International Journal of Technical Innovation in Modern Engineering & Science (IJTIMES)
Impact Factor: 3.45 (SJIF-2015), e-ISSN: 2455-2585
Volume 4, Issue 4, April-2018

Optimised Seismic Structural Performance by Energy Management Devices Using Multi-criterion Genetic Algorithm

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Abstract:***Energy dissipation devices such as Fluid Viscous Dampers have proved quite effective in safeguarding the buildings in the event of an earthquake. This study has shown optimized usage of these devices as regard to total amount of supplemental damping provided in context of multiobjective optimized response control. Base shear and interstorey drifts have been used as important multiple control parameters to implement the optimization strategy for supplemental damping. Amongst several optimization algorithms the genetic algorithm has created its niche over last three decades in every field and is followed in this study. Dynamic analysis is carried out with strong ground motions which have shown excessive damage to buildings in the past and their effect on set of five and ten storey buildings is investigated and presented.***

Keywords:***Energy dissipation, passive devices, genetic algorithm, Multi-criteria Optimization, interstorey drift.***

I. INTRODUCTION

The structural control strategies including passive control, semi-active control, active control and hybrid control is now well accepted technology for dissipating earthquake energy and reducing the undesired levels of dynamic responses of structures. In the last two decades, many control algorithms and devices have been proposed in order to reduce the seismic responses of structures and increase the structural seismic protection without modifying the existing structural strength, rigidity and ductility. There are various types of control devices which dissipate seismic energy through different mechanisms such as friction dampers, metallic dampers, viscous fluid dampers and viscoelastic dampers which absorb a large amount of earthquake energy. Fluid viscous dampers dissipate energy through the heat in piston motion in fluid they have advantages such as:

- High energy dissipation capacity.
- They enjoy highest reliable dissipation through viscous fluid force.
- Their performances are not affected by the amplitude of exciting load and the frequency content of earthquakes
- Easy installation, simple mechanism and less maintenance cost are other advantages.

Passive control devices provide a supplemental damping which incorporates the principle of energy dissipation by friction and heat. The response control is thus achieved by diverting the input earthquake energy from structure to this loss mechanism. The important aspect of these devices is that they successfully control the seismic response of structures during an event of earthquake while still maintaining the functionality of structure at normal. Post-earthquake, the damaged devices can be replaced and small damage to the structure can be repaired easily. Since its first inception in civil engineering in 1960s, with the invention ofdifferent types of damping devices and systems, improvement of modelling techniques and development of new computational methodologies, use of these devices has become a mature technology in designing of new structures and retrofitting of existing facilities all over the world. Structural control systems

Four types of structural control systems have been implemented so far in buildings. These are:

i) Passive control systems
ii) Active Control systems
iii) Semi-active control systems
iv) Hybrid control systems

A. *Passive control system*

The passive control system utilizes the structural motion to dissipate seismic energy so that response of structure can be controlled in favourable manner. Fig. 1 shows schematic setup of passive control system mounted on structure. Passive control systems possess several advantages over other systems including cost. It is usually relatively inexpensive, consumes no external energy, inherently stable, highly reliable during major seismic event, easily replaceable low or zero cost of maintenance, do not affect functionality of buildings, and many times add to aesthetics of buildings. However, this kind of control system cannot make real time changes in system and provide no extra assistance, so it cannot adapt to varying loading conditions needing proper design for desired performance.

Passive devices include variety of devices. Viscous fluid dampers consisting of a hollow cylinder filled with a fluid. As the damper piston rod and piston head are stroked, the fluid flows at high velocities, resulting in the development of high friction. In viscoelastic dampers, viscoelastic materials are used to dissipate energy through shear deformation. Such materials include rubber, polymers, and glassy substances. Friction dampers use friction between sliding faces is used to dissipate energy. Metallic Yield Dampers relies on the principle that the metallic device deforms plastically, thus dissipating vibratory energy. Fig. 1 shows few typical devices.

