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Optimal distribution of steel plate slit dampers for seismic retrofit of structures

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Abstract. In this study a seismic retrofit scheme for a building structure was presented using steel plate slit dampers. The energy dissipation capacity of the slit damper used in the retrofit was verified by cyclic loading test. Genetic algorithm was applied to find out the optimum locations of the slit dampers satisfying the target displacement. The seismic retrofit of the model structure using the slit dampers was compared with the retrofit with enlarging shear walls. A simple damper distribution method was proposed using the capacity spectrum method along with the damper distribution pattern proportional to the inter-story drifts. The validity of the simple story-wise damper distribution procedure was verified by comparing the results of genetic algorithm. It was observed that the capacity-spectrum method combined with the simple damper distribution pattern leaded to satisfactory story-wise distribution of dampers compatible with the optimum solution obtained from genetic algorithm.

Keywords: seismic retrofit; slit dampers; optimum design; genetic algorithm; capacity spectrum method

1. Introduction

Recently various energy dissipation devices have been applied to protect structures from earthquake-induced ground motions. For economic use of energy dissipation devices or passive dampers in multi-story structures, it is essential to determine the appropriate location for damper installation throughout the stories. The assignment of damper locations within a building may be determined using a variety of methods. Gluck *et al.* (1996) developed an optimal damper allocation procedure based on active control theories. Furuya *et al.* (1998) attempted to identify a suitable distribution of dampers for vibration control of a 40-story building subjected to various seismic excitations and with consideration given to economic issues. Singh and Moreschi (2002) determined both the optimal number and optimal distribution of dampers for seismic response control of a 10-story linear building structure, and demonstrated that the number of dampers required using an optimal distribution is significantly less than that required when a uniform distribution is utilized. Moreschi and Singh (2003) developed optimum design procedure for combined use of yielding metallic and friction dampers based on genetic algorithm. Wongprasert and Symans (2004) utilized objective functions as minimization of the response in the second mode of vibration instead of the dominant first mode. Most of dampers tend to be concentrated on the lowermost and uppermost stories. Takewaki (2009) introduced optimal performance-based design procedure of structures for earthquakes using passive dampers. Fujita *et al.* (2010) proposed a gradient-based optimization methodology for optimal design of viscous dampers to minimize an objective function defined for a linear structure. Aydin (2012) considered optimal damper placement based on base moment in steel building frames. Whittle *et al.* (2012) compared the effectiveness of five viscous damper placement techniques for reducing seismic performance objectives including peak interstory drifts, absolute accelerations, and residual drifts. Martínez *et al.* (2013) used the sequential quadratic programming method and proposed a new objective function to find the optimal damper design based on a linear combination of the maximum inter-story drift and base shear force in planar steel frames. Adachi *et al.* (2013) proposed an optimum design procedure for framed structures based on sensitivity analysis using nonlinear time-history response analyses. Murakami *et al.* (2013) purposed a practical method for simultaneous optimal use of oil and dampers by formulating an optimum design problem to minimize the maximum inter-story drift under design earthquakes. Martínez *et al.* (2014) carried out optimum design of nonlinear hysteretic dampers in frequency domain, and Uz and Hadi (2014) carried out optimal design of semi active control system for adjacent buildings connected by MR damper based on integrated fuzzy logic and multi-objective genetic algorithm. The review of the previous research confirms that application of optimal distribution methods may enhance the effectiveness of damping devices significantly. Miguel *et al.* (2016) proposed a methodology to simultaneously optimize the location of friction dampers and their friction forces based on the backtracking search optimization algorithm.

For medium to high-rise structures with strong participation of higher vibration modes, more sophisticated optimization algorithm for damper distribution is required. One of the efficient methods used for optimum design of structures is the genetic algorithm (GA), which is a robust optimization technique based on the principles of natural biological evolution. GA has been widely applied for optimum design of structures (Rajeev and Krishnamoorthy

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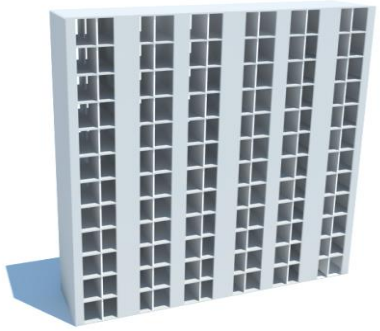
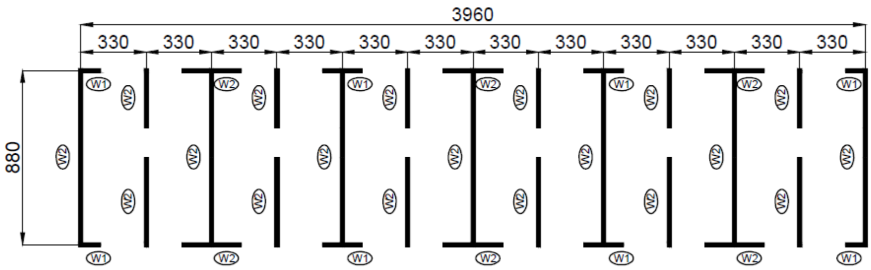


(a) 3D view



(b) Structural plan (unit: mm)

Fig. 1 Configuration of analysis model structure

1997, Hultman 2010). Moreschi and Singh (2003) applied GA to calculate the optimum design parameters for metallic and friction dampers to satisfy a pre-selected design objective. Movaffaghi and Friberg (2006) applied the GA-based method for the optimal damper placement of a given number of passive viscoelastic dampers in a nuclear power plant in order to reduce the acceleration responses at a nuclear reactor. Arfiadi and Hadi (2011) applied the hybrid coded genetic algorithm to optimize placement and properties of tuned mass dampers. All of the previous studies confirm that GA is a robust and reliable method for optimum damper distribution in building structures.

