

Determination of Active Force of Adjustable Active Mass Damper (ATMD) In Concrete Structure Using Z-Number

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Abstract

In this research, in order to solve the difference between the values of the active force of the damper ATMD in the case of using equations of motion and experiments, it is suggested to use z-number in fuzzy logic. The obtained results indicate that considering z-number causes significant changes in the output results of the active force so that it is closer to the real values. On the other hand, these results show that the existing equations of motion are not accurate enough and need to be modified and add coefficients. These results are consistent with previous articles and have been confirmed in other articles as well. Finally, it is suggested to the designers of this field to use the proposed process in order to increase the accuracy in active force calculations.

Keywords: Damper active force, atmd damper, concrete structure, z-number

Introduction

Engineering structures such as buildings and towers may shake violently or even collapse [1] and [2] when they are subjected to strong earthquake or wind stimulation. The design of structures resistant to seismic damage such as earthquakes or wind is always considered by structural designers and it is at this point that control science shows itself with the progress of research in the field of strengthening structures, control systems as one of the Effective ways to reduce vibrations and protect structural members against earthquake force have been introduced. These systems are divided into four main categories based on the use of energy sources, including: passive control systems [3] and [4]; semi-active [5] and [6]; They are classified as active [7] and compound [10]. One of the most important established methods in controlling vibrations on structures is the use of mass dampers (MDs, which are also referred to as energy absorbers (TMD), passive type of adjustable mass dampers; it can be called which has a mass, a spring and a damper which is added to the main structure and vibrates with it. The control system provides energy and these actuators introduce forces into the structure in accordance with the predefined states [8]. The external force by the actuator improves its performance [10]. Active adjustable mass dampers (ATMD) can be defined as a system that adds an active control mechanism (sensor; controller and actuator) to the system (TMD).) in order to increase its use in variable frequencies (Figure 1) [11]. Linear dynamics of variable control force with time is used [12].

There are several practical examples of ATMDs, such as Shinjuku Park Tower (227 m) in Tokyo, Japan, Incheon International Airport Control Tower (100.4 m) in Incheon, Korea, Air Traffic Control Tower (57 m) in Edinburgh, UK, and Shanghai World Financial Center (492 m) in Shanghai, China (Figure 2) [13].

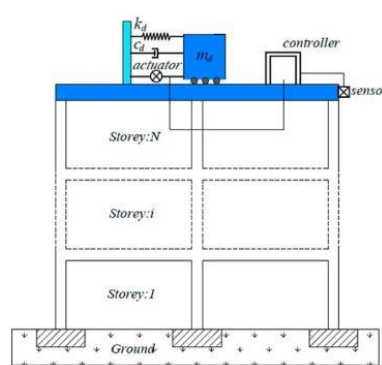


Fig 1. General component of structure with an active tuned mass dampers (ATMD) system[1].



Fig 2. Taipei 101 with a sphere-shaped tuned mass damper [1]

As stated, the damper ATMD is an active damper. In this damper, while creating vibration in the structure, information from external stimulation, including ground acceleration and the state of the structure, including the displacement, speed and acceleration of different parts, is sent to the main processing core by the receivers[14]. The processing core of the control system by analyzing the above information determines the best response to reduce the forces and change the shape caused by the stimulation created in the structure[15]. In this case, using different methods and tools such as active variable mass and stiffness, appropriate control force is applied to the structure. In this way, the active control system makes the necessary changes in the dynamic characteristics of the structure by using external energy during an earthquake. This process shows that in order to use and correctly choose these dampers, it is necessary to calculate the active force of the damper[16]. When choosing these dampers, structural designers use equations based on which the amount of active force of the damper is calculated. The equations used by the designers are based on displacement values and the relative speed of the last floor of the structure, which are obtained through the motion equations governing the structure. But previous researches have shown that the values of speed and relative displacement obtained in the equations are not the same as the experimental values. While designers cannot repeat the laboratory process for every structure. Therefore, in the current research, the idea of using Z-Numbers is presented. We know that every decision is based on information. To be useful, information must be reliable. Basically, the concept of z number is related to reliability. Each z-number consists of an ordered pair as $z = (\tilde{A}, \tilde{R})$. The first component $\tilde{A}$ is a limit on the values that the true uncertain variable X is allowed to take, and the second component $\tilde{R}$ is the reliability value of the first component. Compared to classical fuzzy numbers, z-numbers have a greater ability to describe human knowledge, in other words, they can simultaneously describe limitations and reliability [17]. According to the characteristics of numbers z-number, various researches have been conducted in the field of their use. The paper [31] presented a

