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TUNED MASS DAMPER FOR BASE ISOLATED STRUCTURES

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Résumé

Sous des séismes de forte intensité le système d'isolation parasismique peut être mené aux conditions critiques et subir des grands déplacements. Dans cette étude un système de contrôle hybride est proposé pour le contrôle des vibrations sous séismes de forte intensité, un amortisseur à masse accordé est installé sur une structure isolée pour réduire le déplacement de l'isolateur.

Une structure à comportement élastique de six dégrées de liberté et simulée sur MATLAB.

Le système hybride proposé est testé sous les chargements sismiques suivants; El Centro, Hachinohe, Kobe and Northridge. Les résultats sont comparés avec une structure équipée seulement d'un isolateur parasismique.

Les résultats trouvés montrent que le système hybride (isolation parasismique plus un amortisseur à mass accordée) est plus performant qu'a l'isolation parasismique seule en réduisant le déplacement et l'accélération de la base de la structure.

Mots clés *: Isolation parasismique ; système de contrôle hybride ; amortisseur à masse accordée ; déplacement de la base.*.

Abstract

Under strong earthquakes base isolator system could be bring to critical conditions as large displacement. In this study a hybrid control system for controlling vibration against strong earthquakes is introduced. A tuned mass damper is mounted on base isolated structure.

Simulation on MATLAB is carried out on six degrees of freedom base isolated structures with elastic behaviour.

The proposed hybrid system is tested under El Centro, Hachinohe, Kobe and Northridge earthquakes. Results are compared to the same structures equipped just with a base isolator system.

Results show that a base isolation system and a tuned mass damper (hybrid system) is more effective than a base isolation system alone, in reducing base isolation displacement and acceleration.

Key words*: Base isolation; hybrid control system; tuned mass damper; base displacement*.

ملخص

تحت تأثير الزلازل قوية الشدة يمكن لأنظمة العزل الزلزالية ان تخضع لضروف حرجة مثل التشوهات الاكبيرة.

في هذه الدراسة تم اقتراح نظام تحكم زلزالي هجين لمراقبة الاهتزازات اثناء الزلازل خاصة القوية منها،حيث يتم تثبيت كتلة اضافية على الهيكل الاساسي المزود بنضام عزل زلزالي ,للحد من حركة العازل في حد ذاته.

البناية عبارة عن هيكل سلوكه مرن ذا 6 درجات حرية, تمت محاكات الدراسة بواسطة برنامج **MATLAB**

نظام التحكم الزلزالي الهجين المقترح تم اختباره تحت اربعة تسجيلات زلزالية كالأتي: ***El centro, Hachinoche, Kobe*** و***Northridge***. النتائج المحصل عليها تمت مقارنتها مع نفس البناية المزودة فقط من عازل زلزالي على مستوى الاساسات.

النتائج المحصل عليها تبين ان النظام الهجين المقترح (عزل زلزالي في الاساسات و والكتلة المضافة) اكثر فعالية من العزل الزلزالي وحده, من خلال الحد من التشوهات والتسارع في الهيكل الاساسي على مستوى العازل.

كلمات مفتاحية *: التعليق النشط، النظام المانع للانغلاق، مسافة الكبح، التحكم بالمنطق الضبابي.*

In recent years, considerable progress has been made in the area of aseismic protective systems for civil engineering structures. Maintaining the structural integrity becomes particularly important when the structures are subjected to violent earthquakes, such as the 1994 Northridge, USA the 1995 Kobe, Japan and the 1999 Kocaeli, this kind of earthquakes can bring structures to critical conditions which result in large displacement, high velocity and acceleration.

To date, many control systems can be mounted on structures to mitigate and protect structures to earthquakes. According to the principle of operation those control systems can be classified into three general categories: passive control systems, active control systems and semi-active control systems Ahmadi (1995) [1].

The passive control systems are designed to absorb and dissipate energy; this type of system does not require an external source of energy or any algorithm of control.

Contrary to passive systems, active control systems are able to oppose to dangerous loads in a controlled manner by producing appropriate reaction forces on the structure. The intensity and variation of the force control are supervised by a controller. The active control systems are suitable for high rise buildings.

Semi active systems are a passive system which require external source of energy, this energy is used to modify parameters of the control systems, i.e. changing the damping or the stiffness.