In this study a seismic retrofit scheme for a reinforced concrete shear wall structure using steel slit dampers is presented. The stiffness and the strength of the slit damper used in the retrofit are obtained by cyclic loading test. Genetic algorithm is applied to find out the optimum locations of the slit dampers satisfying the target displacement. A simple procedure for story-wise damper distribution is suggested using the capacity spectrum method along with the damper distribution pattern proportional to the inter-story drifts.

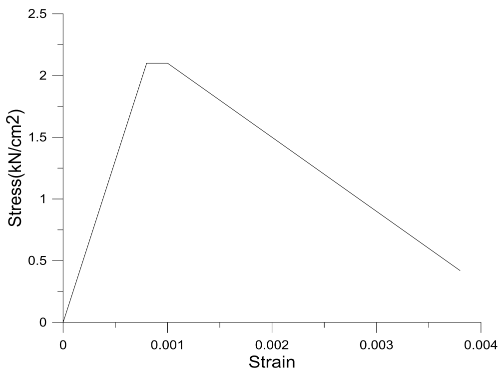
2. Design and analysis modeling of example structure

2.1 Design of the model structure

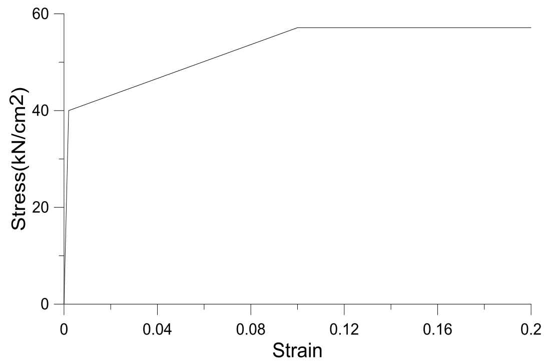
The analysis model structure is a 12-story reinforced concrete apartment building as shown in Fig. 1. The structure is designed to resist wind load as well as gravity loads, and therefore the structural system is composed of short shear walls located along the longitudinal direction, where wind load is small, and long shear walls along the transverse direction, where wind load is large. The design dead and live loads are 4.1 and 2.0 kN/m^2, respectively, and the wind load is obtained based on the basic wind speed of 30 m/sec. The building has uniform story height of 2.6 m and a rectangular plan shape with 8.8 m overall dimension along the transverse direction and 3.3 m span length along the longitudinal direction. The 200 mm-thick shear walls are reinforced vertically with D13@300 and horizontally with D10@350. The 150 mm thick slabs are assumed to be rigid diaphragm and the strengths of reinforced concrete and re-bars are assumed to be 21 MPa and 400 MPa, respectively. The fundamental natural period of the model structure is 2.7 second along the longitudinal direction and 2.3 second along the transverse direction.

2.2 Seismic performance of the model structure

The stress-strain material model for reinforced concrete is shown in Fig. 2. Overstrength factors of 1.5 and 1.25 are multiplied to the nominal strengths of concrete and reinforcing steel, respectively, in the nonlinear static and dynamic analyses as recommended in the ASCE 41-13 (2013). The shear walls are modeled by fiber elements provided in the Perform 3D (2006) as shown in Fig. 3. The shear stress–strain relationship of the wall is modeled by bi-linear lines with yield and ultimate strains of 0.004 and 0.012 respectively. The damping ratio of 5% of the critical damping is assumed in the dynamic analysis.



(a) Concrete



(b) Reinforcing steel

Fig. 2 Nonlinear models for reinforced concrete

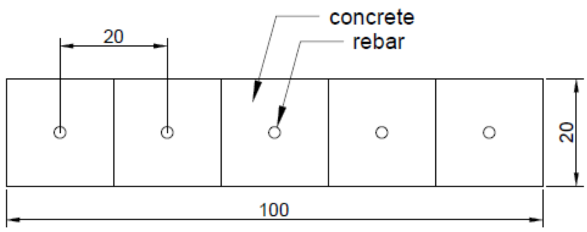


Fig. 3 Fiber-element model for wall elements

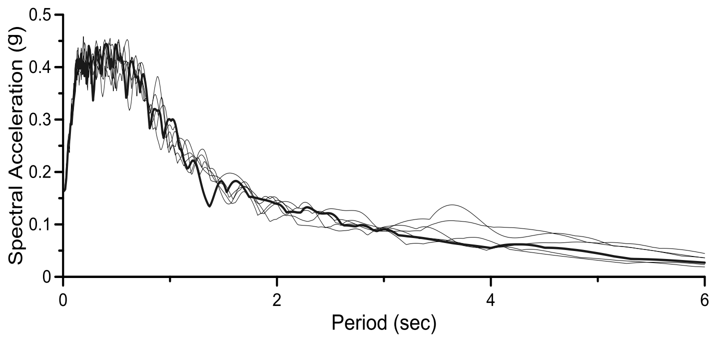


Fig. 4 Response spectra of seven artificial records

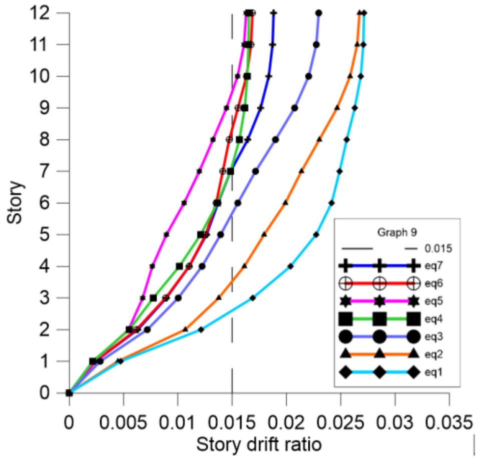
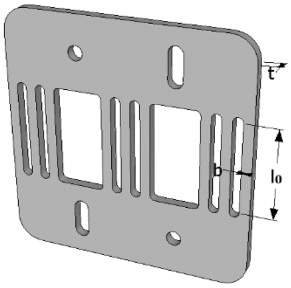
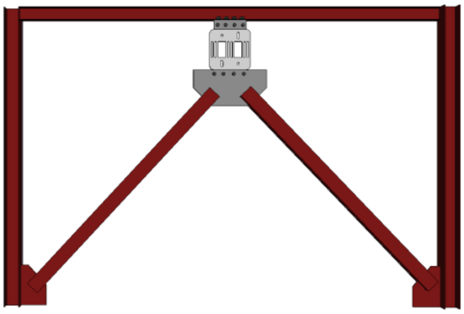


