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Progress of Applications and Studies on Earthquake Resistance Design of Bridges in Korea

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ABSTRACT >> This paper describes the state-of-the art research activities on seismic isolation systems for improving the seismic capacities of the bridges in Korea. Though Korea is located in a region of low-to-moderate seismicity, the construction of seismic isolation systems has increased rapidly. The application of seismic isolation system has become popular worldwide because of its stable behavior and economical construction especially for bridge structures. Since optimal reliability level of isolated bridges can be determined as the one that provides the highest net life-cycle benefit to society, or the minimum Life-Cycle Cost (LCC), an optimal design procedure based on minimum LCC concept is more expedient for the design of seismically isolated bridges in areas of low-to-moderate seismicty. To verify the adequacy of the new design concept based on the LCC minimization, experimental studies on seismically isolated bridge are introduced as well, which include pseudo-dynamic test of scaled pier and dynamic field test of full-scale. With the application of seismic isolation systems, many kinds of dampers to improve the seismic capacity of structure are also applied not only to new bridges but also to existing bridges.

Key words Seismic isolation system, earthquake resistance design, bridge, seismic retrofit

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1. INTRODUCTION

The seismic characteristic of Korea is commonly recognized as low-to-moderate seismicity. However, historical records report that there have been many earthquakes over 1900 times during these hundred years. In particular, seismic activities in the Korean Peninsular are observed more frequently in recent years. Therefore, recognition for potential seismic risk in the Korean Peninsula is growing steadily. Accordingly, the seismic protection system against structural vibration due to the seismic event has been emphasized. In addition, the deterioration of most of the infrastructures built during the industrialization period of the 1970's, the recent construction activities over 30 long-span bridges in the Southeastern coast to link some of the 3000 islands to the mainland, and the growing number of large and tall structures have also increased the need for preventive measures against catastrophic structural failure from the seismic events (Ha, 2000).(1)

The devastating Hyogoken-Nanbu earthquake of January 17, 1995 sent mental shock waves that awakened the public concern about the possible earthquake disaster in Korea. Many seismologists pointed out that a disastrous earthquake could occur at any time soon. The government began to realize that preparatory measures had to be implemented at national level. The consensus among the design engineers and researchers resulted in the foundation of the Earthquake Engineering Society of Korea (EESK) in November 28, 1996. The Yeongweol earthquake of December 13, 1996 was of only magnitude 4.5 but the shaking was felt throughout the country. The structural damage was minimal even at the epicentral region. However, that earthquake gave very strong impact to the public frightened already because of the

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본 논문에 대한 토의를 2007년 10월 31일까지 학회로 보내 주시면 그 결과를 게재하겠습니다.

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disaster in Kobe City. Immediately after the earthquake, the Korean government announced research plans for the development of seismic design codes and long-term research plans for the accurate evaluation of the seismic hazard in Korea. EESK was entrusted the task to develop seismic performance requirements and code systems for the facilities under the jurisdiction of the Ministry of Construction and Transportation.

The seismic design codes for buildings, bridges, and other facilities have borrowed the basic idea heavily from those developed for the high seismic region, i.e., California without critical review. However it became evident that they cannot be applied directly to the seismic design in low or moderate seismic regions. The seismic design of structures in the region of high intensity ground motion is based on the ductile behavior and large energy absorbing capacity. However, it is highly possible that well designed structures may behavior within elastic limit under the design ground motion in the moderate seismic region.

Another critical problem of the current code system was found to be lack of coordination. The performance requirements and the design principles are different from one code to another. The seismic zoning, seismic coefficients and design response spectrum are found to be in the same situation. It was felt very strongly that certain kind of coordinated approach must be taken to achieve uniform level of protection from earthquake hazards.

