A STUDY OF THE HISTORICAL EARTHQUAKE CATALOG AND GUTENBERG-RICHTER PARAMETER VALUES OF THE KOREAN PENINSULA

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The KIER's Korean historical earthquake catalog was revised for MMI≥VI events recorded from the years 27 A.D. to 1904. The magnitude of each event was directly determined from the criteria suggested by Seo. The criteria incorporated the damage phenomena of the Japanese historical earthquake catalog, recent seismological studies, and the results of tests performed on ancient structures in Korea. Thus, the uncertainty of the magnitudes of the Korean historical earthquakes can be reduced. Also, the Gutenberg-Richter parameter values were estimated based on the revised catalog of this study. It was determined that the magnitudes of a maximum inland and minimum offshore event were approximately 6.3 and 6.5, respectively. The Gutenberg-Richter parameter pairs of the historical earthquake catalog were estimated to be a=5.32±0.21, b=0.95±0.19, which were somewhat lower than those obtained from recent complete instrumental earthquakes. No apparent change in the Gutenberg-Richter parameter is observed for the 16^{th}-17^{th} centuries of the seismically active period.

KEYWORDS : Historical Earthquake Catalog, Magnitude, Gutenberg-Richter Parameter

1. INTRODUCTION

PSHA (Probabilistic Seismic Hazard Analysis) has been performed more than ten times in Korea for Nuclear Power Plant sites since the 1980's. The seismicity parameters such as seismic source, the Gutenberg-Richter (G-R) parameter, maximum magnitude, and focal depth were assessed by experts or expert teams, and these data were statistically processed during a PSHA. The uncertainty of the seismic hazard results was large due to wide variations of the input data provided by the experts.

A recent study by Seo et al. [1] of the sensitivity of a seismic hazard to seismicity parameters showed that in Korea the G-R parameter was more sensitive than the attenuation equation. Accordingly, we analyzed the historical earthquake catalogs and G-R parameters, which are basic materials in a PSHA. There are several historical earthquake catalogs which compile the damage records for earthquakes that occurred from year 2 A.D. to 1904. Wide variations exist in the occurrence time, magnitude (or intensity), epicenter, and number of events. Also, the details of determining the G-R parameter values are quite different among the experts.

By reflecting the results of sensitivity analysis, firstly, we revised the historical earthquake catalog studied by Seo [2] by adding the results of other seismological studies. Originally, he tried to reduce the uncertainties inherent in the magnitude and epicenter of the KIER(Korea Institute of Energy and Resources)'s catalog [3] by determining the magnitude directly from damage records and leaving the unreliable epicenters undetermined. Using the revised historical earthquake catalog of this study, we estimated the G-R parameter values of the Korean Peninsula.

2. REVIEW OF THE HISTORICAL EARTHQUAKE CATALOG AND THE G-R PARAMETER IN KOREA

2.1 Historical Earthquake Catalogs

Many researchers have studied the Korean historical archives which recorded earthquake damage. Among the various historical catalogs, typical ones are the KIER's [3], Kim et al.'s [4], and Lee and Yang's [5]. The KIER's catalog contains 309 records with MMI≥III, which occurred from 27 A.D. to 1904. Kim et al.'s catalog lists 389 events with MMI≥V, which were recorded for 2 A.D.-1904. Lee and Yang's catalog compiles 2186 earthquakes with MMI≥III (or M≥3.5) which occurred from 2 A.D. to 1904. The major differences of these catalogs are: 1) the KIER's and Kim et al.'s catalogs list only the main events whereas

Lee and Yang's catalog contains main events and aftershocks, 2) In KIER's and Kim et al.'s catalogs, the earthquake sizes are indicated by the MM intensity scale, which were determined through a panel discussion, while in Lee and Yang's catalog, the earthquake sizes are shown in the MM intensity scale and local magnitude. The maximum sizes of the historical earthquakes in the KIER's, Kim et al.'s, and Lee and Yang's catalogs are MMI VIII, IX, and IX, respectively. 3) The KIER's catalog only describes the felt area of each event, while Kim et al.'s and Lee and Yang's catalogs indicate the precise epicenter of each event listed. In these catalogs, the epicenter was determined by a general method described by Lee and Yang. It should be noted that there is no offshore epicenter in Kim et al.'s and Lee and Yang's historical earthquake catalogs.

