MONTE CARLO SIMULATION-BASED SENSITIVITY ANALYSIS OF MR DAMPER USING RISK ANALYSIS

Abstract

Magnetorheological Damper, a semi-active controlled damper with its instantons damping and control, has applications in various engineering fields. In structures, MR dampers are used to provide structural damping during seismic excitation. To achieve the optimum performance of the Damper, its damping effects must be adaptive to varying current and magnetic fields under operating conditions. Some of these parameters which determine the behavior of MR damper under seismic excitation may have uncertainty in their values. Hence, a probabilistic approach is needed for the analysis of such systems. In this present study, the parameters that influence the damping properties of Magnetorheological (MR) Damper are adopted using Risk Analysis Software incorporating the Monte Carlo Simulation Approach. The stroke length, annular gap, viscosity, coil turns, magnetic flux density, field intensity, current and voltage are the parameters adopted. The considered parameters were compared with random analysis using MS Excel. These adopted parameters estimated were used in the design of the MR damper for Earthquake Resistant Structures

Keywords: Monte Carlo Simulation, Sensitivity Analysis, Risk Analysis, Parameters, Magnetorheological Damper, MR

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I. INTRODUCTION

The Monte Carlo simulation technique was developed in the early 20th century. It is a computer-based analytical tool that uses statistical sampling techniques to approximate the solution of a mathematical equation or model with a probability-based approach by using random number sequences as model inputs. This process's results provide relevant data on how well the developed model performed. [1-2]. Numerous applications in science, mathematics, project management, and system dependability have extensively used Monte Carlo simulations. The results of a Monte Carlo simulation computes using statistical analysis and repeated random sampling. This simulation technique is identical to random experiments, which are tests where the precise outcome is uncertain. [3-4]. Most engineering projects employ Monte Carlo simulations to evaluate the dependability of newly developed products. It aids in component analysis and aids in estimating the product's lifespan.

Additionally, this method is quite adaptable and can tackle a range of perspectives of uncertainty, but they may not always be approximate. [5-6]. Based on the range of estimations, a random value is chosen for each activity in a Monte Carlo Simulation. These randomly optimized parameters serve as a basis for the model or product. In order to arrive at optimized random values for every uncertain parameter, simulations are performed hundreds or thousands of times using the output of the designed model or product as input. When more than two values are enabled to change concurrently, the traditional sensitivity analysis—which involves adjusting one or more probability or utility estimates from baseline data to estimate if the optimal strategies change—becomes tedious[7].

Sensitivity analysis quantifies the influence of every uncertain input to the uncertainty of the planned product's outputs. [8]. As a result, a more recent method of sensitivity analysis was devised that allows 'n' parameters to be investigated, correlated, and optimized using Monte Carlo simulation. The paramount concept in sensitivity approaches uses partial differentiation, but the most straightforward method calls for altering the parameter values one at a time. In order to ascertain the links between independent and dependent variables, correlation analysis is employed. The most comprehensive sensitivity metric is provided by regression analysis, which is frequently used to create response surfaces that roughly match complicated models. [9].

An experimenter can always use Monte Carlo simulation to investigate every input variable's wide range of risks carefully. We find a statistical distribution in Monte Carlo simulation for each input parameter we may utilize as a source. We generate a set of output parameters for every set of input parameters. Each output parameter's value is recorded during the simulation run. The output variation may well be described using the sampling statistics of the output parameters. [10-11]. Similarly for Tuned Mass Damper, Viscous damper, friction and rubber damper also the mote carlo simulation is studied for optimization [12-16]. In our research work, we have incorporated the parameters obtained in this study for the design of the MR damper tested experimentally for off-state and on-state rheology [17]

In this paper, various parameters on which the damping force of the Magnetorheological Damper depends were identified, and the range of values for each parameter was studied. Further Sensitivity Analysis using Monte Carlo Simulation Technique was performed on these uncertain parameters using Risk Analysis Software, and the results were compared with Random Analysis using Excel.