Seismic isolation is the first passive control system proposed which consist to put between the foundation and the superstructure devices that have a very large horizontal deformability and very high vertical stiffness. These devices are able to uncouple the movement of the structure of the ground in order to reduce the forces transmitted to the superstructure. The first isolation system utilizes laminated rubber bearings; Kelly (1993) [2].

Semi-active approach consists of incorporating devices within the structure whose properties can be adjusted in real time during earthquakes improves system performance control. (Yang *et al*, 2000) [3] proposed a new resetting semi-active stiffness damper (RSASD). The performances of the proposed RSASD were investigated using two models; the first one is a three-story scaled and the second one is an eight-story full-scale building. (Agrawal *et al*, 2000) [4] proposed a semi-active electromagnetic friction damper SAEMFD, the friction force between two sliding plates is regulated by controlling the normal force using an electromagnetic field. The proposed SAEMFD is mounted on a base-isolated building. Cao (2004) [5] used an active tuned mass damper to examine the performance of new control strategies. The tuned mass damper is proposed on response parameter analysis. The Nanjing TV tower is considered in the simulation. (Kumar *et al*, 2007) [6] used the linear- quadratic optimal control algorithm to design active control system for buildings against earthquake excitations. A single degree of freedom building the proposed active tuned mass damper can reduce up to 35% in vibration of the structure than passive control.

(Aldawod *et al*, 2001) [7] studied the effect of applying a control force to a 306 –meter benchmark office tower for the city of Melbourne, Australia. The control force is generated by the mean an active tuned mass damper using the Fuzzy logic controller. The effectiveness of the proposed is tested under a long wind excitation. (Pourzeynali *et al*, 2007) [8] used a combined application on genetic algorithms and fuzzy logic controller to reduce vibration of an eleven 2D frame building to different earthquakes records.

Combining two control systems can be more effective so that, some failures noted for some system control can be avoided i.e. large lateral displacement in the case of lead rubber bearing base isolation system due to low stiffness (Tavakoli *et al*, 2014) [9]. To reduce base isolator displacement many mechanism can be used. Tsai (1995) [13] studied the effect of a tuned mass damper on the seismic response of base isolated building. The building under consideration was a 2D frame shear with six ground including basement. Palazzo (1996) [10] applied a tuned mass damper on a base isolated system subjected to random excitations.

Providakis (2008) [11] examined the Effect of LRB isolators and supplemental viscous dampers on the seismic performance of seismic isolated 3D reinforced concrete buildings under near-fault excitations. Khoshnoudian (2012) [12] applied a semi-active magneto-reologic damper to control base displacement for a 3D steel braced frame structure equipped with a high damping rubber isolators.

The main purpose of this paper is to study the effect of tuned mass to reduce base isolator displacement and acceleration; Six degrees of freedom structural system is simulated. The structural system is the same used by Tsai (1995) [13].

The tuned mass damper is installed in base slab objective to reduce base isolator displacement and acceleration. Simulations are carried under four earthquake excitations.

1. PRINCIPE OF TUNED MASS DAMPER

While passive base-isolation systems are effective for protecting seismic excited buildings, there are limitations. Passive systems are limited to low-rise buildings against moderate earthquakes. In tall buildings, uplift forces may be generated in the isolation system, leading to an instability failure. Furthermore, in some base-isolation systems, such as lead-core elastomeric bearings, large deformations may accumulate after each earthquake episode. Thus, the passive protective system alone is not sufficiently proven for the protection of seismic-excited tall buildings.

Tuned mass damper (TMD) is one other passive control, this system showed a performance on many type many types of structures and under several conditions. A tuned mass damper (TMD) is a device consisting of a mass, a spring, and a damper that is attached to a structure object to reducing undesirable vibration. The frequency of the damper is tuned to a particular structural frequency so that when that frequency is excited. Energy is dissipated by the damper inertia force acting on the structure.

The objective of this paper is to enhance the performance of a hybrid system composed of a base isolation system coupled with a TMD under strong earthquake excitations.

2. MULTI DEGREES OF FREEDOM MODEL

A six (6) story base isolated lamped structure with an elastic behavior presented by [13] figure.1 is used for applying a tuned mass damper. Only horizontal degrees of freedom are considered. The base of isolated structure is assumed as rigid mass m_b, and its displacement relative to the ground is denoted as u_b..

The isolation system has lateral stiffness k_b and damping c_d.The displacement of the tuned mass-damper relative to the base is denoted as u_d. The superstructure has 5 degrees of freedom each degree of freedom has lamped mass m_i. The corresponding displacement component u_i represent the super-structural deformation relative to the base.