2.1.1 Magnitude of the Historical Earthquake Catalog

A general method for estimating the magnitude of an earthquake from a damage record is to determine the intensity (MM or JMA) first, and then convert it into a magnitude using empirical conversion equations. However, the MM intensity of a record usually differs by one or two scales depending on experts. Additionally, a magnitude difference of approximately 1.0-2.0 often occurs during the conversion from the MM intensity scale to a magnitude depending on the equation. Typical intensity-magnitude conversion equations which have been used by seismologists in Korea are as follows:

Lee and Yang (2006) [5]:

$$M_l = 0.58 I_e + 1.75$$

Gutenberg-Richter (1956) [6]:

$$M_l = \frac{2}{3} I_e + 1.0$$

Nuttli and Herman (1978) [7]:

$$M_l = \frac{1}{2} I_e + 1.75$$

Mei (1960) [8]:

$$M_l = \frac{2}{3} I_e + 0.44$$

Okamoto (1973) [9]:

$$M_l = \frac{1}{2} I_{JMA} + 0.5$$

Where, M_l is the local magnitude, and I_e and I_{JMA} are the MM and JMA intensity scale, respectively. Recently, empirical conversion criteria to determine directly the magnitude from a damage record were proposed by Seo [2] to reduce the uncertainty. This will be discussed in more detail in Section 3.

2.1.2 Epicenter of the Historical Earthquake Catalog

The epicenters of Kim et al.'s and Lee and Yang's historical earthquake catalogs were determined by the conventional method described by Lee and Yang: 1) when a severely damaged locality is reported among felt places, the epicenter is determined as that locality, 2) when felt places are listed without a severely damaged area, the center of felt places is assumed to be an epicenter, 3) when no specific felt locality is reported, the capital city of the corresponding kingdom is assumed to be the epicenter. These assumptions are reasonable for Korea, which is characterized by the low occurrence rate of small and medium size magnitude earthquakes. Figure 1 shows the epicenters of Kim et al.'s historical earthquake catalog. Epicenters are well dispersed in southern Korea and clustered in the northwestern part of Korea. The regions with very few epicenters shown in Figure 1 are the sparsely populated mountainous areas. For comparison, Figure 2

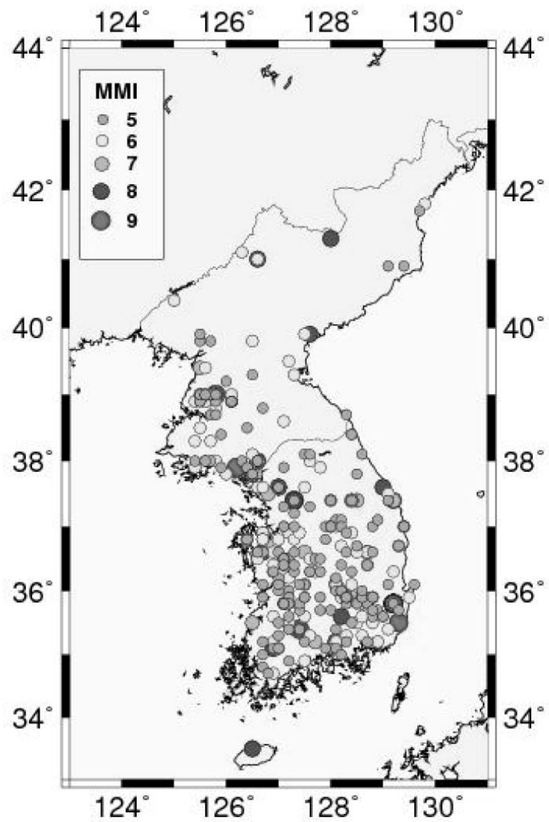

Fig. 1. Epicentral Distribution of the Historical Earthquakes (2 A.D.-1904, Kim et al.[4])

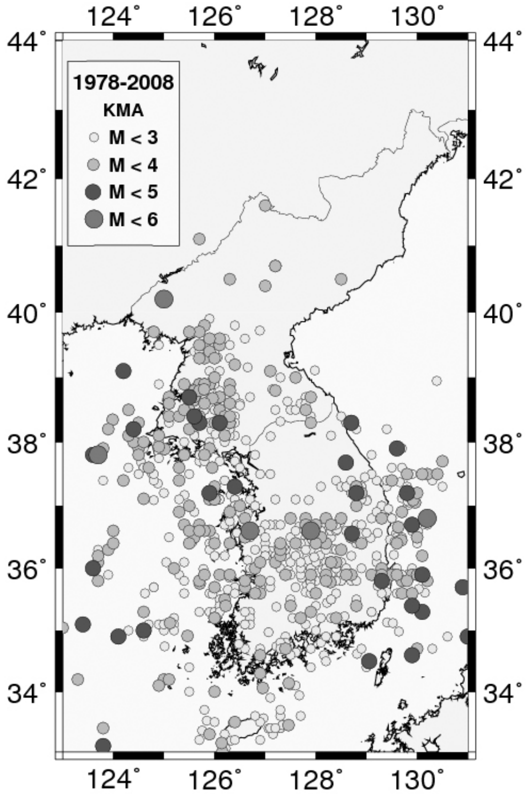

Fig. 2. Epicentral Distribution of the Instrumental Earthquakes (1978-2008, KMA[10])

