13th World Conference on Earthquake Engineering
Vancouver, B.C., Canada
August 1-6, 2004
Paper No. 2993

STATUS OF APPLICATIONS OF PASSIVE CONTROL TECHNOLOGIES IN TAIWAN

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SUMMARY

Research and application of passive control technologies for structures in Taiwan have become very active in the 1990's. Many passive control devices, such as triangular steel plates, buckling restrained braces, viscoelastic dampers, viscous dampers, and various forms of seismic isolators, etc., have been studied extensively. These studies have resulted in many practical applications and design provisions for seismic isolation design of bridges and buildings, especially after the 1999 Chi-Chi earthquake. This paper summarizes the progress of code development and applications of seismic passive control devices in Taiwan. Typical construction examples for various passive control devices are also introduced.
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INTRODUCTION

Research and application of earthquake protection system in Taiwan have become very active since late 1980's thanks to very significant investments in experimental facilities in the universities [1]. Many passive control devices, such as triangular steel plates (TADAS)[2], buckling restrained braces [3], viscoelastic dampers [4], viscous dampers [5], and various forms of seismic isolators [6,7,8] such as lead rubber bearings, high damping rubber bearings, etc., have been studied extensively. However, before the major earthquake of 1999 Chi-Chi earthquake occurred, there were only limited applications of the passive control techniques, including about a dozen bridges design with seismic isolators and a few buildings designed with active or passive dampers for wind response control. After Chi-Chi earthquake, the applications of various seismic passive control devices have been quite extensive in Taiwan. To date the seismic control technologies, including seismic isolation and energy dissipation, have been applied to the constructions of national freeway bridges, Taiwan High Speed Rail brides, medical centers, high-tech industrial structures, bank data center, residential buildings, elementary school buildings, etc. These applications include new construction and retrofit design. Up to July 2003, there are at least 17 buildings constructed or retrofitted with seismic isolators and 47 buildings constructed with various passive energy dissipation devices, in addition to more than twenty bridges constructed with lead rubber bearings or high damping rubber bearings. In addition, a seismic isolation design code for buildings has become a national

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building code and a draft design provisions for seismic isolation design of bridges and buildings have been proposed.

This paper first summarises the progress on the code development of passive control devices in Taiwan. Selected examples on the design and construction of buildings and bridges using passive energy dissipation devises and seismic isolators will be illustrated and discussed.

PROGRESS OF THE DESIGN CODES

Seismic isolation of structures has been widely used in many countries such as Japan, U.S. and China, and the buildings with isolation design have been proven to be very effective during the 1994 Northridge Earthquake and the 1995 Kobe earthquake. As this new seismic resistant design technology becomes more and more mature, the associated design codes and specifications have also been developed [9,10]. In Taiwan, the effort on developing seismic design codes for seismically isolated buildings started in 1997 as a research project funded by the Architecture Research Institute of the Minister of Internal affairs. The rational of this draft design code follows that UBC94 and UBC 97. It was under a series of official reviews and finally became an official design code in April 2002. Major sections in the code includes Introduction, Static Analysis and Design, Dynamic analysis and design, Regulations for inspection and testing, etc. Under this design code, the structure would remain elastic under the 475 year return period design earthquake in Taiwan. The need to carry out ductile design and construction for structures with seismic isolation design has also been lessen.

A new draft design code for seismic design of buildings has been proposed in 2002. New features in this draft include microzonation of the seismicity in Taiwan, addition of a 2500 year return period design earthquake, a chapter for seismic isolation design, and a chapter for seismic design of structures with passive energy dissipation devices. This draft code is in the final phase of review and debate before being announced as an official seismic design building code in Taiwan.

SUMMARY OF APPLICATIONS

Hysteretic Type Dampers

The hysteretic dampers used in Taiwan include the triangular added stiffness and damping damper (TADAS), reinforced ADAS damper (RADAS), low yield steel shear panel (LYSSP), Buckling Restrained Braces (BRB) or unbonded brace, etc. Typical examples adopting these dampers are shown in Figs. 1-6. Among the hysteretic energy dissipation systems, the number of applications of the BRB is increasing due to the reason that the brace can improve the weakness of the traditionally concentrical brace system and the eccentrical brace system.