While v_i. For $i = 1, \ldots, n$, denote the relative displacement between two consecutive floors, e.g. v_1 is the relative displacement between m_b and m_1.

The total mass is

$$m_f = m_b + \sum_{i=1}^{5} m_i \qquad (1)$$

The response of this base isolated building excited by ground acceleration $\ddot{u}_g$ can be written as the followings equations:

$$(m_f + m_d)\ddot{u}_b + m_d\ddot{u}_d + \sum_{i=1}^{5} m_i\ddot{u}_i + c_b\dot{u}_b + k_b u_b = -(m_f \qquad (2)$$

$$m_d\ddot{u}_b + m_d\ddot{u}_d + c_d\dot{u}_d + k_d u_d = -m_d\ddot{u}_g \qquad (3)$$

$$m_i\ddot{u}_b + m_i\ddot{u}_i + \sum_{j=1}^{5} c_{ij}\dot{u}_j + \sum_{j=1}^{5} k_{ij}u_j = -m_i\ddot{u}_g \qquad (4)$$

For $i = 1, \ldots, n$, in which c_{ij} and k_{ij} are the entries of the damping and stiffness matrix respectively of the superstructure without TMD installed on the structure.

The matrix M, C and K are given as follow :

$$M = \begin{bmatrix} m_b + \sum_{i=1}^{5} m_i & m_1 & m_2 & m_3 & m_4 & m_5 \\ m_1 & m_1 & 0 & 0 & 0 & 0 \\ m_2 & 0 & m_2 & 0 & 0 & 0 \\ m_3 & 0 & 0 & m_3 & 0 & 0 \\ m_4 & 0 & 0 & 0 & m_4 & 0 \\ m_5 & 0 & 0 & 0 & 0 & m_5 \end{bmatrix}$$

$$C = \begin{bmatrix} c_b & 0 & 0 & 0 & 0 & 0 \\ 0 & c_1 + c_2 & -c_2 & 0 & 0 & 0 \\ 0 & -c_2 & c_2 + c_3 & -c_3 & 0 & 0 \\ 0 & 0 & -c_3 & c_3 + c_4 & -c_4 & 0 \\ 0 & 0 & 0 & -c_4 & c_4 + c_5 & -c_5 \\ 0 & 0 & 0 & 0 & -c_5 & c_5 \end{bmatrix}$$

$$K = \begin{bmatrix} k_b & 0 & 0 & 0 & 0 & 0 \\ 0 & k_1 + k_2 & -k_2 & 0 & 0 & 0 \\ 0 & -k_2 & k_2 + k_3 & -k_3 & 0 & 0 \\ 0 & 0 & -k_3 & k_3 + k_4 & -k_4 & 0 \\ 0 & 0 & 0 & -k_4 & k_4 + k_5 & -k_5 \\ 0 & 0 & 0 & 0 & -k_5 & k_5 \end{bmatrix}$$

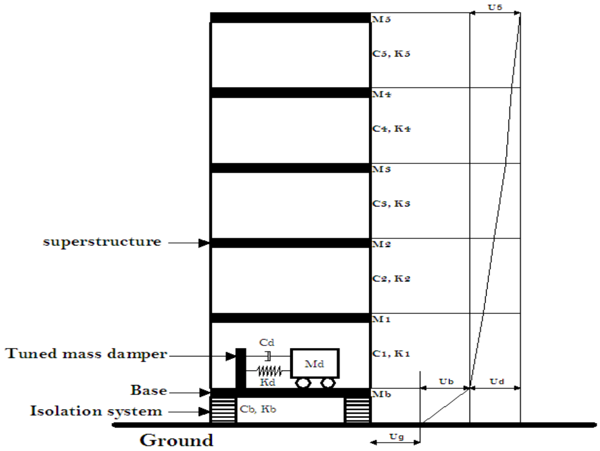

Figure 1 : Base-isolated structure with tuned mass damper

3. SIMULATION PROCEDURE

In this study, MATLAB SIMULINK with fuzzy Toolbox is used to determinate the performance of the tuned mass damper in reducing base isolator displacement and acceleration; the 6 story structure presented by [13] is used for testing the performance of the proposed hybrid control. The base isolated structure can be simplified as six degrees of freedoms. Each floor has the same mass, 3500 kg the same stiffness, 35

KN/mm and the same damping 35 Ks/mm. The total mass of the base isolated structure m_f = 21000g.

