Passive and semi-active vibration control of base-isolated structure under blast loading at medium to long distances

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ABSTRACT

With the increasing development of military weapons around the world and the variety of explosives, terrorist attacks are growing threats. The vibration control technology is well developed against natural loads. Although blast loads are different than natural loads, this technology can also be used to reduce explosive load responses. For this purpose, passive and semi-active methods including tuned mass damper (TMD) and magnetorheological (MR) damper have been used to reduce the vibrations caused by the blast load in the base-isolated structure. In this study, a type-2 fuzzy system has been used to determine the appropriate voltage of the MR damper so that the existing uncertainties do not adversely affect its performance. The numerical simulation of two explosives at 15m from a 5 degrees of freedom system, has been performed through theoretical and empirical equations. The use of the proposed control tools along with the base isolation system showed that not only these methods can maintain the proper performance of the base isolated system but limit the displacement and possible damages at larger excitations. The comparative results show that the use of MR damper along with the base isolation system can have the best performance against blast and seismic loads. The use of this system on average reduces the maximum drift of the stories to about 36% in blast loads, 68% in far-field earthquakes and 46% in near-field earthquakes. Furthermore, the drift of the isolation bearing is significantly limited compared to the base-isolated system with TMD.

Keywords

Blast loading, magnetorheological damper, type-2 fuzzy control algorithm, tuned mass damper, base isolation.

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1. Introduction

Explosion is the process of releasing energy by a large-scale stimulus that can occur rapidly and suddenly. Explosion can produce a pressure of 10-30 GPa and a temperature of 3000-4000 [1, 2]. The explosive charge mass and the distance from the target are the two most important parameters affecting the type and severity of damage. Many researchers have proposed solutions such as protective sacrificial coatings [3] and a variety of foams [4] for local protection against blast loads. These solutions can reduce the amount of debris and restrict the damage to structural members. In addition to comprehensive local protection, the overall behavior of the structure is also very important and should be taken into consideration.

Blast loads, unlike seismic loads, are not related to the mass of the structure. Therefore, they affect the structural system in a completely different manner. Zhang and Phillips [5] used a base isolation system with shock absorbers at foundation level to reduce the response due to blast loading. Kangda and Bakre [6] simulated three different weights of explosives material at a certain distance from a 5-degree-of-freedom (5-DOF) system and studied the LRB isolators for reducing the positive and negative phase of the blast load.

Tuned Mass Damper (TMD) is a vibration control system consisting of mass, spring and shock absorber, which is usually installed at the highest elevation of the structure. The application of TMDs was successful to reduce the dynamic response of high-rise buildings or flexible long-span bridge structures subjected to fluctuating loads such as wind loads or even far-field earthquakes [7-9].

Adaptive devices have been recently gaining attention [10]. Magnetorheological dampers use fluids with the ability become semi-solid with controllable resistance due to exposure to an electric or magnetic field. The variation in properties takes place in a very short time (in the order of milliseconds) and enables the device to perform well against instant loads. The combined application of base isolation and MR dampers has been investigated in recent research papers [11, 12]. In recent years, the development and application of fuzzy logic has increased due to its flexible application and stability in nonlinear systems with uncertainty [13, 14]. Numerous studies have been conducted on type-1 fuzzy systems in the time domain [15, 16]. Recently, increasing attention has been paid to the more advanced type of fuzzy systems, named type-2 fuzzy systems [17, 18].

A control system that is not specific to a particular type of load and can perform well against a variety of possible loads and is not affected by existing uncertainties, is a reliable control system. Previous studies have shown the promising performance of seismic isolators against blast loads. Furthermore, various passive and semi-active dampers were employed to compensate for the weaknesses of base isolation systems. Nowadays, there is a need for investigating control tools and systems with the most robustness against uncertainty and the ability to effectively reduce the response of the structure. In the present study, the performance of two different control strategies in reducing the response of a 5-DOF system subjected to blast loading is investigated and compared to each other. The first control strategy includes a base isolation system with a TMD at the base level to improve the performance. The second strategy uses the MR damper to improve the performance of the isolation system at the foundation level. Due to the uncertainties related to sensor noises and the time delay, a type-2 fuzzy controller is used to determine the control voltage of the MR damper. Controlling the vibrations due to the blast load should not lead to ignoring the other important loads such as earthquakes. Therefore, the performance of the proposed methods against far- and near-field seismic loads is also evaluated.