Fig. 5 Inter-story drift ratio of the model structures before seismic retrofit



(a) Damper configuration



(b) Typical installation scheme

Fig. 6 Configuration of a slit damper

For seismic performance evaluation of the model structure, seven artificial earthquake records are generated to fit the design spectrum constructed with $S_{ds}=0.45$ and $S_{d1}=0.29$ in the ASCE 7 – 13 (2013) format. Fig. 4 shows the response spectra of the generated seven artificial records. Fig. 5 shows the maximum inter-story drifts of the model structure obtained from nonlinear dynamic analyses using the seven earthquake records applied along the longitudinal direction. It can be observed that the maximum inter-story drifts of the model structure far exceed 1.5% of the story height which is considered to be the limit state for the life safety performance objective in the KBC 2016 (Korea Building Code, 2016).

3. Testing and analytical modeling of steel slit dampers

3.1 Properties of a slit damper

A steel plate slit damper, which is composed of many vertical strips as shown in Fig. 6, has been applied for efficient seismic design and retrofit of building structures. It is generally placed between stories where inter-story drifts are relatively large, and dissipates seismic energy by hysteretic behavior of vertical steel strips. Chan and Albermani (2008) carried out cyclic loading test of steel slit dampers and verified their seismic energy dissipation capacity. Kim and Jeong (2015) showed that steel plate slit dampers could be efficiently used for seismic retrofit of existing structures. Slit dampers are easily combined with other energy dissipation devices to maximize the efficiency of seismic retrofit (Lee and Kim 2015, Lee *et al.* 2017).

Based on the assumption that each strip in the slit damper has fixed end condition, the stiffness and the yield strength of a slit damper can be derived as follows (Chan and Albermani 2008)

$$k_s = n\frac{12EI}{l_o^3} = n\frac{Etb^3}{l_o^3} \tag{1}$$

$$P_{ys} = \frac{2nM_p}{l_0} = \frac{n\,\sigma_y\,tb^2}{2l_0} \tag{2}$$

$$M_p = \sigma_y\frac{tb^2}{4} \tag{3}$$

where n = number of strips, t = thickness of strips, b = width of strips, and l_o = length of the vertical strip. The overall width and height of the steel slit plate tested in this study are 500 mm and 700 mm, respectively. The plate used in the experiment has nine strips: the width (b), thickness (t), and the height (l_o) of each strip are 20 mm, 15 mm, and 200 mm respectively. The yield and the ultimate strengths of the steel slit plate obtained from coupon tests are 325.6 and 376.5 N/mm2, respectively. Even though a simple bilinear curve is used in this study to model the behavior of the damper, more elaborate model can be used to increase the reliability of the analysis model as in Karavasilis *et al.* (2012), who modified the Bouc-Wen model to capture the combined kinematic and isotropic hardening in the hysteresis of steel devices.

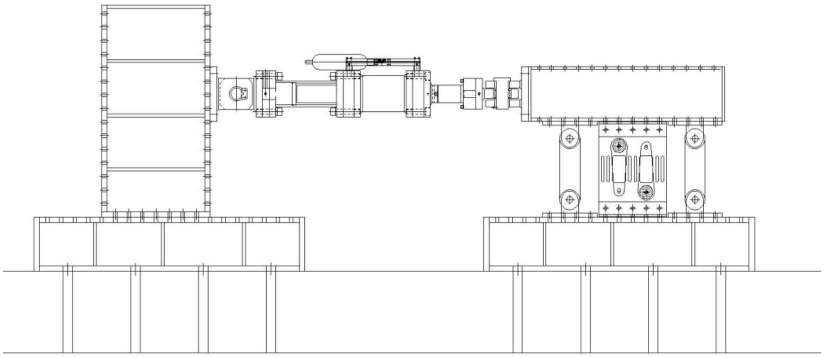
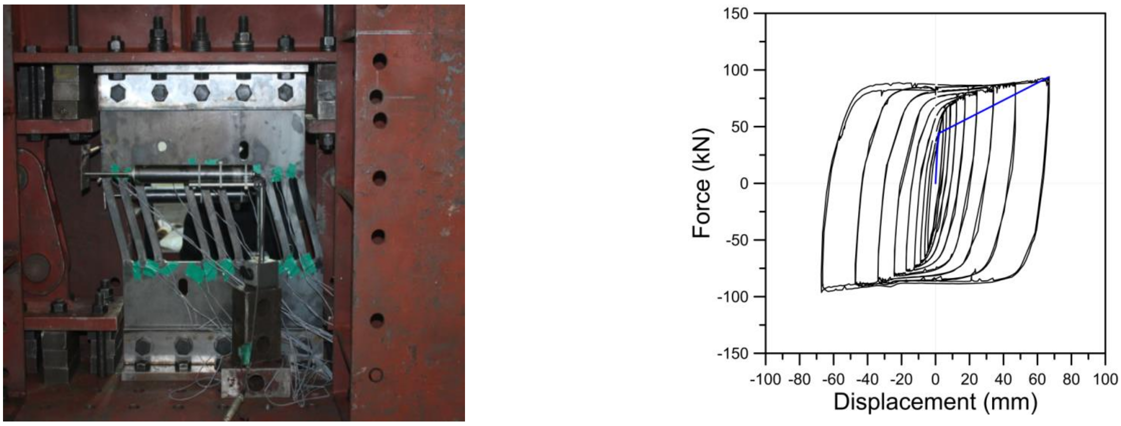