II. MATERIAL AND METHODS

1. **Magnetorheological Damper:** A vibration absorber is magnetorheological damper, which regulates damping using MR fluid. The damper may instantly alter its damping qualities because the MR fluid inside of it can alter its texture in reaction to a magnetic field. This makes MR dampers excellent for applications like vibration control, robotics, and automobile suspension systems where the damping force needs to be changed rapidly and accurately. In an MR damper, a piston keeps a magnet apart from a cylinder containing the MR fluid. The iron atoms in the MR fluid align and form chains when subjected to a magnetic field, increasing the fluid's thickness. The damping force produced by the damper increased by altering the magnetic field's intensity, damping can be controlled. MR dampers have a number of benefits over conventional hydraulic dampers, including quicker reaction times, increased precision and control, and the capacity to deliver non-linear damping. Additionally, they require less upkeep and are more ecologically friendly. Though MR dampers have many advantages, they are still a relatively new technology. As a result, ongoing efforts are being made to improve their functionality and address some of the problems that come with using them, such as their limited temperature stability and the requirement for a strong magnetic field to produce noticeable changes in viscosity.

2. **Magnetorheological Fluid:** When subjected to a magnetic field, magnetorheological (MR) fluid, a smart material, changes in its viscosity and fluidic characteristics. These micron-sized iron particles, which make up the material, are suspended in a liquid medium like silicone or synthetic oil. When exposed to a magnetic field, MR fluid can quickly change from a fluid to a semi-solid state. MR fluid is widely used in many industries, including clutch systems, shock absorber, and vibration reduction devices for seismic applications. For active suspension systems and haptic feedback in consumer electronics, it has been also used in the aerospace and automobile industries. MR fluid has certain advantages over conventional hydraulic fluids, including the ability to quickly and precisely modify viscosity and the supply of non-linear damping. MR fluid is also non-toxic, biodegradable, and environmentally benign. Despite its advantages, MR fluid still faces numerous challenges, including a restricted ability to withstand high temperatures and the requirement for a strong magnetic field in order to cause significant viscosity changes. Nevertheless, MR fluid remains the subject of intensive study and development, resulting in the continuous development of novel structural vibration control applications. These fluid properties were optimized to used in MR damper to provide more damping force. Figure 1 shows the schematic representation of the MR fluid subjected to magnetic field and not

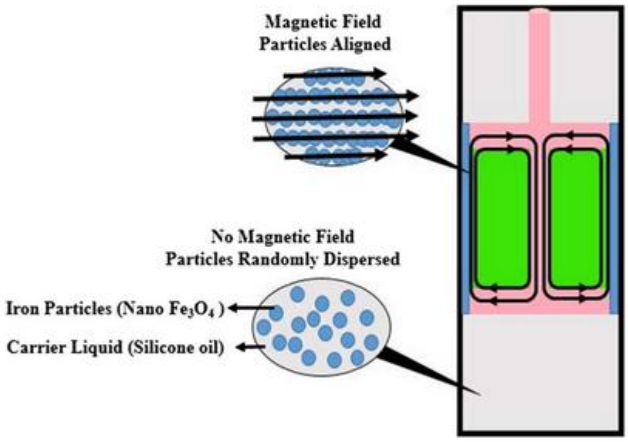

Figure 1: MR Damper with and without Magnetic Field [12]

Various parameters on which the damping force of the Damper has been identified and the minimum and maximum range of variation of each parameter is tabulated as given in Table 1.

Table 1: Maximum and Minimum Range MR Damper Parameters

Sl. No	Parameters	Abbreviation	Min. Range	Max. Range	Units
1	Annular gap	Ga	0.2	4	mm
2	Wire gauge (20)	Wg	200	500	windings
3	Input current	Ii	0.2	2	Ampere
4	Input voltage	Vi	0	10	volt
5	Stroke length	Ls	5	15	cm
6	Viscosity	ϒf	0.1	1000	Pa-s
7	Yield stress	ζs	50	150	kPa
8	Shear rate	ζ	0	1000	s-1
9	Magnetic field intensity	H	0	0.8	T
10	Magnetic flux density	B	0.001	1	T
11	Piston Velocity	Vp	0.04	0.2	m/s
12	Peak ground acceleration	PGA	0.2g*	0.9g*	M/s^2

