Characteristics of Korean Earthquakes and Research Activities for the Seismic Hazard Mitigation in Korea

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ABSTRACT

Korea is not considered to be one of the safe zones for earthquakes any more. According to the records of the historical records and recent earthquake events in Korea, the possibility of disastrous seismic hazards cannot be ignored. Korea Earthquake Engineering Research Center (KEERC) and Earthquake Engineering Society of Korea (EESK) have been established by that consensus. In this paper, historical earthquake records and seismicity in Korea are reviewed. And the research activities and the research system for the earthquake hazards mitigation of KEERC are introduced and the efforts of EESK to renovate seismic design code system and to optimize the protection levels against earthquake disasters is explained.

Key words : *KEERC, EESK, earthquake, seismicity, hazards, mitigation, code*

1. Introduction

Recently there have been many destructive seismic events in Northridge, California, USA in 1994 and Kobe, Japan in 1995, etc. These events demonstrated the importance of mitigating these hazards in the design of new structures. It has been considered that Korea is a safe area from the peril of earthquakes because it is located away from the plate boundary and does not belong to a seismically active zone. However, historical records show that there occurred big earthquakes several times in the past 2000 years and they claimed human casualties and serious property damages. Also they show some descriptions indicating the occurrences of big earthquakes which triggered destructive damages with ground fissures, surface depression, liquifaction and landslide.

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The devastating Hyogoken-Nanbu earthquake of January 17, 1995 in Japan sent mental shock waves that awakened the public concern about the possible earthquake disaster in Korea. Many seismologists pointed out that a disastrous earthquake might 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 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 disaster in Kobe, Japan. Immediately after the earthquake, the Korean government announced research plans for the development of seismic design criteria 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 core members of EESK in joint with other researchers made a proposal to establish an earthquake engineering research center to the Korea Science and Engineering Foundation (KOSEF). After long review process, the proposal was finally approved by KOSEF. The Korea Earthquake Engineering Research Center (KEERC) is nominated as an engineering research center by KOSEF. KEERC began to receive fund from KOSEF since June 1, 1997 for the period of 9 years. The mission of KEERC is to perform integrated researches and disseminate the results for the mitigation of earthquake hazards. The organization and research plans of KEERC will be described more fully later in this paper. Currently, EESK and KEERC are two main organizations active in the field of earthquake engineering research in Korea.

2. Seismicity in and around the Korean Peninsula[1,2]

The Korean Peninsula lies within the Eurasian Plate in terms of the plate tectonics. The Pacific Plate subducts under the Eurasian along the Japan Trench, and Indian Plate collides with the Eurasian Plate along the Hymalayas. Earthquakes in the Korean Peninsula belong to the category of the intraplate seismicity (Fig. 1). The Korean Peninsula occupies the southeastern part of the Korea-Chinese Heterogen, a microcraton extending from china through Manchuria to Korea. A long term synchronous variation in seismicity since 1400 A.D. exists in the intraplate region from northeastern China to the Inner Zone of Southwest Japan through the Korean Peninsula. Short term synchronous variation in seismicity since 1900 is also found in the region from northeastern China and the Korean Peninsula to the western part of the Inner zone of Southwest Japan. Historical volcanic activity in and around the Korean Peninsula is closely correlated with active seismicity.

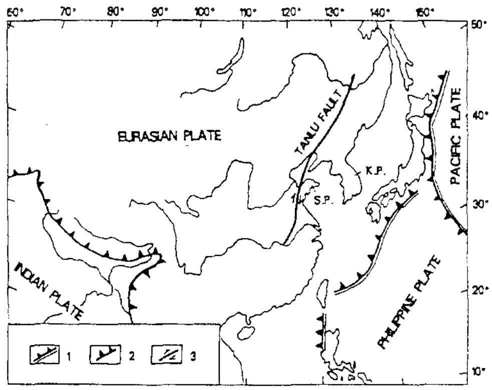

Fig. 1 Tectonic Location around the Korean Peninsula(1. subduction zone; 2. collision zone; 3. Tanlu fault)