shows the epicenters of instrumental earthquakes [10] monitored since 1978. It should be noted that the inland epicenters of about 1900-year long historical earthquake catalog and the 30-year long instrumental earthquake catalog are in general very similarly distributed, whereas, there is no offshore epicenter in Kim et al.'s and Lee and Yang's historical earthquake catalogs.

As previously noted, many damage records in a historical earthquake catalog only list the felt or damaged locations with similar damage phenomena so that a severely damaged area is not distinguishable. In such cases, the center of felt or damaged areas was designated as the epicenter. However, the application of this practice to Korea requires some caution. That is, when an earthquake occurs in China or in the surrounding sea, the epicenter may lie inland in Korea if it is determined to be the center of felt or damaged areas. For example, the Haicheng earthquake [11] (1975, M=7.2) which occurred in Manchuria was felt throughout the entire Korean Peninsula and the Yongwol earthquake [12] (1996, M=4.5) which occurred in the north-eastern part of South Korea shook all of South Korea. If some earthquakes in history had occurred in the same area and were similarly recorded, then the epicenter in the catalog would be quite different from the actual one.

2.2 G-R Parameter Values

It should be noted that most previous studies of the G-R values were performed assuming the Korean Peninsula to be one seismic zone, without distinguishing any source zone based on a seismo-tectonic structure. Wide variations in the G-R value, especially the b-value, are observed depending on the researcher due to many factors involved in the analysis.

Based on a historical earthquake catalog, Lee and Yang [5] presented the G-R parameter values of a=6.09, b=0.71 for the whole Korean Peninsula. KEPRI (Korea Electric Power Research Institute) [13] obtained b values of 0.61-0.64 for South Korea by dividing it into 16 lattices (from 33 deg. to 37 deg. of latitude and from 126 deg. to 130 deg. of longitude; a unit lattice consists of 1 deg. longitude $\times$ 1 deg. latitude) whose value varies depending on the location of the lattice. Considering only the instrumental earthquake catalog, Lee and Jung [14] provided b=0.8, and Noh et al. [15] suggested a=5.66, b=1.11, all over Korea. Neither the completeness of the catalog nor the seismic source zones were considered in the studies of [5,13,14]. Noh et al. considered the completeness of the minimum magnitude rather than the parameter estimation itself.

KEPRI [13] also considered the completeness of the historical and instrumental earthquake catalogs and suggested G-R parameter values for the same lattices as mentioned above. In the case of instrumental earthquake only, all 16 lattices showed b=0.98. However, when both the historical and instrumental catalogs were considered, the b-value of each lattice varied from 0.89 to 0.92 depending on the location of a lattice. KEPRI used Kim et al.'s historical earthquake catalog and the Gutenberg-Richter's intensity-magnitude relationship.

Like China, the Korean Peninsula lies on the Eurasian Plate, however, the G-R parameter values of the historical earthquake catalog obtained by previous studies differs much from those of China [16] (mean values of a=4.772 ±0.096, b=1.016±0.107), and those of the instrumental earthquake catalog. These differences are judged to originate from the various catalogs, intensity-magnitude conversion, and the treatment of the incompleteness of a catalog. The incompleteness of the historical earthquake catalog is large temporally and spatially depending on the magnitude of an event. In addition, the lack of data is another factor that must be considered.

