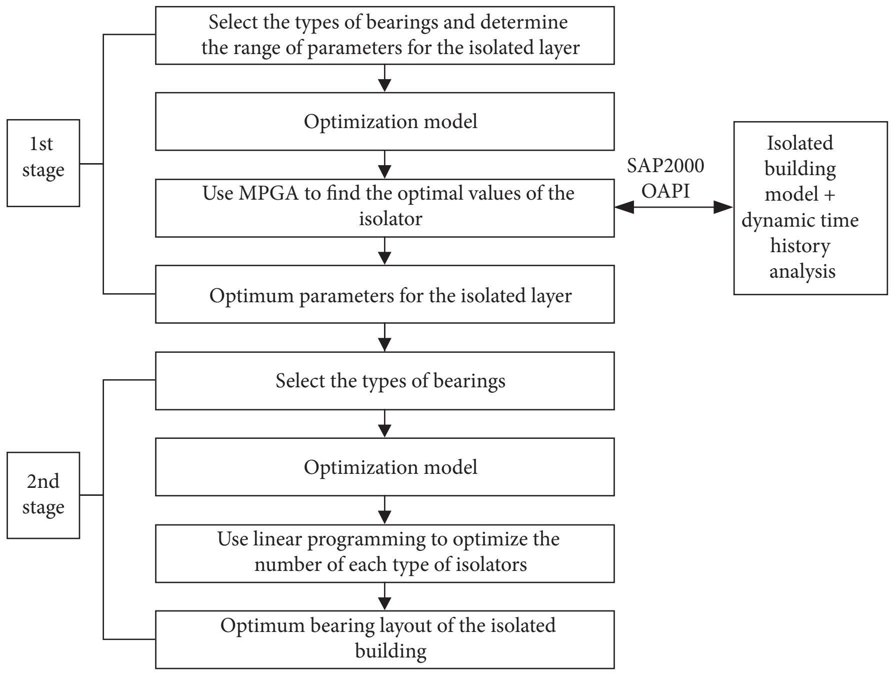

Figure 1: Two-stage optimization method for isolation bearing layout.

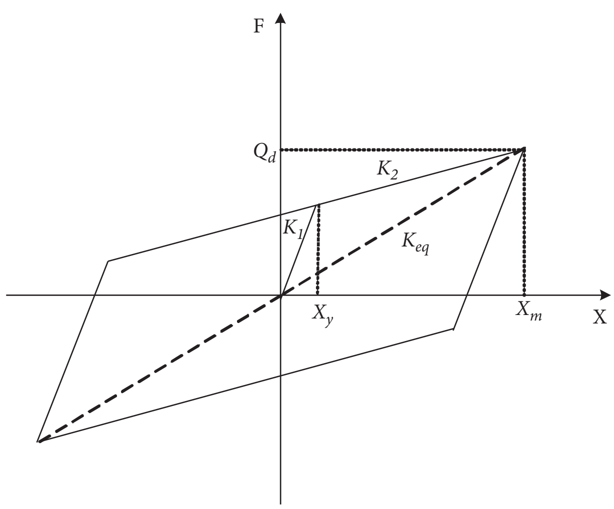

Figure 2: Bilinear model for an isolation bearing.

isolated structure should satisfy the preset earthquake reduction target. Second, the isolation bearing displacement and the interstory drift of the superstructure cannot exceed the peak displacement limit. The allowable isolated buildings must effectively satisfy the three demands. Hence, the three aforementioned objectives can be normalized and considered equally important. The objective function is expressed as follows:

$$a = \text{minimize}\left[\frac{((\beta/\beta_{\max}) + (u/u_{\max}) + (\theta/\theta_{\max}))}{3}\right], \quad (2)$$

where β is the earthquake reduction coefficient of the isolated structure; $\beta_{\max}$ is the limit value of the earthquake reduction coefficient that is generally equal to 0.4 in accordance with [10]; that is, the earthquake shearing force of the superstructure should be reduced to half. u is the bearing displacement; $u_{\max}$ is the limit value of the bearing displacement, and $u_{\max} = \min(0.55\ D, 3t_r)$ [10]; D is the bearing diameter; and t_r is the total thickness of the rubber layer. θ is the interstory drift ratio of the superstructure, and $\theta_{\max}$ is the limit value of the interstory drift ratio of the superstructure; when a building is reinforced concrete frame structure, $\theta_{\max} = 1/150$ [11].