In general, the seismicity of the southern and western parts of the peninsula is higher than that in the northwestern part. It appears that the later orogenies in the peninsula which occurred during Mesozoic severely ruptured the southern and western crustal layers of the Korean Peninsula. Earthquake occurs in zones of weakness of the crust, mainly along faults. The close correlation between seismicity and Quaternary tectonics is well observed in many areas of the world. In the Korean Peninsula Quaternary tectonism is rather limited to volcanic eruptions on the Cheju and Ulleung Islands, Mt. Paektusan and along the chungaryeong Rift Zone. However, the seismicity of the peninsula implies that there exist a number of active faults in the peninsula. It appears that the Mesozoic orogenies greatly ruptured the crust of the peninsula and many of the faults thus created have generated earthquakes afterwards.

The stresses required for triggering earthquakes in Korea may be mainly supplied from collision of the Eurasian Plate with the Indian Plate and the Pacific Plate along the Himalaya and Japan Trench, respectively. The collision between these plates causes a high stress which transmits over broad areas of the Eurasian Plate and triggers earthquakes. The Eurasian Plate behaves like a rigid plastic medium and suffers internal deformation including faulting when subjected to external stresses. Zones of weakness, mostly preexisting faults and boundaries between tectonic provinces, are usually sites of faults and earthquakes.

The intraplate seismicity is characterized by a high degree of irregularity both in space and time. The exceptionally high seismicity between the 15-18th centuries is quite remarkable. More than half of seismic energy released in the peninsula since the 1st century was released during this period. Fig. 4 shows the number of earthquakes occurring in and in the vicinity of the peninsula and an extremely high seismicity during the 15-18th centuries. The higher seismicity in the southern and western parts of the peninsula can be seen clearly in Fig. 2 and 3. The important thing to be noted in Fig. 2 and 3 is the good correlation among epicenters and major faults and tectonic boundaries in the peninsula. It appears that a number of major faults and tectonic boundaries in the peninsula are active faults even though they were formed before the Cenozoic.

3. Earthquakes in Korea[1,2,3]

The earthquake records found in various historical literatures constitute the historical data and those after 1905 make up the instrumental data. Historical earthquake records date back to early 1st century and can be found in historical literature such as Samguksagi, Koryeosa, Koyeosajeolyo, Choseonwangjosilok and some other official records.

Before 936 A.D.(era of three dynasties; Shilla, Paekche, and Koguryo), there are 102 earthquakes reported in records. According to records, most of these earthquakes have been felt at the capitals of the three dynasties. Due to the sparse population in these places during that period, a number of earthquakes occurring in other places has been failed to be reported. The size of earthquake can be estimated only in terms of intensity. MM intensity of historical earthquakes of Korea may be evaluated by description of earthquakes or felt areas. Among 102 earthquakes occurred during the era of three dynasties, 16 events are damaging earthquakes with MM intensity equal to or greater than VIII. They occurred in the vicinity of Kyeongju and this point implies that the Yangsan Fault which runs from Pusan to Youngdeok through Kyeongju is seismologically active. The earthquake occurred in 779 destroyed a number of houses and killed about 100 people in Kyeongju.

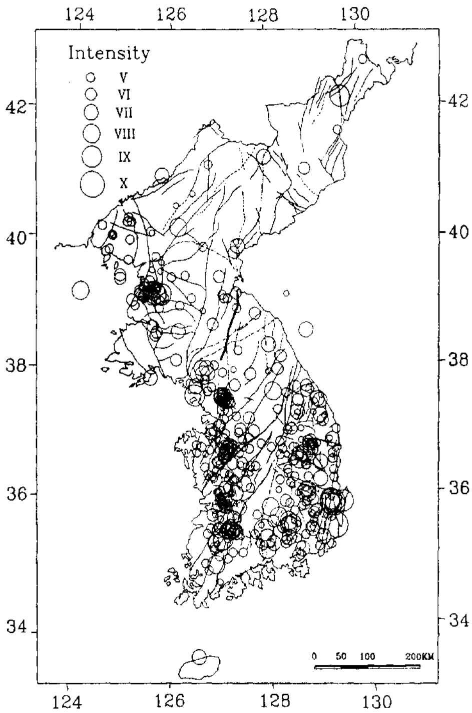

Fig. 2 Epicenters of Korean historical earthquakes having MMI equal to or greater than V during A.D. 2-1905

