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Research Article

A systematic review of hybrid seismic control strategy

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ABSTRACT

There are numerous examples where combinations of seismic isolation and energy dispassion technology is employed in the real world. However, seldom articles has been found to provide a systematic review on this application area. This article will first give some real-world cases showing the hybrid seismic method used in the structures, especially in the seismic isolation structure. Then, the introducing of base isolation combined with TMD and other energy dissipation techniques will be reviewed. Finally, some new research areas will be given. Mainly it will be related to the study of TMD and BRBs in the base isolated structure and the application of TMD in a complex structure named twin-tower shear-wall base isolated structures with an enlarged basement.

Keywords: seismic isolation structure, energy dissipation structure, hybrid seismic control strategy

1. INTRODUCTION

Many researches has done for the earthquake and structures[1-17].In addition to the adoption of a single seismic isolation technology, there are numerous instances where a combination of seismic isolation and energy dissipation is employed. This approach provides more flexible means for mitigating seismic effects in complex structures. This article initially presents two real-world cases, followed by the introduction of base isolation combined with TMD and other energy dissipation techniques. Finally, it addresses the absence of studies on comparation between TMD & buckling-restrained braces (BRBs) in base isolation structures and the application of TMD in twin-tower shear-wall base isolated structures with enlarged basements. The detailed outline of the content is presented as follows(shown in Figure 1):

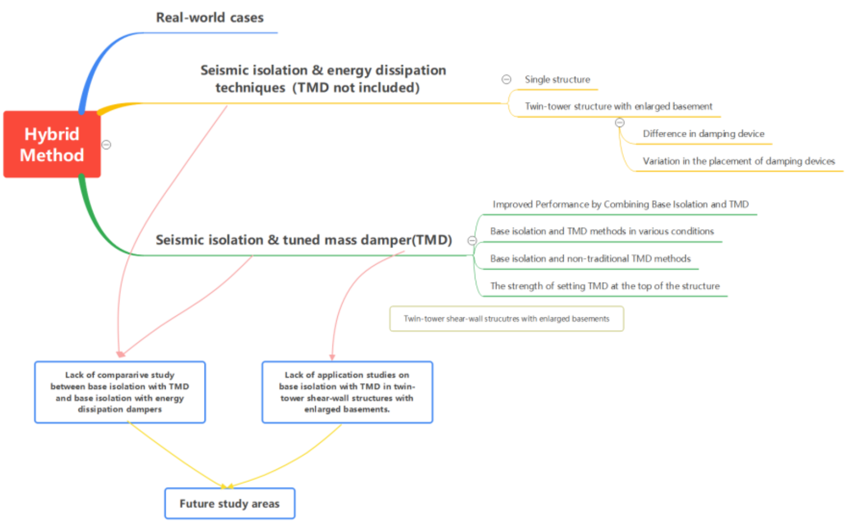

Figure 1 The outline of the study

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2. REAL-WORLD CASES

There are numerous practical applications of hybrid seismic control strategies in engineering.

- Nishimura et al. [18] presents a practical case study that combines base isolation with energy dissipation techniques. The building, which is 145m tall and consists of three towers of 42 floors each, is connected by a large base plate at the bottom and three sky-garden trusses at different heights to better resist overturning moments and coordinate structural deformation[18].
  This structure employs base isolation beneath the large basement, broad-band damper and oil damper in the sky-garden trusses connecting three towers, and Zinc-Aluminum Alloy damper on the top floor [18]. These damping devices effectively reduce inter-story acceleration [18]. The seismic effectiveness of the entire structure has been verified [18], and finally, its aerial gardens is installed.
- According to a practical structural drawing, Domenico & Ricciardi [19] established three models: fix-based structure, base isolated structure, and base isolated structure with TMD at the basement. The addition of TMD can improve seismic performance by reducing the bending moment and shear force of columns by nearly half, as well as decreasing the interlayer drift ratio by around 50%[19].

