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PROGRESS OF APPLICATION AND R&D FOR SEISMIC ISOLATION AND PASSIVE ENERGY DISSIPATION FOR CIVIL AND INDUSTRIAL STRUCTURES IN KOREA

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ABSTRACT

Research and application of seismic protection systems in Korea have become active since the early 1990's despite the fact that Korea is not considered as a region with high seismic risk. Earlier activities were researches on the application of passive seismic protection systems to nuclear related facilities that are subjected to most stringent seismic performance requirements. However, due to recent evidences of increasing seismic activities in Korea and lessons learned from the Northridge and Kobe earthquakes, seismic performance requirements for civil and industrial structures have also been strengthened. Accordingly, there was a need for effective and economical seismic design alternatives which prompted research on the use of seismic protection systems. Among such systems, seismic isolation and passive energy dissipation are generally accepted as most effective systems considering the low to moderate seismicity of Korea. This paper describes recent research activities and applications for such systems for civil and industrial structures in Korea.

1. INTRODUCTION

Application and R&D for seismic isolation and passive energy dissipation for civil and industrial structures in Korea have been activated since the early 1990's partly because of deteriorating infrastructure systems mostly built in the rapidly industrialized period of 1970's, and partly because of increasing recognition of the risk due to natural hazards such as typhoons and earthquakes. Earlier activities were researches on the application of passive seismic protection systems to nuclear related facilities. For civil structures, there had been more concern on the control of vibration due to wind and other man-made actions because of low seismic risk in the country. However, due to recent evidences of increasing seismic activities in Korea and lessons learned from the Northridge and Kobe earthquakes, the recognition of potential devastating disruption of industrial and infrastructure systems which the economy of Korea is so much relying on has aroused. Accordingly, seismic performance requirements for civil and industrial structures have been strengthened, which prompted systematic works on the research and application of seismic protection system. Due to these several activities, many theoretical and experimental researches have been carried out during the past decade in Korea to develop efficient base isolators and passive energy dissipation devices for the seismic performance of various structures, such as building, bridge, liquid storage tank and liquid metal nuclear reactor.

Currently, seismic isolators have been or are to be installed on more than 40 major bridges in Korea. The number of bridges equipped with viscous dampers or shock transmission devices are also increasing. Many studies on seismic protection systems concern the development and application of seismic isolators such as lead rubber bearings and high damping rubber bearings, and passive energy dissipation devices such as viscoelastic dampers and viscous dampers. These activities are mostly performed jointly by industries, universities and research institutes. Among them, the Korea Earthquake Engineering Research Center supported by the Korea Science and Engineering Foundation, and Earthquake Engineering Society of Korea with the support of the Ministry of Construction and Transportation are the two leading institutes that execute a systematic research and collaborative program in this field.

2. SEISMIC ISOLATION SYSTEM

Earlier activities on seismic isolation system in Korea are summarized in previously reviewed paper (Yoo et al. 1999, Chang et al. 2000). These include experimental studies for building and bridge structures using shaking table(Koh et al., 1998, Yun et al., 1998, Chung et al., 1999, Park et al., 1999) and some applications (Kim et al., 1998).

Recent researches and applications of seismic isolation system in Korea focus on its economical and effective feature as a seismic design alternative considering low and moderate seismicity. Because of this advantage of economical seismic design, it became natural to use seismic isolator in bridge design. The number of bridges equipped with seismic isolator grows rapidly. In 2001, there are about 20 bridges equipped with seismic isolator and more than 40 cases of bridge design using isolator. The base isolated bridges in Korea are listed in Tab. 1

There are also some applications to special structures such as LNG tanks and nuclear facilities due to stringent seismic performance requirements. However, because isolator system has little beneficial for the building structures under current seismic design code, the use of it is very limited. Currently, only two buildings adopted isolator system in Korea.