Fig. 7 Test setup for a slit damper



(a) Deformed shape (b) Force-displacement curve

Fig. 8 Cyclic loading test of a slit damper

3.2 Cyclic loading tests of the damper

Displacement-controlled cyclic loading test of the specimen is carried out using a 500 kN hydraulic servo actuator to evaluate the seismic performance of the hybrid damper. Fig. 7 depicts the test setup for the cyclic loading test, and a LVDT (linear variable differential transformer) is installed to measure the horizontal displacement of the specimens. The loading protocol for quasi-static cyclic tests specified in the FEMA-461 (2007) is followed for tests of the specimens. For the slit and the hybrid dampers the minimum displacement (Δ_o) is determined to be 1.5 mm which corresponds to 0.15% of the inter-story drift in a structure with 3 m story height. After each two cycles of loading, the displacement amplitude is increased to 1.4 times the previous one until the displacement reaches the target displacement of 60 mm which corresponds to 2% of the story height. After reaching the target displacement the specimen is further displaced until fracture. Fig. 8 shows the photograph of the deformed slit damper and the force-displacement relationship obtained from the cyclic loading test. For structural analysis, the nonlinear behavior of the slit damper is modeled by a bi-linear curve as shown in the figure. The second line is formed by connecting the yield point obtained from Eq. (2) with the upper right end point of the hysteresis curve obtained from the experiment. The post-yield stiffness of the slit damper obtained in this way is 2.5% of the initial stiffness, which is used in the following sections for analysis modeling of the slit damper.

4. Story-wise optimum damper distribution

4.1 Simplified modeling with reduced DOF

Genetic algorithm (GA) is an effective search technique carried out by combining good solutions to a certain problem over many generations to gradually improve the result. Since huge number of nonlinear time history analyses are generally involved in the optimization process using GA, the use of the 12-story full scale model structure in the algorithm is almost impossible. To reduce the computation time significantly, the model structure is transformed into an equivalent 12 degrees of freedom system with a single degree of freedom per floor. The force-displacement relationship of each story of the equivalent structure is obtained from the pushover analysis of the original structure, and is tri-linearized for nonlinear analysis as shown in Fig. 9. Then to match the first mode vibration period of the simplified model with that of the original

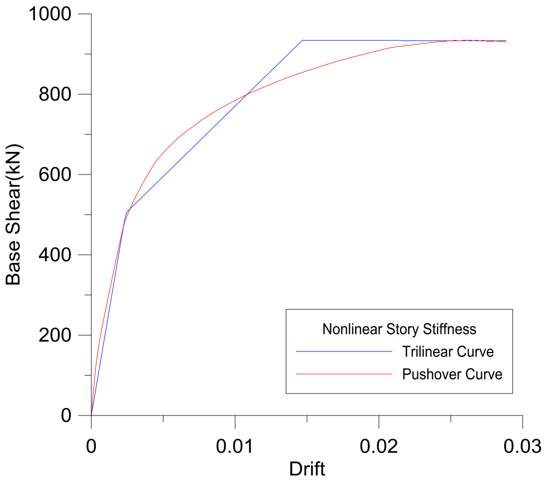
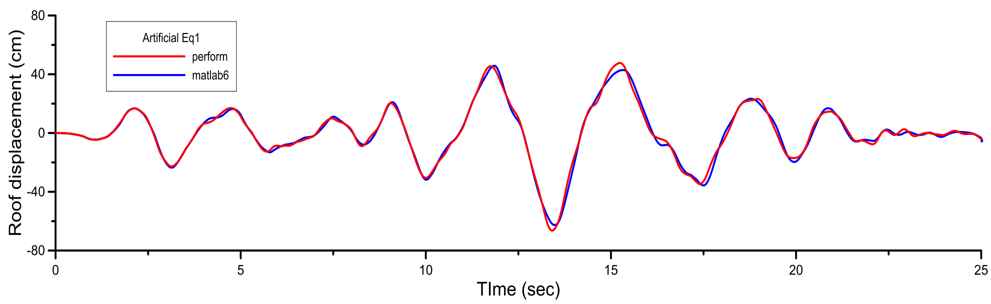
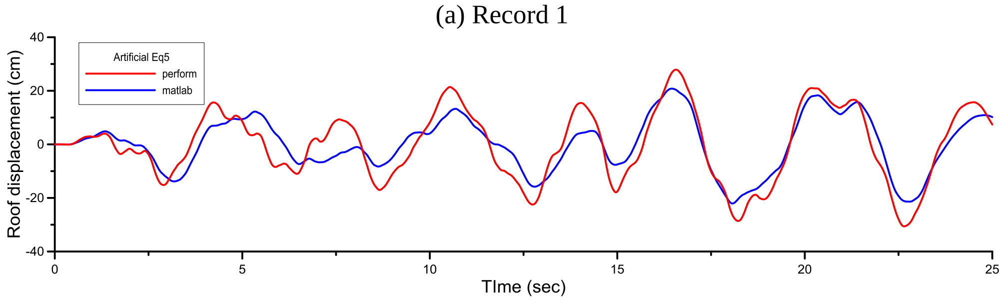


