Global Journal of Pure and Applied Mathematics.
ISSN 0973-1768 Volume 12, Number 1 (2016), pp. 875-886
© Research India Publications
http://www.ripublication.com

Particle Swarm Optimized Fuzzy Control of structure with Tuned Liquid Column Damper

Salsala Abubaker[1], Dr. S Nagan[2] and Dr. T Nasar[3]

[1] *Ph.D Research Scholar, Department of Civil Engineering,*
Noorul Islam University, Thucklay, India.

[2] *Associate Professor, Department of Civil Engineering,*
Thyagarajar College of Engineering, Madurai, India.

[3] *Assistant Professor, Department of Applied Mechanics and Hydraulics,*
National Institute of Technology Karnataka, Surathkal, India.

Abstract

Modern civil engineering structures are long and slender and they have less damping. Therefore they are subjected to large vibrations when earthquake or wind acts. These excitations may cause structural collapse of the structure. Therefore to control these vibrations supplementary control devices are used. Tuned liquid column damper (TLCD) is one of a passive control device to reduce the excitations. TLCD will transfer the energy from the structure to TLCD by the motion of water in a U-shape tube like devices fitted with an orifice opening. Due to this motion the excitations will reduced. Also a fuzzy controller is designed to control the output of the TLCD. In this paper, particle swarm optimized (PSO) fuzzy controller was introduced in to the TLCD-structure system. The PSO will optimize the IF-THEN rules of fuzzy controller. The optimized results are compared with structure without TLCD, and fuzzy controlled TLCD-structure system. From this paper, the vibrations can be effectively suppressed with the proposed fuzzy controller.

Keywords Vibrations, Tuned liquid column damper, Control device, Fuzzy logic controller, Particle swarm optimization.

INTRODUCTION

Recent civil engineering structures are light, long and low damping structures. Hence the excitation will affect the stability of the structures. Hence the researchers focus on the structural control which decreases the excitations by dissipating the energy. The structural control can be done in three ways: as active, passive and semi active. There is no need of external force in passive system, but in an active system a large amount of external force was needed for its working. A small external power source like battery is used in Semi active devices.

Tuned liquid column dampers (TLCD) are one of the varieties of a tuned liquid damper (TLD). This will reduce the vibrations by transferring the energy from the main structure to TLCD by the motion of water in a U-shape tube. Firstly the TLCD was proposed by Sakai *et al* [7]. The review of control devices is given [1]. Hybrid liquid column damper was suggested by Haroun *et al* [2]. Abe *et al* [3] studied the control laws for semi active TLCDs. Yalla *et al* [4], [5], Hrovet *et al* [6] etc were worked with semi active TLCD. Zeigler [8], Soong [9], Adeli [10] etc were also worked with various aspects of TLCD. Xu *et al* [12], Kareem [13], Sun *et al* [14] etc were studied the response of structures with TLCD to wind excitations. T.k Datta [15] studied about the active control devices. The response of structures with TLCD in earthquake loading was studied by Won *et al* [19]. Control algorithms are detailed in [11] and [18]. Pourzeynali [17] applied fuzzy control in variable stiffness device.

The nonlinear behaviour of the structure due to excitation can be accounted by fuzzy logic. Fuzzy logic has been used in semi active control to vary mechanical properties. The fuzzy theory was first introduced by Zadeh [20] and Mamdani [21] successfully used ‘IF-THEN’ rule on the control of a steam generator, by applying Zadeh’s theories of linguistic approach and fuzzy inference. Brown and Yao [22], Juang and Elton [23] etc were applied the fuzzy set theory in civil engineering.

Smart control methods provide a method of approximate reasoning like human decision making process. Fuzzy controller is one of a smart control method. Fuzzy logic provides a formal idea for presenting and implementing human knowledge about how to control a system. The effectiveness of the fuzzy controlled system which is subjected to unit step force is studied.

THE STRUCTURE-TLCD SYSTEM

The structure-TLCD system is shown in Fig 1.