A typical example for seismic retrofit application is the She-Hwa Bank that locates in Taichung, the central city of Taiwan (Fig. 5). The forty-seven story building was under construction when the 1999 Chi-Chi earthquake occurred. Although the building experienced the major earthquake without any damage, in order to upgrade the seismic capacity of the building due to the code change (design PGA from 0.23g to 0.33g), the bucking restrained braces (BRB) have been adopted to improve its seismic capacity (Fig. 5).

A typical example for the new design case is the Tzu-Chi TV Station located in Taipei (Fig. 6). By using the BRB, the story drift of the building has been improved from 0.37% to 0.3%.

Velocity Type Dampers

The velocity type of damper encompasses visco-elastic dampers (VE), viscous dampers (VD) and viscous damping walls (VDW). The applications are given in Figs. 7-12. Currently, there have been more applications using viscous dampers than other velocity type dampers. This may be due to the facts that the design procedure for implementing the viscous damper is relatively simpler and the analytical model is available in the popular computational tools such as SAP2000N and ETABS.

A typical example of application of the VE damper is shown in Fig 7. In order to upgrade the seismic capacity to a design earthquake of 0.35g while keeping the architectural functions intact, this building adopted both the panel type (Fig.7b)and brace type VE dampers. Since the panel type VE dampers were the first time to use, an extensive research program was carried out jointly by NCREE, TIT and Nippon Steel. In addition to testing of the reduced scale model using the shake table, dynamic cyclic loading tests of full-scaled models were carried out to confirm that the dampers satisfy the design criteria (Fig.7c).
The first application of the viscous damper is the Taishin bank in Taipei (Fig. 8). The building has started construction when the Chi-Chi earthquake occurred. In order to improve the lateral drift, viscous dampers were added to the ductile steel moment resisting frame in inverted V shaped. Due to the addition of the viscous dampers, the drift ratio of this building under the design earthquake has been improved from 1.9% to 0.9%.

Seismic Isolation of Bridges

The first seismically isolated bridge in Taiwan was completed in early 1999. Seven new bridges (Fig. 13a) of the Second National Freeway located at Bai-Ho area, a region which is considered to be of high seismic risk, have been designed and constructed with lead-rubber seismic isolation bearings (Fig 13b). Since this is the first application of seismic isolation method to the practical construction in Taiwan, field tests were conducted for one of the seven bridges to evaluate the assumptions and uncertainties in the design and construction [11]. The test program is composed of ambient vibration tests, forced vibration tests, and free vibration tests. For the free vibration tests, a special test setup composed of four 1000kN hydraulic jacks and a quick-release mechanism was designed to perform the function of push-and-quick release (Fig. 13c). Valuable results have been obtained based on the correlation between measured and analytical data so that the analytical model can be calibrated. Based on the analytical correlation, it is concluded that the dynamic characteristics and free vibration behavior of the isolated bridge can be well captured when the nonlinear properties of the bearings are properly considered in the modeling.
The recorded Bai-Ho bridge response data under the 1022 Gia-Yi earthquake is used to assess the adequacy of the bridge model under a moderate earthquake. Based on the integration of measured acceleration records, the estimated deformation of the LRB is approximately equal to 3.4 cm. According to the result of the full-scale component tests, the bilinear behaviour of the LRB is not apparent under such a small displacement. The viscous damping provided by the rubber material is comparable to the hysteretic damping provided by the bilinear behaviour. Thus, a linear viscous damper element with 5% damping ratio is added in the modelling to simulate the viscous damping behaviour of the LRB. Besides, 2% inherent damping ratio is assumed for the bridge.

Seismic Isolation of Buildings

Regarding the base isolation applications, the Tzu-Chi medical centers at Taipei and Tai-Chung are typical examples. It is worthy of mentioning that the medical center at Tai-Chung is located 400 meters away from the surface rupture line of the 1999 Chi-Chi earthquake. Special consideration was given for the design of isolation system. Lead-Rubber bearings with viscous dampers are designed to resist possible near-filed type earthquake ground motions which may induce extraordinarily large displacement at the isolation system. The reason to adopt the viscous damper in this isolation system is to take the advantage of the 90 degree phase lag between the force and displacement of the damper. In other words, the viscous damper can help minimize the displacement in the isolation layer while the maximum base shear force transmitted by the isolation system will not be dramatically increased.
For some structural applications, a combination of energy dissipation and seismic isolation are applied as shown in Fig. 10. The structure is basically designed with additional dampers to protect the structural system. In addition, for some floors where important facilities such as computer servers are located, floor isolation system id also implemented to further secure these important facilities.