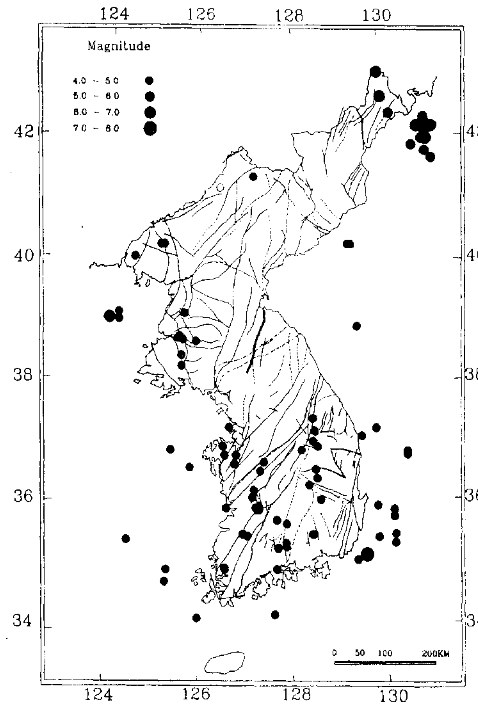

Fig. 3 Epicenters of Korean instrumental earthquakes having magnitude equal to or greater than 4.0 during A.D. 1905-1993

During the Koryo Dynasty (936-1391) 170 earthquakes were felt and 13 events among them are damaging earthquakes of MM intensity equal to or greater than VII. As in the case of the era of three dynasties, most of the earthquakes during that period were reported to have been felt at the capital, Kaesung. 133 earthquakes among 170 events were felt there and the rest at other densely populated places such as Kyeongju and Pyeongyang, and other places.

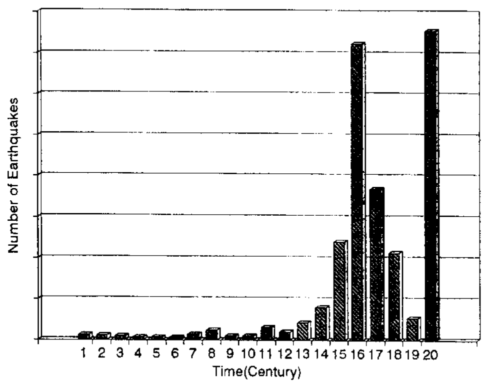

Fig. 4 Numbers of Korean earthquakes per century

The distribution of population during the Koryo Dynasty was not quite even over the peninsula like the era of three dynasties. It is likely that in reality more earthquakes occurred in the peninsula than were recorded in historical literature; during the three dynasties and the Koryeo Dynasty a number of events has not been registered in historical literature because of the sparse population and the poor communication system.

In the Chosun Dynasty, earthquake data appears to have been more faithfully collected and registered in historical literature compared to the previous times due to increased population and better communication system. Seismic data during the Chosun Dynasty is found in a number of historical literatures and so far these have not been surveyed completely.

A large number of earthquakes in the 20^{th} century is quite noticeable. However this does not imply a corresponding increase in seismicity. Establishment of seismograph stations enabled small earthquakes which human can miss to be detected. Recent earthquakes in and around the Korean Peninsula are not big in size, which occurred infrequently and are typical characteristics of intraplate seismicity. In Korea, rather detail earthquake information from the instrumental data is only available for last two decades. Considering the meager seismicity in Korea, this short period earthquake information is not enough to understand the earthquake occurrence pattern in Korea. Modern demands on seismology require earthquake data which are as accurate, homogeneous and complete as possible as so that hidden tectonic features may be revealed and seismic hazard assessed. Records of 1592 earthquakes were found and it turned out these earthquakes occurred almost all over peninsula.

Epicenter of all historical earthquakes of MM intensity equal to or greater than V and instrumental earthquakes of magnitude equal to or greater than 4.0 during A.D. 2-1993 are shown in Fig. 3 and 4. Fig. 5 shows recent seismicity map since 1978 from Korea Meteorological Agency (KMA). At the southern part of Korea, narrow zone of epicenter is defined from northwest to southeast. Fig. 6 shows epicentral map from north Korea covering the 24-years period between 1960 to 1983. At the northern part of Korea, epicenters are rather concentrated on the western part of the Korean Peninsula.