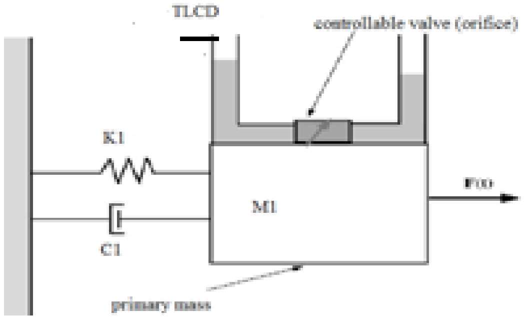


Figure 1: The structure-TLCD system

The equation of motion of the above system can be written as [1]:

$$\begin{bmatrix} M_1+m_d & \propto m_d \\ \propto m_d & m_d \end{bmatrix}\begin{bmatrix} \ddot{x}_s \\ \ddot{x}_d \end{bmatrix}+\begin{bmatrix} C_1 & 0 \\ 0 & 0 \end{bmatrix}\begin{bmatrix} \dot{x}_s \\ \dot{x}_d \end{bmatrix}+\begin{bmatrix} K_1 & 0 \\ 0 & k_d \end{bmatrix}\begin{bmatrix} x_s \\ x_d \end{bmatrix}=\begin{bmatrix} F(t) \\ 0 \end{bmatrix}+\begin{bmatrix} 0 \\ 1 \end{bmatrix}u(t) \qquad (1)$$

Where,

M_1 –structural mass
C_1 – damping coefficient of the structure
K_1 – structural stiffness
x_s – structural displacement
$\dot{x}_s$ – structural velocity
$\ddot{x}_s$ –acceleration of the structure
m_d –mass of the water column in the damper=(ρA*l*)
k_d –stiffness of the water column in the damper=(2ρAg)
x_d –displacement of the water in the damper
$\dot{x}_d$ –velocity of the water in the damper
$\ddot{x}_d$ –acceleration of the water in the damper
ρ _ density of water
A-area of cross section of the tube
l-total length of the water column
α-length ratio (= b/*l*)
b-horizontal length of the column
g-gravitational constant
F(t)-external force acting in the structure
u(t)-control force

In state space form (1) represented as,

$$M\ddot{x}(t)+C\dot{x}(t)+kx(t)=E_1W(t)+B_1u(t) \qquad (2)$$

Then the state space form,

$$\dot{x}(t)=AX+Bu \qquad (3)$$

Where X=$\begin{bmatrix} x \\ \dot{x} \end{bmatrix}$

A=$\begin{bmatrix} 0 & I \\ -M^{-1}K & -M^{-1}C \end{bmatrix}$

B=$\begin{bmatrix} 0 \\ M^{-1}B_1 \end{bmatrix}$

The building response can be represented as

$$Y=CX+Du \qquad (4)$$

Where,

C=[I], D=[0]

FUZZY CONTROL

The schematic diagram of fuzzy controller is shown in Figure 2.