Fig. 9 Tri-linear idealization of the story force-displacement relationship



(a) Record 1



(b) Record 5

Fig. 10 Roof displacements of the original and the equivalent structures obtained from nonlinear dynamic analysis

model, the following technique is applied. The natural frequencies of a structure with mass and stiffness matrices *M* and *K* are generally obtained from the following eigenvalue analysis

$$\det(-\omega^2[M]+[K]) = \det([M]^{-1}[K]-\omega^2) = 0 \quad (4)$$

where det(A) represents the determinant of a matrix A. With the known fundamental natural frequency of the original structure, $\omega_{n,1}$, the scaling factor α can be computed from the following equation

$$det([M]^{-1}[K]\cdot\alpha - \omega_{n,1}^{2}) = 0 \quad (5)$$

where *M* and *K* are the mass and the stiffness matrices of the simplified model, respectively. By multiplying the scaling factor to the stiffness matrix of the simplified model, the fundamental natural frequencies of the original and the simplified systems can be matched. The Rayleigh damping of 5% of the critical damping is used in the first and the second modes to construct the damping matrix of the simplified model.

Fig. 10 shows the nonlinear time history analysis results for roof story displacement of the original system obtained using the software Perform 3D and the displacement of the simplified system obtained using the Matlab software. Among the results of the seven artificial earthquake records, the best fit (Record 1) and the worst fit (Record 5) are presented in the figure. It can be noticed that, even in the worst fit case, the correspondence of the two results are satisfactory considering the significant reduction of the degrees of freedom.

4.2 Optimum damper distribution

For optimum seismic retrofit of the model structure using slit dampers, genetic algorithm is applied to minimize the total amount of slit dampers while the maximum inter-story drift is maintained to be below 1.5% of the story height. The Global Optimization Toolbox in Matlab is used for performance of genetic algorithm. The design objective to be optimized is to minimize the total amount of the slit dampers while the maximum inter-story drift limitation is not exceeded. The constraint of the maximum inter-story drift ratio limited to 1.5% of the story height corresponds to the limit state for a Risk Category III structure when it is subjected to the design seismic load.

In the first step of the optimization process, a number between 1 ~ (2^{12}-1) is randomly selected and is changed to a binary number, which is allocated to a string or a gene composed of 12-bits which represent the degrees of freedom of the structure. The bits allocated with the number '1' represent the stories with dampers and those with '0' represent the stories without dampers. In the second step a random number is generated for yield force of the damper in each story. In this study total of 300 strings containing different information about story-wise distribution of damper slip force are randomly generated, and are put into breeding process over 1,000 generations until optimum solution is derived. This results in 300,000 nonlinear dynamic analyses of the model structure per an earthquake record. The fitness value of each string of damper distribution, which is the maximum inter-story drift, is evaluated by nonlinear time history analysis of the equivalent 12-degrees of freedom system using the artificial earthquake records. One of the main advantages of a slit damper is the flexibility of producing the desired yield force by changing the number and geometry of the slits. In this study each damper unit is assumed to have yield force of 180 kN, and maximum of 6 dampers are installed per story. The genetic algorithm is applied to the equivalent MDOF structure to obtain the optimum damper distribution pattern for each of the seven artificial earthquakes. Fig. 11 shows the optimum distribution of damper yield force obtained from genetic algorithm for the artificial record 1. It can be observed that generally larger damper yield force is allocated to the higher stories. The total damper yield force summarized over all stories is 6,840 kN. The assumption of 180 kN yield force of a unit slit damper results in total of 38 dampers. The unit cost of a slit damper is assumed to be $ 3,800 including supporting frame and labor cost for installation, which leads to total cost of $ 144,400 for the seismic retrofit using the slit dampers.

To check the validity of the optimum damper distribution pattern obtained using the equivalent MDOF structure, nonlinear dynamic analyses are carried out with the original model structure after installing the optimally distributed dampers. Fig. 12 shows the nonlinear dynamic analysis results of the original structure subjected to the seven artificial earthquake records after it is retrofitted with the optimally distributed slit dampers. It can be observed that the maximum inter-story drifts of the model structure for the seven artificial earthquake records are restrained within 1.5% of the story height as desired in the optimization process. The mean value of the seven maximum inter-story drifts is about 1.0% of the story height, which is between the immediate occupancy and life safety limit states.

4.3 Retrofit by increasing shear wall thickness

For comparison with the seismic retrofit using the slit dampers, the same optimization algorithm is applied to the seismic retrofit of the structure by increasing the thickness of the longitudinal shear walls which are the main lateral load resisting system in that direction. As in the previous optimization case, the design objective is to minimize the total cost of the retrofit while the maximum inter-story drift limitation of 1.5% is not exceeded. As constraints the maximum thickness of the jacketed walls is limited to 900 mm, and the thickness of the walls in the upper stories is maintained to be equal to or smaller than those of the walls in the lower stories. Only the thickness of the shear walls is increased because lengthening of the shear walls is not a possible option for functional reasons. The cost required for increasing wall thickness is estimated based on the RSMeans (2014) including both material and labor costs.