The stiffness of the isolation system is k_b = 0.21 KN/mm, the isolation damping is c_b = 2.66 Ns/mm.

Generally a base isolated structure can be simplified as a SDOF system; hence the natural frequency of the used base isolated structure is:

$$w_b = \sqrt{\frac{k_b}{m_f}} = 0.503 Hz \quad (5)$$

Parameters of the TMD are chosen to respect [14] for minimum displacement response of the primary structure.

$$w_d = \frac{w_b}{1+u} \quad (6)$$

Where w_b denotes the natural radial frequency of the primary structure and u is the selected mass ratio

$$u = \frac{m_d}{m_f} \quad (7)$$

and the damping ratio ξ_b and viscous damping coefficient c_b become

$$\xi_b = \sqrt{\frac{3u}{8(1+u)^3}} \quad (8)$$

$$c_b = 2\xi_b m_b w_s \quad (9)$$

The ration u is selected to be equal to 0.05; parameters of the chosen TMD are represented in table 3

Table 3 : Parameters of the TMD

Mass ratio u	Mass of TMD m_d	Stiffness k_b	Damping c_b
0.05	1050 Kg	9.5238e+003 N/m	845.15 NS/m

In order to compare the effectiveness of the proposed hybride systeme in reducing the base isolator displacement and acceleration; structure is excited with four strong earthquakes.

4. RESULTS AND PERFORMANCE OF THE PASSIVE HYBRIDE SYSTEM UNDER HARMONIC EXCITATION:

The response results of uncontrolled base isolated structure are compared to the same structure equipped with a TMD.

Figure 2 to figure 5 show the comparison of the base isolation displacement of structure under El Centro, Hachinohe, Kobe and Northridge earthquakes respectively.

As can be seen from the figures 2 to figure 5, a significant reduction in the base isolation displacement is obtained after few cycles of vibration where TMD mobilizes energy absorbed from the structure to oppose the vibration.

In the other side a reduction of more than 30% in base acceleration is obtained, figures 6 to figure 9. Therefore, it is seen that the proposed hybrid system is more effective than a base isolation system alone in view of reducing the base isolator displacement, acceleration response of the example structures under strong earthquakes.