3. REASSESSMENT OF THE KOREAN HISTORICAL EARTHQUAKE CATALOG AND G-R PARAMETER

3.1 Reassessment of the Magnitude and Epicenter of the Historical Earthquakes

As discussed in Section 2.1, this study applied the criteria for estimating the magnitude of a historical

Table 1. Relationship of Damage State Versus Magnitude in Usami's Catalog, and Comparison of Damages Recorded during Earthquakes in Korea (Seo, [2])

Magnitude (M_L)	Major damage phenomena in Usami's catalog	Remarks
4.0-5.0	- ground fissure, collapse of mud-plastered wall, fall of roof tile, ock slide	Similar to damages recorded during major events occurred in the 20th century in Korea
5.0-5.5	- minor damage of a house (crack, tilting, partial collapse) - collapse of mud-plastered wall, damage of stonework, landslide,	Similar to damages recorded during major events occurred in the 20th century in Korea
5.5-6.0	- collapse of a house. crack, tilting, fall of wall and roof tile, some occurrence of death - fall of a stone lantern, a stone monument, and a stone pagoda (M ≒5.5). - minor damage of a castle wall, collapse of stonework,	
6.0-6.5	- many collapsed houses, many death toll (several tens). - damage of a solid structure (palace, temple). fall of a stone pagoda, and a Buddha statue - collapse of a castle gate, castle wall. collapse of stonework, fall of bridge. damage of road.	Similar to damage record of a stone pagoda during the earthquake in1036
6.5-7.0	- collapse of temple and palace buildings - many collapsed houses. large death toll (several hundreds) - tsunami, coast uplift, formation of a pond	
7.0-7.5	- major collapse of temple and palace buildings, corridors, and embankments. collapse of a bell tower. - many collapses of houses and embankments. large death toll (several thousand).	

earthquake directly from a damage record proposed by Seo [2]. Additionally, Seo's initial catalog was revised in this study. Firstly, the damage states of KIER's catalog were compared with those of Usami's Japanese historical earthquake catalog [17]. Table 1 shows the typical states of damage described in Usami's catalog depending on the magnitude at an epicenter. Especially, the damage phenomenon of a house was classified with an increasing magnitude from M 4.0 to M 7.5 in 1/2 magnitude increment. The basis of comparison is that an ancient house or a temple structure is very similar between the two countries so that the magnitude of the Korean earthquakes can be inferred directly from Usami's catalog with less uncertainty. In addition, the damaged states of several major events which occurred in the 20th century in Korea were compared with those of Usami's catalog. The events considered are the Ssanggyesa Eq. (1936/7/3, M=5.0), Hongsung Eq. (1978/10/7, M=5.0), Yeongweol Eq. (1996/12/13, M=4.5), and Kyeongju Eq. (1997/6/26, M=4.3), whose damaged states at the epicenter and at many felt locations are well documented, especially at the epicenter due to the proximity to populated areas. It is noteworthy that the damaged states of these earthquakes are quite comparable to those of Usami's catalog for $4.0 \leq M \leq 5.5$. In additin, the damage of the stone pagoda at Bulguksa temple during the July 1036 earthquake can be estimated as $6.0 \leq M \leq 6.5$ based on Table 1 or Usami's catalog. It should be noted that the July 1036 earthquake, whereas the damage and repair record was found in 2007, was duly added to the catalog and identified as the largest inland earthquake in the Korean Peninsula up to now.

Secondly, the shaking table test results for different types of ancient structures [2] were also considered. These include a straw-thatched house, a tile-thatched house, a loophole in a castle wall, a beacon mound, and a stone pagoda. These tests were performed from the mid 1990s to estimate the acceleration level versus damage states. Seo [2] identified that the damage to an ancient house, which was heavily dependent on the foundation condition (soil or rock), occurred at approximately M>5.0 at an epicenter. With the increase of an acceleration level, the damage mode of the house became more severe from

Table 2. Criteria for Determining a Magnitude Based on Damage Phenomena (Seo, [2])

Major damage phenomena in the KIER's catalog	Base magnitude	Remarks
No death with ground fissure and water spring	4.0-5.0	
Collapse of a house	≒5.0	
Collapse of houses with a few death toll	5.0-5.5	
Collapse of houses with some death toll	≒5.5	Increase magnitude by 0.5 when a felt area is large
Collapses of a loophole in a castle and a beacon mound	5.0-5.5	Increase magnitude by 0.5 considering the felt area when collapses of a house or a fence are accompanied

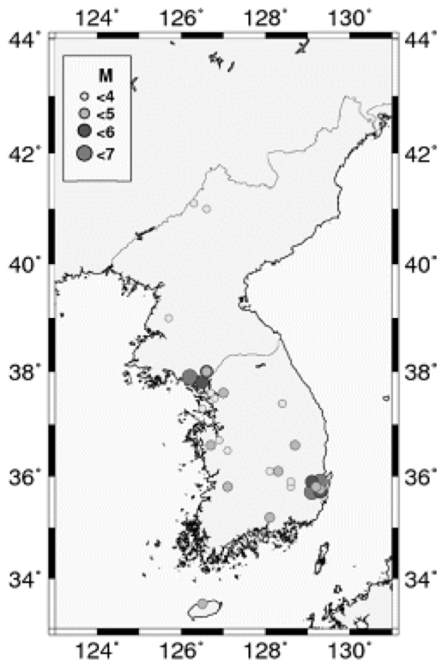

Fig. 3. Epicenters of the Revised Historical Earthquakes (2 A.D.-1904, This Study)