Year	**Owner**	**Structure**	**Constructor**
1999	Korea Highway Co.	2nd sec. of Pankyo-Toikyewon Highway	Kyeryong Const. Co.
1999	Korea Highway Co.	16th sec. of Jungbu Highway	Poonglim Ind. Co.
1999	Korea Highway Co.	14th sec. of Jungbu Highway	Poonglim Ind. Co.
1999	Korea Highway Co.	15th sec. Of Seohaean Highway	Hanjin Heavy Ind. & Const.
1999	Seoul Metropolitan Subway Co.	Dang-san Railway Bridge	POSEC
1999	Gyung-gi Province Office	Jang-an Bridge	Hyundai Heavy Ind. Co.
1999	Inchon Int. Airport Constr. Co.	Airport Terminal Highway Bridge	Hanjin Consocium
1999	Korea highway Co.	Juck-won 1st Bridge	Poonglim Industrial Co.
		Gyo-yeo Highway Bridge	Kye-ryong Const. Co.
		Nok-chun 3rd Bridge	
		Dan-san Bridge	
		Shin-yuong Bridge	
		Hye-wol Bridge	
		Man-gyung River Bridge	
		Jin-wi chun Bridge	
		Dong-Jin Bridge	
		Habun chun Bridge	Ssangyong Const. Co.
		Sae-dl Bridge	
		Tong-chun Bridge	
		Sangbun-chun Bridge	Ssangyong Const. Co.
1999	Seoul City	New you-ju Grand Bridge	
1999	Won-ju City	Gui-rae Bridge	
1999	Ik-san Province	Yong-am 3rd & 4th Bridge	
1999	Dae-gu City	Yun-ho Highway Bridge	
1999	Dae-gu City	Non-gong Grand Bridge	
2000	Won-ju City	Hoingsung-Chudong road	Hyundai Const. Co.
2000	Dae-gu City	Bummul-Ansim 4th Loop Road	Kolon Const. Co.
2000.	Korea Highway Co.	3rd sec. of e Jungbu Highway	Doosan Const. Co.
2000	Korea Highway Co.	10th sec. of Jungbu Highway	Taeyoung Co.
2000	Pusan City	3rd sec. of Kwang-an Road	POSEC
		Munduk-yugang Road	Hyundai Development Co.
		Nakdan Bridge	Hyundai Const. & Eng. Co.
2000	Korea Highway Co.	3rd section of Chunan-Nonsan	LG Const. Co.
2000	Andong City	Danho Bridge	Sambu Const. Co.
2001	Sungnam City	Jungangno-Tanchunno Connection Road	Hyukji Const. Co.
2001	Korea Highway Co.	2nd sec. of Jungbu highway	Ssangyong Const. Co.
2001	Kwang-ju Province Office	Access Road of PyungDong Ind. Area	Kumho Co.
2001	Chunan-Nonsan Highway	6th sec. of Chunan-Nonsan	Kumho Co.
2001	Seoul Regional Const. Management Office	Tong-il Bridge	Hyundai Const. & Eng. Co.
2001	Ulsan City	Connection Ramp of Bunyoung Road	Kyungnam Enterprises Co.

Tab.1 List of Base Isolated Bridges in Korea

Some examples below shows that isolation system in Korea is used as effective and economical seismic design alternatives not only for the retrofit of existing structure but also the new structures.

2.1. Dangsan Railway Bridge

(a) Old bridge (b) New bridge

Fig. 1 Dangsan Railway Bridge

Dangsan railway bridge spanning Han river in Seoul was a steel truss bridge completed in 1983(Fig 1a). It had 15 spans with the each span length of 90m. This bridge was used for Seoul Subway Lane 2, and its importance was unquestionable. In 1992, however, train speed was limited to 30km/h on the bridge because several cracks were found in major truss members. In 1996, Seoul City Government decided to replace the superstructure of the bridge.

For the rehabilitation, it was necessary to increase seismic capacity of the bridge due to seismic code revision in 1992. As an economical design alternative, reuse of foundations, retrofit of concrete piers and seismic isolation system was chosen. New steel box superstructure with isolator system was completed in 1999 (Fig 1b).