study on the development of the theory and application of Z numbers since its inception in 2011. It reviews the formalization of Z-number-based mathematical operators, the role of Z-numbers in word computation, decision making and trust modeling, the application of Z-numbers to real-world problems such as multi-sensor data fusion, dynamic controller design, security analysis and natural language understanding, a brief comparison With similar conceptual paradigms, and some potential areas of future research, this paradigm currently has at least four extensions to its definition. Multidimensional Z-numbers, parametric Z-numbers, hesitant-non-deterministic Z-numbers, and Z*-numbers. Z numbers have also been used in conjunction with rough sets and granular calculations to handle increased uncertainty. The paper [32] proposed a multi-criteria decision making method based on Dempster-Shafer (DS) theory and generalized Z numbers. To do this, inspired by the concept of fuzzy fuzzy linguistic set of terms, he expanded the Z number into a generalized form that is more in line with human expressive habits. After that, he built a bridge between Z-number knowledge and DS evidence theory to unify Z-valuations. Article [33] is the basis for choosing online media that public administration uses when communicating with citizens. The proposed method is based on multi-circle decision-making using fuzzy analytic hierarchy process (Fuzzy AHP) - Z-number model - fuzzy multi-document boundary approximation area comparison (Fuzzy MABAC), which eliminates the traditional visual ranking of PR services. The paper [34] presented Z-number based fuzzy logic control for tracking the path of differential wheeled mobile robots. The approach of this research avoids the complexity of coding error gradients. Experiments in this research using physics-based simulations and real-world experiments based on the Pioneer 3DX robot architecture show the superior performance and feasibility of the proposed controller in terms of accuracy, robustness, and smoothness compared to other well-known related frameworks such as fuzzy logic type 1, fuzzy logic Type 2 and fuzzy logic with PID turned on. The article [35] presented a model for choosing a location for a brigade command post during combat operations. Considering that this is a very complex model that can be addressed from different aspects, this article is limited only to the criteria related to the construction or layout of the command post, respectively, the engineering aspect. The selection process is done using the FUCOM – Z-number – MABAC hybrid model. The paper [36] proposed a simple computational method for Z-score ranking for multi-criteria decision-making (MCDM) problems. And a comprehensive probability degree of Z numbers is defined, as inspired by the concept of probability degree of interval numbers. The superiority relations of Z numbers are also discussed based on the proposed method. Then, a weight acquisition algorithm is presented according to the degree of possibility of Z numbers. The paper [37] proposes a combined preference-based MADM method with spherical fuzzy numbers (Z)-SZFNs to solve the fuzzy information problem of green product design. SZFNs are designed to extract the internal hidden information of traditional Z numbers and feature the capability constraints. The reliability of Z-numbers and the advantages of spherical language sets are defined in this study The effectiveness and robustness of this proposed method are adopted. Comparative analysis, sensitivity analysis and comprehensive discussion are carried out in this research. The results confirm that this proposed method has improved performance and provides resources for designers. According to this feature of z-numbers, in this article, a corrective method to solve the problem has been presented with the help of z-numbers. For this purpose, in the first part of the research, a fuzzy logic system is presented and the results are evaluated as a case study, and the process of converting the fuzzy logic control system to the z fuzzy logic control system is expressed. In the second part, the basic concepts needed are discussed. In the third section, the correction method is fully explained. In the fourth part of the research, the research findings are shown. And in the fifth section, the final result is stated.

2. Basic concepts and Definitions

Definition 2.1

The fuzzy set A on the global set X is defined as relation (9) [24]

$$(9)A = \{(x, \mu_A(x)) | x \in X\}$$

In this relationship $\mu_A: X \rightarrow [0, 1]$, the membership function of the set, $\mu_A(x)$, A is the degree of membership and expresses the degree of belonging of $x \in X$ in the set A.

Definition 2.2

A z-number consists of a pair of fuzzy numbers in the form $z = (\tilde{A}, \tilde{R})$, so that the first factor ($\tilde{A}$) is a limit on the non-deterministic real value of X and the factor ($\tilde{R}$) is also a measure of The reliability rate is without the first factor. The numbers $\tilde{A}$ and $\tilde{R}$ also represent two fuzzy numbers. For example, if $\tilde{A}$ is a trapezoidal fuzzy number and $\tilde{R}$ is a parabolic fuzzy number, these numbers can be shown as in figure (2) [2].

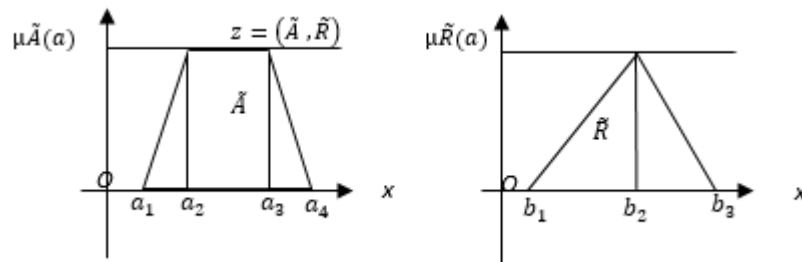


Fig2: An example of a Z number

Definition 2.3

Fuzzy expectation of a fuzzy set is defined by equation (10). This concept is different from the expected value in probabilistic environments [24]

$$(10) E_A(x) = \int_x x \mu_A(x) dx$$

In this regard, A is a fuzzy set and $\mu_A: X \rightarrow [0, 1]$ is the membership function of the set A .