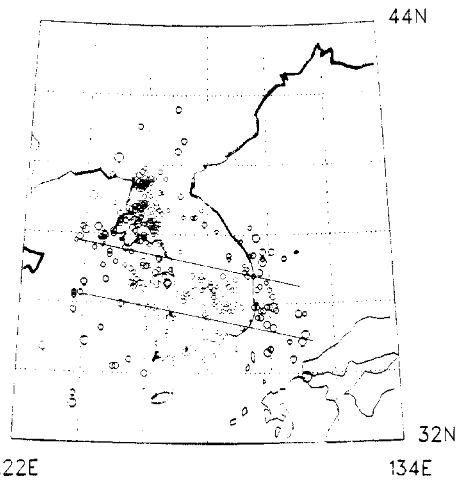

Fig. 5 Seismicity map for the period from 1978 to 1996 by Korea Meteorological Agency (KMA)

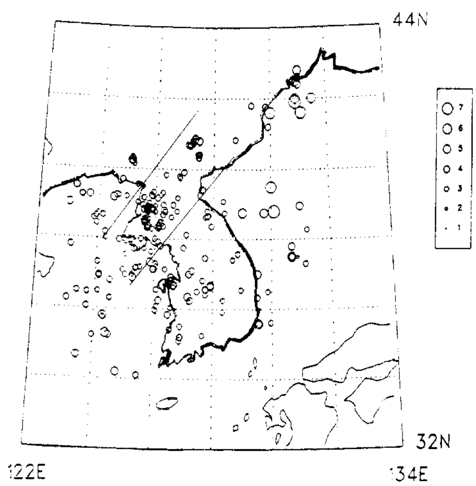

Fig. 6 Seismicity map for the period from 1960 to 1983 by Seismological Institute of North Korea

4. Organization and research areas of KEERC

The Korea Earthquake Engineering Research Center is headquartered at Seoul National University. It is established with the grant from KOSEF. The support of KOSEF will last for 9 years. The primary goal of the center is to contribute to the mitigation of earthquake hazards through researches in the area of seismic hazard evaluation, seismic analysis and design technology and social preparedness. Eventually the aim of KEERC is to protect the people and the social and economic system from the seismic hazards and contribute to the development of national economy. It is concluded that the seismic design is the organic integration of scientific investigations and engineering solutions for earthquakes (Fig. 7).

The 31 prominent researchers from 16 organizations are participating in the coordinated and integrated research activities. The majors of researchers are geology, civil and architectural engineering, etc., which are related to earthquake engineering and science. The center is composed of two divisions: research and support and has three committees: steering committee, advisory committee, and evaluation committee (Fig. 8). The research division is subdivided into 6 research groups: Seismic Hazard and Ground Motion, Geotechnical Engineering, Buildings, Infra Systems, Seismic Risk Management and Innovative Seismic Design. Each group performs one integrated project that consists of several research topics. To perform the researches of the seismic hazard mitigation successfully,