As the anti-seismic or anti-vibration system for civil structures, especially for the bridges, seismic isolation system is well accepted as an effective and economical alternative for improving the seismic capacities of the bridges. Following, lots of bridge designs have concentrated on the application of the efficient seismic isolation system. However, most of the bridges with seismic isolation system at that time have been constructed without the properly-developed seismic design code. The early seismic design code for those bridges has just borrowed the basic idea from that developed for the high seismic region without serious review and extensive investigation. However, it is self-evident that the seismic design code developed for high seismicity may not be directly applicable to the bridges in region of low-to-moderate seismicity. Thereafter, many engineers and researchers began to realize that long-term systematic studies and research plans have to be implemented on the development of the appropriate seismic protection systems for the low-to-moderate seismic zone, especially for Korea.

Accordingly, many theoretical and experimental researches have been carried out in the past decade in Korea to develop efficient isolators for the seismic performance of various structures. Since optimal reliability level of isolated bridges can be determined as the one that provides the highest net life-cycle benefit to society, or the minimum Life-Cycle Cost (LCC), an optimal design procedure based on minimum LCC concept is more expedient for the design of seismically isolated bridges. Koh *et al.* (2000)(2) have already provided a new design concept and cost-effectiveness evaluations based on the LCC analysis for the seismic isolation of bridges. Studies have reported that a seismic isolation system is more cost-effective in low-to-moderate seismic regions than highly seismic zones. In addition, more flexible isolators are seen to be efficient in such regions. However, the numerous assumptions adopted for analysis and design of such bridge structures have not been validated extensively and thoroughly. Therefore, field testing of full-scale isolated bridge structures and related analyses were performed in Korea to experimentally verify the design methods of the seismically isolated bridge and to calibrate analytical models for future analytical correlation and prediction.

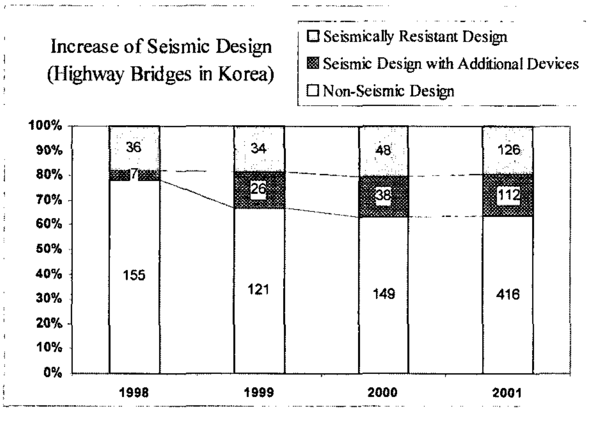
This paper intends to give an overview of the latest research achievements on the innovative seismic isolation system and the up-to-date information on the application of various kinds of seismic isolation system to bridges in Korea.

2. SEISMIC ISOLATION SYSTEMS IN KOREA

The applications of seismic isolation design for building structures are not widely accepted however, the applications to bridges are generally well accepted in Korea since researchers found out that the seismic isolation design could be much more beneficial than the conventional designs in view of economics, safety margins and seismic performance increment (Koh *et al.* 2000).(2) The number of bridges equipped with seismic isolators showed a rapid growth since 1999 (Fig. 1), in addition the seismic retrofit of highway bridges are started in 2005 by Korea Highway Corporation. More than 30% of highway bridges in Korea will be retrofitted to improve their seismic performance and many of them will be equipped with seismic isolators.

2.1 Development of New Design Guidelines based on the Minimum LCC Concept

In regions of high seismicity, current design concept for the seismic isolation of bridges is based on the strength-based design concept in which the force response of the total system is reduced by lengthening its period of vibration and providing additional damping properties. However, in regions of low to moderate seismicity, a design based on such concept may not provide a more effective design alternative for mitigating seismic damage of bridges. Since the low-to-moderate seismicity region is located in the stable continent, it shows the different characteristics such as slow recurrence rate and clear local effect from the region of high seismicity with earthquake fault, and has the higher seismic hazard than the region of high seismicity. Moreover, since earthquake is essentially a probabilistic event which occurs with diverse characteristics, or randomness, concerning peak ground acceleration, frequency content and site condition, it may be inappropriate to quantify the greatest earthquake according to the fault length only. Therefore, probabilistic approach is more appropriate for the design of seismic isolation because earthquake is essentially a probabilistic event, and comprehensive optimization is required that has a lifetime perspective from design, construction, maintenance to decommissioning (Koh *et al.* 2000).(2) As an optimal design method of the seismically isolated bridge in Korea, the optimization design approach minimizing the life-cycle cost (LCC) is a risk-based probabilistic approach with lifetime perspective to consider the seismic hazard of the bridge during its total lifetime and seismic characteristics in region of low-to-moderate seismicity.