3. Convert z-numbers to classical fuzzy numbers

Direct calculations using z-numbers are difficult and long calculations and have limiting conditions [18], therefore, to use these numbers, first they are converted to classical fuzzy numbers and then calculations are performed using fuzzy numbers. This process makes calculations easier [24]

If $z = (\tilde{A}, \tilde{R})$ is a z-number and the fuzzy numbers $\tilde{A}$ and $\tilde{R}$ are

$\tilde{A} = \{(x, u_A(x)) | x \in X[0, 1]\}$ and $\tilde{R} = \{(x, u_R(x)) | x \in X\}$ are defined, in these relationships $\mu_{\tilde{A}}$ is a trapezoidal membership function and $u_{\tilde{R}}(x)$ is a triangular membership function. Otherwise, to convert the z-number into a classical fuzzy number, the following steps are performed:

1. First, the second component of the z-number (reliability value) is converted into a numerical state (Relation 11)

$$(11) \alpha = \frac{\int x \mu_R(x) dx}{\int \mu_R(x) dx}$$

2. The weight of the second component (reliability value) is combined with the first component (restriction). The weighted number z will be in the form

$$\tilde{Z}^\alpha = \{(x, \mu_A^\alpha(x)) | \mu_A^\alpha(x) = \alpha \mu_A(x), x \in [0, 1]\} \text{ (Relation 12 and 13)}$$

$$(12) E A^\alpha(x) = \alpha E_{\tilde{A}}(x), x \in X$$

$$(13) s. t. \mu_{\tilde{Z}^\alpha}(x) = \alpha \mu_{\tilde{A}}(x), x \in X$$

3. Now, the unusual fuzzy number (weight limit) is converted to the usual fuzzy numbers (Relation 14 and 15).

The obtained fuzzy set can be expressed as $\tilde{Z}' = \{(x, \mu_{\tilde{Z}'}(x)) | \mu_{\tilde{Z}'}(x) = \pi \tilde{A}(\frac{x}{\sqrt{\alpha}}), x \in [0, 1]\}$ showed and it is expressed through equation (16) that $\tilde{Z}'$ has the same fuzzy expectation as $\tilde{Z}^\alpha$.

$$(14) E_{\tilde{Z}'}(x) = \alpha E_{\tilde{A}}(x), x \in \sqrt{\alpha} X$$

$$(15s.t. \mu z'(x) = \mu \tilde{A} \left(\frac{x}{\sqrt{a}} \right), x \in \sqrt{a}X$$

From relation 4 and 6, relation (8) can be concluded .

$$(16) \quad E_{\tilde{z}'}(x) = E_{\tilde{A}}(x)$$

4.Theoretical

4.1.Equation of motion of the system without dampers

In this article, an eleven-story concrete building, which is part of medium-sized concrete buildings in terms of structural system, is modeled. The characteristics of the modeled structure include: the mass and hardness of each floor are shown in Table 4[29] .

(3)

$$b_o = \xi_j \times \frac{2}{\omega_i + \omega_j}$$

$$d_o = \xi_j \times \frac{2\omega_i \times \omega_j}{\omega_i + \omega_j}$$

In this way, having the mass, stiffness and damping matrices of the structure, the equation of motion for a structure under seismic acceleration can be $\ddot{u}_g(t)$ Without a control system, it should be written as follows .

(4)

$$[M_T]\{\ddot{u}\} + [C_T]\{\dot{u}\} + [K_T]\{u\} = -[M_T]\{r_T\}\ddot{u}_g(t)$$

that in the above relationship $\ddot{u}$, $\dot{u}$, u respectively are the relative displacement vector and the relative speed and acceleration of each floor and r_T is a vector with dimensions (n×1) which is considered as degrees of freedom in the direction of earthquake acceleration [3]

4.2. Equation of motion of the structure with active adjustable mass damper

In this article, an ATMD active mass damper is installed on the last floor of this structure.

(5

$$k = \begin{bmatrix} k_1 + k_2 & \dots & 0 \\ -k_2 & \ddots & \vdots \\ \vdots & k_{ij} & \ddots & -k_n \\ 0 & \dots & -k_n & k_n \end{bmatrix}$$

$$m = \begin{bmatrix} m_1 & \dots & 0 & 0 \\ \vdots & m_2 & & 0 \\ 0 & & \ddots & \vdots \\ 0 & 0 & \dots & m_n \end{bmatrix}$$

Then, according to equation 6, the damping matrix is determined from the combination of the mass and stiffness matrix of the structure, and the coefficients a_o, b_o for the first and second modes of the structure are obtained by considering the damping $\xi_{ij} = \%5$ according to equation 3.

(6)

$$[c] = a_o[M] + b_o[k]$$

The active mass damper consists of a mass, a spring, damping and an active control force, which is applied to the structure based on the control algorithm and its physical characteristics, including the mass of the damper (M_t), stiffness (K_t) and coefficients (C_t) is determined with the help of relations 7.