2. Numerical simulation

In this study, in order to investigate the performance of different control systems under blast loading, the experimental model of a 5-story steel frame structure is used. The structural properties of the frame structure are presented in Table 1.

Table 1: The structural properties of the 5-DOF model

St	M(kg)	K(kN/m)	C(kg/s)
Base	$m_0 = 61200$	$k_0 = 2129.8$	$c_0 = 69938$
1	$m_1 = 53073$	$k_1 = 101196$	$c_1 = 348140$
2	$m_2 = 53073$	$k_2 = 87279$	$c_2 = 301380$
3	$m_3 = 53073$	$k_3 = 85863$	$c_3 = 296180$
4	$m_4 = 53073$	$k_4 = 74862$	$c_4 = 259810$
5	$m_5 = 53073$	$k_5 = 57177$	$c_5 = 197450$

3. Simulation of control strategies and analyses

In this study, in order to reduce the responses of the structure under blast loading at medium to long distances, two different control systems are used (Figure 1). The performance of different strategies is evaluated based on the vibrations during and after the loading phase. In the first control system, the structure is isolated from the fixed base using the isolation bearing and controlled using the TMD. In the second control system, instead of TMD, the MR damper controlled by the type-2 fuzzy algorithm, is used to mitigate the isolator displacements.

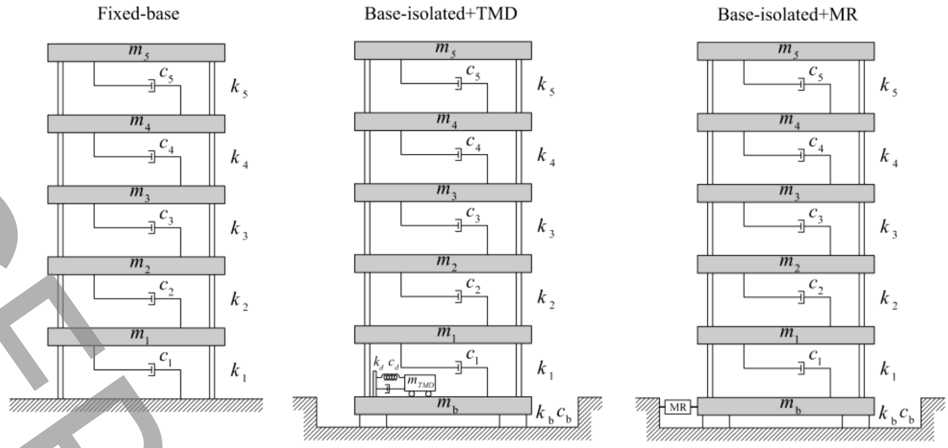

Figure 1: The 5-DOF system and control systems proposed in the current study

4. Results and Discussion

The results show that the base isolation system with MR damper has the ability to reduce the maximum and the norm displacement of the base level, which is reflected in the rapid damping in displacement response. For blast loadings, if a final force of 0.01 of the maximum force is considered, the loading times for 500 and 1000 kg of TNT will be 0.14 and 0.18 seconds, respectively, which is less than 25% of the main period of the structure. Therefore, the blast load is applied as an impact load. The results of the time history analysis using blast loading show that the maximum displacement response occurred after loading, and therefore the MR damper performs well. However, during the loading phase, the control strategies perform almost similarly, and no meaningful difference is observed.

5. Conclusions

Comparison of performance criteria describing he maximum displacement and acceleration of the base level and floors as well as the base shear of the structure, showed that the control system with an MR damper has a promising performance. This control system was able to reduce the relative displacement of the isolation bearing by 39.08% for blast load, 59.66 for far-field seismic load, and 63.81% for near-field seismic load, compared to other control systems. Moreover, the base isolation control system with MR damper was able to reduce the base shear by 95.35% for blast load, 93.07% for far-field seismic load, and 79.48% for near-field seismic load, compared to the structure with a fixed support.