cracks in the wall, tilting of the house, dropout of a wall, to collapse of the house. Taking into account the above studies, Seo [2] suggested the criteria for determining the magnitude of Korean earthquakes as shown in Table 2. He assumed the damage state of a house collapse without any casualties to be the base and estimated it to be M 5.0. The base magnitude increases with a rising death toll. The base magnitude is increased by M 1/2 when a felt area is widespread and (or) it is accompanied by strong structural damage. The damage phenomena in Table 2 are typical descriptions in the KIER's catalog. In case of an offshore earthquake which accompanied a tsunami, the magnitude of that event was determined as M>6.5 based on Usami's results [17].

Table 3 compares the revised magnitude of this study and other catalogs by choosing the KIER's catalog with MMI≥VI events as the base. The reason for using the KIER's catalog as the base is that it was completely documented and the intensity of the catalog had been determined by joint researchers, when compared with other catalogs. Each column in Table 3 represents the event sequence of the KIER's catalog, year-month-date of occurrence, epicenter, MMI of the existing catalogs, and magnitude of this study, respectively. In the comparison of the MMI, both the MMI and magnitude are shown for Lee and Yang's catalog.

The epicenter of Kim et al.'s catalog was followed in this study, because the KIER's catalog did not specify the epicenter of each event and the epicenters of Kim et al.'s and Lee and Yang's catalogs are almost the same. When the epicenter of a damage record in Kim et al.'s catalog was judged unreliable due to the limitations described in Section 2.1.2, the epicenter of that record was indicated by parentheses in Table 3. When an epicenter lies in the sea, the nearest inland city was given after the name of the sea for an epicenter. Recent studies by Baag et al. [18] and Chu [19] were reflected in the epicenters in Table 3. The revised epicenters are the events of October 1597, July 1643, July 1668, June 1681, and February 1810. The eastern China event of July 1668 caused tsunami in the Yellow Sea, while three other events of July 1643, June 1681, and February 1810 were accompanied by tsunamis in the East Sea. Figure 3 shows the epicenters of the revised historical earthquake catalog for inland events with M>4, where thirty events with reliable epicenters are shown. It should be noted that relatively large events occurred more frequently in the Kyeongju area (southeast region) and the Gaesong area (mid-west region). Further review is required in the future in a separate study regarding the epicenters, as the G-R parameter is very sensitive to the number of events in a seismic source zone, in other words, the location of epicenters, when refined seismic source zones are defined in a PSHA.

It was estimated that the maximum magnitude of inland and minimum magnitude offshore events were about 6.3 and 6.5, respectively. The number of events with M≥5.0 was estimated to have occurred approximately 15 times for about 1,900 years. The epicenters of many earthquakes were undetermined. Four offshore earthquakes were accompanied by tsunami. Relatively large events occurred more frequently in the southeast and northwest