(7)

$$c_t = 2\xi \times \sqrt{k_t m_t}$$

$$K_t = M_t \times (\beta \times w_1)^2$$

$$M_t = m_o \times M_{building}$$

In the relations mentioned above, m_o is the ratio of the mass of the mass damper to the mass of the whole structure, and ξ is the damping percentage of the mass damper. To obtain the optimal values of the ATMD system parameters in Figure 5, the ratio of the displacement of the last floor in the controlled state to the uncontrolled state per $m_o = \%3$, the percentage values of damping $\xi = \{20\%, \dots, 2\%, 1\%\}$ and the value of adjustment factor $\beta = \{1/2, 1/1, 1, 0.9\}$ are compared under the selected earthquake record and the parameter is The obtained optimal values are the same as those by Posinali et al. [29]. For optimization, an active control system is presented, which shows the accuracy of the research results up to this stage. After determining the optimal parameters, the mass, stiffness and damping values of the mass damper are added to the mass, stiffness and damping matrix of the entire structure, based on these values, the equation of motion for a multi-degree of freedom system under seismic acceleration and control force $\{f\}$ is in the form of relation 8.

(8)

$$[M_T^*]\{\ddot{u}\} + [C_T^*]\{\dot{u}\} + [k_T^*]\{u\} =$$

$$-[M_T^*]\{r_T^*\}\ddot{u}_g(t) + [D]\{f\}$$

In the above relationship, k_T^* and M_T^* are the mass and stiffness matrix of the structure equipped with a mass damper, and the parameters $\ddot{u}, \dot{u}$ are respectively the relative displacement vector, relative velocity and acceleration of each floor with dimensions is $(n + m) \times 1$. and $\{r_T^*\}$ is a vector with dimensions $(n + m) \times 1$, which is like degrees of freedom in the direction of earthquake acceleration, where m represents the number of active mass dampers and n is the number of floors, and the matrix $[D]$ is a vector that places It shows the application of external force by the active mass damper to the structure.

5. Materials and methods

As stated, the aim of the present research is to obtain the amount of the active force of the damper Z-Numbers using Z-Numbers in order to reduce calculation errors. For this purpose, a fuzzy inference system is provided, based on two inputs of relative velocity and relative displacement of the last floor, the amount of active force of the damper is obtained. with the difference that the system is checked in two modes. In the first case, the data of relative speed and relative displacement are obtained from the equations, and the second case is the data of relative speed and relative displacement obtained from the test of the structure. According to the obtained results, the data of relative speed and relative displacement are not the same in two cases. Therefore, the obtained active force values are not the same. For this purpose, the Z-Numbers are used in the current research to resolve this difference. and it is applied as a coefficient in the conditions of fuzzy logic. To determine the Z-Numbers, instead of experts' opinion, dividing and averaging the data obtained from experiments and equations has been used, so that the entire process of calculating the Z-Numbers has been done with this The difference is that the experimental data is considered as the opinion of experts. And the process of fuzzification and dephasing of calculations has been done in such a way that it can be used as a coefficient in fuzzy logic conditions. In this research, an 11-story concrete structure with mass and stiffness values according to Table 1 is considered. Also, the values of other parameters of the structure and damper are fixed and optimal according to Table 2.

Table 1. Mass and hardness values of the structure

stories	Mass (ton)	Stiffness (kN/m)
1.	215	4680
2.	201	4760

3.	201	4680
4.	200	4500
5.	201	4500
6.	201	4500
7.	201	4500
8.	203	4370
9.	203	4370
10.	203	4370
11.	176	3120

Table 2 values of other parameters of structure and damper[1]

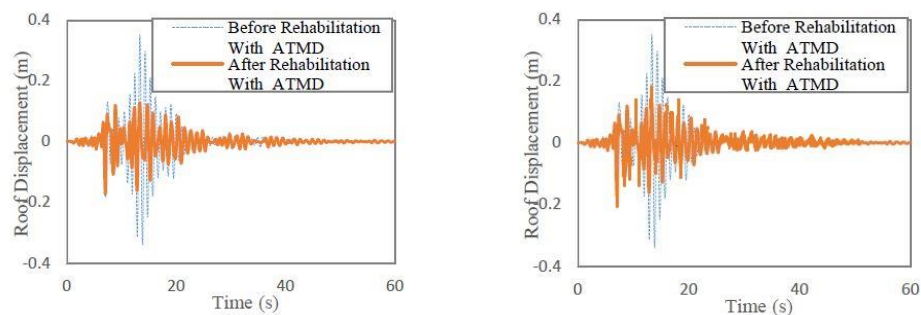
parameter	scale
ξ	0.7
β	1.2
M0	0.3
ξ_{ij}	%5
ao	0.125
bo	0.35
Number ATMD	1

It should be noted that in the current study, the characteristics of seismic acceleration Northridge have been considered. The duration of this earthquake was approximately 10 to 20 seconds, and its maximum ground acceleration was 1.82 g, the highest recorded in an urban area in North America. The characteristics of this earthquake are shown in Table 3.

Table 3 Seismic acceleration characteristics Northridge

DATA	Magnitude (Ms)	Station number	Component (deg)	PGA (cm/s ²)	Scale factor
0.1/17/94	6.8	24278	360	504.2	1.073

In figure 3 and a and b respectively, the output graph of the relative displacement obtained from the equations and the laboratory is shown. Also, Figure 4 show speed obtained from the equations and the laboratory, respectively.