The constraint conditions are presented as follows:

$$\beta < \beta_{\max}, \quad (3a)$$

$$u \le u_{\max}, \quad (3b)$$

$$\theta \le \theta_{\max}. \quad (3c)$$

In addition, given that $\mu = X_m/X_y$, μ is the isolated layer ductility coefficient. An appropriate selection of the isolated layer ductility coefficient is required, and a wrong value may occasionally be unsolvable. From the result of more than 10 actual isolated projects, a range of the isolated layer ductility coefficient is provided as follows:

$$10 \le \mu \le 30. \quad (3d)$$

The optimization model in the first stage is presented as equations (1)–(3d).

MPGA [12] is used to find the optimal values of isolator parameters. This study constructs a hybrid framework in which nonlinear time history analyses are conducted using the software SAP2000, and genetic optimization is accomplished using MATLAB. The former provides dynamic responses of interest; the latter calculates the associated objective function and generates the offspring population with better designs until converging to an optimal design. The functions of SAP2000 OAPI are used to construct a model of an isolated building and transfer the dynamic analysis results to MATLAB. Figure 3 presents the flowchart of the multiobjective genetic optimization algorithm.

The hybrid optimization procedure is presented as follows:

(1) The range of isolation bearing diameters is predicted on the basis of gravity load in each bearing, and the design variables K_{eq}, X_y, and X_m are provided.

(2) The initial population is generated using MATLAB and transmitted to SAP2000 through SAP2000 OAPI. A set of 3D isolated structure models is constructed, and nonlinear time history analyses are conducted on SAP2000. Since the isolated layer is supposed to be installed with one type of isolated bearing, the mechanical parameters of the type of isolation bearing are derived from the parameters of the isolated layer [13] as follows:

$$k_{eq} = \frac{K_{eq}}{N}, \quad (4)$$

$$\xi_{eq} = \left[\frac{2(1-\alpha)(1-(1/\mu))}{\pi[1+\alpha(\mu-1)]}\right]\frac{\mu^{0.58}}{6-10\alpha}, \quad (5)$$

$$k_1 = \frac{k_{eq}}{((1+\alpha(\mu-1))/\mu)\left[\left(1/\left(1-0.737\left((\mu-1)/\left(\mu^2\right)\right)\right)\right)\right]^2}, \quad (6)$$

where ξ_{eq} is the equivalent viscous damping ratio of the isolated bearing. α is the stiffness before yield-to-stiffness after yield ratio of the isolated bearing, and $\alpha = 0.08$–0.1 [14]. In this study, $\alpha = 0.1$. μ is the ductility coefficient of the isolated bearing, and $\mu = X_m/X_y$; k_1 is the preyield stiffness of the isolated bearing [13].

To achieve an isolation design that performs effectively under different earthquake excitations, an artificial acceleration wave with characteristics to cover various earthquake hazards is considered in the design. The error between the response spectrum of this artificial wave and the Chinese seismic code design response spectrum is less than 5%. The selected artificial waves as the input ground motion and the corresponding response spectrum are shown in Figure 4.

(3) With the responses of each initial population, the constraint conditions and objective function values are implemented. If one of the constraint conditions is unsatisfied, then the objective function value will be increased several times, and the fitness of individuals in the population will be obtained.

(4) The individuals generate offspring populations until converging to the set termination condition, and the program ends.