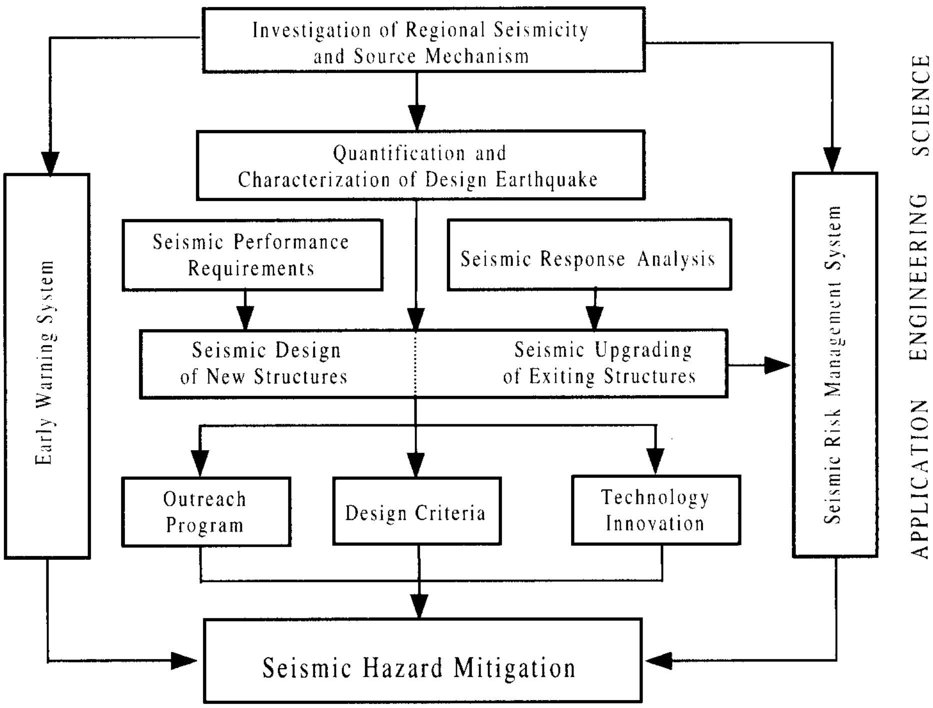

Fig. 7 Research developments scheme of KEERC

our 6 research groups have a close relationship each other as shown in Fig. 9. Along with the fundamental researches by the fund from KOSEF, the center is engaging in practical researches upon the request of and with the support from industries. The centeris encouraging international cooperation in researches and knowledge exchange. Eventually the research outcome will be returned to the society through outreach program: training, education and technology transfer.

The ongoing research topics of research groups are as follows:

- Seismic Hazards and Ground Motion
  - *Seismicity and Seismotectonic Structure of the Korean Peninsula:* Kim, Sung-Kyun
  - *Estimation of Design Response Spectrum*