(a) (b)

Fig 3 a and b are respectively the output graph of the relative displacement obtained from the equations and the laboratory

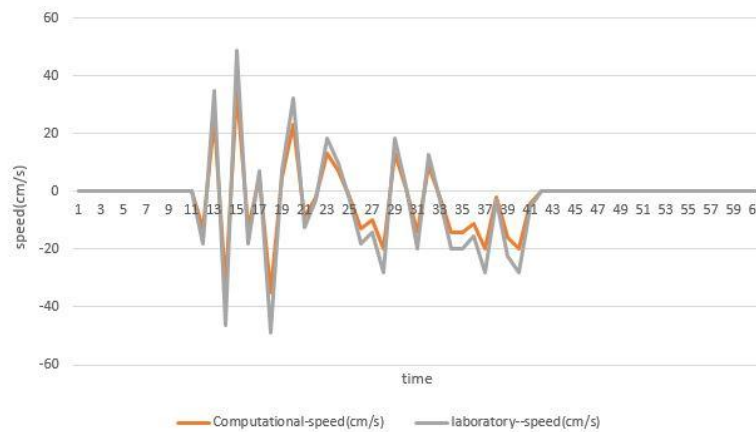


Fig 4. The speed obtained from the equations and the laboratory

5.1. Calculation of Z-NUMBER values

As mentioned, Z-NUMBER consists of two fuzzy components as $z=(A,R)$. So that A is a trapezoidal fuzzy number and represents the values obtained from the results of solving the equations in the previous step. and R is a triangular fuzzy number that predicts the probability of occurrence of A as determined by experts. Considering that in the current research, instead of experts' opinions, the results of the laboratory were used, therefore, to determine the fuzzy value of R, it was done in such a way that an initial value of the obtained data in the relative speed or relative displacement in the obtained data was used. It is considered from solving the equations of the previous step, and then the fuzzy value of that number is calculated according to the laboratory data, which shows the value of R. It is also shown in the diagram below (Figure 5). In the next step, this number can be converted into a classic fuzzy number using the described method. For this, we do steps in order. The first step was to convert the reliability of the laboratory results into a failure number by using equation 11. In the second step, the reliability weight was added to the limit or using equation 12. In the third step, the weighted number Z is converted into a normal fuzzy number with the approach mentioned above. Finally, by converting the number into a trapezoidal fuzzy number, you can use classical fuzzy topics. In other words, the new values obtained represent the values of relative speed or relative displacement after applying Z-NUMBER values. Therefore, it is necessary to calculate the amount of active force again using the governing equations of the structure (with damper) and new relative velocity and relative displacement values. In the next step, by using the changes applied in the fuzzy logic conditions, the fuzzy logic system should be designed that by entering the values of the relative speed or the relative displacement obtained from the data of the manual solution of the equations, the value of the active force after applying Z- Calculated NUMBER. that after the stated calculations and the implementation of the described process, the conditions of the new fuzzy logic were determined.

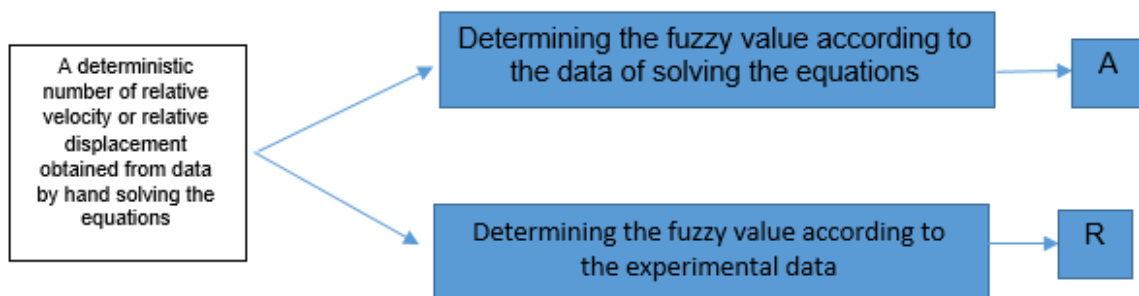


FIG5: The process of determining the values of A, R

In other words, the new values obtained represent the values of relative speed or relative displacement after applying Z-NUMBER values. Therefore, it is necessary to calculate the amount of active force again using the

governing equations of the structure (with damper) and new relative velocity and relative displacement values. In the next step, by using the changes applied in the fuzzy logic conditions, the fuzzy logic system should be designed that by entering the values of the relative speed or the relative displacement obtained from the data of the manual solution of the equations, the value of the active force after applying Z- Calculated NUMBER. that after the stated calculations and the implementation of the described process, the conditions of the new fuzzy logic were determined.

6.Results(Fuzzy logic system implementation and application Z-Numbers)

Considering that in this section, the values of relative displacement and relative speed of the last floor of the structure have been obtained in two computational and experimental methods, in the following, these data are used as input to the fuzzy logic and the value of the active force of the damper ATMD is obtained.

