J. Electrical Systems 20-10s (2024):4013-4026

[1] Randolph Y. Mambia

[2] Jagdeep Singh

Exploring the Structural Response of High-Rise Buildings using Fuzzy Logic and Genetic Algorithms

Abstract: - Exploring the dynamic behaviour of high-rise buildings presented a critical challenge. In this study, Fuzzy Logic and Genetic Algorithm (FLGA) were employed to comprehensively investigate the structural response of high-rise buildings (HRBs) for adaptive vibration control systems employing semiactive damper devices. The study integrated a fuzzy logic inference system with a Genetic Algorithm (GA) to create FLGA, which was then employed in a 3-story shear building under real earthquake conditions and multi-dimensional wind loads. The analytical model for a semi-active tuned mass damper (STMD) was examined and evaluated before integrating it into the proposed FLGA system. The results indicated that FLGA reduced story acceleration by an average of 20% and story drift by approximately 50% while efficiently controlling the structure within allowable movement limits and resident comfort criteria under multi-directional wind loads. The suggested optimal controller mitigated both displacement and acceleration responses by 15 to 20% without amplification. The study demonstrated FLGA's effectiveness as a model-free control strategy for managing structural response uncertainties.

Keywords: High-Rise Buildings (HRBs), Semi-active dampers, Fuzzy Logic, Genetic Algorithm (GA), Vibration Control System.

I. INTRODUCTION

Excessive structural vibrations caused discomfort to individuals and could affect the safety of the buildings. Hence, the management of the maximum reaction of a structure exposed to dynamic forces like earthquakes and storms has become increasingly important [1]. There has been a lot of research on vibration management for high-rise buildings that were vulnerable to dynamic stresses like earthquakes and winds in the last several years [2]. Multiple algorithms and controllers, such as passive, active, and semi-active control systems, have been established to address this issue [3-5]. Out of these passive control devices, the Tuned Mass Damper (TMD) was considered to be among the most effective and widely employed passive controller mechanisms [6-8]. However, TMDs possessed certain drawbacks, such as being extremely sensitive to parameter changes and having a narrow range of frequency coverage [9]. In order to overcome these limitations, various studies have proposed multiple TMDs (MTMDs) with diverse mechanical characteristics [10].

Recently, semi-active control devices, such as MR dampers, have gained interest due to their effective performance in mitigating structural vibrations [11][12]. MR dampers were considered reliable and adaptable, as they could change their properties to mitigate the structure's response to excitation optimally without destabilizing the structure [13][14]. The real-time structural control mechanism, which was adaptive and intelligent, was regarded as the most crucial and challenging element that influenced the dynamic response and stability of structures when subjected to unsteady loads [15]. Studies have utilized fuzzy logic control to tackle the non-linear behaviour and uncertainties linked with these control systems [16][17]. Fuzzy logic control was recognized as a robust framework for non-linear control laws that could effectively adjust to ambiguities and complexities [18-20]. High-rise buildings, commonly referred to as HRBs, were becoming increasingly prominent in modern architecture due to the increasing population and concentration of urban areas, as well as the high demand for urban core locations [21]. The expansion of HRBs was necessary to meet these demands, and their construction was rapidly increasing in both quantity and quality [22]. In fact, a total of 219 skyscrapers were scheduled to be built globally in 2019. However, constructing HRBs posed complex technical challenges and required the use of advanced construction technologies [23][24].

The combination of fuzzy logic and evolutionary algorithms offered a cutting-edge approach to effectively oversee the construction of skyscrapers in challenging environments. Fuzzy logic, known for its ability to model and control intricate construction variables, addressed imprecision and uncertainty within a mathematical framework [25].

---

[1] *Corresponding author: Research Scholar, Department of Civil Engineering, Chandigarh University, Punjab, India, rmambia2013@gmail.com

[2] Assistant Professor, Department of Civil Engineering, Chandigarh University, Punjab, India, jagdeepsingh.civil@cumail.in

Meanwhile, evolutionary algorithms, inspired by natural selection, provided an optimization strategy for the complex decision-making processes inherent in construction management [26]. This innovative method held promise for enhancing project outcomes, mitigating risks, and promoting sustainability in the dynamic realm of skyscraper development. Despite the advantages of using fuzzy logic control, one major challenge arose when a fuzzy system needed to make decisions based on a pre-existing understanding of the dynamic behaviour of the system [27]. In order to address this issue, researchers explored combined fuzzy logic with other techniques, such as GAs, which could be used to optimize the fuzzy rules and membership functions. This research contributed to enhancing the construction management of HRB projects by developing an integrated framework that combined fuzzy logic and GAs. The proposed approach addressed the inherent uncertainties, complexities, and dynamic nature of HRB projects, aiming to optimize various aspects of project management and structural performance.

- To enhance scheduling, resource allocation, and cost management in HRB building projects, Fuzzy Logic and GA models were developed for optimization.
- An STMD system was implemented to control building vibrations induced by wind loads.
- The benefits of employing both an active vibration control technique for tall buildings vulnerable to earthquakes and implementing Fuzzy Logic and GA for optimizing project completion time, resource utilization, and cost efficiency were evaluated.

A literature review reveals that many authors have employed various methods in this area and reported their findings.

Zain et al., (2024) [28] proposed a novel approach combining GAs for non-linear modeling with Artificial Neural Networks (ANNs) for fragility analysis. The ANN model established yielded correlation coefficient 0.9972, R2= 0.95 which demonstrated adequate performance. Additionally, Kontoni et al., (2023) [29] studied two irregular steel HRBs using 3D models considering Soil-Structure Interaction (SSI) effects as well as TMD systems. In addition, Ansari et al., (2022) [30] aimed to identify effective criteria for high-rise buildings' safety issues and rank the most critical risks to level up the safety of these projects. The results indicated that safety training and monitoring, which accounted for approximately 35% of the total weight, were the most influential criteria for risk occurrence. Furthermore, Xu et al., (2022) [31] investigated on whether Tuned Mass Damper Inverter (TMDI) could control bridge vibrations especially vortex-induced vibration (VIV). It described more efficient control and practical precision than existing methods. Conducted by Khazaei et al., (2020) [32], a study was designed to investigate the effectiveness of MTMDs at reducing seismic responses in tall steel buildings. Then acceleration, displacement, and base shear responses decreased significantly with 50%, 40%, and 40% respectively as average reductions were made. Seismic reliability–based parameter optimization of magnetorheological (MR) dampers for structural control in semi-active modality under stochastic earthquake ground motion was done by Peng et al., (2020) [33]. Comparative studies demonstrated that this method resulted into more efficient and safer structural systems as opposed to statistical moments-based approaches. Zhao et al., (2017) [34] carried out an empirical analysis to understand how building technology, resident behaviour, as well as their combined effect affects residential energy consumption patterns. It had been revealed through this study that only around 42% of technological advancements directly contribute towards home energy efficiency thus underscoring importance for both technical advances along with behavioural change when conserving energy.