Table 3. Revised KIER's Historical Earthquake Catalog for MMI≥VI

No.	occurrence year-month-date	Epicenter [1] longitude/latitude		MM Intensity or magnitude			magnitude M
				KIER [3] MMI	Kim et al. [4] MMI	Lee & Yang[2] [5] MMI / M	This study
1	27 -	(127.3)	(37.4)	VII	VIII	IX / 6.4	≒5.0
4	89 -	(127.3)	(37.4)	VIII	IX	IX / 6.7	5.5-6.0
5	100 -	129.2	35.8	VIII	IX	IX / 6.7	5.0-5.5
7	304 -	(129.2)	(35.8)	VIII	IX	IX / 6.1	4.0-5.0
8	304 -	129.2	35.8	VIII	IX	IX / 6.7	5.0-5.5
9	458 -	129.2	35.8	VIII	VIII	VIII / 6.4	4.0-5.0
11	502 -	(125.8)	(39.0)	VIII	IX	IX / 6.7	5.0-5.5
12	510 -	(129.2)	(35.8)	VIII	IX	IX / 6.7	5.0-5.5
13	664-9-12	(129.2)	(35.8)	VII	VIII	VIII / 6.4	≒5.5
16	768 -	129.2	35.8	VI	VII	VIII / 6.4	≒4.5
17	779 -	129.2	35.8	VIII	IX	VIII –IX / 6.7	≒6.2
23	1036-7-23	129.2	35.8	VII	VIII	VIII / 6.4	6.0-6.5
29	1226-11-5	126.6	38.0	VII	VII	VII / 5.8	4.0-4.5
31	1260-6-24	126.5	37.8	VII	VIII	VII / 5.8	≒5.0
45	1385-8-1	126.6	38.0	VII	VIII	VII / 5.8	≒5.0
49	1409-7-26	126.5	37.3	VIII	–	–	< 4.0
54	1416-5-23	128.7	36.6	VII	VII	VI / 5.2	≒4.5
70	1455-1-24	(127.4)	(35.4)	VIII	IX	VIII –IX / 6.7	5.5-6.0
78	1518-7-2	126.2	37.9	VIII	IX	VIII –IX / 6.7	≒6.0
87	1519-11-15	128.4	37.4	VI	VI	V / 4.7	< 4.0
114	1529-11-15	127.1	36.5	VI	VI	V / 4.7	< 4.0
128	1546-6-30	(127.0)	(37.6)	VII	VIII	VIII / 6.4	5.0-5.5
139	1552-2-4	126.8	37.5	VI	VII	V / 4.7	< 4.0
148	1555-3-13	128.6	35.8	VI	VI	VI / 5.2	< 4.0
170	1564-3-6	126.6	41.0	VI	VIII	V / 4.7	< 4.0
199	1594-7-20	(126.7)	(36.6)	VI	VIII	VIII / 6.4	4.0-4.5
204	1597-10-6	North Eastern China		VI	VIII	VIII / 6.4	
209, 210	1601-3-7	128.6	35.9	VI	V	V / 4.7	< 4.0
217	1604-3-19	126.3	41.1	VI	VI	V / 4.7	< 4.0
218	1604-12-19	126.7	37.6	VI	VI	V / 4.7	< 4.0
220	1613-7-16	127.0	37.6	VII	VI	VII / 5.8	4.0-4.5
231	1643-6-9	127.1	35.8	VIII	V	VIII / 6.4	4.5-5.0
233	1643-7-24	East Sea near Ulsan		VIII	IX	VIII –IX / 6.7	>6.5
237	1660-2-6	128.1	36.1	VI	VII	V / 4.7	< 4.0
238	1662-4-21	126.9	36.7	VI	VII	V / 4.7	< 4.0
248	1668-7-25	Eastern China		VIII	–	VI / 5.2	
250	1669-10-8	125.7	39.0	VI	VI	V / 4.7	< 4.0
252	1670-10-30	(126.9)	(35.1)	VII	VIII	VII / 5.8	4.0-4.5
253	1670-11-15	126.5	33.5	VII	VIII	VII / 5.8	4.0-4.5

260 - 263	1681-6-12	East Sea near Yangyang		VIII	VIII	VIII –IX / 6.7	>6.5
268	1682-3-19	128.4	37.4	VII	VII	VI / 5.2	< 4.0
275	1692-11-2	(127.5)	(36.6)	VI	VII	VIII –IX / 6.7	4.5-5.0
279	1700-4-29	128.1	35.2	VIII	VIII	VII / 5.8	4.5-5.0
301	1727-6-20	(127.6)	(39.9)	VII	VIII	VII / 5.8	5.0-5.5
307	1757-7-30	126.7	36.6	VIII	–	VIII –IX / 6.7	<4.5
308	1760-8-30	128.3	36.1	VIII	–	V / 4.7	4.5-5.0
–	1810-2-19	East Sea near Chungjin				VIII –IX / 6.7	>6.5

Note: 1) epicenter in a brace means that epicenter of the corresponding event is quite uncertain.
2) As Lee and Yang's catalog lists aftershocks, the largest event among records with the same occurrence year-month was selected and compared

regions compared with other parts of Korea. It should be noted that, during the 16th and 17th centuries, the number of damage records significantly increased as shown in Table 3, however, the magnitude of the majority of the events is estimated to have been M≤5.0.