In this research, for the input membership functions, the change of location and speed of the last floor is considered, which has 5 linguistic variables, respectively, including large negative (LN), small negative (N), zero (Z), small positive (P), large positive (LP) and for the output membership functions of the active force of the mass damper, which has 7 linguistic variables, which respectively include large negative (NL), medium negative (NM), small negative (NS), zero (ZR), and small positive (PS). Medium Positive (PM), Large Positive (PL). Also, the obtained z-number values are according to Figure 6(c), which has the ranges of very low(VL), low (L), medium (M), high (H), very high (VH)

Fuzzy rules are written to determine the active control force that is the output of the system using input and output variables. Each of these rules is shown in Table 4. Mamdani fuzzy system has been used in this research to determine the active force of the mass damper. As mentioned earlier, this control system includes two input membership functions and one output membership function, all of which are in the range of -1 to 1, so to determine the active control force, the values of these input and output functions must be scaled to values by scale coefficients. become real. The determined coefficients are considered according to Table 5.

Table 4. Fuzzy control rules

Velocity					
Displacement	LN	N	Z	P	LP
LP	NS	NS	NM	NL	NL
P	NS	NM	NM	NM	NL
Z	PS	ZR	ZR	ZR	NS
N	PL	PM	PM	PM	PS
LN	PL	PL	PM	PS	PS

Table 5. Scale coefficients of fuzzy control functions (Mamdani)

parameter	Scale factor
relative displacement	2.5
relative Velocity	0.5
active power (output)	0.05*(modeled building weight)

After calculating the values of z-number and applying them to the fuzzy conditions, the result is obtained as shown in Table 6.

Table 6. Fuzzy control rules after applying z-number

Velocity					
Displacement	LN	N	Z	P	LP
LP	NS/0.33	NS/0.62	NM/0.42	NL/0.68	NL/0.57

P	NS/0.81	NM/0.64	NM/0.69	NM/0.74	NL/0.74
Z	PS/0.71	ZR/0.64	ZR/0.57	ZR/0.91	NS/0.66
N	PL/0.92	PM/0.65	PM/0.47	PM/0.64	PS/0.74
LN	PL/0.32	PL/0.41	PM/0.36	PS/0.19	PS/0.21

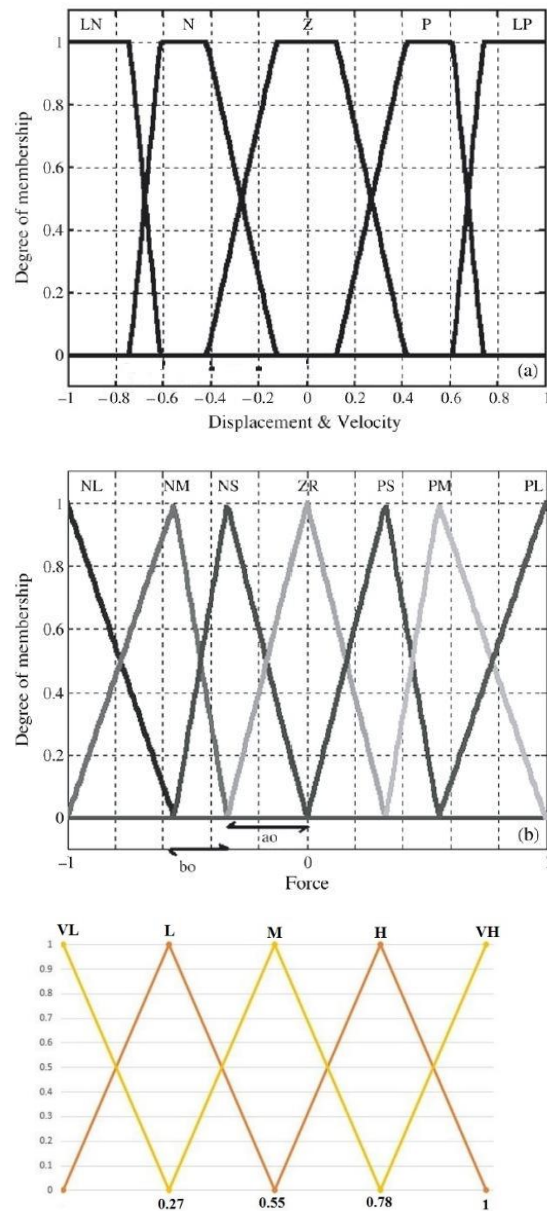


Fig. 6. (a) Membership functions of input variables (displacement and velocity). (b) Membership functions of output variable (Active control force). (c) The z-number intervals are obtained.

Finally, for the desired structure, the output of the active force of the damper is obtained in two cases without using z-number and using z-number according to Figure 7 and 8.