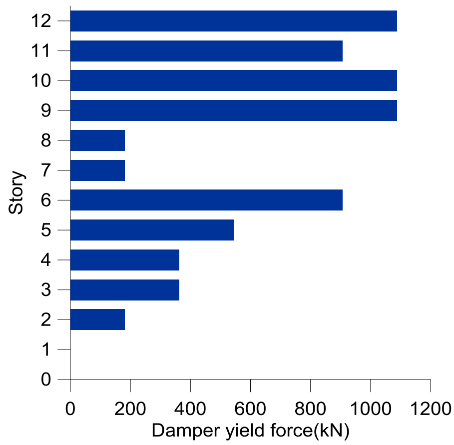


Fig. 11 Optimum distribution of damper yield force obtained from genetic algorithm

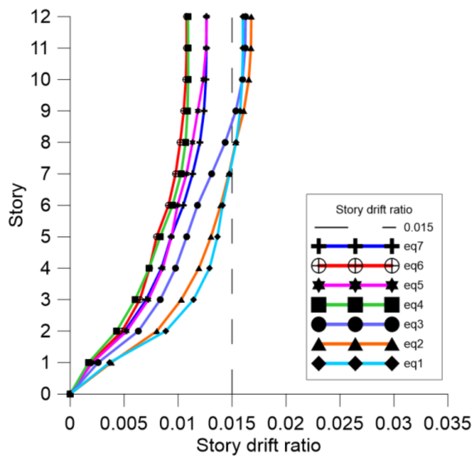
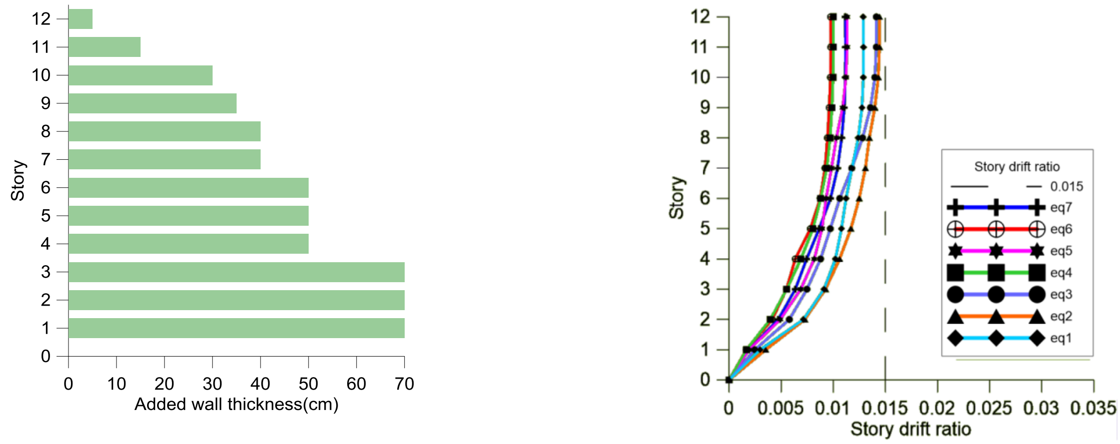


Fig. 12 Maximum inter-story drifts of the structure retrofitted with the optimally distributed slit dampers



(a) Optimum increase of wall thickness (b) Maximum inter-story drift

Fig. 13 Seismic retrofit of the model structure by increasing wall thickness

Fig. 13 depicts the optimum thickness of longitudinal shear walls to be increased to satisfy the design objective and the maximum inter-story drifts obtained from time history analysis using the seven artificial earthquake records. It is observed that the maximum inter-story drifts of the retrofit structure are within 1.5% of the story height for all earthquake records. The increase in wall thickness is largest in the lower stories and decreases in the higher stories, which is the opposite trend compared with the retrofit using the slit dampers. The total volume of concrete to be added is 409.5 m^3 , and the total cost is estimated to be \$165,800 including the labor cost and the material costs such as concrete, rebars, formworks, chemical anchors, etc. The retrofit cost of this scheme is somewhat higher than the cost of the retrofit using the dampers. The result is compatible with the findings of previous studies. Beardall *et al.* (1996) demonstrated that cost breakdown of conventional strengthening is higher than installing viscoelastic dampers, and Syrmakezis *et al.* (2006) also showed that the damper brace application is more effective than application of concrete jackets. Moreover, the increase of shear walls up to 900 mm is not feasible in a 12-story apartment building. Therefore Fig. 13 just demonstrates that the jacketing of shear walls is not a practical option for the given model structure.

5. Optimum vertical damper distribution pattern

As mentioned previously, significant amount of computation is required in the execution of genetic algorithm to reach optimum distribution of slit dampers throughout the stories. This makes the genetic algorithm difficult to apply in structural engineering practice. In this section more practical method for vertical damper distribution is proposed and its validity is verified by comparing with the result of genetic algorithm. The proposed scheme obtains the amount of required damping to satisfy a given target point based on the capacity spectrum method recommended in the ASCE 41, which is distributed to each story based on the inter-story drifts obtained from nonlinear dynamic analysis of the model structure subjected to design seismic load.

5.1 Optimum vertical damper distribution pattern

The vertical distribution pattern for dampers generally varies at each execution of genetic algorithm. In this study the genetic algorithm with the same constraints is applied ten times and the results are averaged to obtain more generalized vertical distribution pattern. Figs. 14 and 15 show the ten optimum distribution patterns obtained from genetic algorithm and their mean values, respectively. Each optimum distribution pattern presented in Fig. 14 is the mean of the results obtained by the time history analysis using the seven artificial earthquake records presented in Fig. 4. It can be noticed that in all seven cases the total yield force of the dampers added in a story generally increases as the height of that story increases. The optimum damper distribution pattern is similar to the story-wise maximum inter-story drift distribution pattern of the model structure depicted in Fig. 12. This implies that more dampers are placed where larger inter-story drift occurs.

Fig. 16 compares the mean optimum distribution curve (trend curve) with the inter-story drifts of the model structure subjected to the seven artificial earthquake records. It can be noticed that the trend curve has a double curvature shape, while the inter-story drift curves generally have single curvature shapes. Even though the overall shapes of the trend curve and the inter-story drift curves are not identical, they are generally compatible with one another. Based on this observation, the validity of using the inter-story drift as vertical damper distribution pattern will be verified in the following sections.