⟨Figure 1⟩ Increase of seismically designed highway bridges using additional devices in Korea

Therefore, in Korea, the researches to develop new design guidelines for seismically isolated bridges focused on the optimal design method based on the LCC minimization. The analytical investigation on the new design concept has been completed and the results was reported previously (Koh *et al.* 2001).(3) Studies have reported that a seismic isolation system is more cost-effective in low-to-moderate seismic regions than highly seismic zones. In addition, more flexible isolators are seen to be efficient in such regions.

2.2 Application of Various Seismic Isolation Systems in Korea

Currently, seismic isolators have been or are already 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.

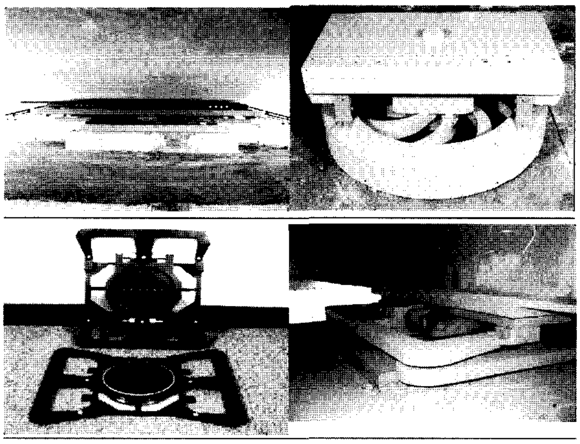
Recent researches and applications of seismic isolation system in Korea focus on its economical and effective seismic design alternatives, considering the low to moderate seismic activity in Korea. Because of the economical advantage of a seismic design, using seismic isolators in bridge designs have become a standard. The number of bridges equipped with a seismic isolator is growing rapidly, especially to long-span and/or large bridges. In 2001, there are about 20 bridges equipped with a seismic isolator and more than 40 cases of bridge design using isolators. The base isolated bridges in Korea are listed in Table. 1.

〈Table 1〉 List of base isolated bridges in Korea (continue)

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	Hyundai Const. Co.
		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.