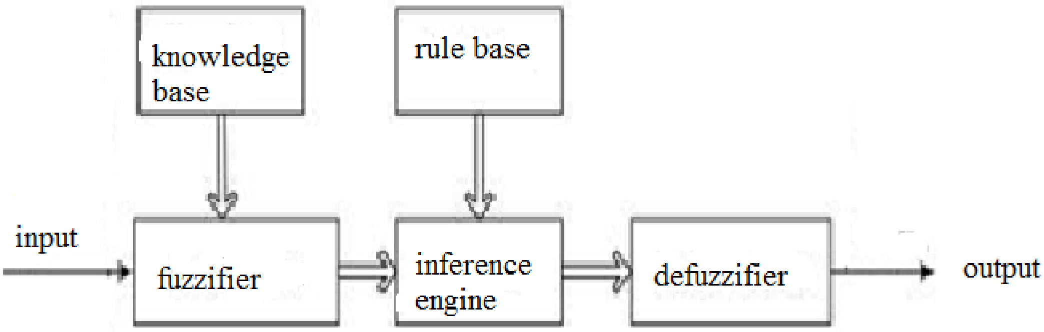


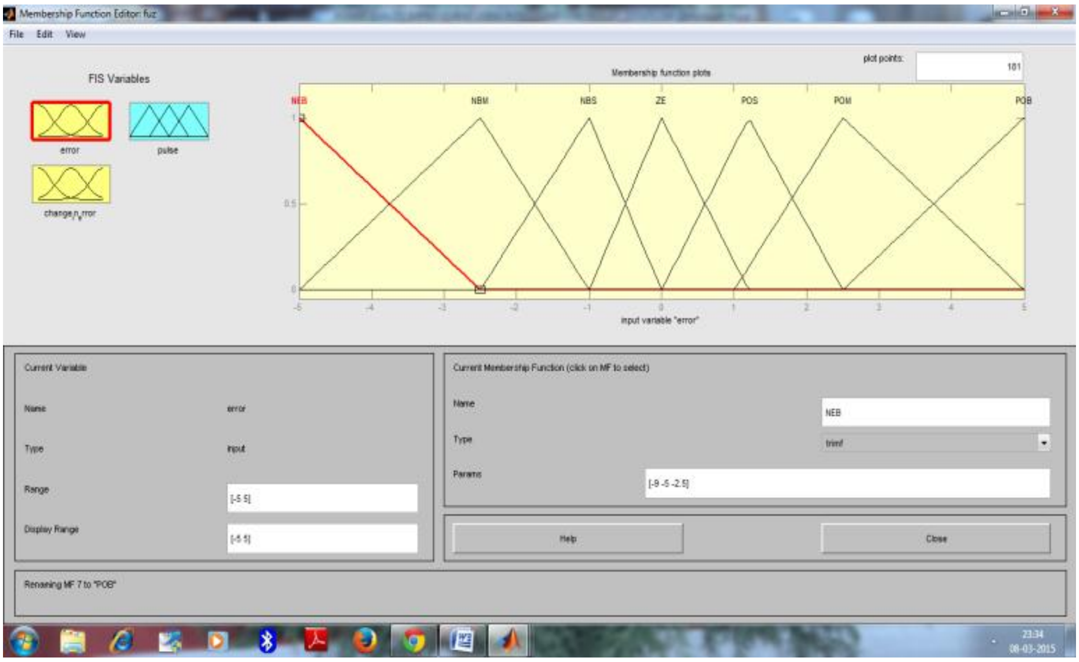
Figure 2: Fuzzy controller

Fuzzification (fuzzifier) part converts crisp input values into fuzzy values. The knowledge base consists of a database of the plant. It gives all the required definitions for the fuzzification process. Rule base represents the controlling system of the network. It is represented as a set of if-then rules. Inference applies fuzzy reason to rule base to obtain the output. Defuzzification process converts fuzzy output to crisp values.

The fuzzy logic controller designed here consists of two inputs, namely error (er), change in error (cer) and an output (cf). Seven linguistic variables are selected and they are NEB, NEM, NES, ZE, POS, POM and POB. A rule base with strength of forty nine rules is created by interconnecting different variables. The rule base is given in Table 1. Triangular shaped membership functions are chosen and are shown in the Figures 3 to 5. Fuzzy logic controller is implemented by using fuzzy logic toolbox of Matlab Simulink.

Table 1: Rule base for fuzzy controller

e \ de	NEB	NEM	NES	ZE	POS	POM	POB
NEB	NEB	NEB	NEB	NEB	NEM	NES	ZE
NEM	NEB	NEB	NEB	NEM	NES	ZE	POS
NES	NEB	NEB	NEM	NES	ZE	POS	POM
ZE	NEB	NEM	NES	ZE	POS	POM	POB
POS	NEM	NES	ZE	POS	POM	POB	POB
POM	NES	ZE	POS	POM	POB	POB	POB
POB	ZE	POS	POM	POB	POB	POB	POB



Current Variable

Name error

Type input

Range [-5 5]

Display Range [-5 5]

Current Membership Function (click on MF to select)