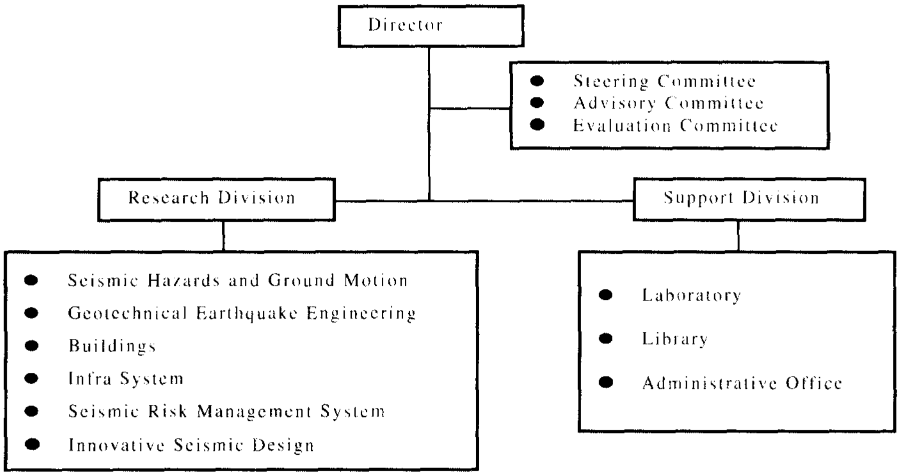

Fig. 8 Organization of KEERC

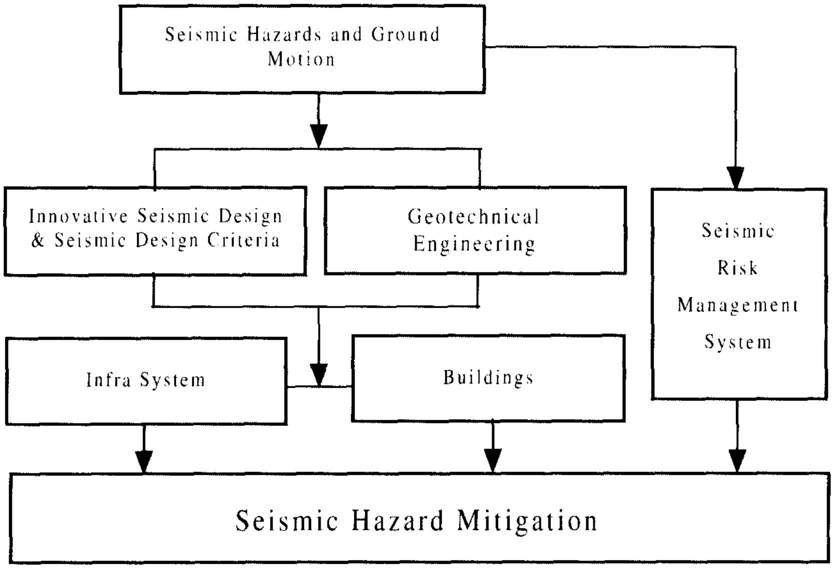

Fig. 9 Relations between research areas of KEERC

Compatible to the Seismotectonic Characteristics of the Korean Peninsula: Kim, Jun-Kyung

- *Characteristics of Earthquake Sources and Crustal Structures in the Korean Peninsula:* Baag, Chang-Eob
- *Tsunami Simulations for a Nuclear Power Plant Site in Northern Korea of the East Sea:* Choi, Byung-Ho

■ Geotechnical Engineering

- *A Study on the Evaluation of Liquefaction Susceptibility of Korean Marine Deposits:* Kim, Soo-Il
- *The Research for Seismic Design Concepts and Analysis Methods of Infra-Structure:* Kim, Myoung-Mo
- *Study on Site Characterization and In-Situ Monitoring*: Kim, Dong-Soo

■ Buildings

- *Earthquake Resistant Design of Building Structures:* Lee, Dong-Gun
- *Shear Strength of Reinforced Concrete Columns:* Hong, Sung-Gul
- *Improving the Seismic Performance of Steel Beam-Column Joints*: Lee, Seung-Joon
- *Development of Composite Beam for Improved Seismic Performance:* Kim, Wonki
- *An Analytical Study on the Seismic Behavior of Masonry Structures*: Kim, Hee-Churl

■ Infra Systems

- *Development of a Seismic Analysis Program for Bridges:* Chang, Sung-Pil
- *Seismic Analysis of Skew Slab Bridges:* Chung, Young-Soo
- *A Study on Seismic Behavior of Reinforced Concrete Bents:* Shin, Hyun-Mok
- *Development of Seismic Analysis Techniques of Tank Structures:* Joe, Yang-Hee
- *Reliability Estimation of the Seismic Performance of Bridges:* Kim, Sang-Hyo
- *Seismic Retrofit of Bridges:* Lee, Jong-Sae
- *A Study of Lifeline Seismic Design Criteria and Method*: Kim, Moon-Kyum

■ Seismic Risk Management

- *Damage Assessment and Optimal Maintenance Methods for Large Structures:* Yun, Chung Bang
- *Nondestructive Evaluation and Seismic Hazard Monitoring Methods for Large Structures*: Rhim, Hong Chul

■ Innovative Seismic Design

- *A Study on the Current and Next Generation Seismic Design Concepts in Foreign Countries:* Kim, Jae-Kwan
- *Development of Seismic Response Control Technique*: Koh, Hyun-Moo
- *Development of seismic response analysis methods for the historical monuments:* Kim, Jae Kwan

5. New seismic design criteria and code system in Korea[4]

In 1988 seismic design requirements was included into the Building Standard Law system. New buildings of 6 stories or higher are required to be designed against earthquake load. Requirements for the seismic design of highway bridges were introduced into the standard specifications for the highway bridges in 1992. There exist seismic design criteria for dams, high-speed railway bridges and tunnels. The seismic design has been applied to nuclear power plants from the beginning of the industry. However, still there are many kinds of facilities that do not have their own seismic design codes. Moreover, the existing ones have serious shortcomings such as disparity in seismic zoning, seismic coefficients, design response spectrum. More seriously the performance objectives and design principles are different from code to code.

As mentioned in the introduction, the Ministry of Construction and Transportation entrusted EESK the task to develop new seismic design codes for the facilities under its jurisdiction late 1996. EESK proposed a radically new code system. The underlying concept is similar to the performance-based-design criteria.[5,6,7] However the idea was evolved from the seismic design regulatory system for nuclear power plants. The unique structure of the present code system is that it consists of two-level design criteria: the high level and the low level. Fig. 10 describes the outline of the code system.