2.2. Kwangan Bridge

Fig. 2 Kwangan Bridge with Lead Rubber Bearing

An approach section of the Kwangan Bridge in Pusan, which is a suspension bridge under construction with the center span length of 500 m, is the first base-isolated bridge in Korea (Kim, 1998). The bridge and base isolators using LRB are illustrated in Fig. 2. It is a continuous double-deck truss section with 3 spans. The length of each span is 120m. Because of the heavy weight of the truss section, it is natural to adopt seismic isolation system for effective seismic design of piers. It was designed for the earthquake load with a PGA of 0.14g. The design effective natural period is 1.82 sec. The earthquake responses were evaluated in the longitudinal direction for various levels of the earthquake excitation.

2.3. Pilot LNG tank

Fig. 3 Base-isolated Pilot LNG Tank under construction

The Korea Gas Corporation and the Korea Gas Eng. & Cons. Co., Ltd. are constructing the Pilot LNG tank system for their new commercial tank system with their own developed membrane system. Because the LNG tanks are often constructed on the flexible foundation as compared to other safety-related structures, seismic isolators are introduced to reduce the earthquake stresses on the tank structure due to the effect of flexible foundation. The study on optimal isolator design for the new tank system on flexible foundation is being performed by Korea Power Engineering Company.

Fig. 3 shows a view of the pilot LNG tank in which the seismic isolators are placed on top of pedestals, which are supported by a thick concrete foundation slab on piles. The pilot LNG tank structure is approximately 1/4 scale of commercial tank system, but some geometrical dimensions such as wall thickness could not reduced by the same scale, i.e. these are relatively thicker than others. The properties of isolator were adjusted with seismic analysis changing seismic isolator characteristics.

2.4. Development of design guidelines for isolated bridge

Provisions for the use of seismic isolation in the Korean design specification for bridges has been developed. The Ministry of Construction and Transportation has launched a multi-year research project which will eventually develop a draft of provision for seismic isolation design of bridges. In this project, analytical investigations for optimal ductility demand and life cycle cost effectiveness and experimental works are being performed. Based on minimum life-cycle cost concept, an economical efficiency evaluation method for seismic-isolated bridges was developed (Koh and Song, 1999). The results of study on optimal design of seismically isolated bridges with life-cycle cost minimization indicate that the pier could be designed to behave elastically as the seismic force is greatly reduced by using more flexible isolator. This result is verified by experiment in Fig. 4 where the cyclic loading test of isolated pier and elastic behavior of pier are shown. The pseudo-dynamic tests of seismically isolated bridges are also in progress. With this experiment, it is expected that the verification of the effectiveness of seismic isolation in low to moderate seismicity regions and the applicability of optimal design method with life-cycle cost minimization.