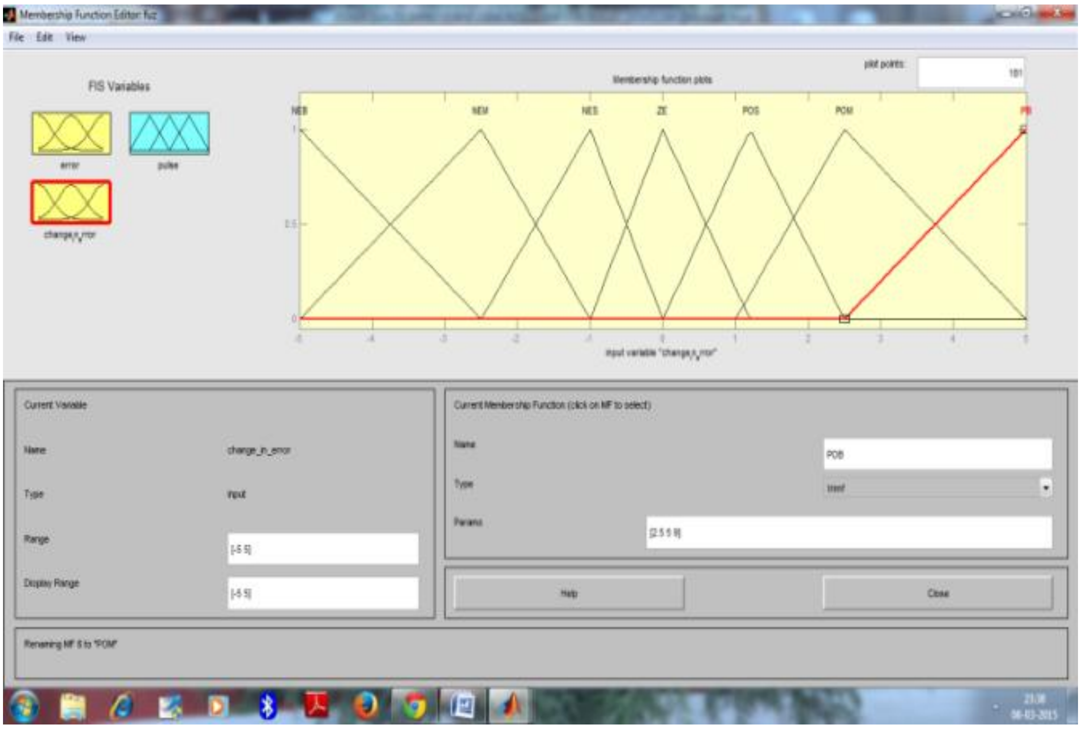
Name NEB

Type trimf

Params [-9 -5 -2.5]

Renaming MF 7 to "POB"

Figure 3: Membership function for input1.



Current Variable

Name change_in_error

Type input

Range [-5 5]

Display Range [-5 5]

Current Membership Function (click on MF to select)

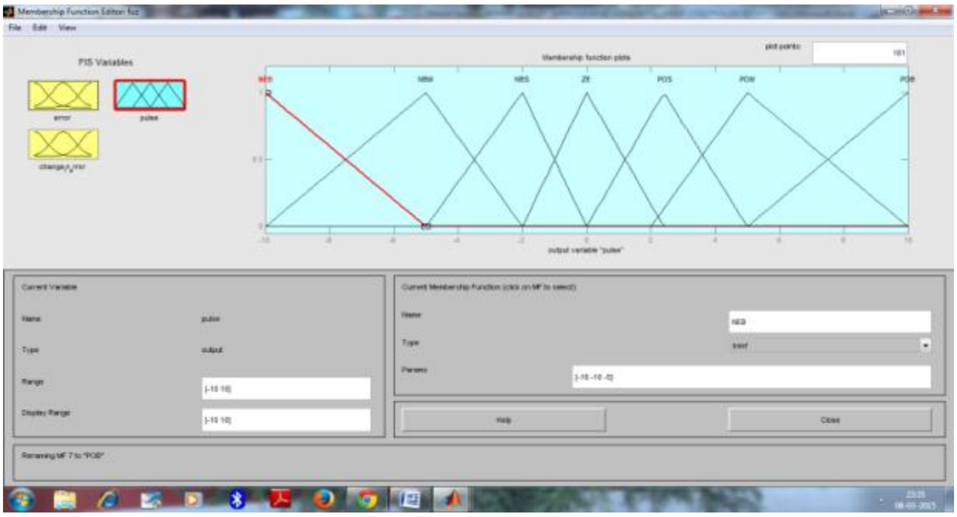
Name POB

Type trimf

Params [2.5 5 9]

Renaming MF 6 to "POM"

Figure 4: Membership function for input 2.



Current Variable

Name pulse

Type output

Range [-10 10]

Display Range [-10 10]

Current Membership Function (click on MF to select)

Name NEB

Type trimf

Params [-10 -10 -5]

Renaming MF 7 to "POB"

Figure 5: Membership function for output

PROPERTIES OF TEST SYSTEM

The system is shown in Figure 6,[6]. The lumped mass on each floor of the structure is 1313386 kN and the stiffness matrix K in kN/m is

$$\left(\frac{4.5}{0.0254}\right)\begin{bmatrix} 2000 & -1000 & 0 & 0 & 0 \\ -1000 & 4800 & -1400 & 0 & 0 \\ 0 & -1400 & 6000 & -1600 & 0 \\ 0 & 0 & -1600 & 6600 & -1700 \\ 0 & 0 & 0 & -1700 & 7400 \end{bmatrix}$$

The damping ratio of structure is assumed to be 3% in each mode. From the eigen value, we got the natural frequency as 0.23, 0.35, 0.42, 0.49 and 0.56 Hz.