*g-acceleration due to gravity $9.81 m/s^2$

III. MONTE CARLO SIMULATION

Monte Carlo simulation is a mathematical approach used to simulate, analyse, and forecast the behaviour of complex systems. It is a computer-based technique that creates several simulations of a system, each with slightly varied input variables, using random sampling. The outcomes of these simulations are then used to estimate the probability of multiple activities and assess the risk involved with certain choices. When making decisions, as is often the case in industries like engineering, and risk management, Monte Carlo simulation is very helpful. Monte Carlo simulations enable professionals to weigh the probable effects of each course of action and arrive to well-informed judgements. The ability to take into account the interactions and dependencies between variables, which can be challenging to represent using conventional statistical techniques, is one of the key benefits of Monte Carlo simulation. Additionally, Monte Carlo permits the simulation process to include irrational data, such as expert judgements and historical data. Despite its numerous advantages, Monte Carlo simulation has its drawbacks and is not a panacea. For instance, the reliability of Monte Carlo simulations is influenced by the accuracy and quality of the input data as well as the quantity of simulations performed. Monte Carlo simulations can also be computationally demanding and may need a lot of processing power.

IV. SIMULATION AT RISK SOFTWARE

Palisade, based on RISK software, can perform simulations to optimize uncertain parameters using the Monte Carlo simulation technique. Number of simulations can be performed and the statistical data set of the output- adopted values could be recorded and used to design the product.

In the present research study, a thousand simulations were simultaneously run on all the parameters one by one, and optimum values for each defined parameter were recorded. The simulated parameters and the output are shown in Figure 2.

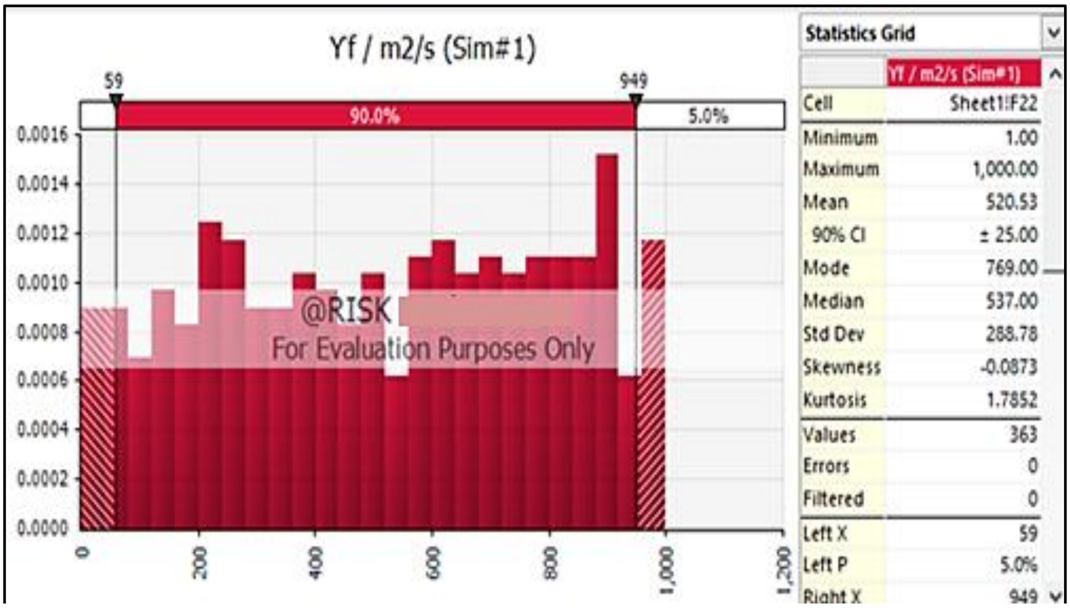

Figure 2: Simulation of Parameters

The adopted values of the parameters identified were generated using the Risk Analysis software data sheet after 1000 simulations, as shown in Table 2. Random analysis of the parameters mentioned in Table 3 was performed in Excel. The maximum and minimum ranges are also incorporated in the investigation

V. RESULT AND DISCUSSION

The optimum output values recorded after simulations using Monte Carlo Technique and Random Analysis in Excel were compared. It was found that the Monte Carlo Simulation resulted in more accurate optimization of parameters for the design of MR damper. The comparison of optimum values and parameters are shown in Fig 3. The stroke length of the piston is adopted to ± 5.2 cm. The adopted annular gap of 1.5 mm is provided for the MR Damper for fabrication. The MR fluid viscosity made to 270 Pa-s to achieve the maximum force of 0.5 kN. The optimized coil winded for 374 turns in the piston pole to generate 1 tesla.