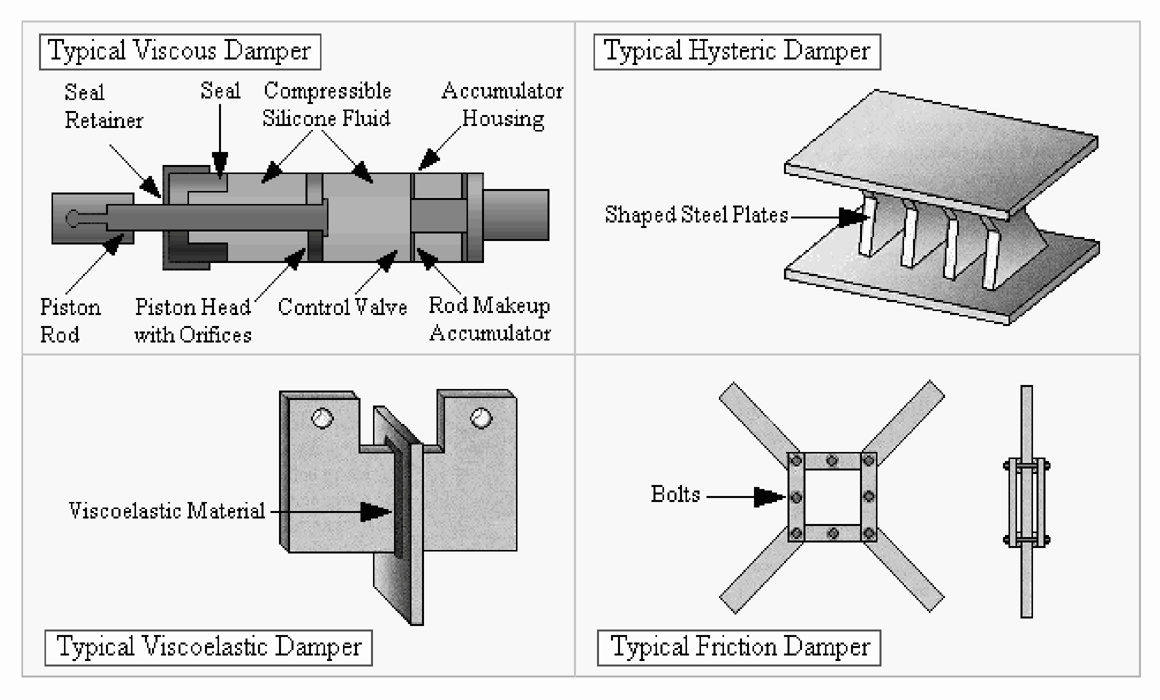


Fig.1:Typical energy dissipation devices

B. Active control systems

An active structural control system has the basic configurations as shown schematically in Fig. 2. It consists of (i) sensors located about the structure to measure either external excitations, or structural response variables, or both; (ii) devices to process the measured information and to compute necessary control force needed based on a given control algorithm; and (iii) actuators, usually powered by external sources, to produce the required forces. Active control requires a power supply to activate the dampers and hence may be undependable during seismic events where the power supply could be disrupted.

C. Semi active control systems

Semi active control systems are similar to active control except that the controlling does not require an actuator and external power for functioning of the system. Small battery-operated circuit enables operation of controlling valves for adjusting force levels in controlling devices in response to excitation force magnitudes.

D. Hybrid control systems

Hybrid control systems implement combination of ideas from passive, semi active and active control systems.

II. OPTIMIZATION OF CONTROL SYSTEMS: A BRIEF REVIEW

The passive energy dissipation systems, such as fluid viscous devices and visco-elastic devices, act as energy sinks and absorb some of the input vibration energy so that less is available to cause deformation of structural elements. Importance of this approach is highlighted and emphasized in several studies ([1,[2],[3],[4]). In their work [5] presented optimal control of adaptive building structures subjected to blast loading, a first for blast loading. Other study [6] proposed an optimal layout design in truss bridges using genetic algorithm by minimization of weight. Following this, [7] sped up the convergence in the optimization of truss structures. Next, [8] developed a new hybrid control system including a semiactive tuned liquid column damper (TLCD) system for vibration control of structures. Work by [9] considered hybrid control.