DISCUSSIONS

The applications of seismic control devices to the construction of structures in Taiwan are flourishing after the 1999 Ch-Chi earthquake. The general public and the builders seem to have learned the lessons from the quake. The practical design and construction of these passive control devices have fed back some precious research ideas regarding the theoretical development and the effectiveness of installation. The current status is encouraging. However, certain aspects regarding the practical applications such as quality assurance will need more efforts from the construction and design law legislation, local manufacturing capability, etc.

ACKNOWLEDGEMENT

Results of this study are supported by grants from the National Science Council (NSC91-2625-Z-0020029 and NSC 92-2625-Z-011-002). The survey data from all the agencies are also appreciated.

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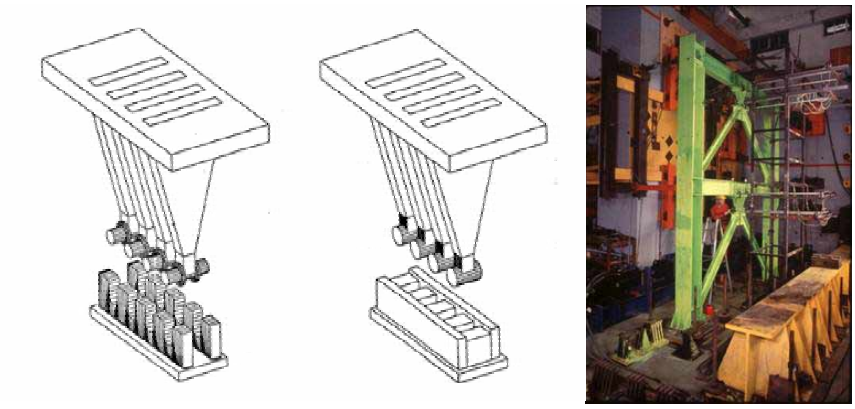