3. SEISMIC ISOLATION & ENERGY DISSIPATION TECHNIQUES（TMD NOT INCLUDED）

Seismic isolation and energy dissipation techniques can be combined to create a hybrid seismic control technology, which effectively mitigates the seismic response of structures. This part of the article presents research results on the application of hybrid seismic control technology (excluding TMD) in single and twin-tower structures with enlarged basements.

3.1 Single structure

- Wang & Wang [20] established four models using ETABS: ordinary seismic-resistant model, seismic energy-dissipation model, seismic isolation model and hybrid seismic-controlled model of isolation and energy dissipation techniques. After comparing their seismic reduction effects, it was found that the hybrid seismic-control scheme had the best effect, reaching 93% of the sum of the effects of separate use of energy dissipation and isolation[20].
- Wei[21] also established four similar models for a frame-shear wall structure: ordinary seismic-resistant model, seismic energy-dissipation model, seismic isolation model and hybrid seismic-controlled model of isolation and energy dissipation techniques. Wei[21] concluded that hybrid seismic control technology can best control story drift, followed by energy-dissipation technique alone, base isolation and ordinary seismic-resistant technique in descending order of effectiveness.
  The above has confirmed that the combination of base isolation and seismic energy dissipation technology (excluding TMD) exhibits superior seismic reduction effectiveness for single structures compared to using either technology alone.

3.2 Twin-tower structure with enlarged basement

Both Wang & Wang [20]and Wei [21] concur that hybrid control techniques (excluding TMD) have a positive impact on the seismic reduction effectiveness of structures. Therefore, the next part of this article will introduce the application of hybrid control techniques (excluding TMD) in a twin-tower structure with an enlarged basement. Additionally, it will explore the effects of different damping devices and their placement on the effectiveness of hybrid control techniques (excluding TMD).

1) Difference in damping device

- Cui & Wang [22] established four models for a twin-tower structure with enlarged basement: a. ordinary seismic-resistant structure; b. inter-story isolation at the junction of the tower and basement; c. inter-story isolation + metal dampers at the basement; d. inter-story isolation + viscoelastic dampers at the basement. Through analysis, Cui & Wang [22] concluded that for this type of twin-tower structure employing hybrid seismic control technology, viscoelastic dampers are more effective than metal dampers when used at the basement.
- In addition, Tan & Zhou [23] implemented interlayer seismic isolation measures for a twin-tower structure with an enlarged basement and utilized variable orifice (VO) damping and non-linear viscous dampers on the

isolation layer. The results indicate that the variable orifice(VO) is more effective than the non-linear viscous damper in reducing seismic response of this type of interlayer isolation structure.

2) Variation in the placement of damping devices.

Apart from the difference in damping devices, the location of these damping devices can also affect the seismic isolation effectiveness of twin-tower structure with enlarged basement.

- Liu [24] established four models of a twin-tower structure with an enlarged basement: Model 1 is an ordinary base-fixed structure; Model 2 is an interlayer isolation structure, which has an isolation layer at the junction of the tower and basement; Model 3 adds viscous dampers to the basement in Model 2; and Model 4 adds viscous dampers to floors 4-6 in Model 2. The conclusion is that this hybrid seismic control technology can improve seismic reduction effectiveness, and it works better when subjected to higher peak ground acceleration during earthquakes [24]. Additionally, placing viscous dampers in the basement provides better results than placing them on upper structures.
- Zhang et al. [25] employed a Compositive Passive Control method (CPC method): shock absorption devices were added between two towers in the interlayer-isolated structure. The analysis revealed that the CPC method exhibited superior performance in seismic response[25], particularly when the passive control element between the two towers was positioned at a higher elevation [25], as compared to the case utilizing solely the interlayer isolation technique.

4. SEISMIC ISOLATION & TUNED MASS DAMPER(TMD)

The preceding part introduced the combined employment of base isolation and conventional energy dissipation techniques. Subsequently, the following part will introduce the combined application of base isolation and TMD, which is mainly utilized in single structures.