3.2 Reassessment of the G-R Parameter Values of the Historical Earthquakes

The G-R a- and b-values were evaluated using the revised earthquake catalog in Table 3 under the assumption that the Korean Peninsula to be one seismic source. The following three cases were considered: 1) earthquakes with M≥5.0 from 2 A.D. to 1904, 2) events with M≥4.25 occurred during the 16th - 17th centuries when damage records significantly increased compared to other centuries, and 3) events from 1392 to1904 with M≥4.75. Offshore earthquakes were not considered in this study because their epicenters could not be determined. Many of them could be located in Korea's East Sea or the western part of Japan. In the first case, the magnitude threshold level of M=5.0 was determined subjectively by considering the felt area of several instrumental earthquakes for M≥4.3 with shaking felt across the Korean Peninsula as discussed in Section 3.1. Accordingly, the possibility of intentionally or unintentionally missing a record is considered small in the historical records of the Korean kingdoms up to the 10th century. The year 1392 was selected as a boundary in case 3, because the earthquake damage records became rather more complete with the beginning of the Lee (Joseon) Dynasty from 1392, whose territory covered the whole Korean Peninsula.

The historical earthquake data for estimating the G-R parameter are not generally well defined so the Weichert's maximum likelihood method [20] is reliable. However, linear regression analysis was also used in order to discern the differences between the two methods. In fact, linear regression analysis has been used by many experts in getting the G-R parameters during PSHAs. The maximum magnitude of M=6.75 for a time span of 1,900 years with

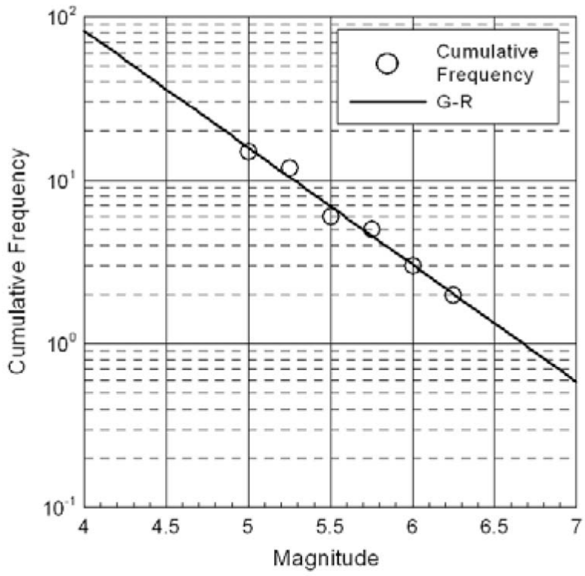

Fig. 4. Cumulative Number of Events vs. Magnitude Plot for Case 1 (M≥5.0 and Year 2 A.D.-1904)

a small probability of occurrence was assumed in the Weichert's method for all cases. A magnitude of 6.75 was determined to compensate for the usual error of 0.5 unit in magnitude, and the July 1036 (M=6.0-6.5) event was assumed to be the maximum historical event (M≒6.25) in this study.

Table 4 lists the number of events in 1/4 magnitude increment for each case. Also, Figures 4 to 6 show plots of the cumulative frequencies and linear regression lines for each case. The G-R parameter values of the above three cases are summarized in Table 5. Linear regression analysis (LR) yielded much lower G-R values than the maximum likelihood method (ML) in the 2nd and 3rd case, whereas the LR produced much higher values than the ML in the 1st case. Also, the G-R values of the 3rd case

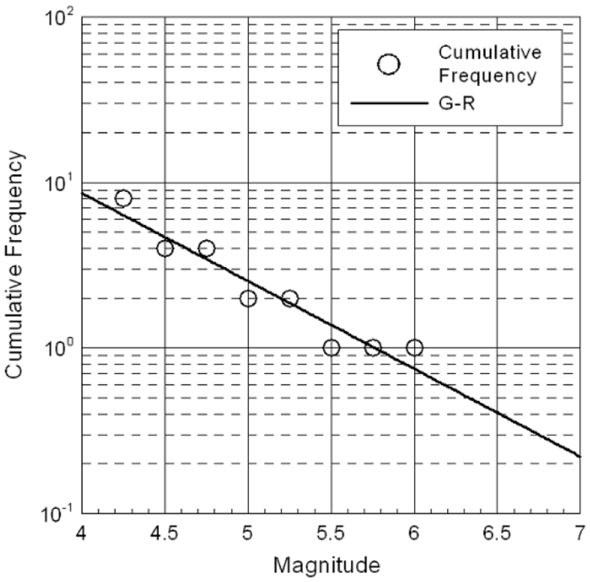

Fig. 5. Cumulative Number of Events vs. Magnitude plot for case 2 (M≥4.25 and 16th-17th Century)