Optimization studies [10] and [11] provided a framework for multiobjective optimization methodology in evolutionary computing by GA, to optimize performance of building to given seismic excitation by means of energy dissipation devices.

All studies discussed above included either explicitly or implicit into their formulation only single objective except [10] and [11]. Even though work of these studies was able to set certain direction to multiobjective optimization with passive devices, it also admitted the shortfalls of their study.

This study handled a multiple objectives methodology to solve problems identified in scientific literature sufficiently accurately by using genetic algorithm.

III. GENETIC ALGORITHM AND OPTIMISATION

In order to find optimal designs, the GA processes populations of fittest chromosomes, successively replacing one such population with another. The procedures required to achieve this goal and organize the task in systematic but stochastic way are termed as operators in GA. The simplest form of genetic algorithm involves three types of operators: selection, crossover and mutation.

Computational steps used in GA:

1. Generate randomly the initial population of even number of chromosomes. (Candidate solutions to a problem).
2. Fitness evaluation of each candidate chromosome in the population.
3. Following sub-steps are repeated until population of offspring is created:

    a. Selection: Select a pair of parent chromosomes from the current population, the probability of selection being an increasing function of fitness. Selection is generally done "with replacement," meaning that the same chromosome can be selected more than once to become a parent.
    b. Crossover: With chosen probability of crossover called "crossover probability" or "crossover rate", cross over the pair at a randomly chosen section to form two offspring. There are also "multi–point crossover" versions of the GA in which the crossover rate for a pair of parents is the number of points at which a crossover takes place.

    c. Mutation: Mutate the two offspring at each locus with the mutation probability or mutation rate, and place the resulting chromosomes in the new population. If population size is odd, one member from new population can be discarded at random.

4. Replace the current population with the new population.

Each iteration of this process is called a generation. A GA is typically iterated for anywhere from 50 to 500 or more generations. The entire set of generations is called a run. At the end of a run there are often one or more highly fit chromosomes in the population.

IV. CONTROL AND OPTIMIZATION METHODOLOGY

Base shear and Interstorey drifts are key performance indicators in seismic response analysis of buildings. A close insight shows that these two quantities are mutually related if considered for simultaneous optimization. A high amount of drift reduction puts more amount of shear to be resisted in each storey and will automatically cause corresponding increase in base shear. On the other hand, limiting the base shear to bare minimum will cause increase in interstorey drifts and total roof displacement of buildings, both of which may cross the limits prescribed by code. Hence, the appropriate trade-off is essential when these two quantities are used as simultaneous performance objectives to be achieved i.e design of optimum damping for minimum drifts and minimum design base shear.The goal of GA chosen in this study is to select the optimized amount of damping which results in minimizing both base shear and interstorey drifts simultaneously.

In order to quantify results and demonstrate the usefulness of multiobjective optimization the viscous fluid dampers (FVD) are used as control devices.

V. STRUCTURAL MODELLING WITH DEVICES AND SEISMIC ANALYSIS

A.*Viscous fluid dampers (FVD) modelling*

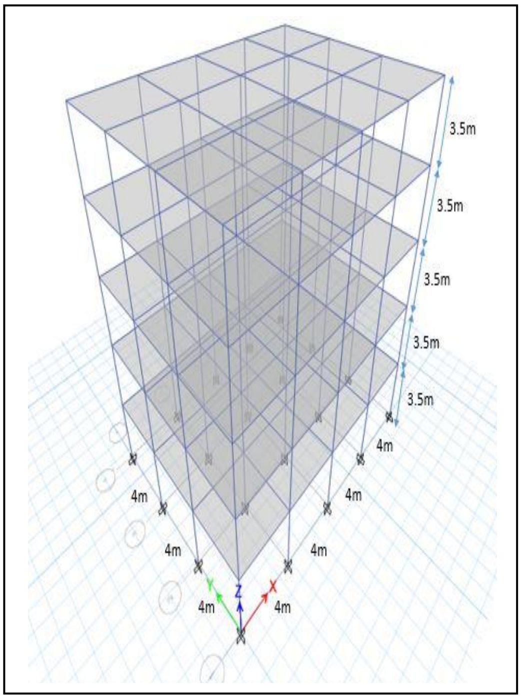
The generalized characteristic relation of FVD is stated as