4.1 Improved Performance by Combining Base Isolation and TMD

Although the seismic reduction effectiveness of a structure using TMD alone may not be as effective as one using base isolation alone [26], these two technologies are not mutually exclusive and their advantages can be combined. The integration of TMD and base isolation can result in even greater effectiveness than either technology used independently [27]. Instead of incorporating viscous or hysteretic damping into the isolation layer to mitigate displacement, which may increase seismic response for the superstructure, a combination of base isolation and TMD methods can effectively reduce overall structural seismic response [27]. Arfiadi et al. [28] also agrees that combining base isolation and TMD methods can reduce the displacement at the bottom of the basement without increasing story drift.

4.2 Base Isolation and TMD Base isolation and TMD methods in various conditions.

Under different ground conditions, the combination of seismic isolation and energy dissipation technologies can still effectively mitigate seismic response [29]. Furthermore, the damping performance is sensitive to ground motion frequency [27]; Wang et al.[30], TMD mass [31]and structure height [32]. When the earthquake frequency approaches the resonant frequencies of a structure, Tuned Mass Dampers (TMDs) can effectively reduce the structural seismic response [27]; Wang et al. [30]. Increasing the mass of TMD can also improve seismic reduction efficiency [31],[32]. Moreover, taller buildings benefit more from using TMD for seismic reduction [32].

4.3 Base isolation and non-traditional TMD methods

All of these traditional tuned mass dampers (TMDs) mentioned above are not directly connected to the ground and are typically installed on floors, especially on the topmost floor. Placing TMDs directly on the structure's floor can increase its vertical load, particularly for those with significant mass, which is detrimental to the structure's vertical bearing capacity. This issue can be avoided by installing TMDs at the bottom of the structure and connecting them to the ground[33].

Naderpour et al.[34] proposed a novel system that integrates both base isolation and non-traditional TMD connected to the ground, resulting in over 80% reduction of seismic response. However, this requires additional clearance at the bottom due to TMD displacement. Based on this, it has been suggested by Hashimoto et al.[33] to introduce an inertia mass damper between the bottom of the isolation layer and TMD for mitigating excessive displacement of TMD.

Another approach involves connecting TMD to the ground by introducing other energy dissipation dampers between them, thereby enhancing its performance. Domenico & Ricciardi [35] added an inerter between the TMD and the ground, thus becoming the Tuned Mass Damper Inerter (TMDI). Combining TMDI with base isolation techniques forms a new system. The TMDI enhances the stability of the structure under diverse seismic conditions by reducing its sensitivity to both tuning and earthquake frequencies [35]. Similarly, Zhang et al. [36] has developed a tuned interaction damper, which effectively mitigates the basement displacement while maintaining the interlayer drift and acceleration of the superstructure at a relatively low level.

4.4 The strength of setting TMD at the top of the structure

Although connecting the non-traditional TMD with an extra energy dissipation device to the ground at the bottom of the structure has additional benefits. For those structure that use traditional TMDs (not connecting to the ground) with base isolation system, placing the traditional TMD on the top floor of the structure can more effectively reduce seismic response [37]. Stanikzai et al [32] developed three base-isolation models consisting of 5, 10, and 15 floors respectively, placed Tuned Mass Dampers (TMDs) on different floors, and evaluated their displacement at the isolating bearings and top floor acceleration as illustrated. It is evident that for a higher base isolation structure, locating TMDs on the top floor results in minimal seismic response in terms of bearing displacement and top floor acceleration[32].

5. CONCLUSION AND FUTURE STUDIES

This article primarily introduces the combined application of base isolation and energy dissipation technology, including real-world cases, the integration of seismic isolation with tuned mass damper (TMD), and the implementation of seismic isolation in conjunction with other energy dissipation techniques. However, a direct comparison between the use of TMD and BRB in base isolation structures is lacking, as well as the application of base isolation structure with TMD in twin-tower shear-wall structures with enlarged basements. This can be the new study areas for the future

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