9000OPTIMAL DESIGN AND CONFIGURATION OF SEISMIC DAMPERS

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ABSTRACT:

The usage of passive control devices have been increasing for structures under seismic and wind excitations. The optimal configuration of these devices will increase the safety and cost effectiveness. In this study a new reassessed algorithm is proposed that enhances the previous studies and finds more cost effective optimal configuration of dampers. In order to include the overall cost benefit, the new algorithm is updated. Particularly viscoelastic fluid dampers, which have been popular in dampers, are analyzed. The new reassessed algorithm can be adapted to other types of dampers. The results obtained from the new algorithm is compared with the studies of Ribakov and Gluck (1999), Lopez Garcia (2001), and Ribakov et al. (2001) and proven to be as effective and efficient as other algorithms or configurations. In all four examples the algorithm leads to more cost effective results which are also preferable in practical manner. For the examples conducted, the response of the structure increased just a little bit, within the limits chosen by the user, or did not increase at all. When compared to the reduction in cost, the response increase became negligible. With this algorithm it is easy to make cheaper, still efficient and effective damper configurations within the limits that can be defined by user.

KEYWORDS: Optimization, seismic, viscous, dampers, algorithm, passive control

1. INTRODUCTION

With the improvements in computer software the true dynamic analysis has been developed. As a result, the concepts of structural protection have progressed. “The newer building codes, especially the 1997 Uniform Building Code and the 2003 International Building Code, are primarily intended to regulate the design and construction of new buildings, and hence include many provisions that encourage the development of features important for good seismic performance, such as regular configuration, structural continuity, ductile detailing and using material of an appropriate quality... The practice of earthquake engineering is rapidly evolving and both our understanding of the behavior of buildings subjected to strong earthquake and our ability to predict this behavior are advancing.” (Pong et al 2005).

1.1. Structural Protective Systems

One of the approaches for seismic design is to decrease the seismic effects to the structure, in order to reduce the impact of the earthquake itself. The goal is to simultaneously lessen interstory drifts and floor accelerations to limit or prevent damage, not only to the structure but also to its contents, in a cost-effective manner.

A supplemental device, which dissipates energy, is placed on the structure in passive energy dissipation systems. This device is placed within the bracing system. Additionally, these devices can be effective not only against earthquake forces, but also to wind forces. The main aim is to decrease the energy dissipation demand on the structure.
Fluid dampers are one of the most frequently installed passive energy systems. Viscoelastic or viscous fluid

dampers are rate dependent devices. Their response is related to vibration frequency, strain level, and the ambient temperature. These devices can be used against both seismic and wind forces. They can be employed in all kinds of dynamic loads experienced during normal, continuous operation, and during abnormal, potentially disastrous situations. Viscoelastic dampers can dissipate the seismic energy under arbitrary earthquake loadings (Pong et al. 2002).

The use of energy devices to dissipate seismically induced energy is one of the most economical and effective ways to mitigate the effects of earthquakes on buildings (Pong et al. 2002). Installation may save material and money in the long-run. However, the properties of the dampers will remain same after the construction, so we should pay more attention to placing the dampers. Configuring the dampers optimally is more cost effective than non-optimally placed dampers. The results are not only cost effective, but also provide extra safety against seismic or other forces. We can even get better response by using optimal damper configuration.

2. NEW UPDATED ALGORITHM

In order to find a more cost-effective way of configuring the locations of dampers Bozkurt et al (2006) proposed a new algorithm. The new reassessed algorithm is enhancing the previous algorithms that find optimal location. The configuration result from existing algorithms is input for this new updated algorithm. It alters the configuration to find more cost effective configuration. After analyzing this new configuration it is accepted or not according to the limits set by the user.