6. References

[1] N.R. Council, ISC security design criteria for new federal office buildings and major modernization projects: A review and commentary, National Academies Press, 2003.

[2] H. Draganić, V. Sigmund, Blast loading on structures, Technical Gazette, 19(3) (2012) 643-652.

[3] R. Codina, D. Ambrosini, F. de Borbón, New sacrificial cladding system for the reduction of blast damage in reinforced concrete structures, International Journal of Protective Structures, 8(2) (2017) 221-236.

[4] S.P. Santosa, F. Arifurrahman, M.H. Izzudin, D. Widagdo, L. Gunawan, Response Analysis of Blast Impact Loading of Metal-foam Sandwich Panels, Procedia engineering, 173 (2017) 495-502.

[5] R. Zhang, B.M. Phillips, Performance and protection of base-isolated structures under blast loading, Journal of Engineering Mechanics, 142(1) (2016) 04015063.

[6] M.Z. Kangda, S. Bakre, Positive-phase blast effects on base-isolated structures, Arabian Journal for Science and Engineering, 44(5) (2019) 4971-4992.

[7] M. Ramezani, A. Bathaei, A.K. Ghorbani-Tanha, Application of artificial neural networks in optimal tuning of tuned mass dampers implemented in high-rise buildings subjected to wind load, Earthquake Engineering and Engineering Vibration, 17(4) (2018) 903-915.

[8] M. Ramezani, A. Bathaei, S.M. Zahrai, Designing fuzzy systems for optimal parameters of TMDs to reduce seismic response of tall buildings, Smart Structures and Systems, 20(1) (2017) 61-74.

[9] S. Salari, S.J. Hormozabad, A.K. Ghorbani-Tanha, M. Rahimian, Innovative Mobile TMD system for semi-active vibration control of inclined sagged cables, KSCE Journal of Civil Engineering, 23(2) (2019) 641-653.

[10] S. Javadinasab Hormozabad, S. Zahrai, Innovative adaptive viscous damper to improve seismic control of structures, Journal of Vibration and Control, 25(12) (2019) 1833-1851.

[11] S.J. Hormozabad, M.G. Soto, Load balancing and neural dynamic model to optimize replicator dynamics controllers for vibration reduction of highway bridge

structures, Engineering Applications of Artificial Intelligence, 99 (2021) 104138.
[12] S.J. Hormozabad, M.G. Soto, Optimal Replicator Dynamic Controller via Load Balancing and Neural Dynamics for Semi-Active Vibration Control of Isolated Highway Bridge Structures, in: Sensors and Instrumentation, Aircraft/Aerospace, Energy Harvesting & Dynamic Environments Testing, Volume 7, Springer, 2021, pp. 241-244.
[13] A. Celikyilmaz, I.B. Turksen, Modeling uncertainty with fuzzy logic, Studies in fuzziness and soft computing, 240 (2009) 149-215.
[14] R.-E. Precup, H. Hellendoorn, A survey on industrial applications of fuzzy control, Computers in industry, 62(3) (2011) 213-226.
[15] S.J. Hormozabad, A.K. Ghorbani-Tanha, Semi-active fuzzy control of Lali Cable-Stayed Bridge using MR dampers under seismic excitation, Frontiers of Structural and Civil Engineering, 14(3) (2020) 706-721.
[16] A. Sarabakha, N. Imanberdiyev, E. Kayacan, M.A. Khanesar, H. Hagras, Novel Levenberg–Marquardt based learning algorithm for unmanned aerial vehicles, Information Sciences, 417 (2017) 361-380.
[17] P. Melin, O. Castillo, A review on type-2 fuzzy logic applications in clustering, classification and pattern recognition, Applied soft computing, 21 (2014) 568-577.
[18] E. Ontiveros, P. Melin, O. Castillo, High order α-planes integration: a new approach to computational cost reduction of general type-2 fuzzy systems, Engineering Applications of Artificial Intelligence, 74 (2018) 186-197.

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