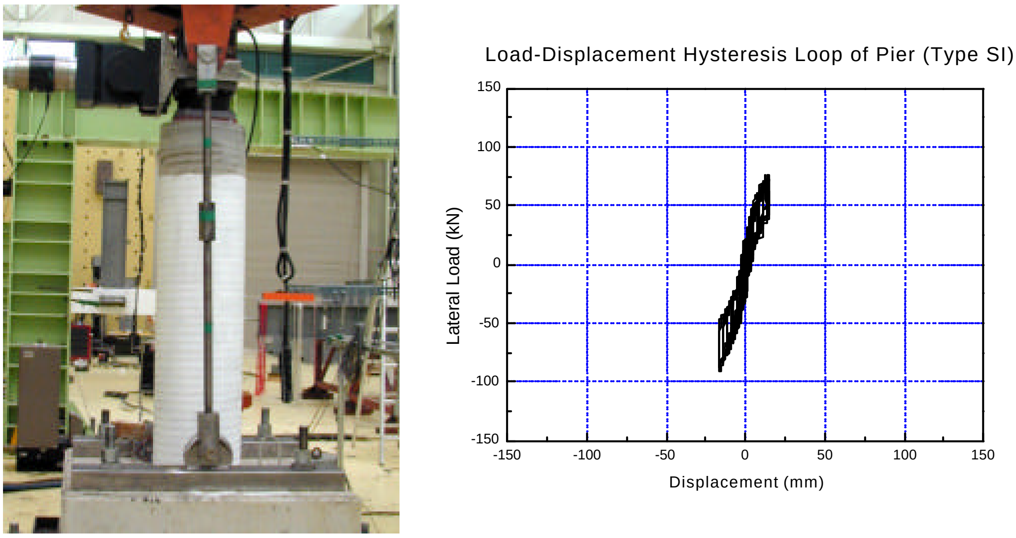


Fig. 4. Cyclic loading test and hysteretic behavior of pier with seismic isolator

3. PASSIVE ENERGY DISSIPATION SYSTEM

Although researches on developing and manufacturing passive energy dissipation devices are recent in Korea, applications and studies focus attention on upgrading seismic capacity of existing structures and optimizing new structures for performance improvement. Some examples are briefly introduced below.

3.1 Revising design of Seohae Bridge

Seohae Bridge is the longest bridge in Korea (length of 7.31 km), which is completed in 2001. The bridge consists of 3 different types of bridges: cable-stayed bridge (990m), FCM bridge (500m), and PSM bridges (5820m). When the design started in the late 80's, there was no seismic code in Korean specifications. The current seismic codes appeared in 1992, and it made Korea Highway Corporation revise the seismic design of the bridge. Based on the new specifications, the cable-stayed bridge and FCM bridge satisfied the requirements. However, PSM bridges needed seismic retrofit.

No. of Bridge Groups	Retrofit Method	Remarks
7 Groups	Increasing the number of fixed piers	Flexible piers