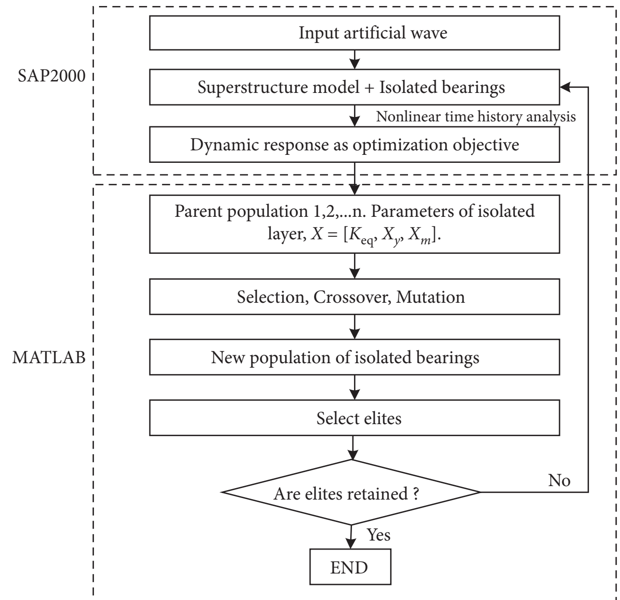

Figure 3: Multiobjective genetic optimization.

3.2. Stage 2: Optimum Layout for Isolation Bearings. In an actual isolated building, the isolated layer is formed by several types of isolation bearings. If the parameters of the isolation bearing layout are close to the optimal parameters of the isolated layer, then the isolation bearing layout is optimal. Therefore, the optimal layout of isolation bearings can be determined on the basis of the optimal parameters of the isolated layer which are obtained in Stage 1.

The design variables of the isolation bearing layout are selected as follows:

$$Z = [\, z_1 \;\; z_2 \;\; \ldots \;\; z_i \;\; \ldots \;\; z_n \,]^T, \quad (7)$$

where z_i is the number of the i^{th}-type isolation bearings.

The problem aims to determine the parameters of isolation bearing layout that can be attached to the optimal parameters of the isolated layer. Moreover, the cost of the isolation bearing layout should be as low as possible.

Therefore, the lowest cost of the isolation bearing layout is selected as an objective function as follows:

$$f = \text{minimize}\left(\sum_{i=1}^{n} z_i p_i\right), \quad (8)$$

where z_i is the number of the ith-type isolation bearing. p_i is the unit price of the ith-type isolation bearing. In this study, the price of a bearing is 10 times its diameter on the basis of the current average price of isolation bearings in China. For example, the price of a bearing with a diameter of 400 mm is 4000 yuan.

The constraint conditions are presented as follows:

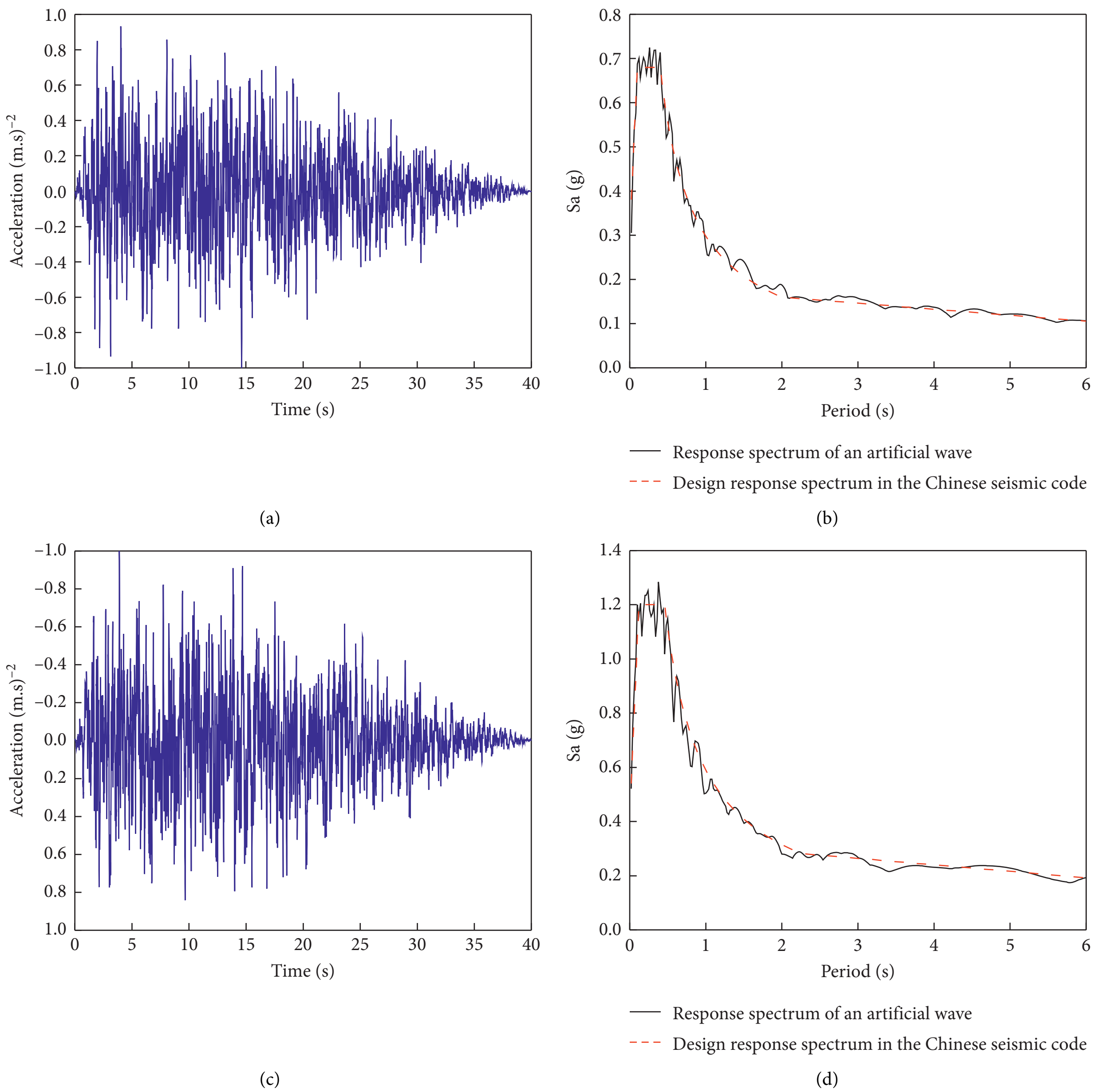

FIGURE 4: Acceleration-time history and response spectrum of an artificial wave. (a) Acceleration-time history under moderate earthquake. (b) Response spectrum under moderate earthquake. (c) Acceleration-time history under strong earthquake. (d) Response spectrum under strong earthquake.

$$K_{eq}(1-5\%) \le \sum_{i=1}^{n} z_i k_{eq,i} \le K_{eq}(1+5\%), \quad (9a)$$

$$\zeta_{eq}(1-5\%) \le \frac{\sum_{i=1}^{n} z_i k_{eq,i} \xi_{eq,i}}{\sum_{i=1}^{n} z_i k_{eq,i}} \le \zeta_{eq}(1+5\%), \quad (9b)$$

$$K_1(1-15\%) \le \sum_{i=1}^{n} z_i k_{1,i} \le K_1(1+15\%), \quad (9c)$$

$$\sum_{i=1}^{n} z_i = N, \quad (9d)$$

$$z_i \ge 0, \quad (9e)$$

where K_{eq}, ζ_{eq}, and K_1 refers to the parameters of the optimal isolated layer which are obtained during the first stage. ζ_{eq} is the equivalent viscous damping ratio of the isolated layer, and K_1 is the preyield stiffness of the isolated layer, as shown in equations (10a) and (10b):

$$\zeta_{eq} = \frac{2(1-\alpha)}{\pi(6-10\alpha)} \cdot \frac{\left(X_m - X_y\right)}{\alpha X_m + X_y(1-\alpha)} \left(\frac{X_y}{X_m}\right)^{0.42}, \quad (10a)$$

$$K_1 = \frac{K_{eq} X_m}{\left[\alpha X_m + (1-\alpha) X_y\right]\left[1 - 0.737\left(X_y\left(X_m - X_y\right)/X_m^2\right)\right]^2}, \tag{10b}$$

where X_y, X_m are the parameters of the optimal isolated layer, which are obtained during the first stage.

$k_{eq,i}$ and $\xi_{eq,i}$. $k_{1,i}$ denote the equivalent stiffness of the ith-type isolation bearing, and they are the given value. N is the total number of isolation bearings.

Equation (9a) indicates that the difference between the actual equivalent stiffness and the optimal value is below 5%. Equation (9b) denotes that the difference between the actual equivalent viscous damping ratio and the optimal value is below 5%. Equation (9c) indicates that the difference between the actual initial stiffness and the optimal value is below 15%.