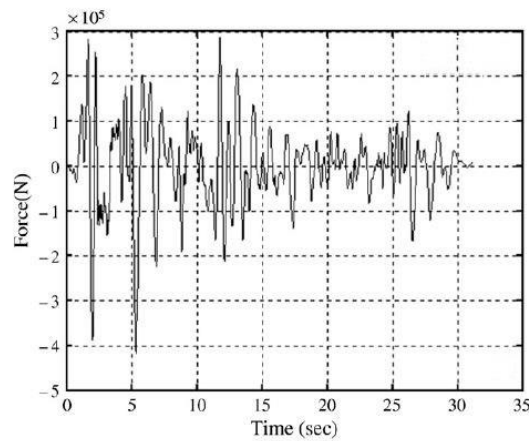


Fig. 7 Active force of the structure without consideration z-number

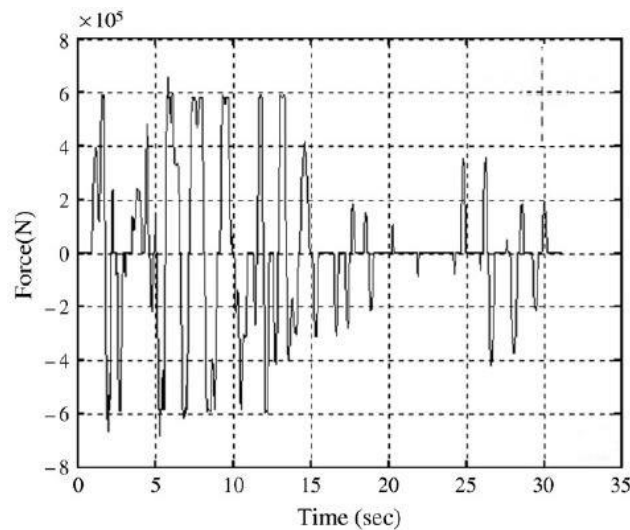


Fig. 8 active force of the structure considering z-number

Conclusion

Fuzzy computing can formulate probabilities and learning, and is accepted as a logical system with a well-defined theoretical framework that itself has no ambiguity or uncertainty. Fuzzy computing is aimed at human inference. This theory simulates the process by formulating the uncertainties and intuitive issues that are extracted from the expression of skills and the way of learning. In this research, a modified method for determining the active force of AMTD damper using z numbers is presented. The obtained results show that the value of the active force of the AMTD damper obtained from the laboratory inputs of the structure is about 5% different from the value of the active force of the AMTD damper obtained by solving the equations of motion of the structures, which indicates that the existing equations of motion are not sufficiently accurate and need to modify or add coefficients. These results are consistent with previous papers and have been confirmed in other papers as well. To solve this problem, in this research, the z-number approach was used to calculate the active force of the AMTD damper. In addition to having the advantages of the fuzzy inference system, it also solves the problem of uncertainty in fuzzy numbers by using z numbers. The results show an 8% difference in the active force of the damper in the z-number fuzzy system with the active force obtained from the laboratory inputs. In addition to the novelty of using the direct relationships of z numbers to calculate the active force of the damper, this research also has a practical aspect.