$$\boldsymbol{F(t) = c_d|\dot{x}|^{\alpha} sgn(\dot{x})}$$

Where x with dot over head is relative velocity across ends of device. $\mathbf{c}_d$ is a generalized damping coefficient and α may take values in the range of about 0.25 to 2. That is, the damper may exhibit nonlinear viscous behaviour (the case a α= 1 is that of a linear device and appropriate for earthquake analysis). The force-displacement hysteresis relation indicating energy dissipation characteristics of such devices is ideally elliptical.

B. Buildings modelling

For the purpose of demonstration, seismic analysis of set of 5 storey and 10 storey buildings is performed independently for three different cases i.e. a bare frame building analysis, buildings fitted with uniform damping devices in each storey and thirdly the analysis of building fitted with GA optimized devices. The structural properties of buildings chosen in each set are in such a way that they provide sufficient range of periods to obtain meaningful results of optimization analysis.



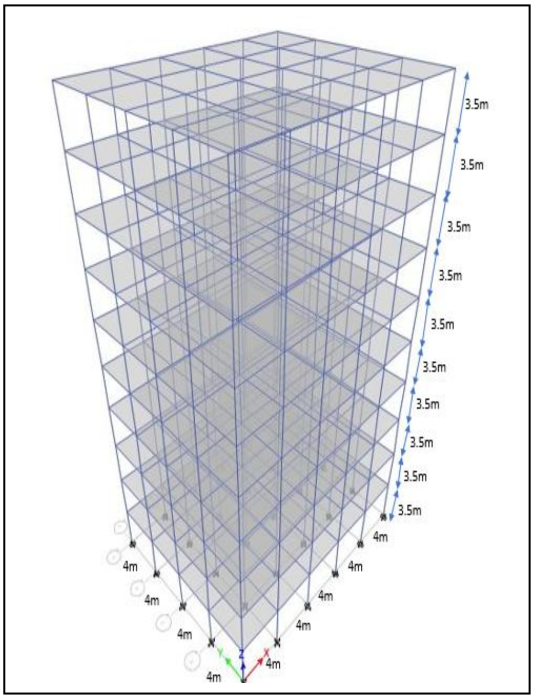


Fig.2:Typical 5 storey buildings layoutFig.3:Typical 10 storey buildings layout

The ground motion chosen for the analysis are as shown in Table I. They are selected with magnitude and peak ground acceleration such that they represent sufficient damage in the past. These ground motion are scaled for design basis earthquake (DBE) indicated in IS1893-2002.

TABLE I
GROUND MOTIONS USED FOR ANALYSIS.

Ground motion	**Station or Site**	**PGA (g)**	**Magnitude (Richter)**
Elcentro Earthquake, 1940	Elcentro Array #9	0.348	6.9
West Washington Earthquake, 1965	Olympia	0.279	6.7
Koyana Dam, Earthquake, 1967	Koyana1A Gallery	0.487	6.5
Uttarkashi Earthquake, 1991	Bhatwari	0.246	6.8
+	San Bernardino	0.582	6.7
Park Field Earthquake, 1982	San Luis Obisbo	0.354	6.2
ImperialValley Earthquake, 1940	ImperialValley,California	0.214	6.9

TABLE II
SEISMIC RESPONSE RESULTS OF MULTIOBJECTIVE OPTIMIZATION ANALYSIS [5 STOREY BUILDINGS]