At the beginning of the algorithm, the maximum limit for the structure response is entered. It might be interstory drift, interstory velocity, total drift, etc. Later, depending on the damper configuration, the algorithm changes the configuration to find the cheaper configuration that has the response under the limit indicated by the user. It takes dampers from the floors that have either minimum number of dampers or that have damper that has the lowest C (damper coefficient), then puts this damper to floor that has maximum number of damper or that has damper with the highest C. This iteration repeats until it finds the cheapest configuration within the tolerance. It gives the results and ends. Detailed flow chart can be seen in Figure 1.

The cost of construction is decreased by combining the dampers. There is labor cost to put the damper on each floor and there is also connection cost for each damper. By combining the dampers these costs are reduced. Instead of placing the dampers to every floor which means labor cost to lay the dampers to each floor and connection cost for each damper, the configuration is arranged to have dampers in one or couple of locations so there will be less labor and connection cost. In order to include the overall cost benefit the new algorithm is updated. The extra cost associated with choosing a larger member due to increase in the forces on the columns and beams is also added in to the algorithm.

The new reassessed algorithm merges the dampers. If the damper coefficients are same, it gets dampers from the floor that has minimum number of damper and places it to floor that has maximum number of dampers. If according to the configuration there is 1 damper in 5th floor and there are 4 dampers in 1st floor, it will take the damper from 5th and put it to 1st floor. If the number of floors with the minimum number of dampers or minimum damping coefficient is more than one, the algorithm chooses upper floors to take damper. Also if there is more than one floor with maximum number of dampers or maximum damper coefficient, the algorithm puts the damper to lower floor. The idea behind this is that the maximum interstory drift or interstory velocity usually occurs on the lower levels.

The floor that has 5 dampers actually means that floor has 1 big damper that has C equal to 5 times of the small damper. With this logic when the algorithm takes 1 damper from the floor that has 1 damper and puts it to floor that has 4 dampers like in the example above, it is actually assuming that there will be one damper in the 1st floor that has damper coefficient equal to 5 times of the small damper. Both 5 small dampers and 1 big damper will have the same result.