5.2 Estimation of the required damping

The capacity spectrum method (CSM) is introduced in the ATC-40 (1996) and the NEHRP guidelines for the seismic rehabilitation of buildings (FEMA-273, 1997). The CSM is an approximate procedure to analyze the seismic response of a structure using a nonlinear static pushover

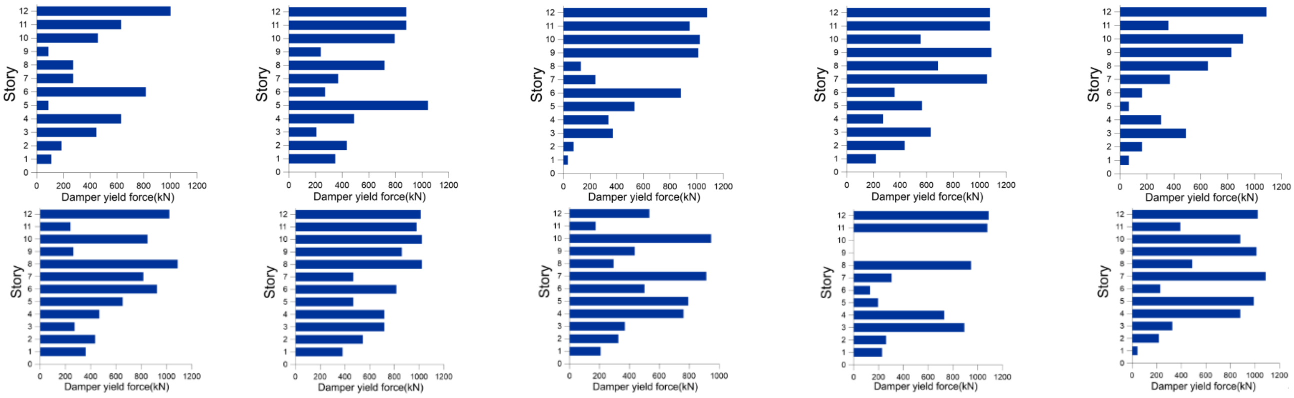


Fig. 14 Ten optimum distribution patterns of slit dampers obtained from genetic algorithm

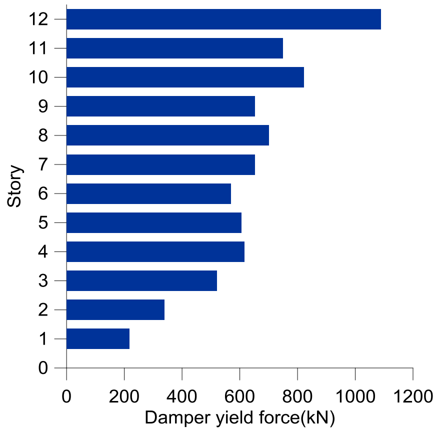


Fig. 15 Optimum distribution of slit dampers averaged over ten results

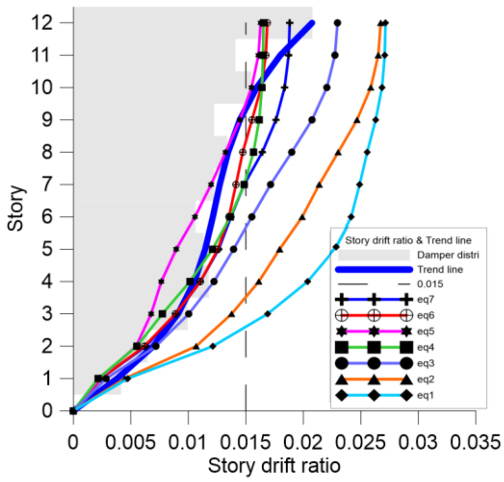


Fig. 16 Comparison of the trend line and the inter-story drifts of the model structure subjected to the seven artificial records

analysis. The pushover curve is transformed into the ‘capacity spectrum’ using the structure's dynamic properties such as modal participation factor and modal mass coefficient. This capacity spectrum is represented in the Acceleration Displacement Response Spectrum format (ADRS), using spectral displacements and spectral accelerations. The response spectrum can be plotted in the ADRS as well and the intersection of the two curves yields the performance point in terms of spectral displacement and acceleration. The procedure is included in the software Perform 3D, which is used in this study to find the effective damping ratio required to meet the target performance point

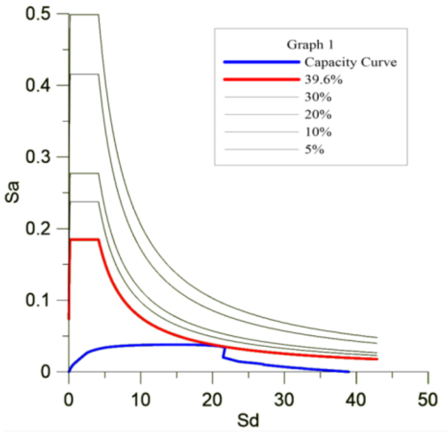


Fig. 17 Determination of effective damping ratio using capacity spectrum method

(maximum inter-story drift of 1.5% of the story height). Fig. 17 depicts the Acceleration Displacement Response Spectrum for the model structure where it can be found that effective damping of 39% is required to satisfy the target performance point.

5.3 Displacement response obtained from simplified procedure

In this section the slit dampers are distributed along the building height in such a way that the summation of the yield force of the dampers installed in a story is proportional to the inter-story drift of that story, and the effective damping ratio of the installed dampers becomes 39 % which is obtained from CSM as the required damping to satisfy the target displacement. To this end the following equations provided in the ASCE 41-13 are used to estimate the desired yield force of the dampers in each story

$$\beta_{eff} = \beta + \frac{\sum W_j}{4\pi W_k} \tag{6a}$$

$$W_k = \frac{1}{2}\sum F_i \Delta_i \tag{6b}$$

where W_j = work done by the dampers in the j^{th} story in one complete cycle of response at the inter-story drift δ_i, W_k = maximum strain energy of the structure when the maximum inter-story drift reached the target value, F_i = seismic design force at Level i, Δ_i = deflection of Level i at the center of rigidity of the structure. Pushover analysis is carried out until the maximum inter-story drift reaches the target value of 1.5 % of the story height to obtain the story and the inter-story drifts of each story required to estimate the work done by the dampers and the maximum strain energy of the structure.