Year	Owner	Structure	Constructor
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.
2002	Seoul City	Hannam Grand Bridge Improvement Work	Hyundai Const. Co.
2002	Posco	Keumdang bridge	POSCO Eng. & Const. Co.
2002	Korea Highway Co.	8th sec. of Daegu-Pohang Highway	Samick Const. Co.
2002	Korea Highway Co.	4th sec. ofDaegu-Pohang Highway	Ssangyong Eng. & Const. Co.
2002	Busan Transportation Corporation	311 th sec. of Busan Subway	Samsung Const. Co.
2002	Korea Highway Co.	1st sec. of Daegu-Busan Highway	Daewoo Eng & Const. Co.
2002	Korea Highway Co.	5th sec. of Daegu-Busan Highway	Hyundai industrial Development & Const. Co.
2003	Korea Highway Co.	7th sec. of Daegu-Busan Highway	Hyundai industrial Development & Const. Co.
2003	Korea Highway Co.	8th sec. of Daegu-Busan Highway	Daelim Industrial Co.
2003	Korea Highway Co.	6th sec. of Gimcheon-Hyunpung Highway	LG Const. Co.
2003	Gyeongsangnam Province Office	Sanglim-Samnang Road	Hyundai Const. Co.
2003	Korea Highway Co.	3rd sec. of Honam Highway Gwangju Bypass	Sambu Const. Co.
2003	Uijeongbu Regional Const. Management Office	Kyunggang Bridge Improvement Work	Advanced Special Eng. & Const. inc.
2003	Korea Highway Co.	2nd sec. of Cheongju-Sangju Highway	Ssangyong Eng. & Const. Co.
2003	Korea Highway Co.	7th sec. of Cheongju-Sangju Highway	Korea Development Co.
2003	Busan Transportation Corporation	1st sec. of Yangsan line, Busan Subway	Ssangyong Eng. & Const. Co.
2003	Korea Highway Co.	2nd sec. of Honam Highway Gwangju Bypass	Korea Development Co.
2004	Korea Highway Co.	4th sec. of Daejeon-Dangjin Highway	LG Const. Co.
2004	Korea Highway Co.	4th sec. of Daejeon-Dangjin Highway	LG Const. Co.
2004	Korea Highway Co.	5th sec. of Daejeon-Dangjin Highway	LG Const. Co.
2004	Korea Highway Co.	5th sec. of Daejeon-Dangjin Highway	LG Const. Co.
2004	Korea Highway Co.	6th sec. of Daejeon-Dangjin Highway	LG Const. Co.
2004	Korea Highway Co.	6th sec. of Cheongju-Sangju Highway	Hyundai industrial Development & Const. Co.

With the application of seismic isolation systems, many kinds of dampers to improve the seismic capacity of structure are also applied not only to new bridges but also to existing bridges. Mainly because of economic reasons, steel dampers (Fig. 2) have many applications as shown in Table. 2. These applications may leave permanent displacement after earthquakes, because individual use of such dampers could not provide restoring force. However, we can change such dampers after earthquakes without significantly increasing the LCC, the seismic characteristics of Korean peninsula make this possible.


〈Figure 2〉 Steel damper

2.2.1 Development of new isolation devices

New isolation devices were developed in this decade. The 3D base isolator was invented (Yoo *et al.*, 1999)(4), which can be used for the simultaneous isolation of the vertical and lateral seismic load. Friction Pot Bearing