Reference

- 1- Wang, L., Shi, W., Zhang, Q., & Zhou, Y. (2020). Study on adaptive-passive multiple tuned mass damper with variable mass for a large-span floor structure. *Engineering Structures*, 209, 110010.
- 2- Rahimi, F., Aghayari, R., & Samali, B. (2020). Application of tuned mass dampers for structural vibration control: a state-of-the-art review. *Civil Engineering Journal*, 1622-1651.
- 3- Shi, W., Wang, L., Lu, Z., & Wang, H. (2019). Experimental and numerical study on adaptive-passive variable mass tuned mass damper. *Journal of Sound and Vibration*, 452, 97-111.
- 4- Rincón, C. G., Alencastre, J., & Rivera, R. (2021). Active Vibration Absorber for a Continuous Structure Model.
- 5- Zhou, K., Zhang, J. W., & Li, Q. S. (2022). Control performance of active tuned mass damper for mitigating wind-induced vibrations of a 600-m-tall skyscraper. *Journal of Building Engineering*, 45, 103646.
- 6- Ümütlü, R. C., Ozturk, H., & Bidikli, B. (2021). A robust adaptive control design for active tuned mass damper systems of multistory buildings. *Journal of Vibration and Control*, 27(23-24), 2765-2777.
- 7- Xu, L., Cui, Y., & Wang, Z. (2020). Active tuned mass damper based vibration control for seismic excited adjacent buildings under actuator saturation. *Soil Dynamics and Earthquake Engineering*, 135, 106181.
- 8- Kayabekir, A. E., Nigdeli, S. M., & Bekdaş, G. (2022). A hybrid metaheuristic method for optimization of active tuned mass dampers. *Computer-Aided Civil and Infrastructure Engineering*, 37(8), 1027-1043.
- 9- Gavgani, S. A. M., & Lavassani, S. H. H. (2024). Vibration mitigation of offshore structures subjected to wave and wind loads using optimum semi-active tuned mass damper inerter (SATMDI). *Ocean Engineering*, 297, 117110.
- 10- Song, C., Xiao, R., Jiang, Z., & Sun, B. (2024). Active-learning Kriging-assisted robust design optimization of tuned mass dampers: Vibration mitigation of a steel-arch footbridge. *Engineering Structures*, 303, 117502.
- 11- Xing, L., Song, G., Zhou, Y., & Zhang, P. (2024). Metamodel-based sensitivity analysis of the optimal outrigger locations for damping outrigger-ATMD systems. *Soil Dynamics and Earthquake Engineering*, 178, 108499.
- 12- Sun, M., Li, Q., & Huang, S. (2024, February). A hybrid output-only scheme for precise modal estimation and uncertainty quantification of large-scale structure through vibration-based measurements. In *Structures* (Vol. 60, p. 105898). Elsevier.
- 13- Chen, P. C., Chou, C. W., & Wang, W. J. (2024). Rapid Controller Generation for Vibration Suppression of Structures Using Direct Excitation with Machine Learning. *Journal of Structural Engineering*, 150(3), 04023237.
- 14- Husain, S. S., & MohammadRidha, T. (2022). Integral sliding mode controlled ATMD for buildings under seismic effect. *International Journal of Safety and Security Engineering*, 12(4), 413-420.
- 15- Golnargesi, S., Shariatmadar, H., & Golnargesi, B. (2022). Structural control of building with ATMD through AN-IT2FLC under seismic excitation. *Civil Engineering Infrastructures Journal*, 55(2), 309-331.
- 16- Chen, Z. Y., Peng, S. H., Wang, R. Y., Meng, Y., Fu, Q., & Chen, T. (2022). Stochastic intelligent GA controller design for active TMD shear building. *Structural Engineering and Mechanics, An Int'l Journal*, 81(1), 51-57.
- 17- Zadeh, L. A. (2011). A note on Z-numbers. *Information sciences*, 181(14), 2923-2932.
- 18- Warburton, G. B. (1982). Optimum absorber parameters for various combinations of response and excitation parameters. *Earthquake Engineering & Structural Dynamics*, 10(3), 381-401.
- 19- Tse, F. S., Morse, I. E., & Hinkle, R. T. (1963). *Mechanical vibrations*. Boston: Allyn and Bacon.
- 20- Jenniges, R. L., & Frohrib, D. A. (1978). Alternative tuned absorbers for steady state vibration control of tall structures.
- 21- ZAHRAEI, S. M., & GHANADI, A. A. (2008). Seismic performance of TMDs in improving the response of MRF buildings .
- 22- Zahrai, S. M., Dehghan-Niri, E., & Mohtat, A. (2007). Design methodology for MTMD performance optimization using a new criterion for robustness. In *Company European Conference on Computational Methods in Structural Dynamics and Earthquake Engineering*.
- 23- Wilson, C. M. D. (2005). Fuzzy control of magnetorheological dampers for vibration reduction of seismically excited structures. The Florida State University.
- 24- Kang, B., Wei, D., Li, Y., & Deng, Y. (2012). Decision making using Z-numbers under uncertain environment. *Journal of computational Information systems*, 8(7), 2807-2814.
- 25- Cheng, R., Kang, B., & Zhang, J. (2021, May). An Improved Method of Converting Z-number into Classical Fuzzy Number. In *2021 33rd Chinese Control and Decision Conference (CCDC)* (pp. 3823-3828). IEEE.
- 26- Holmblad, L. P., & Østergaard, J. J. (1993). Control of a cement kiln by fuzzy logic. In *Readings in fuzzy sets for intelligent systems* (pp. 337-347). Morgan Kaufmann.
- 27- Tanaka, H., & Lee, H. (1998). Interval regression analysis by quadratic programming approach. *IEEE Transactions on Fuzzy Systems*, 6(4), 473-481 .
- 28- Zadeh, L. A. (1965). Fuzzy sets. *Information and control*, 8(3), 338-353.

- 29- Pourzeynali, S., Lavasani, H. H., & Modarayi, A. H. (2007). Active control of high rise building structures using fuzzy logic and genetic algorithms. *Engineering Structures*, 29(3), 346-357.
- 30- Clough, R. W., & Penzien, J. (1975). *Of structures*. New York: McGraw-Hill.
- 31- Banerjee, R., Pal, S. K., & Pal, J. K. (2021). A decade of the Z-numbers. *IEEE Transactions on Fuzzy Systems*, 30(8), 2800-2812.
- 32- Ren, Z., Liao, H., & Liu, Y. (2020). Generalized Z-numbers with hesitant fuzzy linguistic information and its application to medicine selection for the patients with mild symptoms of the COVID-19. *Computers & Industrial Engineering*, 145, 106517.
- 33- Bobar, Z., Božanić, D., Djurić, K., & Pamučar, D. (2020). Ranking and assessment of the efficiency of social media using the fuzzy AHP-Z number model-fuzzy MABAC. *Acta Polytechnica Hungarica*, 17(3), 43-70.
- 34- Abdelwahab, M., Parque, V., Elbab, A. M. F., Abouelsoud, A. A., & Sugano, S. (2020). Trajectory tracking of wheeled mobile robots using z-number based fuzzy logic. *IEEE Access*, 8, 18426-18441.
- 35- Bozanic, D., Tešić, D., & Milić, A. (2020). Multicriteria decision making model with Z-numbers based on FUCOM and MABAC model. *Decision Making: Applications in Management and Engineering*, 3(2), 19-36.
- 36- Qiao, D., Shen, K. W., Wang, J. Q., & Wang, T. L. (2020). Multi-criteria PROMETHEE method based on possibility degree with Z-numbers under uncertain linguistic environment. *Journal of Ambient Intelligence and humanized computing*, 11, 2187-2201.
- 37- Huang, Z., Zhang, H., Wang, D., Yu, H., Wang, L., Yu, D., & Peng, Y. (2023). Preference-based multi-attribute decision-making method with spherical-Z fuzzy sets for green product design. *Engineering Applications of Artificial Intelligence*, 126, 106767.