II. DATASET DESCRIPTION

The dataset used for matrix laboratory (MATLAB) simulation was obtained from a complex sensor network that was integrated into the high-rise building. This network of sensors continuously monitored important structural parameters such as acceleration, displacement, and velocity, providing valuable information about the building's behaviour. By undergoing thorough pre-processing, the raw sensor data was refined, and essential features were extracted for structural analysis purposes, including maximum displacement and peak acceleration.

III. RESEARCH METHODOLOGY

In that section, the techniques employed in the study to investigate the structural response of high-rise buildings, accompanied by an intricate overview of the proposed approach, were presented.

A. Techniques Used

This research employs a variety of techniques, including genetic algorithms and fuzzy logic, which were as follows:

1) Genetic Algorithm

Genetic Algorithms are effectively utilized in managing high-rise building development. Jang (2004) optimized the storage of building supplies in dense urban settings using GA [35]. Additionally, GA enhanced structural performance, including seismic resistance, and aided in space management [36]. It also addressed challenges in building design and retrofitting through computational optimization [37-39]. One way to represent the GA was as follows:

$$\mathrm{GA} = (\mathrm{P}(0), \mathrm{N}, \mathrm{l}, \mathrm{s}, \mathrm{g}, \mathrm{p}, \mathrm{f}, \mathrm{t}) \tag{1}$$

$$\mathrm{X} = \mathrm{X}_1, \mathrm{X}_2, \mathrm{X}_3, \dots \dots, \mathrm{X}_\mathrm{n} \tag{2}$$

The formula took the following values: P (0) for population initialization, N for the population size, l for the binary string length, s for the selection technique, g for the genetic operator, p for the probability of mutation, f for fitness function, t for termination condition [40-42].

2) Fuzzy logic

Fuzzy logic is a method for handling uncertain data, extending beyond traditional binary logic [43]. It was widely applied in multi-story buildings for optimizing construction, structural control, and energy management [44]. Research indicated collaboration between GA and fuzzy logic in optimizing construction factors [45]. Fuzzy logic-based models were used in construction management and technical processes [46]. In expert systems, it accommodated partial truths [47]. Fuzzy logic played a significant role in designing and managing HRBs, particularly in structural control, energy management, and process optimization [48].

B. Proposed Methodology

The proposed methodology, as illustrated in Figure 1, outlined the operational sequence in a diagrammatic format. The following steps explained the process flow of the proposed methodology, which could be effectively implemented using MATLAB. The seismic parameters and location chosen for this analysis is high-seismic zone IV, as defined by IS: 1893-2002, with a damping of 5%. For the RCC special moment-resisting frame (SMRF), the significance factor, I, is assumed to be 1.5, and the response reduction factor, R, to be 5 and building configuration is mentioned in table 1.

Table 1. Building Configuration

Configuration	**Component**
Floors height	3.5m
Plan dimension	7m x 5m
Concrete Poisson’s ratio	0.3
Damping	0.05
Columns size	400m x 500m
Beams size	230 x 500
Thickness of slab	230mm
Thickness of wall	115mm

Step 1: Sensors and Data Acquisition: A network of sensors was installed throughout the building to monitor parameters like acceleration, displacement, and velocity. Additionally, data regarding the seismic activity in the building's location, including earthquake intensity and frequency, was collected.

Step 2: Data Pre-processing: The raw sensor data was processed to filter out noise and extract relevant features for analysis. Earthquake-induced signals were isolated and analyzed separately to understand their impact on the building.

Step 3: Building Modeling: Based on the building configuration, a 3D finite element model (FEM) was developed to simulate the building's response to seismic events. The model considered the material properties, dimensions, and structural elements such as columns, beams, slabs, and walls.

Step 4: Fuzzy Logic Controller (FLC): An FLC was designed to process the pre-processed data, including seismic data from the building model.

- Linguistic variables such as sway, wind force, and earthquake intensity were defined based on the seismic data.
- Membership functions were established to quantify these linguistic variables.
- A set of fuzzy rules was developed to map input variables (e.g., seismic data) to output control actions for the STMD system.

Step 5: GA Optimization: The GA module was integrated to optimize the FLC parameters considering seismic conditions.

- The genetic representation of the controller parameters (e.g., crossover, mutation operators) was defined.
- Fitness functions were set up to evaluate the performance of different FLC configurations under seismic loads.