5 Groups	Viscous fluid damper	Stiff piers
4 Groups	No need to any retrofit	Small mass and moderate stiffness

Tab.2 Seismic Retrofit Method of Seohae Bridge

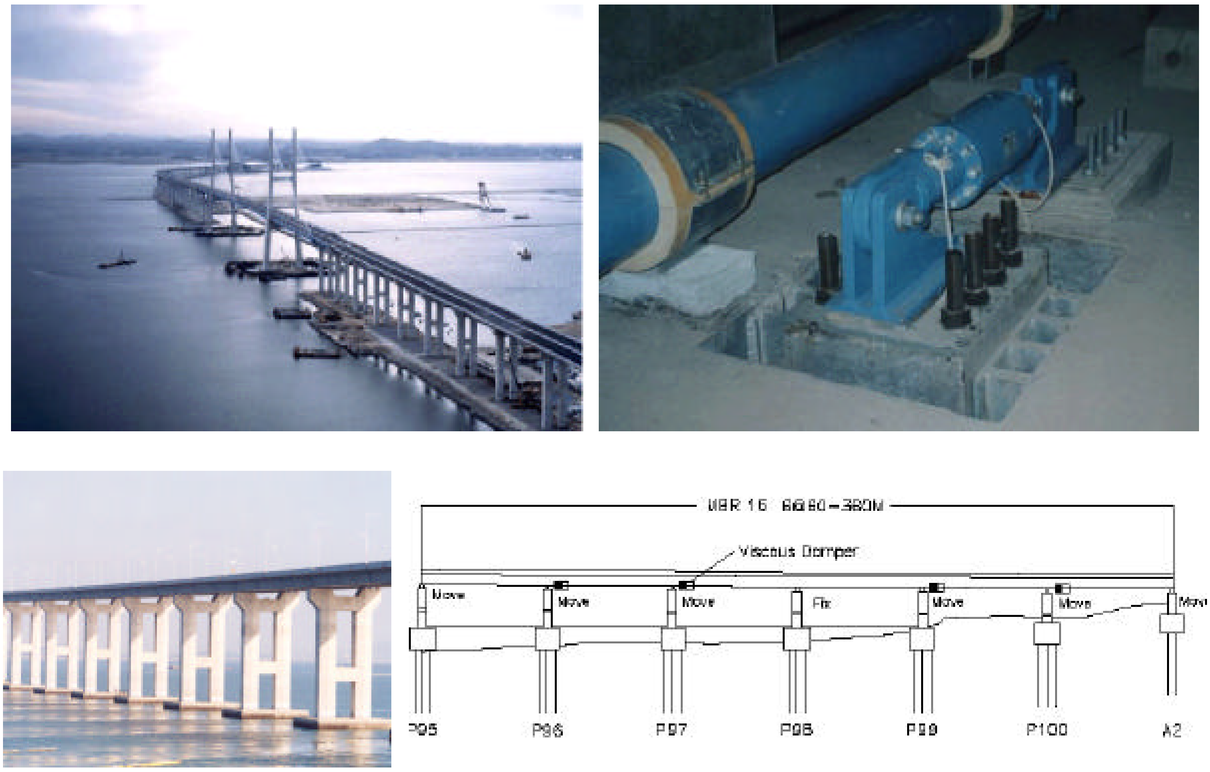


Fig. 5 Seohae Bridge and Installation of Fluid Viscous Damper

Two retrofit methods were adopted. The first one is to distribute the earthquake force to multiple piers by increasing the number of fixed bearings. The second is to reduce the earthquake force using viscous fluid dampers. The results of the seismic retrofit are presented in Tab. 2 (Park et al. 2001). The bridge with flexible piers can withstand the earthquake force by the first method. This is applied to 7 PSM bridges among 16. The viscous fluid dampers are used at 5 PSM bridges with stiff piers (Fig. 5). Total 54 units of 500kN capacity were used (Infanti 2001).

3.2 Optimization of Korean Type High-speed Railway Bridge

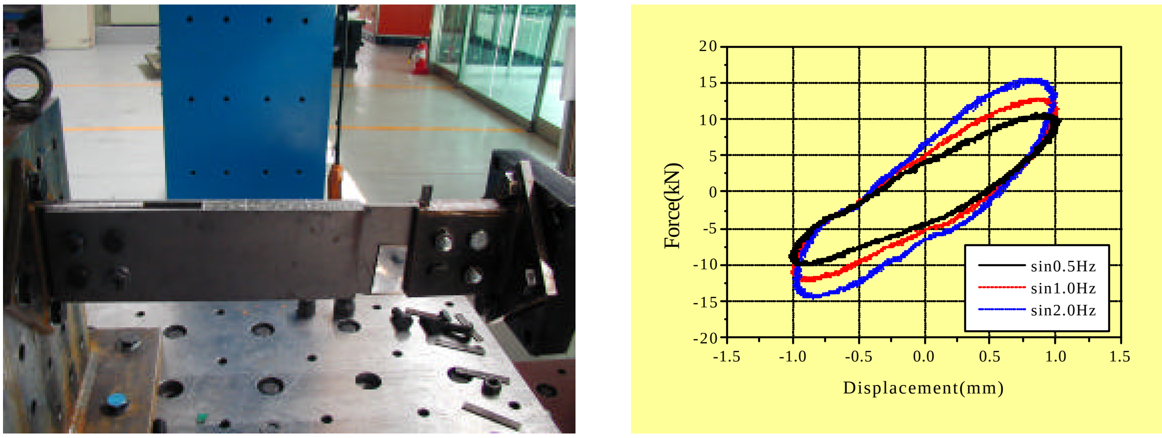
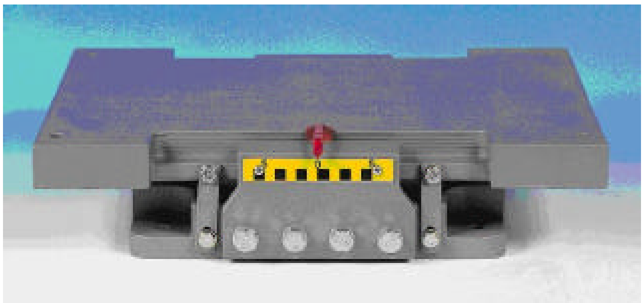