The high level criteria are basically seismic performance requirements. The low ones are technical rules to achieve the required seismic performance objectives. It is quite accidental coincidence but the system agrees in principle with the design procedure that the Architectural Institute of Japan plans to adopt in the future.[8] The coordination and adjustment of the seismic performance objectives and design principles across diversified facilities can be accomplished best at the conceptual level. By incorporating the high-level criteria into the law system, the protection of the society from the earthquake risk can be more strongly imposed and the balance in protection level can be achieved.

Two seismic performance levels are defined for the seismic objectives. The facilities are classified into three categories according to the importance. The performance objectives are given in Fig. 11. With historical records, Korean researchers started to construct the seismic hazards map from 1985 and after some revisions, they completed the maps in 1996. These maps provide the basic information for investigation, revision, and new regulation of the earthquake design standards

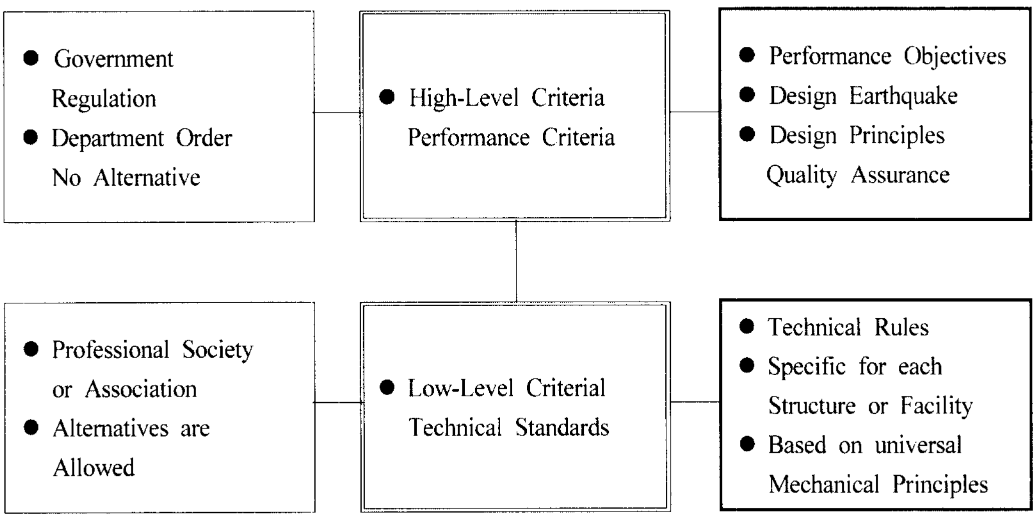

Fig. 10 Two-level seismic design code system

which is constructed for each facility and structure. These maps indicate the peak acceleration with 10% probability of exceedance in 5, 10, 20, 50, 100, 250, 500 years. In other words, the average return periods for each period and probability are 48, 95, 190, 475, 950, 2373, 4746 years. Fig. 12 shows the peak acceleration with 10% probability of exceedance in 50 years in Korean Peninsula.

Design Earthquake (Return Period)	Performance Level	
	Operational	Near Collapse
43 years	●	
95 years	▲	
190 years	■	
475 years		●
950 years		▲
2373 years		■

●: Ordinary Structures and Facilities
▲: Important Structures and Facilities
■: Safety Critical Structures and Facilities

Fig. 11 Seismic performance objectives

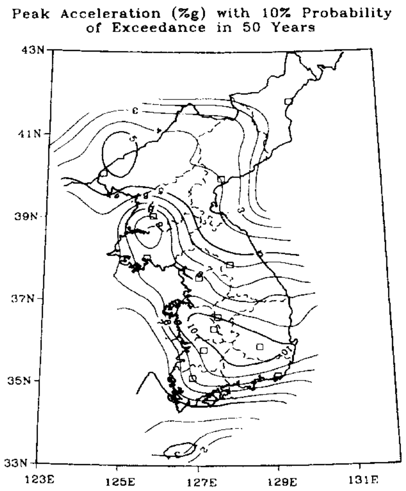

Fig. 12 Korean seismic hazards map

Fundamental requirements on the quality assurance and those on the seismic instrumentation are included in addition to the conventional requirements. The main contents of the high-level criteria are listed as follows:

- Classification of seismic categories
- Seismic performance objectives
- Design ground motion
- Behavior limit states
- Fundamental requirements on the seismic design
- Fundamental requirements on the seismic analysis
- Fundamental requirements on the quality assurance
- Authorized specifications and standards
- Fundamental requirements on the seismic instrumentation

The facilities of which high-level criteria have been completed include building structures; highways and highway bridges; railways and high-speed railways; airport; harbor; dams; and tunnels and underground structures.

It has to be pointed out that the design criteria were based heavily on the research works done in other countries. For the construction of the design response spectrum, it should be based on the seismic characteristics of Korean Peninsula. But currently it is not easy to establish the reliable design response spectrum, because there is not enough information for earthquakes and sufficient investigation has not been performed in Korea. By taking this situation into consideration, the pattern of the design response spectrum which are presented in Uniform Building Code (UBC, 1997) has been selected to adjust Korean code system.

UBC has improved the classification system that has been used in the seismic design of buildings. With this UBC classification, the site profile can be classified quantitatively without ambiguousness. As accumulating the research results on the condition of sites in Korea, the current code system will be adjusted and developed continuously.

The Ministry of the Construction and Transportation approved the draft and it will soon be codified into regulations. To complete the proposed two-level code system, the technical criteria need be developed. EESK is expected to assume the pivotal role in that process. Because the present work has been completed in very limited time period, it need to be reviewed thoroughly in near future.

6. Closure

Korea has a long history of earthquakes but the seismic risk is not very high in Korea. Nevertheless, it is agreed that preparatory measures need to be taken to prevent a potential earthquake disaster. The seismic design or earthquake-resistant design has been introduced very recently for certain class of facilities. As a matter of fact, Korea does not need to adopt the models of countries that are suffering strong earthquakes such as Japan and USA directly. Appropriate code system for Korean environment is required. Korea is trying to adopt very well structured and coordinated seismic design code system and to develop technologies to implement them. Fundamental researches on the earthquake sources, characteristics of ground motions and seismic hazard will contribute to the optimization of protection levels against earthquake hazards. KEERC and EESK will continue to be the hubs of research activities.

The research level is not comparable with other countries yet. But the results will not limited only for use in Korea only but will benefit the earthquake engineering community worldwide. KEERC and EESK are committed to cooperate with the researchers or research institute of other countries and share the knowledge, new findings and research accomplishments with them.

References

1. Lee, Kiehwa, "Earthquakes of Korea," *Proceedings of 1996 Symposium on Seismology in East Asia,* Daejon, Korea, 1996, pp. 5-12.
2. Jun, Myung-Soon, "Earthquake data in and out the Korean Peninsula during 1905-1942," *Proceedings of 1996 Symposium on Seismology in East Asia*, Daejon, Korea, 1996, pp. 87-92.
3. Kyung, J. B., et. al., "Paleoseismological approach in the southeastern part of the Korean Peninsula," *Proceedings of 1996 Symposium on Seismology in East Asia,* Daejon, Korea, 1996, pp. 38-47.
4. Earthquake Engineering Society of Korea, *A Study on the Seismic Design Criteria,* Vol. 1 & 2, Prepared for the Ministry of Construction and Transportation, December 1997.
5. Structural Engineers Association of California, "Performance based seismic engineering of buildings," *Final Report,* Vision 2000 Committee, Structural Engineers Association of California, 1995.

6. Bertero, V. V., "State-of-the-art report on: design criteria," *Paper No. 2005,* Eleventh World Conference on Earthquake Engineering, Acapulco, Mexico, 1996.
7. Bertero, V. V., "The need for multi-level seismic design criteria," *Paper No. 2120,* Eleventh World Conference on Earthquake Engineering, Acapulco, Mexico, 1996.
8. Otani, S., "Recent development in seismic design criteria in Japan," *Paper No. 2124,* Eleventh World Conference on Earthquake Engineering, Acapulco, Mexico, 1996.