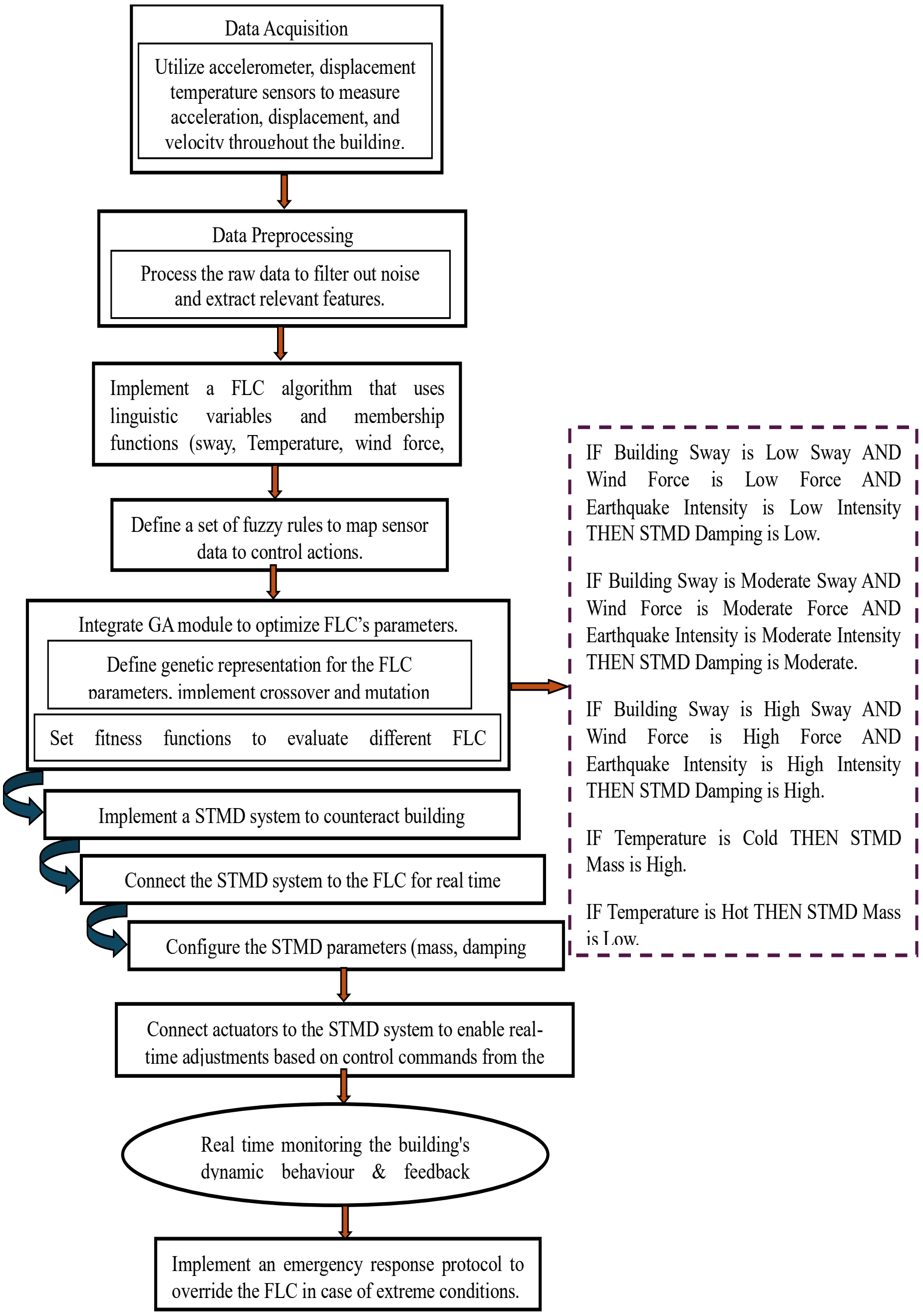


Figure 1. Proposed Methodology

Step 6: Semi-Active Tuned Mass Damper (STMD): An STMD system was implemented to counteract building vibrations induced by seismic events.

- The STMD system was connected to the FLC for real-time control, adjusting its properties based on seismic data.

- Parameters of the STMD system (e.g., mass, damping ratio) were configured based on the FLC output and seismic conditions.

Step 7: Actuators and Control Mechanism: Actuators were integrated to adjust the properties of the STMD in response to FLC commands and seismic data.

- A control mechanism (e.g., motors, servos) was employed for precise adjustments to the STMD system.

Step 8: Real-time Monitoring and Feedback Loop: A continuous feedback loop was established to monitor the building's dynamic behaviour, including its response to seismic events.

- The feedback data, along with seismic data, was processed through the FLC-GA system to dynamically adjust the control actions of the STMD system.

Step 9: Emergency Response System: An emergency response protocol was implemented to override the FLC in case of extreme seismic conditions, ensuring the safety of the building and its occupants.

IV. RESULT AND DISCUSSION

In this section the results are discussed in detail. The proposed FLC comprised 49 sets of rules designed to govern the output for every input instance, as illustrated in Table 2. These rules correlated the inputs with 7 zones, or membership functions, describing distinct values of structural response.

Table 2. Suggested FLC Rules for Earthquake and Wind-Excited Structures.

Acceleration	**Wind Force**	**Building Sway**	**Temperature**	**Earthquake Intensity**	**STMD Mass**	**STMD Damping**
High	Medium	High	High	High	Low	High
High	High	High	High	High	Low	High
High	High	High	Medium	Medium	Medium	High
Medium	High	Medium	Medium	Medium	Low	High
Medium	Low	Medium	Low	Medium	High	Medium
Medium	Medium	Medium	Medium	Medium	Medium	Medium
Low	Medium	Low	Low	Low	High	Medium
Low	Low	Low	Low	Low	High	Low

Table 3 showed the performance of a novel SMTD system through a series of experimental tests conducted under both seismic and wind loading conditions.

Table 3. Testing Programme off-tune for Seismic and Wind Loading with SMTD.

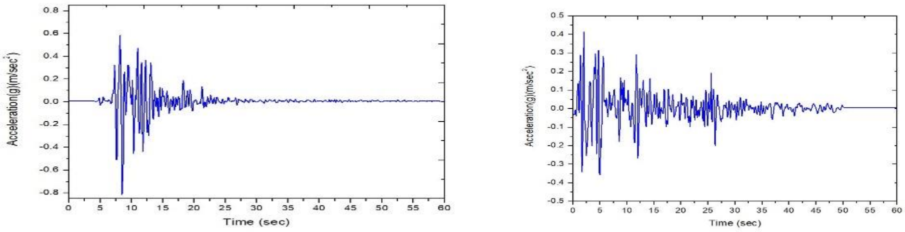
Test number	**Mass added on the top floor**	**Time for measurement**	**Temperature (°C)**	**Ground excitation input**
1	10.0 kg	30	-20	S
2		30	-20	W
3	20.0 kg	30	-10	S
4		30	-10	W
5	30.0 kg	30	10	S
6		30	10	W
7	40.0 kg	30	20	S
8		30	20	W
9	50.0 kg	30	30	S
10		30	30	W

The SMTD model was simulated by applying a 2.5 Hz sine wave displacement with an amplitude of 0.015 m upon completing the MATLAB and SIMULINK development of the mentioned model. Table 4 shows the SMTD model coefficients for the prototype SMTD damper, along with the parameters used for the analytical model, which were applied to earthquake-excited structures.