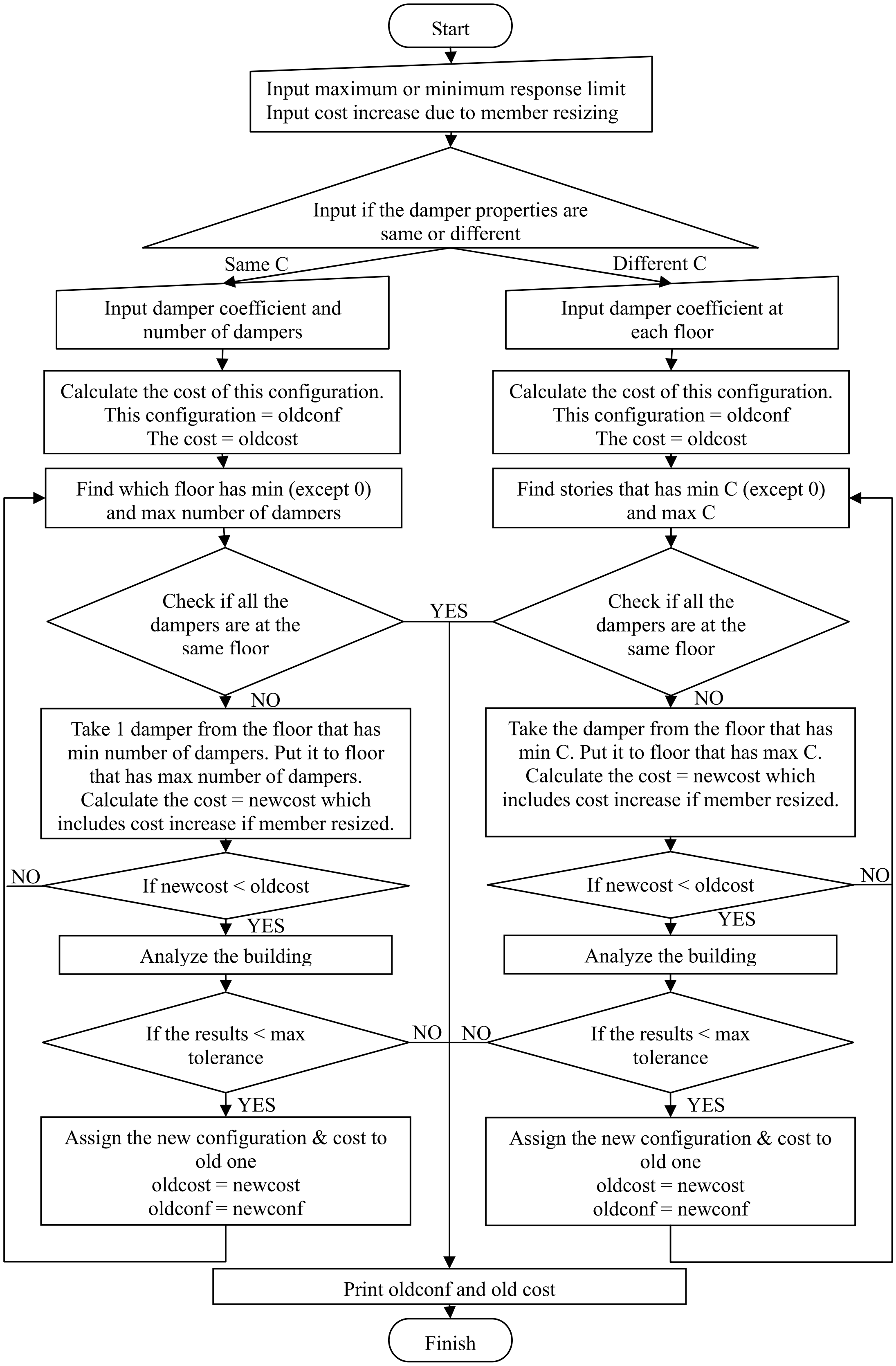


Figure 1 Flow Chart

Joining the dampers might create higher forces on the columns and/or beams. This might result choosing a bigger and more expensive beam or column member. At the beginning, the user also enters the cost associated by this increase. The updated algorithm considers this issue while combining the dampers. If the saving by combining the dampers is less than the cost increase due to choosing a bigger member, than the configuration is not accepted.

2.1. Assumptions and Limitations

There are a number of assumptions that the new reassessed algorithm makes. That is why there are some limitations that the user should be aware of.

The algorithm only tries the option of taking the damper from the floor that has minimum number of damper or minimum damper coefficient. There might be a better structural response by taking from other floors and putting them other than the floor that has maximum number of damper or maximum damper coefficient, but it is more likely to have a better response when it is put to the floor that has maximum number of dampers or maximum damper coefficient.

The first configuration entered to the algorithm is very important. If the initial configuration is different the final configuration might be different. That is why using the configurations of previous studies is suggested so the final configuration will be effective and much cheaper than that initial configuration.

One of the important assumptions that the new reassessed algorithm makes is regarding the cost calculation. The prices are according to the information obtained from Taylor Devices, which is the leading company on dampers. A 5 kip (22.24 kN) damper would cost about the same as a 50 kip (222.42 kN). It's hard to charge much less than $4000 for any damper for seismic purposes. The new reassessed algorithm assumes a damper with the capacity equal to 50 kip (or less) FVD +/-4" will cost $4,000. This force capacity is calculated according to Equation (2.1) by taking k equal to 1. The damper with the capacity equal to 300 kip (1334.52 kN) FVD +/-4" will cost $9,500. For the cost of the dampers in between 50 kip and 300 kip, the algorithm makes an interpolation. 300 kip is assumed as maximum limit for dampers capacity. The algorithm will not combine the dampers that will exceed this capacity. If the initial configuration directly has the damper with this capacity, then the algorithm will give a warning.

$$F = cv^k \tag{2.1}$$

For the connection and labor cost the new reassessed algorithm assumes 2 connections for each damper. For each connection including the labor the cost is assumed to be $1000. If there is no damper, there will be no connection cost for that floor. When calculating the connection and labor cost the new reassessed algorithm assumes 2 connection costs for the floors that has damper. This means it will cost $2000 for each floor for connections if there is damper at that floor.