Fig. 1(a) Experimental Study of TADAS at NTU
and NCREE

Fig. 1(b) Application of TADAS to Taipei Living Mall

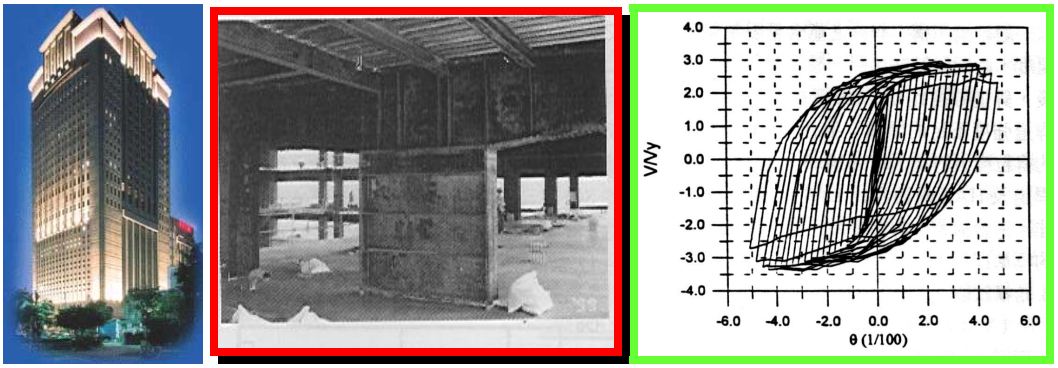

Fig. 2 Application of LYSSP to Hsin-Chu Ambassador Hotel

Fig. 3(a) Application of BRB and LYSSP to Taipei County Hall

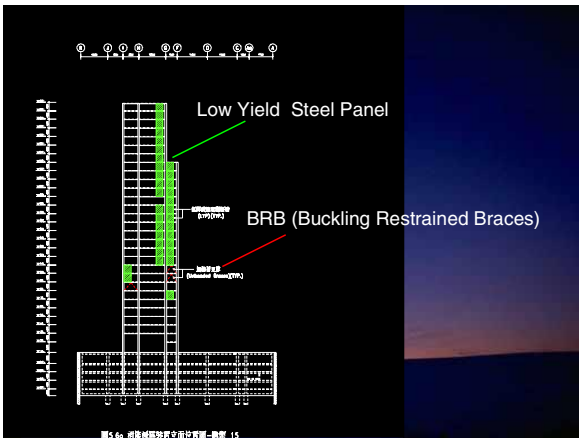

Fig. 3(b) Elevation View of one frame in Taipei County Hall

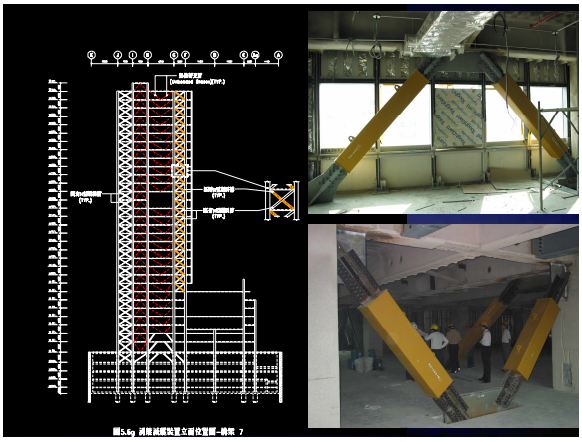

Fig. 3(c) Elevation View of one frame in Taipei County Hall

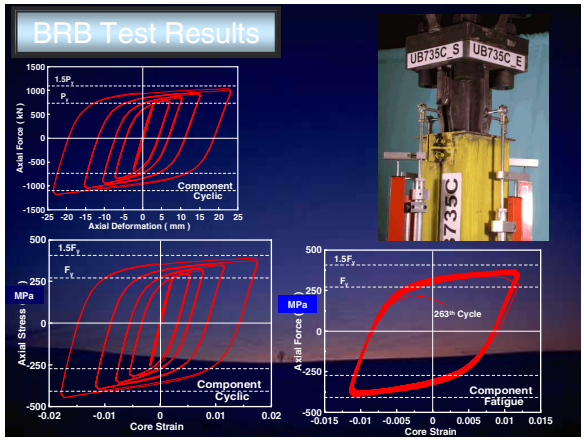

Fig. 3(d) Experimental Study of BRB at NTU & NCREE

Fig. 4(a) Applications of LYSSP and BRB to National Taiwan University of Sci. &Tech.