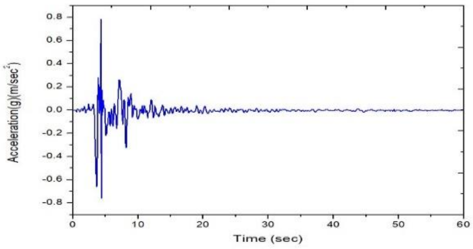
Table 4. The SMTD Model Coefficients for the Prototype SMTD Damper.

Parameters	Value	Parameter	Value
co_a	20 Nscm^{-1}	c_{1a}	275 Nscm^{-1}
co_a	3.2 Nscm^{-1}v^{-1}	ko	45.4 Ncm^{-1}
a_a	130 Ncm^{-1}	k_1	4.5 Ncm^{-1}
a_b	650Ncm^{-1}v^{-1}	xo	13.2 cm
c_{1b}	2.89Nscm^{-1}v^{-1}	γ	352 cm^{-2}
A	285	β	350 cm^{-2}
η	180s^{-1}	n	2

The three-story building in question was presumptively susceptible to three earthquakes, one of which was the El Centro earthquake, which was a far-field, and the other two were the Kobe earthquake and Northridge earthquake, which were near-field earthquakes, as shown in Figure 2.



(i). El Centro earthquake, 1940 (PGA = 0.348 g) **(ii).** Kobe earthquake, 1995 (PGA = 0.834 g)



(iii). Northridge earthquake, 1998 (PGA = 0.843 g)

Figure 2. Historical Earthquake Accelerograms.

The FLC was designed and trained using the suggested optimization approach under seismic loads to obtain the optimal FLC for implementation within the structural system. Table 5 shows the optimization criteria, whereas Figure 3 shows the Pareto optimal solutions. The optimization results showed that, due to the little change in objective function values, there was no discernible variation in solutions across all iterations. Maximum inter-story drift (F1) = 0.02714 and Maximum absolute acceleration (F2) = 9.6245 were utilized to get the best possible control.

Table 5. Optimal settings for a control system that is seismically loaded.

Parameter	Values
Total independent variables	10
Total design variables	110
Number of universes	25
Objective function	4
Archive size	100
Total iterations	25

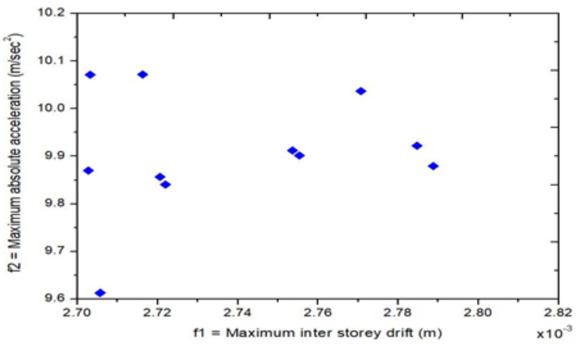


Figure 3. Pareto optimal solutions for earthquake-excited structures using FLGA.

The FLGA system demonstrated superior performance in reducing absolute acceleration and narrative drift across all building stories, with a notable 46% improvement during testing with various earthquake intensities. Figures 4(a) and 4(b) illustrated FLGA's outperformance, particularly evident during near-field high-magnitude Northridge earthquake scenarios. Compared to reference control schemes like CO (Clipped optimal) and Modified Bang Bang (MBB), FLGA proved significantly more efficient, consuming only 50-65% of control power while maintaining effective control action.

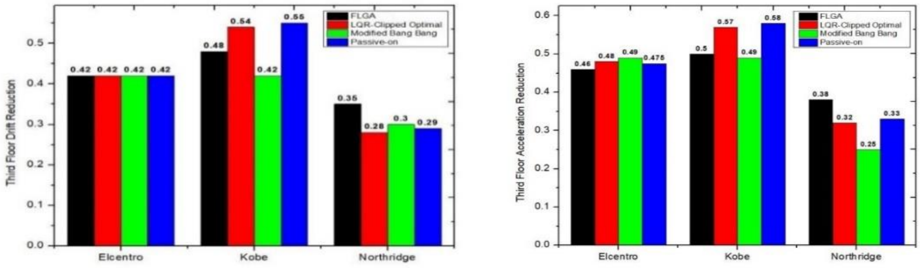


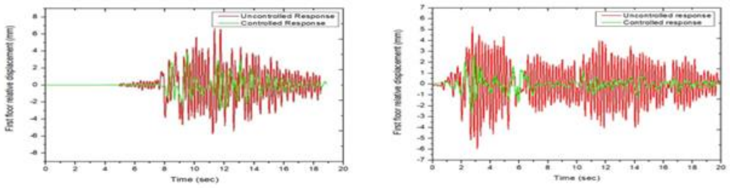
Figure 4. (a) Third Floor Drift Reduction (b) Third Floor Acceleration Reduction.

Table 6 shows the responses of maximum floors under different control techniques. The real-time response of the first story, as depicted in Figures 5 and 6, illustrated the exceptional performance of the control system in reducing the structural response. This response encompassed the drift and acceleration of both floors upon the delivery of seismic excitation to the structure.

Table 6. Response of Maximum Floors under Different Control Techniques.

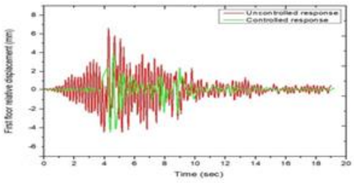
Earthquake	**El Centro**			**Kobe**			**Northridge**		
	Story Acce (m/s2)	Story Drift (m)	Control Force (N)	Story Acce (m/s2)	Story Drift (m)	Control Force (N)	Story Acce (m/s2)	Story Drift (m)	Control Force (N)
Uncontrolled	8.263	0.005	-	10.263	0.0124	-	12.263	0.0091	-
	10.124	0.0023		11.124	0.0102		17.124	0.0043	
	12.421	0.0014		10.421	0.00212		18.421	0.0024	
FLG A	5.423	0.002	740.34	11.423	0.00124	723.56	12.423	0.0052	710.83
	7.523	0.0014		9.523	0.0041		11.523	0.0036	
	6.222	0.0093		10.222	0.0036		12.222	0.0021	
Modified quasi-Bang Bang	8.423	0.0018	1073.44	9.423	0.0028	1143.65	15.423	0.0062	1301.43
	5.432	0.0015		9.432	0.00514		11.432	0.0034	
	5.323	0.0091		11.323	0.0079		12.323	0.0025	