The optimization model during the second stage is presented as equations (7)–(10b). This problem is a typical integer programming problem that can be solved easily by using MATLAB. The optimization procedures are presented as follows:

(1) The type of isolation bearing is predicted on the basis of the gravity load in each bearing, and the parameters of an isolation bearing are determined.
(2) The parameters of an isolation bearing are substituted into equations (7)–(10b). The number of the different isolated bearings is obtained using the optimization toolbox in MATLAB. Otherwise, the types or parameters of the isolation bearings are reselected.
(3) Considering the bearing capacity of each isolation and the eccentricity of the isolated layer, designers should arrange the optimal layout of the isolated layer.

4. Numerical Example and Analysis

4.1. Isolated Buildings. A five-story building with a reinforced concrete frame is designed in China. The following design parameters are applied: precautionary seismic intensity grade 9, peak acceleration of ground motion 0.30 g, and site class II. Figure 5 shows the finite element model of the structure. Table 1 provides the mechanical parameters of the isolation bearings, where t_r is the total thickness of the rubber layer and γ is the bearing shear strain.

The original layout of the isolated layer is shown in Figure 6.

This design can reduce the seismic force of the superstructure by 67%, and the maximum displacement of an isolation bearing is 239 mm, which is less than 275 mm of the allowable displacement. Moreover, all the isolation bearings are under pressure under a strong earthquake. Thus, the original layout of the isolation bearings satisfies design requirements.

4.2. Optimal Layout of Isolation Bearings. The soundness of using the two-stage optimization method in identifying the optimal layout of isolation bearings is examined on the proposed building.

The diameters of the isolation bearings are selected as follows: 400, 500, 600, and 700 mm. Each isolator is either LNR or LRB.

If each bearing is LNR400, then the equivalent stiffness of the isolated layer is $38 \times k_{eq} = 26.79$; the yield displacement of the isolated layer is $X_y = Q_d/k_1 = 0$; the limit displacement of the isolated layer is close to 100% of the bearing shear strain, i.e., $X_m = 100\% \times t_r = 68.6$; the limit value of the bearing displacement is $u_{max} = 205.8$. Similarly, if each bearing is LRB700, then $K_{eq} = 38 \times k_{eq} = 76.648$, $X_y = Q_d/k_1 = 11.32$, $X_m = 100\% \times t_r = 140$, and $u_{max} = 420$. Thus, the ranges of the parameters of the isolated layer are obtained as follows:

$$\begin{aligned} &K_{eq} \in [26.79, 79.648]\ \mathrm{kN/mm}, \\ &X_y \in [0, 11.32]\ \mathrm{mm}, \\ &X_m \in [68.6, 140]\ \mathrm{mm}. \end{aligned} \tag{11}$$

The objective function is

$$\alpha = \frac{((\beta/0.4) + (u/205.8) + (\theta/(1/150)))}{3}. \tag{12}$$

The constraint conditions are expressed as follows:

$$\begin{aligned} &\beta < 0.4, \\ &u \leq 205.8, \\ &\theta \leq \frac{1}{150}, \\ &10 \leq \mu \leq 30. \end{aligned} \tag{13}$$

The optimal parameters of the isolated layer are obtained using hybrid optimization as follows: $K_{eq} = 66.0072\ \mathrm{kN/mm}$, $X_y = 10.6\ \mathrm{mm}$, and $X_m = 119.3\ \mathrm{mm}$

The relationship between MPGA evolution generation and the objective function is shown in Figure 7.

As shown in Figure 7, the optimization results are stable after 11 generations; thus, this method is highly efficient.

On the basis of the preceding results, we obtain the layout of the isolated layer using the second optimization stage. The equivalent damping ratio and the initial shear stiffness of the isolated layer can be obtained by equations (10a) and (10b) as follows: $K_1 = 324.4458\ \mathrm{kN/mm}$ and $\zeta_{eq} = 0.2099$.

For further evaluation of the designed isolation bearings, considering that the compressive stress of the bearing with a diameter of 700 mm is extremely small, the diameters of the isolation bearings are selected during the second optimization stage as follows: 400, 500, and 600 mm. Moreover, to satisfy the limit compressive stress of isolation bearings, less than 12 bearings must be selected as either 500 mm or 600 mm. Each isolator is either LNR or LRB.