The TLCD is placed on the top floor of the structure. The TLCD is designed as the liquid mass of TLCD is 1% of first generalized mass of structure, the length ratio α of TLCD is 0.9 and ξmax=15.

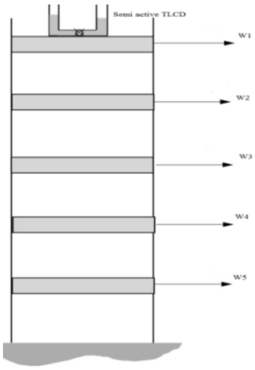


Figure 6: The MDOF structure-TLCD system

The structure only is converted in to single degree of freedom and TLCD represented as second mode. Hence the combined system expressed as two degree of freedom system. The structure-TLCD system is analyses as TMD analogy system as in Figure 1 and simulation done in Matlab Simulink. The system identification in Matlab Simulink was done as state space form. In this paper unit step loading is used for excitation. The analysis was done with structure without TLCD, with fuzzy controlled TLCD and PSO optimized fuzzy controlled TLCD system.

PARTICLE SWARM OPTIMIZATION

Particle swarm optimization (PSO) is one of the optimization techniques in order to optimize the performance of fuzzy logic controller. Here PSO optimize the fuzzy rules of fuzzy logic controller to get the optimized results. In PSO the initial population of the system is selected in a random manner and reaches the optimal solutions by updating the different generations. The potential solutions in PSO is called particles, move through the problem space by following the recent optimum particles [24].

Every particle monitors its coordinates in the problem space, which are related with the best fitness value it has reached so far. The best fitness value is also stored and that value is called pbest. Similarly another best value that is taken by the particle swarm optimizer is the best value, obtained so far by any particle in the neighbours of the particle. This position is called fbest. When a particle takes all the population as its adjacent neighbours, the best value is a global best and is called gbest. The algorithm process can be explained by the following steps:

1. Initialization each particle in the population, and take X(i) and V(i) randomly.
2. Evaluate the objective function of X(i) and calculate the value of fitness(i).
3. Initialize Pbest(i) with a copy of X(i).
4. From the values of fitness(i) select best value and keep it as the new fbest.
5. Choose the particle with the best fitness value from all the particles in the population as the gbest.
6. For each particle calculate velocity of the Particle and update the value of particle position.
7. Check the selected gbest value is right or wrong.
8. Repeat the process from step 2 until maximum iteration is reached.

The new optimized rule base of fuzzy logic controller is given in Table 2.

Table 2: PSO Optimized Fuzzy Logic Rule Base

de e	NEB	NEM	NES	ZE	POS	POM	POB
NEB	NEB	NEB	NEB	NEM	NES	NES	NES
NEM	NEB	NEM	NEM	NES	NES	NES	NES
NES	NES	NES	NES	NES	NES	NEM	NEM
ZE	NES	NES	ZE	ZE	ZE	ZE	ZE
POB	POS	POS	POS	POS	POS	POS	POS
POM	POS	POS	PO	POM	POM	POM	POB
POB	POS	POS	POM	POM	POB	POB	POB

RESULTS

First the system is analyses with structure only i.e. structure without the TLCD. The block diagram of the system is shown in the Figure 7. Then fuzzy controlled TLCD system is analysed. The Matlab Simulink test model is given in Figure 10. Again the fuzzy controlled system optimized using PSO.