Clipped optimal	5.113	0.0023	1103.32	8.113	0.00762	1095.53	14.113	0.006	1351.23
	5.552	0.001		8.552	0.00346		13.552	0.0041	
	0.0011			0.0024	9.033		0.0023	13.033	
Passive on	0.0018		1231.42	0.00323	8.566	1160.43	0.0046	9.566	1354.52
	0.0015			0.00243	9.234		0.0036	12.234	
	0.0078			0.00612	9.624		0.0027	14.324	



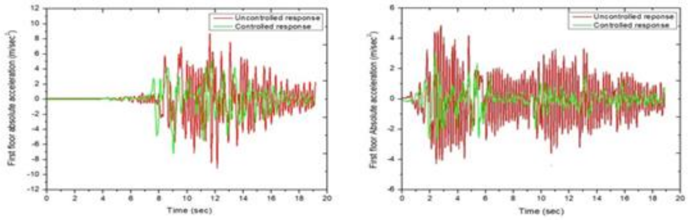
(a). Displacement Response (El Centro)

(b). Displacement Response (Kobe)



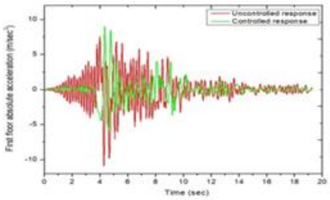
(c). Displacement Response (Northridge)

Figure 5. Real-time displacement response for the 1st floor of the structure



(a). Acceleration Response (El Centro)

(b). Acceleration Response (Kobe)



(c). Acceleration Response (Northridge)

Figure 6. Real-time Acceleration Responses for the 1st Floor of the Structure.

The wind loads for the top story, and for $\theta = 90^\circ$, the wind scenario, were shown in Figure 7. Parameters for optimizing a control system to mitigate structural vibrations caused by wind are shown in Table 7.

Table 7. Control System Optimization Parameters.

Parameters	**Values**
Total independent variables	10
Archive size	100
Number of design variables	110
Objective function	2
Number of universes	20
Number of iterations	4

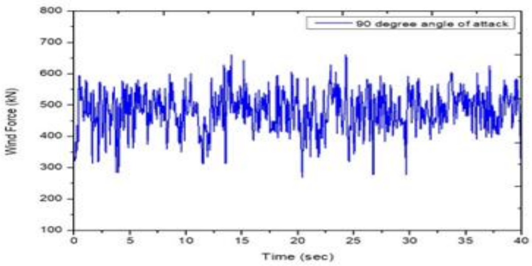


Figure 7. View the Top Story's Wind Time History Load.

An ideal FLC was implemented at each of the eight control points in the high-rise building. Figure 8 illustrates the FLC controllers that were Pareto optimum for wind-excited structures.

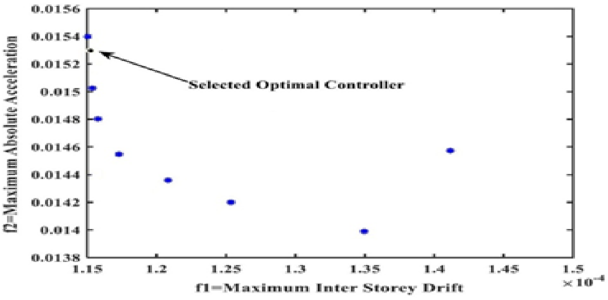
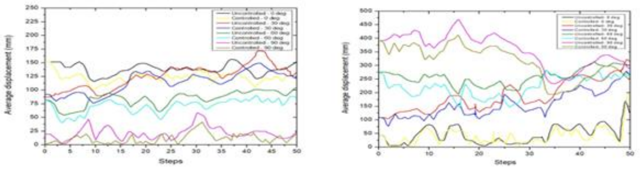
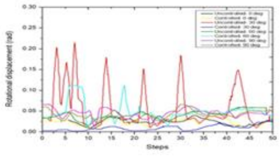


Figure 8. Pareto optimal FLC controllers

Figures 9 (a-c) and 10 (a-c) depicted the displacement and acceleration reactions to a multi-directional wind force in controlled and uncontrolled scenarios. Furthermore, it showed the mean response from four specific sites in every direction, as well as the mean response from all control points associated with the rotational response.

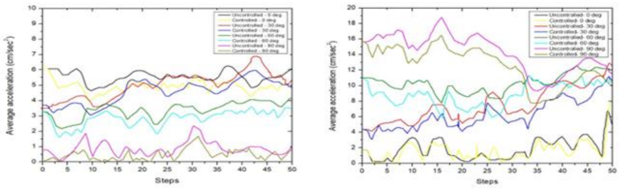


(a) Displacement Response in Y-Direction (b) Displacement Response in X-direction

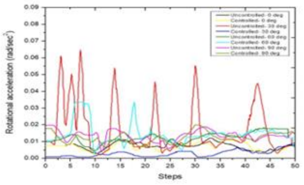


(c) Rotational Displacement Response

Figure 9. Displacement response under multi-directional wind load



(a) Acceleration Response in Y-Direction (b) Acceleration Response in X-direction



(c) Rotational Acceleration Response

Figure 10. Acceleration response under multi-directional wind load

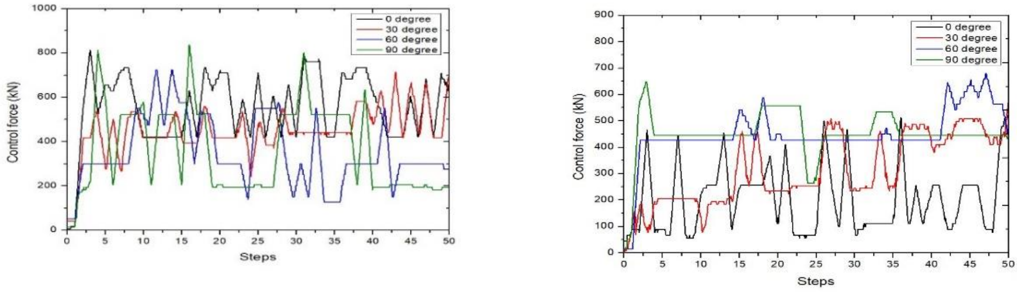
Figures 9 and 10 show that the controller controlled the response at each time step within windward and counterclockwise limits (10.0 mm for tale drift and 0.15-0.25 m/s2 for acceleration). Pure along wind load caused a minor rotational reaction that did not exceed 5 milliradians per second.