The design variable is presented as follows:

$$Z = [\, z_1 \;\; z_2 \;\; z_3 \;\; z_4 \;\; z_5 \;\; z_6 \,]^T, \tag{14}$$

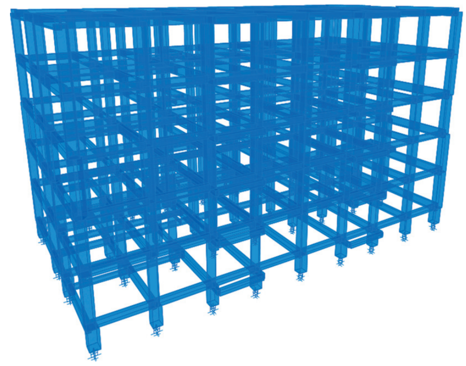

Figure 5: Finite element model of the structure.

Table 1: Parameters of the isolation bearings.

Type	Q_d (kN)	t_r (mm)	k_1 (kN/mm)	k_2 (kN/mm)		k_{eq} (kN/mm)		ξ_{eq} (%)	
				$\gamma = 100\%$	$\gamma = 250\%$	$\gamma = 100\%$	$\gamma = 250\%$	$\gamma = 100$	$\gamma = 250$
LRB400	40.1	68.6	7.23	0.723	0.575	1.309	0.809	26.5	17.8
LNR400	—	68.6	—	—	—	0.705	—	5	—
LRB500	62.6	100	8.07	0.807	0.642	1.433	0.902	26.5	17.8
LNR500	—	100	—	—	—	0.788	—	5	—
LRB600	90.2	120	9.29	0.929	0.739	1.681	1.04	26.5	17.8
LNR600	—	120	—	—	—	0.909	—	5	—
LRB700	122.7	140	10.84	1.084	0.862	2.096	1.213	26.5	17.8
LNR700	—	140	—	—	—	1.060	—	5	—

where z_1, z_3, and z_5 indicate the number of LRB400, LRB500, and LRB600, respectively; z_2, z_4, and z_6 denote the number of LNR400, LNR500, and LNR600, respectively.

The objective function is expressed as follows:

$$f = \sum_{i=1}^{6} z_i p_i = 4000(z_1 + z_2) + 5000(z_3 + z_4) + 6000(z_5 + z_6). \quad (15)$$

The constraint conditions are presented as follows:

$$66.0072 \times (1 - 5\%) \le \sum_{i=1}^{6} z_i k_{\text{eq},i} \le 66.0072 \times (1 + 5\%), \quad (16a)$$

$$0.2099 \times (1 - 5\%) \le \frac{\sum_{i=1}^{6} z_i k_{\text{eq},i} \xi_{\text{eq},i}}{\sum_{i=1}^{6} z_i k_{\text{eq},i}} \le 0.2099 \times (1 + 5\%), \quad (16b)$$

$$324.4458 \times (1 - 15\%) \le \sum_{i=1}^{6} z_i k_{1,i} \le 324.4458 \times (1 + 15\%), \quad (16c)$$

$$\sum_{i=1}^{6} z_i = 38, \qquad \sum_{i=3}^{6} z_i \ge 12, \quad 0 \le z_i \le 38,\ i = 1, 2, \ldots, 6. \quad (16d)$$

Using the second optimization procedure, the result is presented as follows:

$$Z = \begin{bmatrix} 10 & 0 & 0 & 0 & 28 & 0 \end{bmatrix}^T. \quad (17)$$

This result shows that the optimal layout of isolation bearings consists of 10 LRB400 and 28 LRB600.

In addition to their bearing capacity, designers should arrange the eccentricity ratio of these isolation bearings as small as possible. Then, the optimal layout of the bearings can be achieved as shown in Figure 8.

4.3. Analysis and Discussion. After adopting the optimal layout of the isolated layer, the seismic force of the superstructure can be reduced by 69%. A decrease extent of approximately 6% is obtained compared with the original design. By contrast, the optimal design case reduces each bearing displacement to more than 8%, and the maximum bearing displacement decreases from 239 mm to 219 mm. The results show that the seismic force of the superstructure and the displacement of isolation bearings can be reduced simultaneously. Moreover, all the isolation bearings are compressed under a strong earthquake. Thus, the optimal design obtained by implementing the proposed optimization method can improve the overall performance of the isolated buildings.