3. EXAMPLES

For the first example the 7-story building as shown in Figure 2 is used. This example is also used by Ribakov and Gluck (1999), Ribakov et al. (2000), Lopez Garcia (2001), and Ribakov et al. (2001). The inherent damping ratio of the structure ξ_o is assumed as 1%. Same damper coefficient is used for all dampers.

The members for the columns and beams can be different for each building and designer. Therefore the decrease in the cost saving can be different for each design. In our examples it is assumed that dampers having C less than 50 kN-sec/cm will not change the member size. C value between 50 and 100 kN-sec/cm it will increase the cost of member $1500. It is assumed that the cost is going to increase $1500 for each additional 50 kN-sec/cm.

In the first example the configuration that Lopez Garcia (2001) obtained after his study is used as an initial configuration. He used 5, 6, 7, 8, 9 dampers. For each of the configurations he obtained from Simplified Sequential Search Algorithm (SSSA) the first floor has most dampers and the rest are at the second floor. If all these configurations are entered to new reassessed algorithm, the new configuration will be same because it will take the dampers from second floor and put them to first floor. This also proves that this new algorithm gives much more consistent configurations so the user will not be confused with which configuration to use.

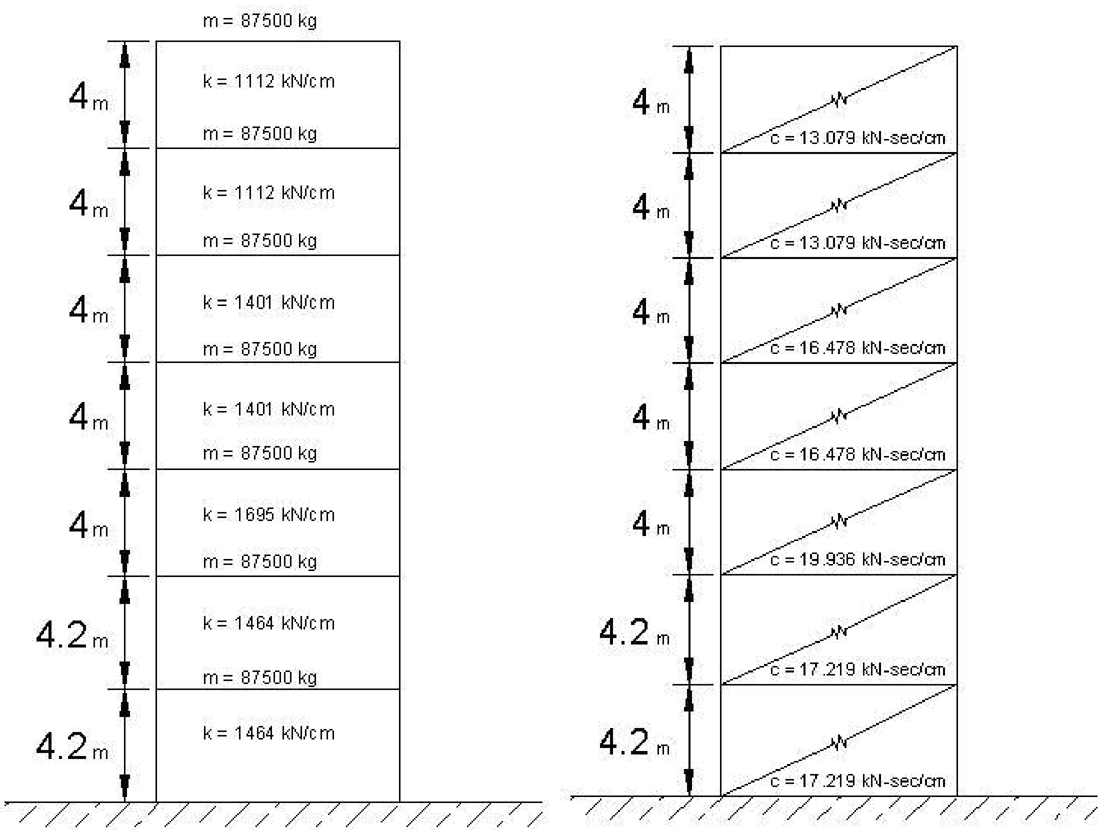


Figure 2 7-Story Building used in examples

Since Ribakov and Gluck (1999) has chosen maximum 0.50% for the maximum interstory drift in order to keep the building in the elastic range, the same limit is chosen as our maximum structural response. The results of structural analysis and comparison with the initial configuration are mentioned in Results section. This example is identified as the first example.

In the second example the configuration obtained by Ribakov and Gluck (1999) after Optimal Control Theory (OCT) is going to be used as an initial damper configuration. This initial configuration is shown in Figure 2. Again 0.5% interstory drift as our maximum limit is chosen. The results of analysis and comparisons with the initial configuration will be shown in Results section. This example is identified as second example.