Table 8 illustrates the maximum structural response under various load orientations. Floor displacement along the Y-axis decreased by 12%, 14.70%, 15.70%, and 16.30% with wind attack angles of 0°, 30°, 60°, and 90°, respectively. Similarly, acceleration response along the Y-axis decreased by 11.80%, 14.60%, 13.80%, and 15.60%. Possible reasons included vortex shedding due to building dimension disparity and optimization criteria initially focused on a single wind attack angle of 90°. A control force tracking approach was employed for active force application.

Table 8. The Maximum Impact of a Multi-Directional Wind on a Structure

Response Type		**Wind load Attack angle**			
		0°	**30°**	**60°**	**90°**
Drift –X (m/s^2)	Controlled	1.853E-03	1.865E-03	1.913E-03	6.793E-03
	Un-controlled	1.76E-03	1.75E-03	1.764E-03	7.806E-03
Drift –Y (m/s^2)	Controlled	2.454E-03	2.356E-03	2.51E-03	4.124E-03
	Un-controlled	2.1E-03	2.3E-03	2.21E-03	5.24E-03
Displacement-X (m)	Controlled	1.36E-01	1.45E-01	1.46E-01	5.49E-01
	Un-controlled	1.43E-01	1.476E-01	1.33E-01	5.40E-01
Displacement-Y (m)	Controlled	1.924E-01	1.654E-01	1.724E-01	2.424E-01
	Un-controlled	1.674E-01	1.645E-01	1.574E-01	7.74E-01
Rotational Displacement (rad)	Controlled	2.45E-04	2.67E-04	2.76E-04	6.85E-04
	Un-controlled	5.24E-05	5.54E-05	5.144E-05	6.64E-05
Acceleration-X (m/s^2)	Controlled	1.57E-01	1.65E-01	1.63E-01	5.547E-01
	Un-controlled	1.71E-01	1.64E-01	1.80E-01	3.71E-01
Acceleration-Y (m/s^2)	Controlled	1.379E-01	1.357E-01	1.423E-01	6.379E-01
	Un-controlled	1.153E-01	1.363E-01	1.114E-01	2.153E-01
Rotational acceleration (rad/s^2)	Controlled	8.57E-04	8.456E-04	8.34E-04	2.57E-04
	Un-controlled	1.82E-04	1.76E-04	1.82E-04	2.82E-04
Rotational velocity (rad/s)	Controlled	3.134E-01	3.743E-01	3.134E-01	2.134E-01
	Un-controlled	6.23E-02	6.43E-02	6.23E-02	7.23E-02

In Figure 11 (a) and (b), the real-time control force was depicted for various wind load attack angles. For wind attack angles of 0◦, 30◦, 60◦, and 90◦ there was an 8.5%, 10.4%, 13.5%, and 10.2% decrease in uncontrolled displacement, respectively, in the X-direction response. At wind load attack angles of 0◦, 30◦, 60◦, and 90◦ there was a corresponding decrease in acceleration response of around 10.1%, 2%, 5.1%, 12.4%, and 13.3%, respectively.



(a). Real-time control force along the Y direction

(b). Real-time control force along X direction

Figure 11. Control force along the Y and X-directions by FLGA algorithm.

Table 9 presented the Structural response with a mass of 20 kg after re-tuning the SMTD by cooling and heating for Seismic and wind loading. Under seismic loading, tests 1, 3, and 7 had increased Root-Mean-Square (RMS) acceleration after re-tuning by heating. For wind loading, the SMTD system consistently increased RMS acceleration in tests 4, 6, 8, and 10 after re-tuning by heating. The variation highlighted the complex interaction between the SMTD mass and structural dynamics.

Table 9. RMS acceleration for heating and cooling response of SMTD dampers

Test Number	**Ground Excitation Input**	**Time for Measurement**	**Cooling Temperature (°C)**	**RMS Acceleration (m/sec^2)**	**Heating Temperature (°C)**	**RMS Acceleration (m/sec^2)**
1	Seismic	30	-40	25	10	31
2	Wind	30	-40	21	10	26.5
3	Seismic	30	-30	26.3	20	32.3
4	Wind	30	-30	22.3	20	27.4
5	Seismic	30	-20	27.5	30	33.5
6	Wind	30	-20	23.4	30	28.5
7	Seismic	30	-10	29.4	40	34.6
8	Wind	30	-10	24.8	40	29.3
9	Seismic	30	0	30.5	50	36.2
10	Wind	30	0	25.6	50	30.8

The effect of temperature (from -40°C to 40°C) on damping and stiffness ratio is given in Figure 12. In contrast to the damping ratio, which was temperature-dependent between -40°C and 0°C, stiffness varied substantially over this temperature range. The mechanical characteristics of the material changed from martensite to austenite at phase changeover temperatures between -25°C and 5°C.

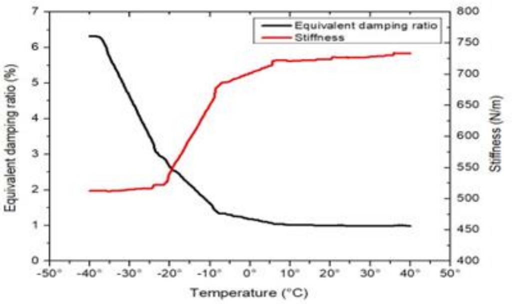


Figure 12. Effect of temperature on stiffness and damping ratio

In general, it was possible to achieve stiffness and damping ratio modifications of up to around 80% and 42%, respectively, within the range of temperatures tested, which showed that SMA might be used in semi-active TMD.

V. CONCLUSION AND FUTURE SCOPE.

This section summarized the main findings and offered insights into potential areas for further investigation.