〈Table 2〉 List of bridges installed steel damper in Korea

Year	Owner	Structure	Constructor
1997	Korea Highway Co.	3rd sec. of Daegu-Andong Highway	NamKwang Eng. & Const. Co.
1997	Korea Highway Co.	4th sec. of Daegu-Andong Highway	Samsung Heavy Industries Co.
1998	Korea Water Resources Co.	Naechon Bridge	Sambu Const. Co.
1999	Gyung-gi Province Office	Kwangdong Bridge	Heunghwa Industry Co.
1999	Korea Highway Co.	13th sec. of Seohaean Highway	Samsung Const. Co.
2000	Incheon City	2nd Ganghwa Grand Bridge	Hansol Const. Co.
2000	Iksan Regional Construction & Management Office	Gui Grand Bridge	LG Const. Co.
2000	Korea Highway Co.	9th sec. of Daegu-Pohang	Daewoo Eng & Const. Co.
2000	Korea Highway Co.	9th sec. of Daegu-Pohang	Daewoo Eng & Const. Co.
2000	Wonju Regional Const. Management Office	Sabuk-Gohan	Byuksan Eng. & Const. Co.
2000	Korea Highway Co.	2nd sec. of Anjung-Pyeongtaek	Hanbo Co. Dongkwang Const. Co.
2000	Korea Highway Co.	23 th sec. of Jinju-Tongyeong	Youwon Const. Co.
2000	Cheonan Nonsan Expressway Co.	1st sec. of Cheonan-Nonsan	Daewoo Eng & Const. Co.
2001	Ulsan City	Mipo-Onsan	Korea Development Co.
2001	Busan Newport Construction Office	1st sec. of Busan Newport	Daelim Industrial Co.
2001	Incheon City	1-1 sec. of Songdo Newtown	Daelim Industrial Co.
2002	Korea Highway Co.	24 thsec. of Jinju-Tongyeong	Hanjin Heavy Industries & Const. Co.
2002	Wonju Regional Construction & Management Office	Sabuk-Gohan	Byuksan Eng. & Const. Co.
2002	Nonsan National Road Management Office	National Road No.32 Maam Bridge	Jiyuong Const. Co.
2002	Jinju National Road Management Office	New Great Geoje Bridge	Recon Remodeling Co.
2002	Chungju National Road Construction & Management Office	Norumok Bridge	Insoung Const. Co.
2002	Incheon Newtown Development Department	1-2 sec. of Songdo Newtown	Kumho Industrial Co.
2002	Korea Highway Co.	Waegwan-Nakdong River Bridge Repair Works	V S L KOREA
2003	Yosu Regional Maritime Affairs & Fisheries Office	Gwangyang Port Road	Kyeryong Const. Co.
2003	Korea Highway Co.	3rd sec. of Jungang Road	Samsung Const. Co.
2003	Korea Highway Co.	3rd sec. of Daegu-Busan	SK Engineering & Const. Co.
2003	Daejon Regional Const. Management Office	Seonsan-Dogye	Hyundai Const. Co.
2003	Daejon Regional Const. Management Office	Ducksan-yesan	KT Const. Co.
2004	Nonsan National Road Construction Office	National Road No.1 Geumnam Bridge	Daeyoung Industry. Co.
2004	Suwon City	Seryu Crossroad Extension Work	Dongbu Const. Co.
2005	Pusan National Territory Management Office	Sancheong-Sudong National Road Extension Work	Poonglim Industry Co.
2005	Korea Highway Co.	1st sec. of Seoul -Chuncheon	Hyundai industrial Development & Const. Co.
2005	Gangwon Regional Supply Administration	Seosang Bridge	Dongbu Const. Co.
2005	Chungcheongnamdo Constr office	Chorak Bridge Building Work	Kyeryong Const. Co.
2005	Korea Highway Co.	4th sec. of Muan-Gwangju (Pyeongdong Bridge)	Hanshin Const. Co.
2005	Busan Metropolitan Corporation	Pusan Newport Northern Container	POSCO Eng. & Const. Co.
2005	Korea Rail Network Authority	Nakdong River Bridge	Hyundai Const. Co.

(KUMHO- UNISON-KAIST) and Friction Rubber Bearing (UNISON) were developed for the isolated bridge (Fig. 3a and b). Friction pad in these bearings provide a seismic isolation and additional friction damping for energy dissipation. The rubber part of FRB provides restoring force for displacement control.

2.2.2 Dangsan railway bridge

Dangsan railway bridge spanning the Han river in Seoul was a steel truss bridge completed in 1983 (Fig 4a). It had 15 spans, each with a span length of 90m. This bridge was used for Seoul Subway Line 2, and its importance in transportation was unquestionable. In 1992, however, the train speed on the bridge was limited to 30km/h because several cracks were found in major truss members. In 1996, the Seoul City Government decided to replace the superstructure of the bridge. For the restructuring, it was necessary to increase the seismic capacity of the bridge due to the seismic code revision in 1992. As an economical design alternative, the reuse of foundations, the retrofit of concrete piers, and seismic isolation system was chosen. A new steel box superstructure with an isolation system was completed in 1999 (Fig 4b).