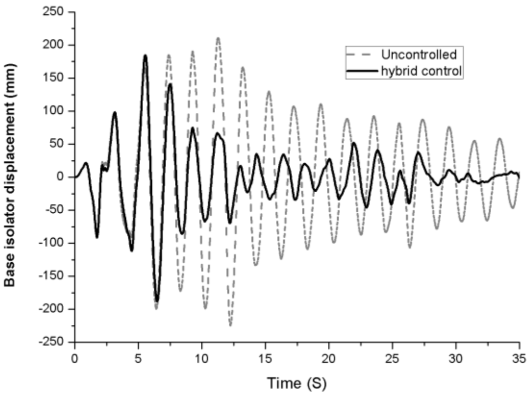

Figure 2 : Base displacement under El Centro earthquake

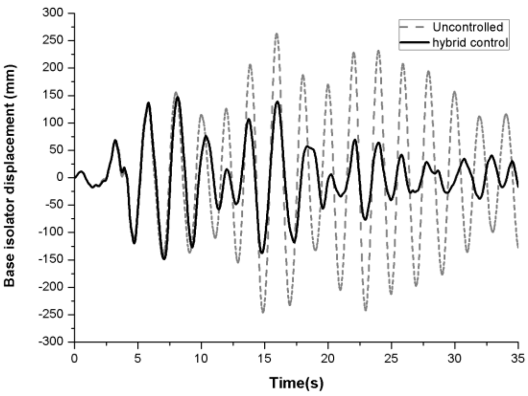

Figure 3 : Base displacement under Hachinohe earthquake

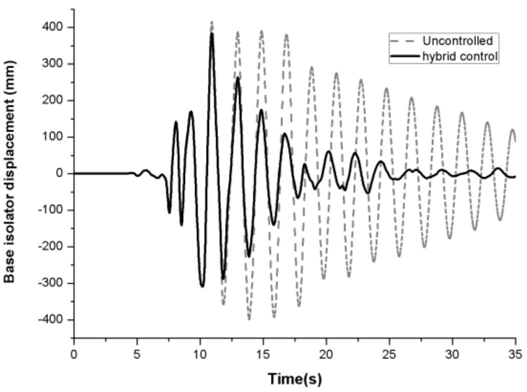

Figure 4 : Base displacement under Kobe earthquake

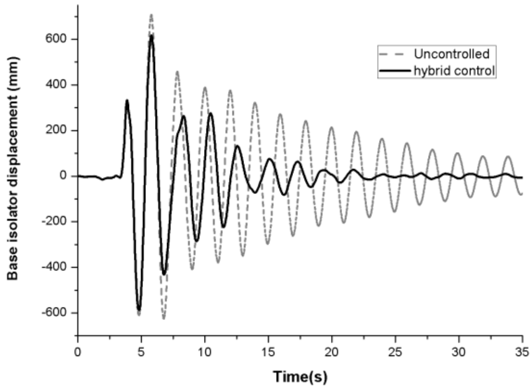

Figure 5 : Base displacement under Northridge earthquake

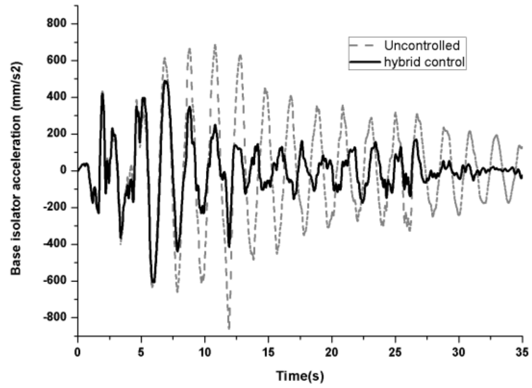

Figure 6 : Base acceleration under El Centro earthquake

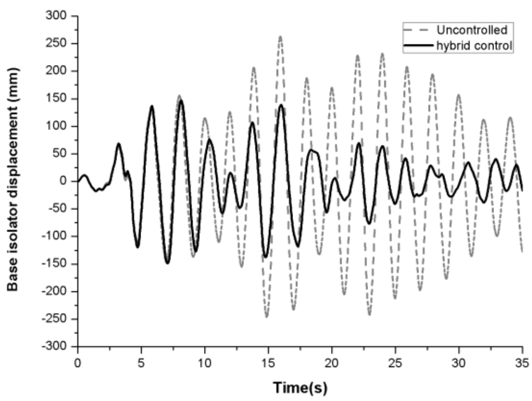

Figure 7 : Base acceleration under Hachinohe earthquake

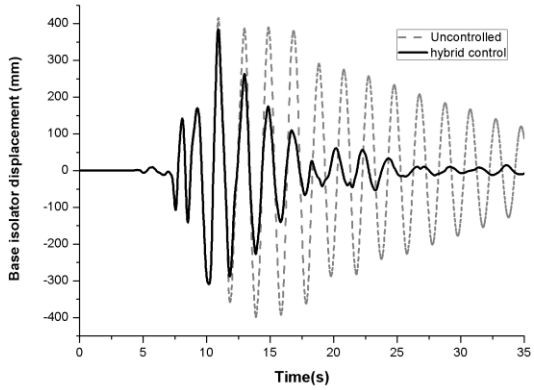

Figure 8 : Base acceleration under Kobe earthquake

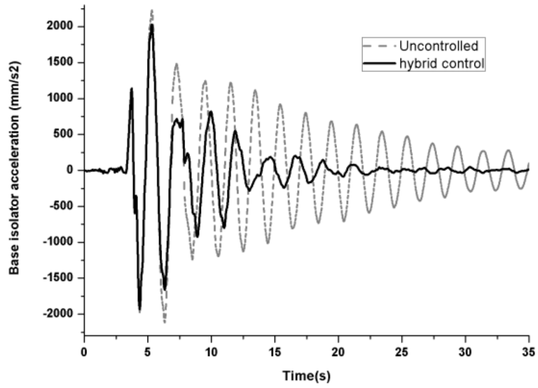

Figure 9 : Base acceleration under Northridge earthquake

CONCLUSION AND RECOMMENDATIONS

The main objective of the proposed study has been to investigate the performances of a hybrid control system within a tuned mass damper in installed on base isolated structures.

A 2D simulation on MATLAB is carried out for six (6) degrees of freedom base isolated structures equipped with a hybrid control. Four strong earthquakes excitations are used as excitation.

The performances of the hybrid control results in important decreasing in base isolator acceleration while an important reduction in base isolator displacement is obtained after several cycles of vibrations.

Further research can be done on bridge or industrial equipements equipped with the proposed hybrid control.

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