- In high rise buildings FLGA was used in adaptive vibration control systems.
- The integration between the fuzzy logic inference system with GA was achieved.
- Displacements as well as accelerations resulting from earthquakes were reduced under wind loads.
- On average reductions were observed: 20% decrease in story acceleration; 50% decrease in story drift.
- This demonstration shows how efficient power-saving capabilities have been provided eliminating damper saturation problems.
- A model-free controller has been identified as FLGA competitive strategy.
- Fuzzy logic for future challenges of predicting high rise building response under earthquake excitation.
- Further work should focus on new technologies to broaden the use of fuzzy logic and genetic algorithms in high-rise construction design practice making it more effective too.

REFERENCES

[1] Shariatmadar, Hashem, and H. Meshkat Razavi. "Seismic control response of structures using an ATMD with fuzzy logic controller and PSO method." Struct. Eng. Mech 51, no. 4 (2014): 547-564.

[2] Liu, Yanhui, Kan Wang, Oya Mercan, Huating Chen, and Ping Tan. "Experimental and numerical studies on the optimal design of tuned mass dampers for vibration control of high-rise structures." Engineering Structures 211 (2020): 110486.

[3] Şahin, Özge, Nurettin Gökhan Adar, Muaz Kemerli, Naci Caglar, İsmail Şahin, Zekeriya Parlak, Salih Kükrek, and Tahsin Engin. "A comparative evaluation of semi-active control algorithms for real-time seismic protection of buildings via magnetorheological fluid dampers." Journal of Building Engineering 42 (2021): 102795.

[4] Tseng, H. Eric, and Davor Hrovat. "State of the art survey: active and semi-active suspension control." Vehicle system Dynamics 53, no. 7 (2015): 1034-1062.

[5] Hiramoto, Kazuhiko, and Karolos M. Grigoriadis. "Active/semi-active hybrid control for motion and vibration control of mechanical and structural systems." Journal of Vibration and Control 22, no. 11 (2016): 2704-2718.

[6] Roozbahan, Mostafa, and Gürsoy Turan. "An improved passive tuned mass damper assisted by dual stiffness." In Structures, vol. 50, pp. 1598-1607. Elsevier, 2023.

[7] Shi, Weixing, Liangkun Wang, Zheng Lu, and Hongtao Wang. "Experimental and numerical study on adaptive-passive variable mass tuned mass damper." Journal of Sound and Vibration 452 (2019): 97-111.

[8] Jung, Hyung-Jo, Billie F. Spencer Jr, and In-Won Lee. "Control of seismically excited cable-stayed bridge employing magnetorheological fluid dampers." Journal of Structural Engineering 129, no. 7 (2003): 873-883.

[9] Salvi, Jonathan, Egidio Rizzi, Emiliano Rustighi, and Neil S. Ferguson. "Optimum tuning of passive tuned mass dampers for the mitigation of pulse-like responses." Journal of Vibration and Acoustics 140, no. 6 (2018): 061014.

[10] Li C and Qu W (2006) Optimum properties of multiple tuned mass dampers for reduction of the translational and torsional response of structures subject to ground acceleration. Engineering Structures 28(4): 472–494.

[11] Oliveira, Fernando, Miguel Ayala Botto, Paulo Morais, and Afzal Suleman. "Semi-active structural vibration control of base-isolated buildings using magnetorheological dampers." Journal of Low-Frequency Noise, Vibration and Active Control 37, no. 3 (2018): 565-576.

[12] Nagamatsu, Shuto, and Toshihiko Shiraishi. "A simple and novel control strategy for semi-active vibration suppression by a magnetorheological damper." Journal of Intelligent Material Systems and Structures 33, no. 6 (2022): 811-821.

[13] Sassi, Sadok, Abdelmonaam Sassi, Khaled Cherif, and Faris Tarlochan. "Magnetorheological damper with external excitation for more efficient control of vehicles' dynamics." Journal of Intelligent Material Systems and Structures 29, no. 14 (2018): 2919-2932.

[14] Hazaveh, Nikoo K., J. Geoffrey Chase, Geoffrey W. Rodgers, and Stefano Pampanin. "Smart semi-active MR damper to control the structural response." Bulletin of the New Zealand Society for Earthquake Engineering 48, no. 4 (2015): 235-244.

[15] Zhou Li, Chang C-C, Wang L-X. Adaptive Fuzzy Control for Non-linear Building Magnetorheological Damper System. J Struct Eng 2003;129(7):905–13. https:// doi.org/10.1061/(asce)0733-9445(2003)129:7(905).

[16] Azizi, Mahdi, and Siamak Talatahari. "Improved arithmetic optimization algorithm for design optimization of fuzzy controllers in steel building structures with non-linear behaviour considering near-fault ground motion effects." Artificial Intelligence Review 55, no. 5 (2022): 4041-4075.

[17] Chen, Tim, Sinngiresu Rao, Ramazaov Tlekkabul Sabitovich, Bertraind Chapron, and C. Y. J. Chen. "An intelligent algorithm optimum for building design of fuzzy structures." Iranian Journal of Science and Technology, Transactions of Civil Engineering 44 (2020): 523-531.

[18] Golnargesi, Siamak, Hashem Shariatmadar, and Hessam Meshkat Razavi. "Seismic control of buildings with active tuned mass damper through interval type-2 fuzzy logic controller including soil-structure interaction." Asian Journal of Civil Engineering 19, no. 2 (2018): 177-188.

[19] Ramezani, Meysam, Akbar Bathaei, and Seyed Mehdi Zahrai. "Designing fuzzy systems for optimal parameters of TMDs to reduce seismic response of tall buildings." Smart Structures and Systems 20, no. 1 (2017): 61-74.

[20] Zabihi Samani, Masoud, and Mohammad Ghanooni-Bagha. "A fuzzy logic controller for optimal structural control using MR dampers and particle swarm optimization." Journal of Vibroengineering 19, no. 3 (2017): 1901-1914.

[21] Ali, Mir M., and Kyoung Sun Moon. "Advances in structural systems for tall buildings: emerging developments for contemporary urban giants." Buildings 8, no. 8 (2018): 104.

[22] Szolomicki, Jerzy, and Hanna Golasz-Szolomicka. "Technological advances and trends in modern high-rise buildings." Buildings 9, no. 9 (2019): 193.