Building.	Ground motion	Building with status of damping provision	Interstorey drift in % excess (+) or smaller (-) than Permitted value	Base shear (kN)
FB-1	Elcentro	I	+12.8	1123.4
		II	0.0	1011.0
		III	-4.0	1004.4
		IV	-5.0	981.3
FB-2	Uttarkashi	I	+12.9	1169.6
		II	0.0	1066.5
		III	-9.7	1038.8
		IV	-10.0	1022.9
FB-3	Uttarkashi	I	+26.5	1299.8
		II	0.0	1063.9
		III	-10.2	1022.3
		IV	-11.9	1013.0
FB-4	Park Field	I	+33.0	1363.9
		II	0.0	1046.7
		III	-6.2	983.3
		IV	-7.3	972.7
FB-5	Uttarkashi	I	+40.4	1516.5
		II	0.0	1135.9
		III	-8.6	1082.4
		IV	-15.2	987.2
I-Bare Frame II-Uniform Damping III-Optimal plan-1 IV-Optimal plan 2				

TABLE III
SEISMIC RESPONSE RESULTS OF MULTIOBJECTIVE OPTIMIZATION ANALYSIS [10 STOREY BUILDINGS]

Building.	Ground motion	Building with status of damping provision	Interstorey drift in % excess (+) or smaller (-) than Permitted value	Base shear (kN)
TB-1	Koyana	I	+16.6	1621.1
		II	0.0	1477.4
		III	-6.4	1477.4
		IV	-6.7	1426.1
TB-2	Imperial Valley	I	+11.9	1735.7
		II	0.0	1564.7
		III	-4.4	1445.0
		IV	-2.5	1445.0
TB-3	Koyana	I	+36.6	1964.3
		II	0.0	1753.6
		III	0.0	1551.3
		IV	0.0	1548.9
TB-4	Imperial Valley	I	+29.1	1830.4
		II	0.0	1482.9
		III	-3.6	1455.6
		IV	-3.0	1400.8
TB-5	NorthRidge	I	+55.5	2256.2
		II	-1.8	1974.5
		III	-0.3	1759.1
		IV	0.0	1800.6
I-Bare Frame II-Uniform Damping III-Optimal plan-1 IV-Optimal plan 2				

VI. RESULTS AND DISCUSSION

The genetic algorithm developed in this study is used to verify the effect of objective priorities of drift and shear on control of buildings. Two different strategies are investigated. In the first strategy (optimal plan-1) the highest priority was set for drift rather than shear accordingly weightage of drift control was set to highest and shear control to lowest. In second strategy (optimal plan-2) the priority was reversed i.e shear at highest and drift at lowest. With these considerations in this study the results are discussed for multiobjective optimization.

Table II shows results for 5 storey buildings and Table III shows results for 10 storey buildings with FVD and without (bare frame). As seen from Table II and Table III, good amount of reduction in drift and shear due to supplemental damping strategies of uniform and both optimal plans is achieved. It can also be noted that both optimal plans offer control of shear and reduction in drift better than that of uniform strategy. Comparison of the two plans from Table II as well as Table-III indicates distinct and consistent characteristics of two optimal plans. Increase in one requirement (e.g. more drift reduction) causes effect on other objective (base shear), which indicates the interrelations of these objectives.

VII. CONCLUSION

This study has developed multiobjective genetic algorithm to study the mutual effect of drift control and shear control which serves as competing objectives and results of all analyses are examined in detail. The objective of achieving seismic response control in desired manner is verified through important criteria of maximum interstorey drifts and maximum base shear. Analysis results of 5 and 10 storey buildings with and without providing supplemental damping by FVD are compared. To verify the efficacy of optimal control genetic algorithm developed in this study, responses and damping distribution are compared with that of uniform damping.

Comparison of results shows that genetic algorithms are best suited for multiobjective optimisation in seismic response control. The multiobjective strategies provide clear scenario and more power in decision making process, so that designer can set and achieve goals as per his priorities.

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