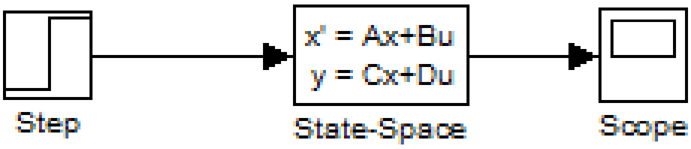


Figure 7: Structure without TLCD

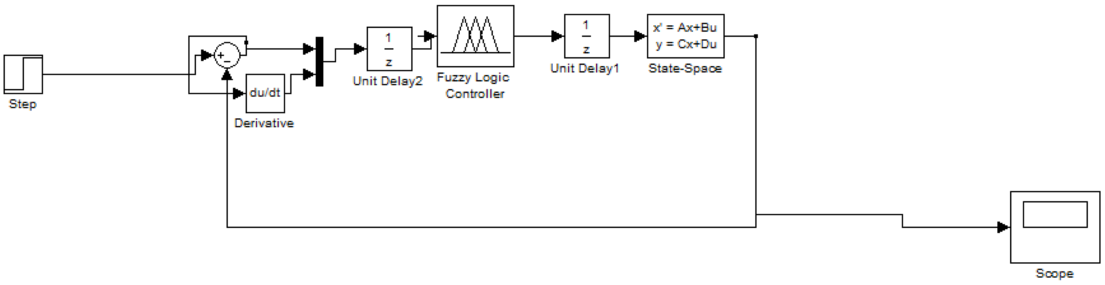
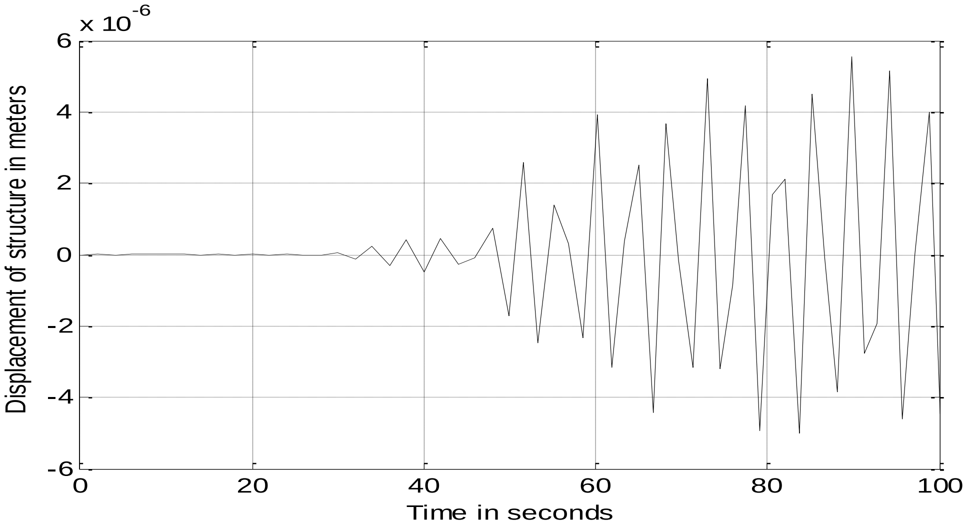


Figure 8: Fuzzy controlled structure-TLCD system.

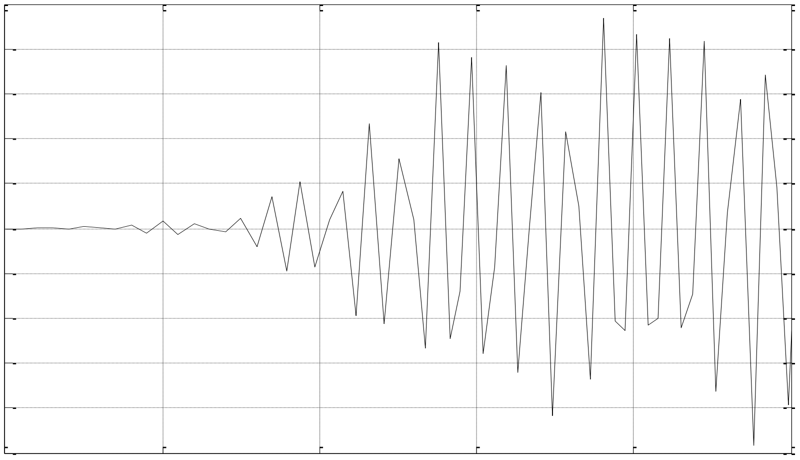
The simulation results of each system are shown in Figures 9, 10 and 11 respectively. The absolute maximum displacement of each system is given in Figures.