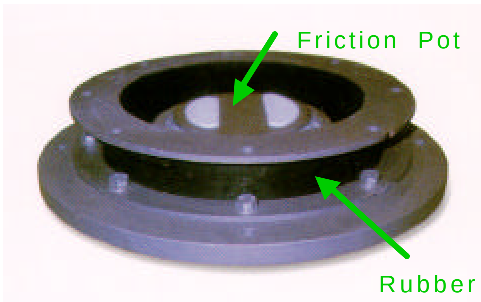
Fig. 6 Sinusoidal Test of Viscoelastic Damper and Hysteresis Loop

An application of passive energy dissipation has been studied for the vibration control of the Korean-type high-speed railway bridge (SNU, 1998). Possible use of viscous and viscoelastic dampers for the vibration control was investigated considering nonlinear behaviors. It was verified that the maximum resonance vibration could be reduced, which enables the use of more compact bridge section. The optimal position and capacity of the damper was also investigated. Currently, development and performance tests of viscoelastic dampers are being performed to establish analytical model (Fig. 6). Thereafter, optimal damper will be designed and applied to scaled bridge model to suppress the vibration induced by vehicle loading.

4. DEVELOPMENT OF NEW DEVICES AND OTHER APPLICATIONS



(a) Friction Pot Bearing(FPB)



(b) Friction Rubber Bearing(FRB)

(c) Coil shaped elastoplatic damper (d) Multi-layer viscous damper

Fig. 7. New Isolation Devices and Passive Dampers

New isolation devices were also developed. The 3D base isolator was invented (Yoo et al., 1999), which can be used for the simultaneous isolation of the vertical and lateral seismic load. Friction Pot Bearing(KUMHO-UNISON-KAIST) and Friction Rubber Bearing(UNISON) were developed for isolated bridge(Fig. 7a and b). Friction pad in these bearings provide seismic isolation and additional friction damping for energy dissipation. Rubber part of FRB provides restoring force for displacement control. Coil shaped elastoplastic damper is under development by UNISON(Fig 7c). Test results show that it has very favorable energy dissipation characteristics, but damping force per volume is relatively small. Multi-layer viscous fluid damper is developed for combined use with isolation system (Fig 7d). It provides additional viscous damping to the horizontal plane motion and controls displacement.

A tuned mass damper(TMD) was considered for control of the wind vibration of the air-traffic control tower at the Yang-Yang International Airport (Kim and Hwang, 1997). The height of the tower is 80.8m and the control room is located at the 15th floor. The TMD is to be installed at the mass center of the 13th floor. The design wind speed for estimation of human comfort is 16.8m/sec with a return period of 1 year. The fundamental period of the tower is 2.59 sec, and the corresponding modal mass is 1174 ton. After wind force coefficients were evaluated through wind tunnel tests using a 1/120-scale model, numerical simulation results indicate that the acceleration at the control room can be reduced to 60% of the case without TMD by using the TMD with a mass ratio of 0.01.

Fig. 8 Cable of Seohae Bridge and Installation of Cable Damper(DGD)

For Seohae bridge, cable damper was also introduced to suppress the motions of a cable excited by wind. The specifications for Seohae grand bridge were med based on the numerical analyses with the aerodynamic coefficients acquired from the wind tunnel test. For the sake of maintenance and economy, damping guide deviators(DGD) were installed from the analysis results(Fig. 8). (Park and Kim, 2001)

5. CONCLUSIONS

Research and application of seismic protection systems in Korea have become active since the early 1990's partly because of deteriorating infrastructure systems mostly built in the rapidly industrialized period of 1970's, and partly because of increasing recognition of the risk due to natural hazards such as typhoons and earthquakes. Among such systems, seismic isolation and passive energy dissipation systems are generally accepted as economically more efficient alternatives for seismic protection against conventional design concept considering the low to moderate seismicity of Korea. Application and development of new devices such as friction-type bearings and various types of dampers has also become a recently emerging topic.

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