2.2.3 Kwangan bridge

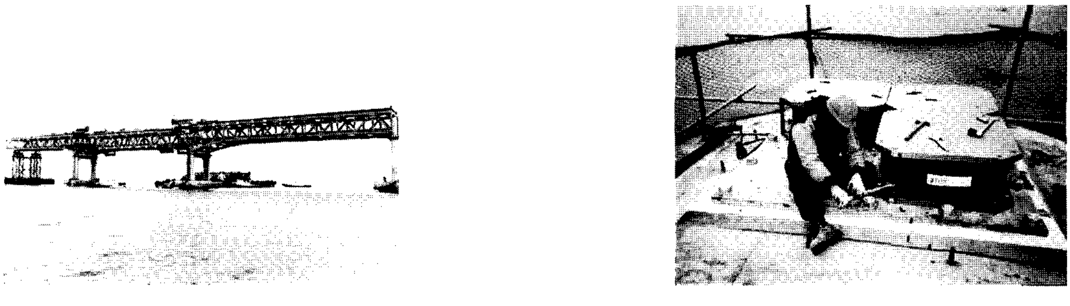
The approach section of the Kwangan Bridge in Pusan, which is a suspension bridge under construction with the center span length of 500 m, is the first base-isolated bridge in Korea (Kim, 1998).(5) The bridge and base isolators using LRB are illustrated in Fig. 5. It is a continuous double-deck truss section with 3 spans. The length of each span is 120m. Because of the heavy weight of the truss section, it was natural to adopt a seismic isolation system for an effective seismic design of piers. It was designed for an earthquake load with a


(a) Friction Pot Bearing (FPB) (b) Friction Rubber Bearing (FRB)

〈Figure 3〉 Friction pot bearing and friction rubber bearing


(a) Old bridge (b) New bridge

〈Figure 4〉 Dangsan railway bridge


〈Figure 5〉 Kwangan bridge with lead rubber bearing

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 Development of Design Guidelines for Isolated Bridge

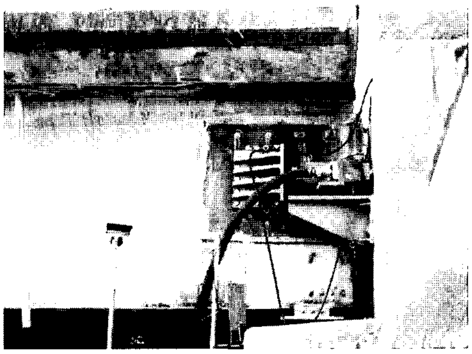
Provisions have been developed for the use of seismic isolation in the Korean design specification for bridges. New bridge design specifications are published in Feb. 2005. One of the main content of revision is the adoption of "the specifications for seismic isolation design of bridges" as a new part. Some of research results of the dynamic field testing by the authors are include in new specifications.

Dynamic field test is being performed jointly by Korean Society of Civil Engineers (KSCE), Seoul National University (SNU) and Korean Highway Corporation (KHC) with industry, supported by the Ministry of Construction and Transportation. This field-testing project of full-scale bridge, the first one in Korea, aims to investigate the dynamic characteristics of isolated bridges and verify the adequacy of the new design concept based on the LCC minimization (Lee *et al*, 2004).(6)

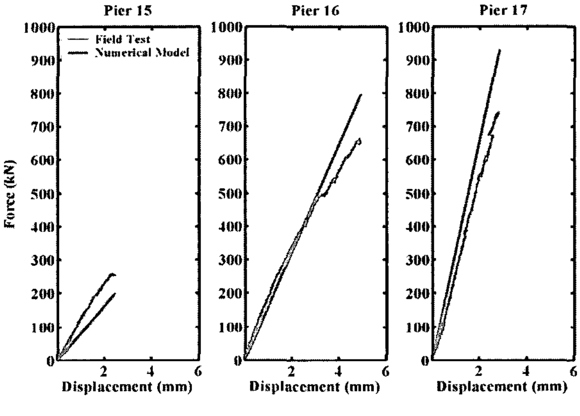
The experiment bridge was the Nam-Han River bridge which is an 18-span continuous PSC I-girder bridge located on a closed highway (Fig. 6). Since the bridge was constructed in 1971 at a time when seismic design was not applied to bridge structure, the existing bridge bearings were replaced with newly designed lead rubber bearings (LRBs). Quick release testing method was adopted for the test and, accordingly, specially designed hydraulic jacks with quick release valves were newly developed (Fig. 7).

Consequently, the isolated frequency of the bridge was identified from bridge's free vibration response after total disappearance of the jack force, and the stiffness of the piers were estimated from the measured data during the loading stage (Fig. 8). The behavioral characteristics of the piers obtained from the data interpretation guarantees the linear behavior of the pier.