From the Figures 9 to 11, the absolute maximum displacement for structure only is 5.5 x10^{-6}m and that for fuzzy controlled systems and optimized systems are 2.28x10^{-6}m and 2.23x10^{-6}m. The absolute maximum displacement of optimized fuzzy controlled system is smaller than other systems. The percentage reduction in fuzzy controlled system is nearly 58.8% and in optimized fuzzy controlled system, the reduction in response is nearly 59.7%. Therefore fuzzy control with TLCD is more effective than structure without any control. It will give more response reduction than structure only. The most effective method to reduce the vibrations due to the loading is the optimized fuzzy controlled system. The displacement is reduced by modifying the rule base. Therefore we can conclude PSO optimized fuzzy control will be more superior to other systems.



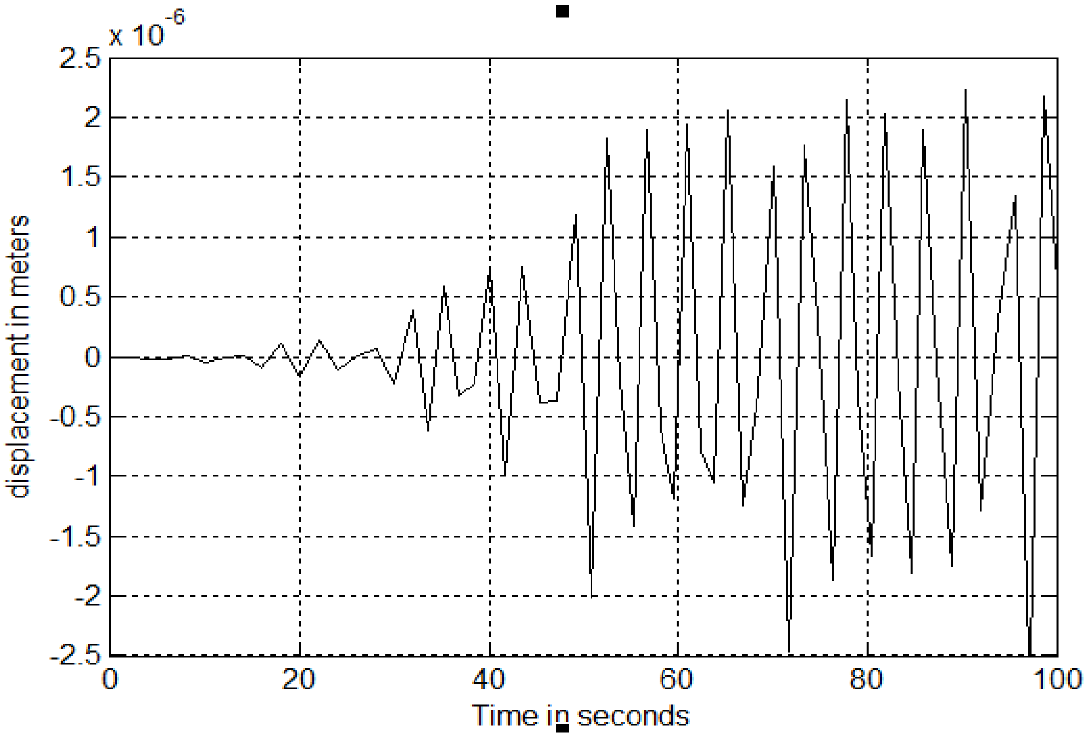
Abs.Max:5.5x10^{-6}m

Figure 9: Output of structure only



Abs.Max: 2.28x10^{-6}m

Figure 10: Output of fuzzy controlled system.



Abs.Max: 2.23x10^{-6}m

Figure 11: Output of PSO optimized fuzzy controlled system.

CONCLUSION

From this study, we can see that optimized fuzzy controlled system is more efficient than other controlled systems. The performance of optimized fuzzy controlled system is increased by modifying the rule bases. TLCD is also very efficient in reducing vibrations due to the external forces. A combination of different intelligent control techniques can be applied for the control of structural displacements. The performance of the structure-TLCD system can be further improved by the application of hybrid optimization techniques.

REFERENCES

[1] Housner GW, Bergman LA, Caughey TK, Chassiakos AG, Claus RO, Masri SF et al. “Structural control: past, present, and future”.J Eng Mech 123(9):897-971,1997.

[2] Haroun MA, Pires JA. “Active orifice control in hybrid liquid column dampers. In: Proceedings of the First World Conference on Structural Control”, vol. I, Los Angeles, FA1. USA: IASC,1994:69-78,1994.