These first two examples are analyzed by using El Centro S00E. Example 3 and 4 are identical with example 1 and 2. The only difference is for the analysis Taft N21E ground motion is used and 0.55% is chosen as upper limit for maximum interstory drift. This will also show that this new reassessed algorithm can be used for all earthquake types.

4. RESULTS AND COMPARISON

4.1. Results for the first example

The maximum interstory drift obtained with new reassessed algorithm (0.48%) is less than what Ribokov and Gluck obtained with OCT and is much less than the drift obtained without any damper. The Table 1 shows the comparison of these results.

Table 1 Displacement (cm) and Interstory Drift (%) results obtained for first example

	Results without dampers		Results with initial configuration		Results with new algorithm configuration		Results with OCT configuration	
	Disp. (cm)	Interstory Drift (%)	Disp. (cm)	Interstory Drift (%)	Disp. (cm)	Interstory Drift (%)	Disp. (cm)	Interstory Drift (%)
ROOF	15.11	0.25	10.70	0.16	10.59	0.15	11.18	0.16
7th Floor	14.13	0.44	10.05	0.30	9.96	0.30	10.50	0.31
6th Floor	12.41	0.48	8.79	0.34	8.73	0.33	9.19	0.35
5th Floor	10.59	0.57	7.37	0.42	7.35	0.41	7.72	0.43
4th Floor	8.29	0.56	5.63	0.38	5.65	0.38	5.93	0.40
3rd Floor	6.00	0.68	4.03	0.46	4.06	0.46	4.26	0.48
2nd Floor	3.08	0.72	2.05	0.47	2.07	0.48	2.17	0.50

Even though the cost saving decreased $1500 because of being forced to choose a bigger member after 6th damper went to first floor it was still beneficial to transfer all the dampers to first floor. For this example the cost saving was 37.5% according to initial configuration.

4.2. Results for second example

In this example the configuration obtained by Ribakov and Gluck (1999) after Optimal Control Theory is used as an initial damper configuration. Again El Centro S00E is used while analyzing the structure. The updated algorithm located all the dampers to 3rd floor. For this example the cost saving was $31,000 which is about 74% saving.