The comparison of the interstory drift ratio of the superstructure in the two schemes is presented in Table 2.

Table 2 shows that the interstory drift ratio of the superstructure is not more than 1/150 in either the original or

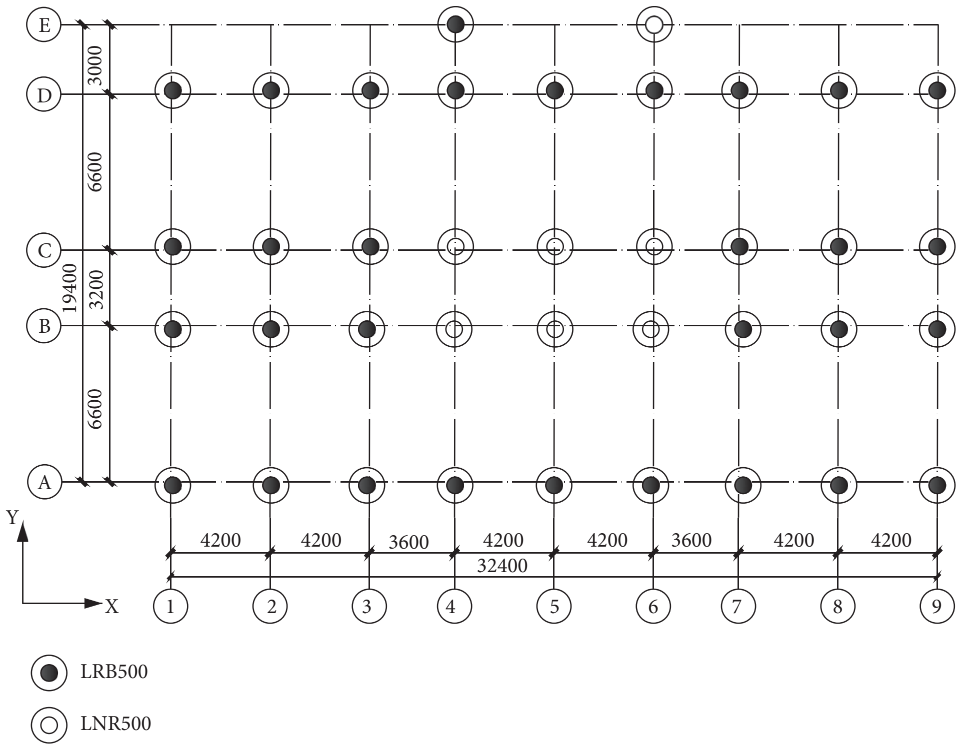

Figure 6: Original layout of the isolated layer.

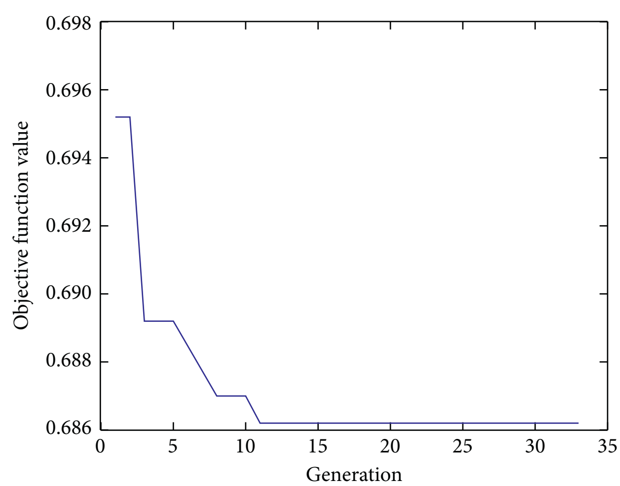

Figure 7: Evolution process of MPGA.

optimized scheme. Moreover, the maximum interstory drift ratio of each layer in the optimal scheme is smaller than that in the original scheme except for the X direction of the first story.

The comparison of costs of the two schemes is provided in Table 3.