As mentioned above, many projects are conducted to improve the seismic capacity of existing bridges by Korea Highway Corporation, Korea Infrastructure Safety & Technology Corporation and Ministry of Construction and Transportation. Fig. 9 shows the main methods of the retrofit operation which are widely applied in Korea. Sometimes, the space of girders and abutments should be expanded for the seismic displacement. These major retrofit operations will be completed within about 5 years.

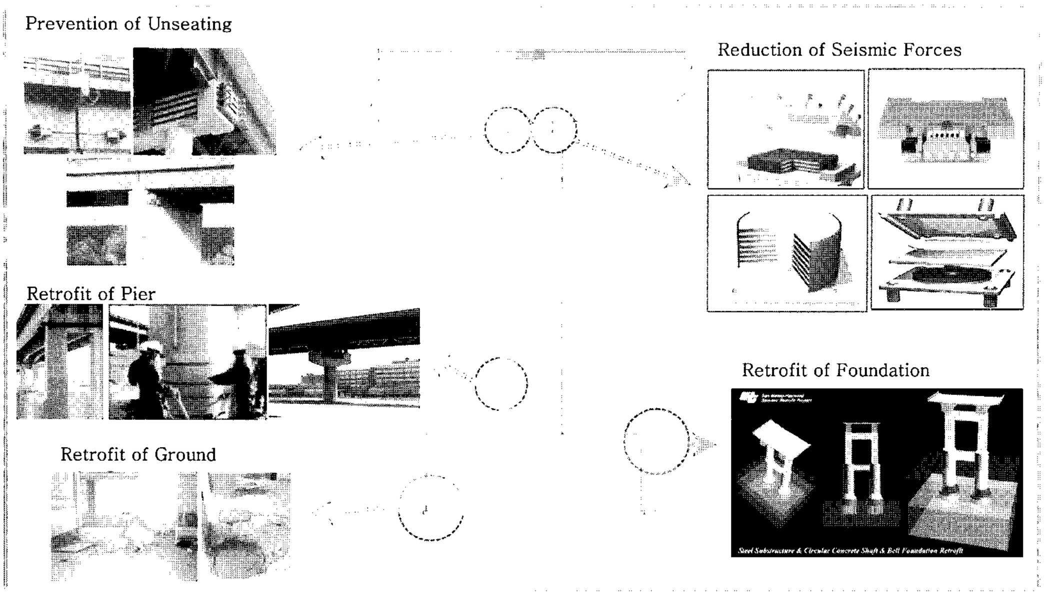


<Figure 7> View of a hydraulic jack



<Figure 8> Hysteretic behaviors of pier 15, 16 and 17

<Figure 6> Nam-Han River bridge



〈Figure 9〉 Retrofit methods for bridges

3. 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 systems in Korea are generally accepted as economically more efficient alternatives for seismic protection against conventional design concept, especially considering the low to moderate seismicity of Korea.

Accordingly, many theoretical and experimental researches have been carried out to develop satisfactorily performing isolators in a view of seismic performance as well as economic cost. Therefore, optimal design procedure based on minimum LCC concept is presented and such approach is accepted to be more expedient for the design of seismically isolated bridges in Korea. Studies have reported that a seismic isolation system is more cost-effective in low-to-moderate seismic regions than highly seismic zones. In addition, more flexible isolators are seen to be efficient in such regions. Field-testing of full-scale bridge to investigate the dynamic characteristics of isolated bridges and verify the adequacy of the new design concept based on the LCC minimization was conducted. Some research results of the field testing are considered into new bridge design specifications published in Feb. 2005. One of the main content of revision is the adoption of "the specifications for seismic isolation design of bridges" as a new part.

Up-to-date applications of the seismic isolation system to the bridges are reported detail, and development of new isolation devices are introduced in this paper. Finally major retrofitting method of bridges structures is described.

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