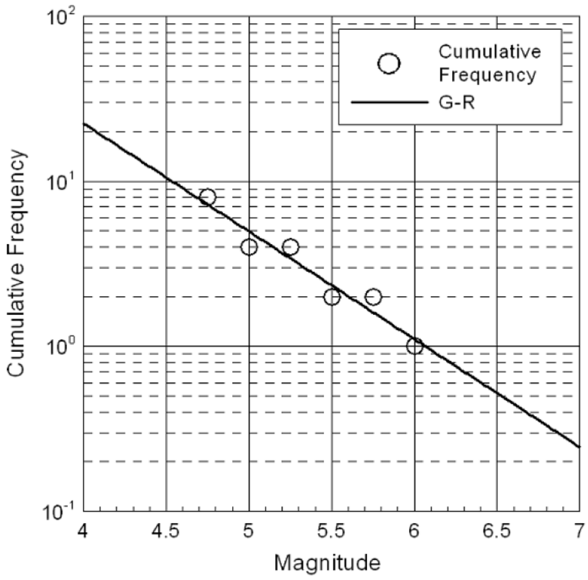

Fig. 6. Cumulative Number of Events vs. Magnitude plot for case 3 (M≥4.75 and Year 1392-1904)

Table 4. Incremental Frequency of Occurrence of the Historical Earthquakes for Estimating G-R Parameter Value for Inland Events

Magnitude range	Magnitude centers	No. of events		
		Case 1 (2 A.D.-1904)	Case 2 (16th-17th century)	Case 3 (1392-1904)
6.0<M<6.5	6.25	2	not applicable	not applicable
M ≒6.0	6.0	1	1	1
5.5<M<6.0	5.75	2	0	1
M ≒5.5	5.50	1	0	0
5.0<M<5.5	5.25	6	1	2
M ≒5.0	5.0	3	0	0
4.5<M<5.0	4.75	not applicable	2	4
4.5	4.5	not applicable	0	not applicable
4.0<M<4.5	4.25	not applicable	4	not applicable

were much higher than the 2nd case in both methods. No significant dependent relationship is recognized between the methods and cases. However, the LR of the 1st case and the ML of the 3rd case yielded quite comparable a-values but somewhat lower b-values compared to Noh et al.'s (a=5.66, b=1.11) which considered the complete period and magnitude of the instrumental earthquake catalog (1978-2000, M≥3.0). The b-values of both cases are somewhat higher than those of KEPRI (b=0.89-0.92) [13] for South Korea, which considered the completeness of both historical and instrumental earthquake catalogs. The G-R values of the 2nd case are quite small compared to Noh et al.'s, but the b-value is quite similar to KEPRI's. Taking the arithmetic average of these three sets of results (LR of the 1st case and ML of the 2nd and 3rd cases), we arrive at a=5.32±0.21, b=0.95±0.19.

The 2nd case of high seismic activity period resulted somewhat in smaller G-R values than the 3rd case using Weichert's method. This might have been probably caused by underestimating the magnitude of some events which had been bigger than M 4.25. We could not distinguish any remarkable difference in the seismicity parameters between the active period of the 16th-17th centuries and the normal (or inactive) period.

Table 5. Estimated G-R Parameter Values of Three Cases for Inland Events

	G-R a-value		G-R b-value	
	linear regression	max. likelihood	linear regression	max. likelihood
Case 1	**5.69±0.47**	4.14±0.58	**0.89**±0.43	0.61±0.23
Case 2	2.52±0.61	**4.85**±0.40	0.53±0.34	**0.96**±0.24
Case 3	3.76±0.47	**5.43**±0.01	0.65±0.32	**0.99**±0.30

4. CONCLUSION

We revised the KIER's historical earthquake catalog for MMI≥VI events recorded from year 27 A.D. to 1904 by using the criteria for determining the magnitude directly from damage records. The criteria suggested by Seo [2] incorporated the damage phenomena of the Japanese historical earthquake catalog, and recent seismological studies and test results on ancient structures in Korea. Also, we estimated the Gutenberg-Richter parameter values based on the revised catalog of this study. It was determined that the magnitude of maximum inland and minimum offshore events were approximately 6.3 and 6.5, respectively. The Gutenberg-Richter parameter pairs of the historical earthquake catalog were estimated to be a=5.32±0.29, b=0.95 ±0.32, which were somewhat lower than those obtained from recent complete instrumental earthquakes. No apparent change in the seismicity parameter is observed for the seismically active period of the 16^{th}-17^{th} centuries. The usefulness of Seo's criteria for determining the magnitude of historical earthquakes was indirectly demonstrated.

A future review in a separate study regarding the epicenters is needed, because the Gutenberg-Richter parameter is very sensitive to the number of events in a seismic source zone, when refined seismic source zones are defined in a PSHA.

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