Table 3 shows that the cost of the isolated layer increased slightly, i.e., by approximately 10%, compared with the original scheme. Considering the advantages of the seismic performance of the building, the additional cost of the isolated layer remains acceptable. If a designer requires an optimal layout scheme of isolation bearings with a relatively low cost, then he/she can add the cost of isolated bearings in the objective function in the first stage and adjust the weight coefficient of the cost.

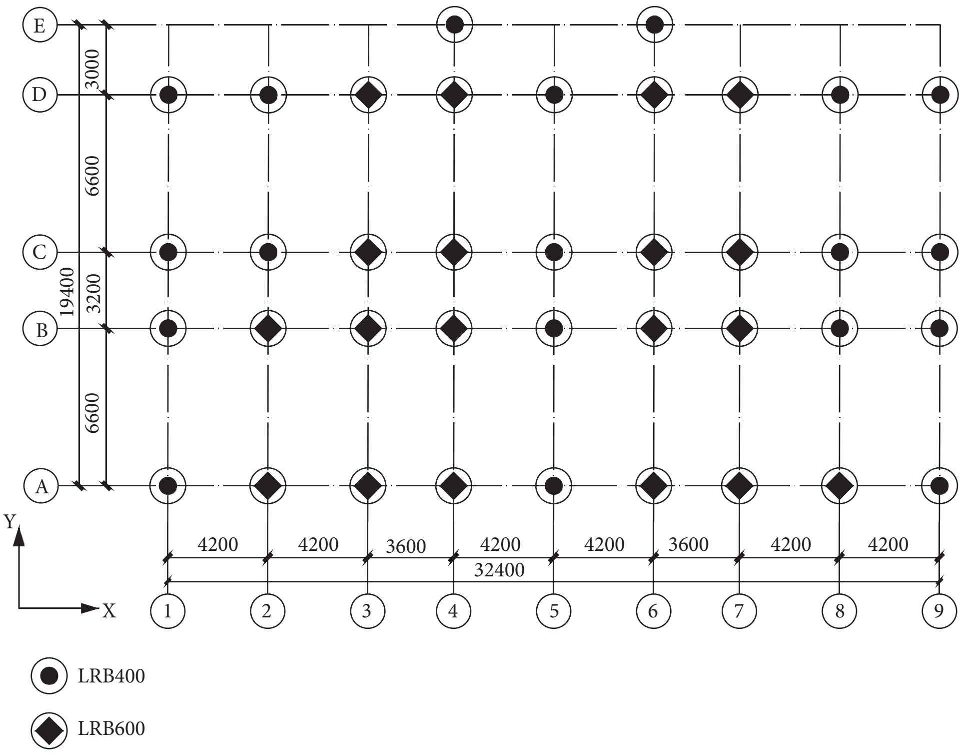

Figure 8: Optimal layout of the isolated layer.

Table 2: Interstory drift ratio in the optimal and original scheme.

i^{th} story	Interstory drift ratio under strong earthquake			
	Original scheme		Optimal scheme	
	X direction	Y direction	X direction	Y direction
5	1/667	1/667	1/769	1/769
4	1/476	1/476	1/526	1/556
3	1/455	1/455	1/500	1/500
2	1/500	1/526	1/556	1/588
1	1/1111	1/526	1/909	1/714

Table 3: Cost of the isolated layer in the optimal and original scheme.

	Original scheme	Optimal scheme
Cost of the isolated layer (thousand yuan)	190	208

5. Conclusion

This study proposed a two-stage optimization method for the design of an isolation bearing layout. A 3D finite element model was adopted for the isolated structure. The layout of isolated bearings was optimized by using the genetic algorithm and integer programming. The main conclusions of this study can be summarized as follows:

(1) This study constructs a hybrid framework in which nonlinear time history analyses are conducted using the software SAP2000 and optimization is accomplished on MATLAB. The former provides the responses of the isolated buildings; the latter calculates the associated objective function and identifies the optimal design. It can be conveniently implemented in the isolated buildings design to determine the layout of isolated bearings.

(2) The numerical results of the actual building indicate that the optimum design of isolation bearings can effectively improve the overall performance of an isolated building, on the other hand, slightly increase the cost of the isolated layer.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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