[3] Abe M, Kimura S, Fujino Y. "Control laws for semi-active tuned liquid column damper with variable orifice opening. Paper presented at 2nd International Workshop on Structural Control", Hong Kong, December 1996.

[4] S.K. Yalla, A. Kareem, J.C. Kantor, "Semi-active tuned liquid column dampers for vibration control of structures",Eng. Structures, 23, pp:1469-1479, 2001.

[5] S.K. Yalla , A. Kareem, "Optimum absorber parameters for tuned liquid column dampers", J. Structural Eng., 126, PP:906-915, 2000.

[6] Hrovat D, Barak P, Rabins M, "Semi-active versus passive or active tuned mass dampers for structural control" J EngMech, ASCE;109(3),pp:691-705, 1983.

[7] Sakai F, Takaeda S, Tamaki T. "Tuned liquid column damper-new type device for suppression of building vibrations",In: Proceedings of international conference on high rise buildings,pp: 926-31, 1989.

[8] Ziegler F, "The tuned liquid column damper as the cost-effective alternative of the mechanical damper in civil engineering structures", Int J Acoustics Vib, pp: 12(1):25-39, 2007.

[9] Soong TT "Active structural control-theory and practice" London and New York: Longman and Wiley, 1991.

[10] Hojjat Adeli, "Smart structures and building automation in the 21st century", The 25th International symposium in automation and Robotics in construction, June 26-29,2008.

[11] Felix Weber, GlaucoFeltrin, and Olaf Huth,"Guidelines for Structural Control", SAMCO Final Report 2006.

[12] Xu Y L, Samali B, Kwok KCS. "Control of along-wind response of structures by mass and liquid dampers" J Eng Mech, 118(1):20-39, 1992.

[13] Kareem A. "The next generation of tuned liquid dampers" In: Proceedings of the First World Conference on Structural Control, vol I, Los Angeles, FB5. USA: IASC, 19-28,1994.

[14] Sun L, Goto Y. "Application of fuzzy theory to variable dampers for bridge vibration control" In: Proceedings of the First World Conference on Structural Control, Los Angeles, CA. USA: IASC, 31-40,1994.

[15] T.K. Datta, "A state-of-the-art review on active control of structures" ,iset Journal of Earthquake Technology, Paper No. 430, Vol. 40, No. 1, pp. 1-17, March 2003.

[16] Nikos G. Pnevmatikos , "New strategy for controlling structures collapse against earthquakes", Natural Science, Vol.4, Special Issue, 667-676 , 2012.

[17] S. Pourzeynali, P. Jooeib, "Semi-active Control of Building Structures using Variable Stiffness Device and Fuzzy Logic", IJE TRANSACTIONS A: Basics Vol. 26, No. 10, 1169-1182,October 2013.

[18] Monica PĂTRAŞCU1, Ioan DUMITRACHE2, Petre PĂTRUŢ3, "A comparative study for advanced seismic vibration control algorithms". U.P.B. Sci. Bull., Series C, Vol. 74, Iss. 4, 2012.

[19] Won AYJ, Pires JA, Haroun MA. “Stochastic seismic performance evaluation of tuned liquid column dampers”, Earthquake Eng Struct Dyn 25:1259-74, 1996.

[20] Zadeh LA, “Fuzzy set” Information and Control, Vol 8:338-353, 1965.

[21] Mamdani EH, “Application of fuzzy algorithms for control of simple dynamic plants” Proceedings of the IEE 121:1585-1588, 1974.

[22] Brown CB, Yao JTP “Fuzzy sets and structural engineering”, Journal of Structural Engineering (ASCE), 109:1211-1225, 1983.

[23] Juang C, Elton DJ “Fuzzy logic for estimation of earthquake intensity based on building damage records” Civil Engineering Systems, 3:187-191, 1987.

[24] F. Valdez, and P. Melin, "Parallel Evolutionary Computing using a cluster for Mathematical Function Optimization", Nafips. San Diego CA, USA, p.p. 598-602, June 2007.

[25] K. R. Suja, I. Jacob Raglend, “Genetic Algorithm-Neuro-Fuzzy Controller (GANFC) Based UPQC Controller for Compensating PQ Problem”, European Journal of Scientific Research ISSN 1450-216X Vol.78 No.2 , pp.184-197, 2012