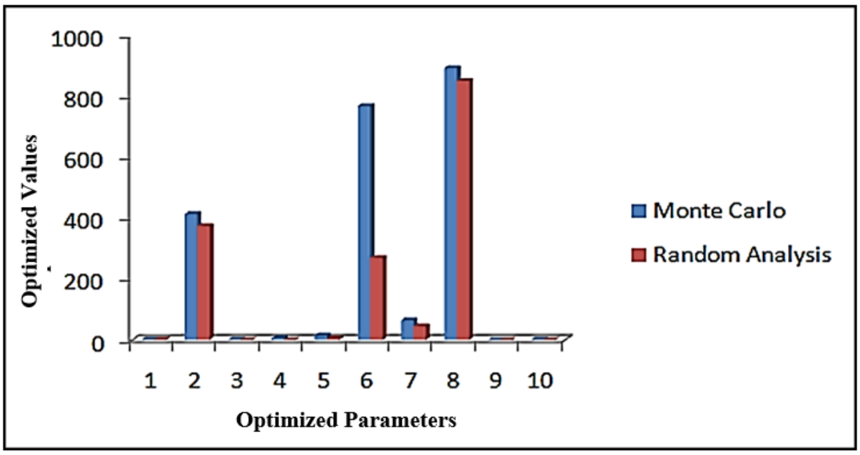

Figure 3: Comparison of Monte Carlo vs. Random Analysis

Table 2: Optimum Values of Parameters using the Monte Carlo Technique

Abbreviation	Min. Range	Max. Range	Value
G_a	0.2	4	2
W_g	200	500	414
I_i	0.2	2	2
V_i	0	10	6
L_s	5	15	15
Υ_f	0.1	1000	769
ζs	50	150	65
ζ	0	1000	894
H	0	0.8	0
B	0.001	1	1
V_p	0.04	0.2	0.2
PGA	0.2g	0.9g	0.9

*g-acceleration due to gravity 9.81m/s^2

Table 3: Results of Random Analysis

SI. No	Parameters	Abbr.	Min. Range	Max. Range	Units	Random Analysis
1	Annular gap	Ga	0.2	4	mm	1.51318925
2	Wire gauge (20)	Wg	200	500	windings	374.1056073
3	Input current	Ii	0.2	2	Ampere	0.523654475
4	Input Voltage	Vi	0	10	Volt	0.098432985
5	Stroke Length	Ls	5	15	cm	5.253468388
6	Viscosity	ϒf	0.1	1000	Pa-s	270.2041788
7	Yield stress	ζs	50	150	kPa	44.88038256
8	Shear rate	ζ	0	1000	s^{-1}	850.8859911
9	Magnetic field intensity	H	0	0.8	T	0.131910562
10	Magnetic flux density	B	0.001	1	T	0.70014778

VI. CONCLUSION

Monte Carlo Simulation used for the sensitivity of parameters of Magneto rheological Damper was quite reliable. The drawback observed in the Risk Analysis is the simulation is performed only in integer values. The comparison of this results provides the adopted design for MR damper. The stroke length of the piston is optimized to ± 5.2 cm. The adopted annular gap of 1.5 mm is provided for the MR Damper for fabrication. The MR fluid viscosity made to 270 Pa-s to achieve the maximum force of 0.5 kN. The coil winded for 374 turns in the piston pole. The magnetic flux density, field intensity, current and voltage is also adopted for the rheological properties of MR fluid. The decimal range of the parameter cannot be accurately computed. The adopted parameters of this study were used in the modeling and design of the MR damper for our further research studies, which made it quite reliable. Numerical analysis has also performed to study the effectiveness of the MR damper in reducing the fragility and increasing the reliability of the nonlinear structure with respect to the uncontrolled structure with the adopted MR damper.

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