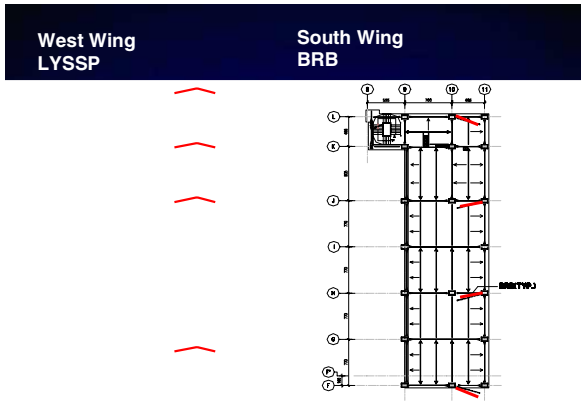

Fig. 4(b) Plane view of west and south wings

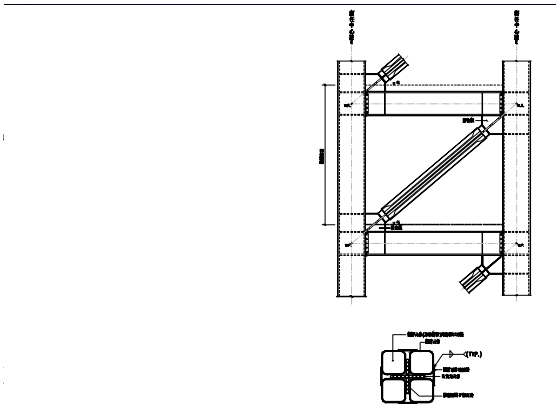

Fig. 4(c) Details of LYSSP and BRB installation

Fig. 5 Application of BRB to She-Hwa Bank

Fig. 6 Application of BRB to She-Hwa Bank

Fig. 7(a) Application of VE dampers to Taipei Treasure Palace

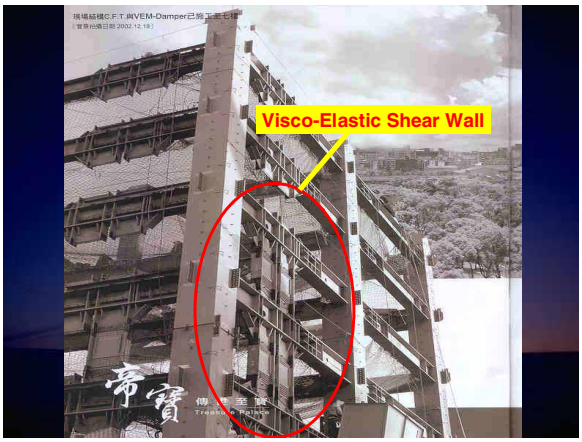

Fig. 7(b) VE shear panels in place

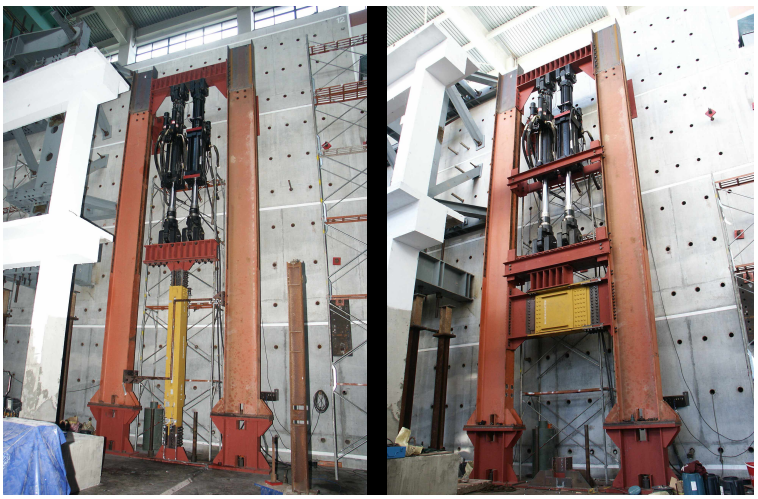

Fig. 7(c) Full scale tests of VE dampers in NCREE

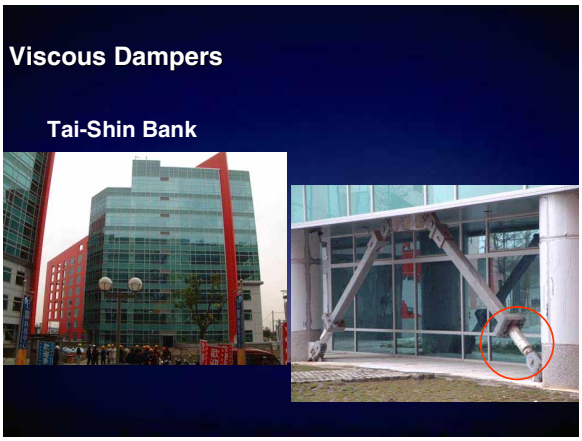

Fig. 8(a) Application of VD to Tai-Shin Bank Data Center

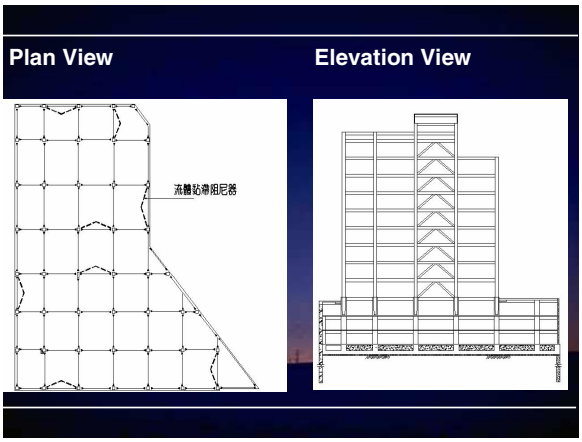