Fig. 18 depicts the story-wise distribution of damper yield force obtained based on the CSM and the inter-story drift patterns. The total damper yield force is estimated to be 4,624.4 kN, which is smaller than the yield force obtained by genetic algorithm. Fig. 19 shows the inter-story drifts of the model structure installed with the dampers obtained from nonlinear dynamic analysis using the seven artificial earthquake records. It can be observed that the model structure installed with the dampers following the above procedure fails to satisfy the target drift ratio of 1.5% for three earthquake records. The maximum inter-story drift ratio of the model structure turns out to be 1.67% of the story height which is slightly higher than the maximum drift of the structure installed with slit dampers obtained from genetic algorithm. Nevertheless, the procedure applied in this section seems to be acceptable for practical application considering the simplicity of estimating the required effective damping and of distributing the dampers throughout the stories.

To verify the accuracy of the capacity spectrum method in comparison with the genetic algorithm, nine and fifteen story structures with the same structural plan are designed in addition to the twelve-story model structure using the same design loads, and the effective damping ratios to satisfy the target performance point (maximum inter-story drift ratio of 1.5%) are computed by both genetic algorithm and the capacity spectrum method. Table 1 compares the effective damping ratios obtained from the two different procedures. In the case of genetic algorithm, the effective damping is obtained from Eq. (6) after the dampers are optimally distributed throughout the stories. It can be observed that the difference between the two methods is less than 10% in all three model structures. This seems to be acceptable considering the simplicity and significant reduction of computation time involved in the capacity spectrum method which can be easily conducted using the commercial software such as Perform 3D.

Table 1 Effective damping ratios of the analysis model structures obtained from the genetic algorithm and the proposed procedure

	β_{eff} (%)		
	GA	CSM	Difference (%)
9F structure	21.46	19.98	7.41
12F structure	39.69	37.07	7.07
15F structure	28.42	28.85	1.49

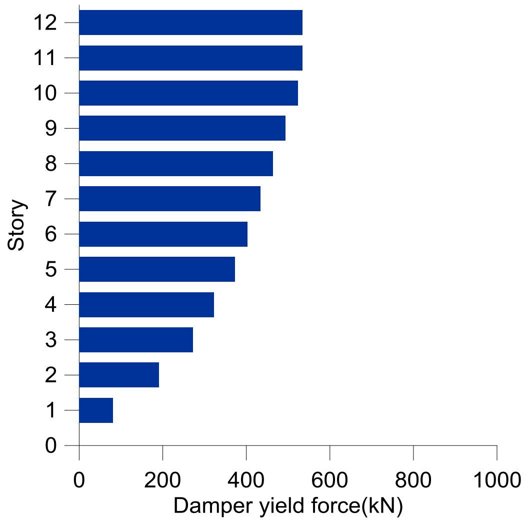
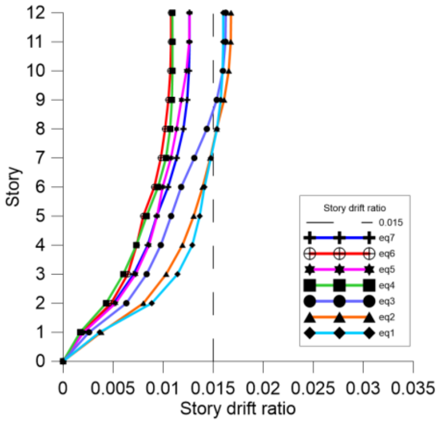


Fig. 18 Damper yield force distribution proportional to inter-story drifts



Drift Ratio : 1.68%

Fig. 19 Inter-story drifts of the model structure installed with slit dampers distributed based on inter-story drifts subjected to the seven earthquake records

6. Conclusions

This study investigated the optimal distribution of steel plate slit dampers using genetic algorithm to effectively reduce the seismic response of a reinforced concrete shear wall structure designed without considering seismic load, and the validity of the capacity spectrum method combined with the story-wise damper distribution based on the inter-story drift pattern was investigated. The energy dissipation capacity of the slit damper and the analytical modeling were validated by cyclic loading test. To apply genetic algorithm the model structure was transformed into an equivalent multi-degrees of freedom system with one degree of freedom in each story to reduce the computation time required for nonlinear dynamic time history analyses. The effective damping of the slit dampers optimally distributed throughout the stories was compared with the effective damping required for seismic retrofit obtained by capacity spectrum method.

The cyclic load test of a slit damper showed stable hysteretic behavior dissipating significant amount of input energy. The analysis results showed that the seismic response of the analysis model structure installed with the optimally distributed slit dampers by genetic algorithm satisfied the given target performance point. The transformation of the 12-story analysis model structure into an equivalent 12 degrees of freedom system turned out to be effective in reducing computational demand involved in the genetic algorithm. The difference between the effective damping ratios provided by the slit dampers obtained from the genetic algorithm and the capacity spectrum methods turned out to be less than 10 % in the three different model structures designed using the same loading conditions. Based on the analysis results it was concluded that the genetic algorithm was effective in optimum slit damper design for seismic retrofit of existing structures, and the simplified method for optimal damper distribution based on the capacity spectrum method and a predetermined damper distribution pattern was acceptable for practical application of energy dissipation devices on seismic design and retrofit of building structures.

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