[23] Dai, Lixian, and Biao Liao. "The Research and Application of Innovative Highly Efficient Construction Technologies in Super High Rise Steel Structure Building." International Journal of High-Rise Buildings 3, no. 3 (2014): 205-214

[24] https://structville.com/2020/12/structural-systems-for-tall-buildings.html

[25] Beljkas, Z., Z. Prascevic, N. Ivanisevic, M. Knezevic, and Meri Cvetkovska. "Application of fuzzy logic on the selection of contractors for construction of high rise buildings." In IOP Conference Series: Earth and Environmental Science, vol. 222, no. 1, p. 012021. IOP Publishing, 2019.

[26] Peng, Junlong, Qi Zhang, Yue Feng, and Xiangjun Liu. "Optimization of construction safety resource allocation based on evolutionary game and genetic algorithm," Scientific Reports 13, no. 1 (2023): 17097.

[27] Duțu, Liviu-Cristian, Gilles Mauris, and Philippe Bolon. "A fast and accurate rule-base generation method for Mamdani fuzzy systems." IEEE Transactions on Fuzzy Systems 26, no. 2 (2017): 715-733.

[28] Zain, Muhammad, Lapyote Prasittisopin, Tahir Mehmood, Chayut Ngamkhanong, Suraparb Keawsawasvong, and Chanachai Thongchom. "A novel framework for effective structural vulnerability assessment of tubular structures using machine learning algorithms (GA and ANN) for hybrid simulations." Non-linear Engineering 13, no. 1 (2024): 20220365.

[29] Kontoni, Denise-Penelope N., and Ahmed Abdelraheem Farghaly. "Seismic control of vertically and horizontally irregular steel high-rise buildings by tuned mass dampers including SSI." Asian Journal of Civil Engineering (2023): 1-20.

[30] Ansari, Ramin, Parisa Dehghani, Mahdi Mahdikhani, and Jaewook Jeong. "A Novel Safety Risk Assessment Based on Fuzzy Set Theory and Decision Methods in High-Rise Buildings." Buildings 12, no. 12 (2022): 2126.

[31] Xu, Kun, Qian Dai, Kaiming Bi, Genshen Fang, and Yaojun Ge. "Closed‐form design formulas of TMDI for suppressing vortex‐induced vibration of bridge structures." Structural Control and Health Monitoring 29, no. 10 (2022): e3016.

[32] Khazaei, Mohsen, Reza Vahdani, and Ali Kheyroddin. "Optimal location of multiple tuned mass dampers in regular and irregular tall steel buildings plan." Shock and Vibration 2020 (2020): 1-20.

[33] Peng, Yongbo, and Zhenkai Zhang. "Optimal MR damper–based semi-active control scheme for strengthening seismic capacity and structural reliability." Journal of Engineering Mechanics 146, no. 6 (2020): 04020045.

[34] Zhao, Dong, Andrew P. McCoy, Jing Du, Philip Agee, and Yujie Lu. "Interaction effects of building technology and resident behaviour on energy consumption in residential buildings." Energy and Buildings 134 (2017): 223-233.

[35] Jang, Hyoun-Seung. "Genetic algorithm for construction space management." KSCE Journal of Civil Engineering 8 (2004): 365-369.

[36] Kargahi, Mohsen, and Chukwuma G. Ekwueme. "Structural optimization of viscous dampers using genetic algorithms for improving seismic performance of existing buildings." In Improving the Seismic Performance of Existing Buildings and Other Structures, pp. 955-966. 2010.

[37] Costa-Carrapiço, Inês, Rokia Raslan, and Javier Neila González. "A systematic review of genetic algorithm-based multi-objective optimization for building retrofitting strategies towards energy efficiency." Energy and Buildings 210 (2020): 109690

[38] Yang, Junbing, and Xiaomin Hu. "Optimal Design and Application of High-rise Building Structure Based on Hybrid Genetic Algorithm." In 2nd International Conference on Internet, Education and Information Technology (IEIT 2022), pp. 761-766. Atlantis Press, 2022.

[39] Tartan, Emre Oner, and Cebrail Ciftlikli. "A Genetic Algorithm based elevator dispatching method for waiting time optimization." IFAC-PapersOnLine 49, no. 3 (2016): 424-429

[40] Li, Tiejun, Guifang Shao, Wangda Zuo, and Sen Huang. "Genetic algorithm for building optimization: State-of-the-art survey." In Proceedings of the 9th International Conference on Machine Learning and Computing, pp. 205-210. 2017

[41] Rooki, Reza, Faramarz Doulati Ardejani, Ali Moradzadeh, Hossein Mirzaei, Vassilios Kelessidis, Roberto Maglione, and Mahmood Norouzi. "Optimal determination of rheological parameters for Herschel-Bulkley drilling fluids using genetic algorithms (GAs)." Korea-Australia Rheology Journal 24 (2012): 163-170

[42] Ramoji, Satish Kumar, Bibhuti Bhusan Rath, and D. Vijay Kumar. "Optimization of hybrid PV/wind energy system using genetic algorithm (GA)." J Eng Res Appl 4, no. 1 (2014): 29-37.

[43] Pourzeynali, S., H. H. Lavasani, and A. H. Modarayi. "Active control of high-rise building structures using fuzzy logic and genetic algorithms." Engineering Structures 29, no. 3 (2007): 346-357.

[44] Klashanov, Fjoder. "Fuzzy logic in construction management." In MATEC Web of Conferences, vol. 170. EDP Sciences, 2018.

[45] Chojecki, Adrian, Michał Rodak, Arkadiusz Ambroziak, and Piotr Borkowski. "Energy management system for residential buildings based on fuzzy logic: design and implementation in the smart meter." IET Smart Grid 3, no. 2 (2020): 254-266

[46] Hernández, José L., Roberto Sanz, Álvaro Corredera, Ricardo Palomar, and Isabel Lacave. "A fuzzy-based building energy management system for energy efficiency." Buildings 8, no. 2 (2018): 14.

[47] Avinash J. Kamble1 and Ravindra P. Rewaskar." Soft computing - Fuzzy Logic: An overview"." Intern. J. Fuzzy Mathematical Archive", pp. 45-52,2020

[48] Khedr, Shaimaa F. Mohamed, M. E. Ammar, and Mohamed A. Mostafa Hassan. "Multi-objective genetic algorithm controller's tuning for non-linear automatic voltage regulator." In 2013 International Conference on Control, Decision and Information Technologies (CoDIT), pp. 857-863. IEEE, 2013.