Fig. 8(b) Plan and elevation view of the structure

Fig.9 (a) Application to Headquarter of Buddhist Association

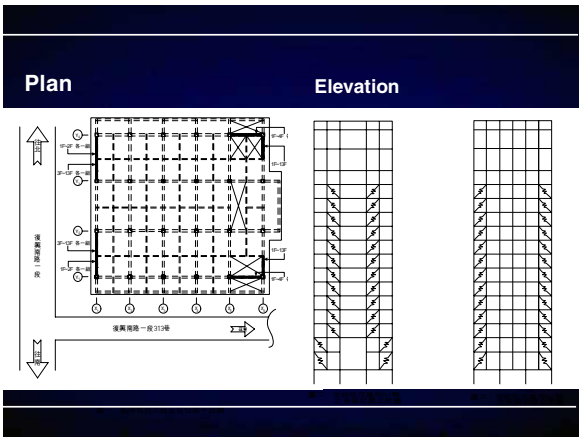

Fig. 9(b) Plan and elevation view of the structure

Fig. 10(a) Application of VDW to Grand Palace of Taipei

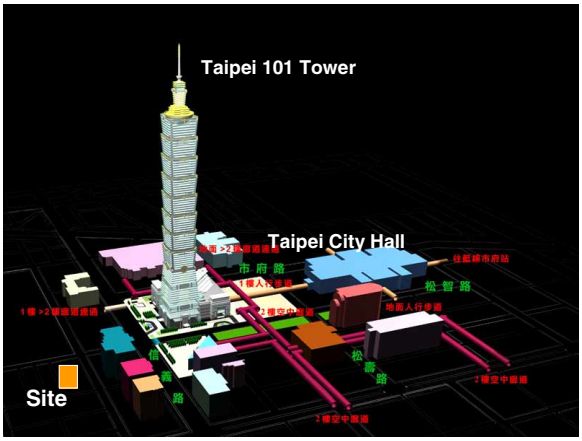

Fig. 10(b) Location of the structure at the core of Taipei City

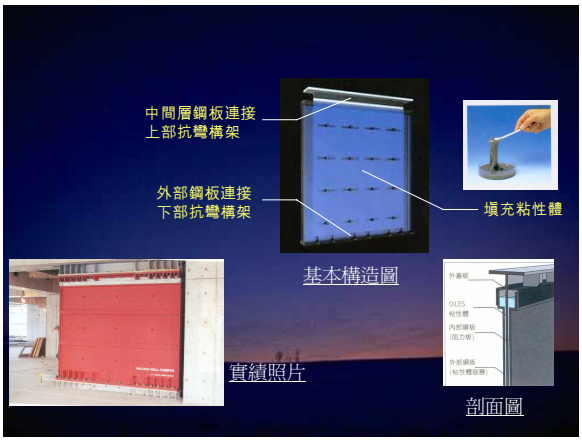

Fig. 10(c) The details of VDW and the damper in place

Fig. 11(a) Application of base isolation to Tzu-Chi Medical Center at Taipei

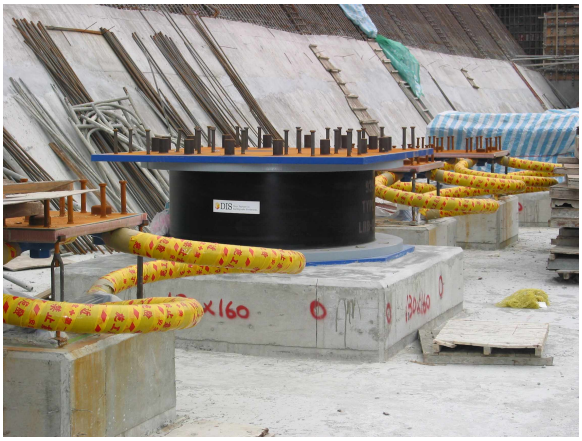

Fig. 11(b) Lead-rubber isolation bearing and coil damper in place