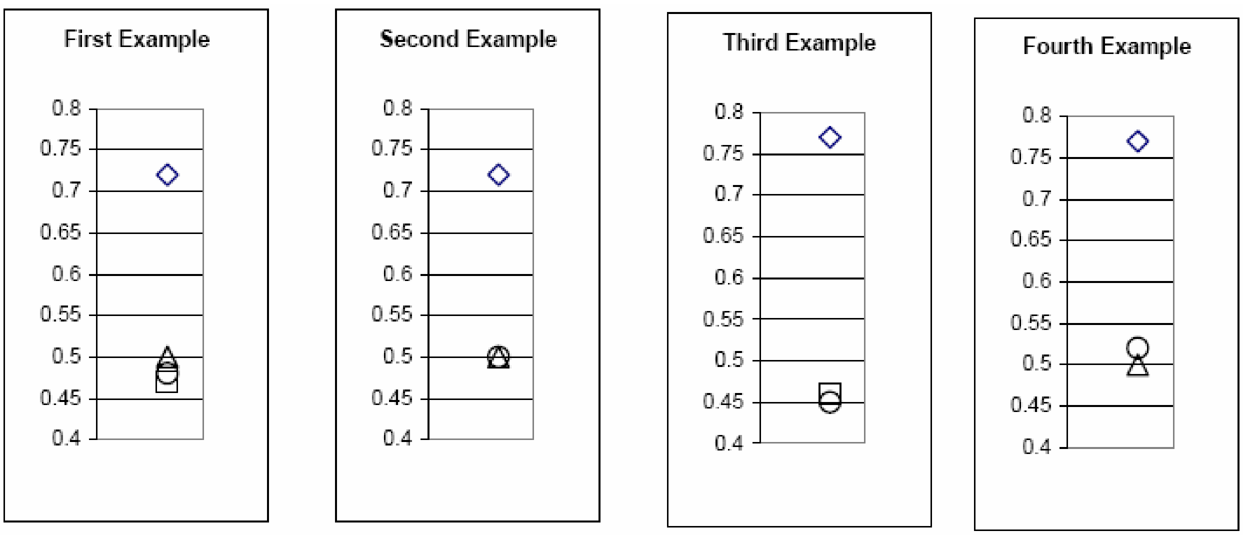
4.3. Other Examples

For the third one, the configuration that Lopez Garcia (2001) found after using SSSA is used as initial configuration. The maximum displacement and maximum interstory drift results are tabulated in Table 2. For comparison the maximum interstory drift for each configuration is shown in Figure 3.

If the configuration, which Ribakov and Gluck (1999) found by OCT, is used as an initial configuration the algorithm puts all the dampers to 3rd floor. After the analysis with the new configuration the maximum interstory drift only increased 0.02%.

Table 2 The maximum displacement and maximum interstory drift results for Example 3

	Results without damping		Results with initial configuration		Results with new algorithm configuration	
	Disp. (cm)	Interstory Drift (%)	Disp. (cm)	Interstory Drift (%)	Disp. (cm)	Interstory Drift (%)
ROOF	15.74	0.27	9.96	0.15	9.85	0.14
7th Floor	14.92	0.47	9.42	0.28	9.30	0.28
6th Floor	13.29	0.51	8.32	0.32	8.19	0.32
5th Floor	11.34	0.63	7.03	0.41	6.91	0.40
4th Floor	8.81	0.61	5.40	0.39	5.30	0.38
3rd Floor	6.37	0.74	3.87	0.46	3.79	0.45
2nd Floor	3.24	0.77	1.94	0.46	1.91	0.45



◊ *Without dampers* Δ *With OCT configuration* O *With New Algorithm* □ *With SSSA*

Figure 3 Comparison Chart for examples

5. CONCLUSIONS

All the examples showed that the updated new reassessed algorithm gives more cost effective configurations with little or no increase in the structure response. While the first and third examples gave 37.5% decrease in the cost the second and fourth examples gave about 74% decrease in the cost. The comparison of the costs for all examples is shown below in Figure 4.

In the second example even though the maximum interstory drift did not increase, the cost decreased tremendously. The cost of initial configuration was $42,000 and this decreased to $9,000.

In the third and fourth examples the results were similar. For the fourth example the increment in the maximum interstory drift became 0.02%, but the cost decreased approximately 74%. The new reassessed algorithm gave also much more consistent results. This will also help design engineers while deciding which configuration to use. Instead of thinking to choose from different configurations they can decide the configuration given by new algorithm. This configuration is also much more cost effective than other configurations.

In summary with this new algorithm much more cost-effective damper configurations are gained with a little or no sacrifice in interstory drifts. It gave much more consistent results. The updated new reassessed algorithm is effective, simple and practical. It can easily be adopted to design software and it is easy to use.

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