Fig. 11(c) Viscous damper in place

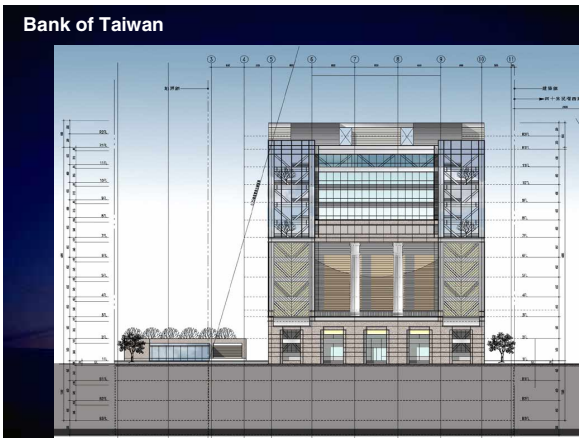

Fig. 12(a) Applications of VD and floor isolation to Bank of Taiwan

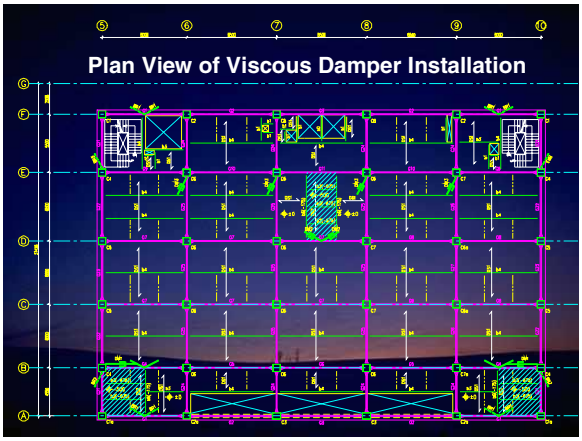

Fig. 12(b) Plan View of VD installation

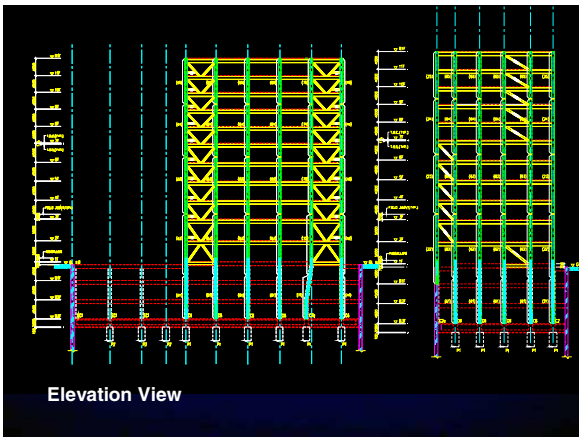

Fig. 12(c) Elevation view of VD installation

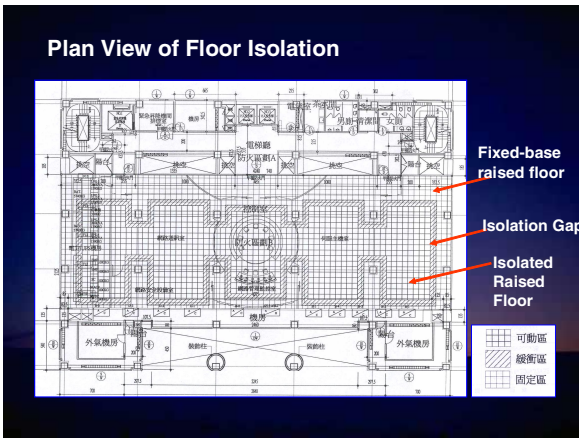

Fig. 12(d) Plan view floor isolation

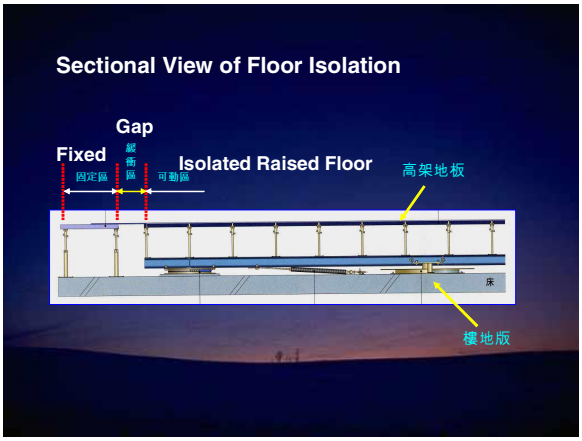

Fig. 12(e) Sectional view of floor isolation

Fig. 13(a) Overview of the seismically isolated Bai-Ho bridge

Fig. 13(b) The lead-rubber bearings used on Bai-Ho bridge

Fig. 13(c) Four hydraulic jacks used in the free vibration test