1996년 12월 13일 영월 지진의 진도 및 에너지감쇠에 관한 연구

A Study on the Intensity and Energy Attenuation of the 13 December 1996 Yeongweol Earthquake, Korea

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국문요약

1996년 12월 13일 강원도 영월에서 발생한 지진에 대한 설문 조사를 남한 전지역에 걸친 262개 지역에서 실시하고 진도 평가를 실시하였으며 남한 지역에서의 지진 에너지 감쇠특성을 분석하였다. 진도평가 결과 이번 지진은 남한지역에서 진도 II ~ 진도 VIII 사이의 분포를 보여 주었다. 이 결과를 토대로 작성된 등진도도는 진도평가에 일반적으로 수반되는 불확실성으로 인하여 약간의 분산된 분포를 보이나 남한 일대의 전반적인 진도분포를 잘 보여주고 있다. 진도 VI 이상의 지역에서는 벽에 금이 가는 등 상당한 지진피해가 있는 것으로 조사되었다. 등진도도에서 나타난 가장 현저한 특징은 이 지진의 규모가 기상청에서 4.5로 보고된 점을 감안할 때 감진 지역이 제주도를 제외한 남한 전지역을 포함하여 타 지진의 경우보다 두드러지게 넓다는 점이다. 이러한 사실은 이 지진의 규모가 실제보다 낮게 평가되었거나 진원의 심도가 보다 깊다는 것으로 해석된다. 이 지진이 기상청 발표와 같이 진원심도가 10km 이하인 천발지진이라고 가정할 때 등진도도에서 진도 IV에서 VII 사이의 등진도 등고선에 의해 둘러싸인 감진 지역의 면적으로부터 규모를 산정한 결과 규모가 평균 5.4로 나타났다. 따라서 앞으로 원거리 지진기록을 이용한 보다 정밀한 규모 및 진원 깊이의 산정이 이루어져야 할 것으로 판단된다.

주요어 : 진도, 에너지감쇠, 비탄성, 불균질성, 감진 지역

ABSTRACT

An intensity survey on the 13 December 1996 Yeogweol earthquake has been made for 262 locations throughout southern part of Korean peninsula, then we investigated attenuation properties in the south Korean region as well as intensities distribution. In this study, intensities are estimated to be from II to possibly VIII. The iso-seismal intensity map we obtained shows general pattern of intensity distribution in the south korean region quite clearly despite the inherent uncertainties included in the process of intensity estimation. In case of intensity larger than VI, considerable damages such as fracturing walls are frequently reported. One of the significant feature of this intensity map is, considering its magnitude 4.5 reported by KMA, the felt area is unusually large covering most of the Korean Peninsular except Cheju island. This result indicates either the magnitude is under estimated or the focal depth is much deeper than expected. Assuming shallow earthquake whose focal depth is shallower than 10km as reported by KMA, we obtained magnitude 5.4 in average by using the felt area enclosed by iso-seismal contour lines for intensity IV to VII, respectively. To resolve this ambiguity, more reliable estimation of focal depth and magnitude by using teleseismic instrumental records should be made in the future.

Key words *: intensity, attenuation, anelasticity, heterogeneity, felt area*

1. Introduction

During this century, records on earthquakes in Korea indicate that the seismic activity is much weaker than neighboring countries such as China and Japan. In this line of context, it has been the common belief that Korea is a safe zone as long as earthquake is concerned and, thus, no particular attention has been paid on earthquakes. However, both plate tectonical settings and results of historical earthquake investigations indicate that there are substantial potential of earthquake occurrence in Korea(Kyung[1], Kyung et al.[2], Zhao et al.[3]).

Together with China and south eastern part of

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Japan, Korea is sitting inside the same Eurasian plate which is well known to be stressed by colliding movements of Pacific plate at the eastern margin and Indo-Australian plate at the Himalayas. Recent frequent occurrence of major earthquakes in China and south eastern part of Japan have similar origins of intraplate stresses subjected by the relative plate motions of those neighboring plates. Thus, it is quite natural to believe that Korea is also subjected by the similar stress field just as China and Japan. In fact, they all share the common ground of geology in that they had been suffered from the same major structural deformations during the Mesozoic era in particular. Meanwhile, reports on earthquakes are frequently appeared in various historical literatures since A.D. 27. After evaluating about 1900 historical earthquakes, Kim (personal communication) has recognized about 40 damaging earthquakes with intensity larger than VII since A.D. 27 in Korea. One of the most important findings from the previous investigations of historical earthquakes is that seismic activities in Korea were very active, possibly, comparable to those of recent China and south-western part of Japan, particularly, during the 15th to 16th century(Kim[4], Kyung[1]). Furthermore, considering the periodic characteristics of seismicity, it is not reasonable to say Korea is a seismically safe region simply due to the recent low seismic activity.

In fact, detailed investigations on the characteristics of seismicity in Korea has been extremely restricted mainly due to the lack of systematic high quality seismic networks. Nevertheless, observations from the KMA network and some portable seismograph networks strongly indicate that there are considerable micro earthquake activities including more than 10 magnitude 3.0 earthquakes annually. Considering that current seismic observation network is very poor, it is easy to understand that several tens of earthquakes of magnitude 3.0 or more would occur every year in average. However, since 1905, when instrumental observation started in Korea, the number of earthquakes of magnitude larger than 4.5, which can cause some damages, is just a few, namely 1936 Ssangyesa event, 1978 Hongsung event, 1981 Pohang event, 1996 Donghae event. In Korea such intermediate size earthquake is extremely valuable since they can be used far more effectively in the seismic investigations than relatively abundant small earthquake generally less than magnitude 3.0.

In this respect, the 13 December 1996 Yeongweol earthquake(M=4.5), bears invaluable significances. However, observation of this earthquake was made only through just a few simple portable short period seismic networks which are considered to be not adequate for the aquisition of data that can be used in the systematic seismic investigations. In this study, accordingly, we attempted an intensity investigation, which is a qualitative approach, to explore the overall characteristics of this earthquake such as intensity distribution, attenuation and propagation of seismic energy as well as to provide fundamental input data in the seismic hazard evaluation. For this purpose, first we evaluated intensities by analyzing data collected through questionnaire sheet and an iso-seismal intensity map is made. Those results are, then, used to investigate the characteristics of wave propagation and attenuation of seismic energy. We also attempted to derive attenuation formula for the southern part of Korean Peninsula from the intensity map and estimated magnitude of this event by using felt area for each intensity level to check the results of other work on this event.

2. Data

Since intensity is a qualitative measure of earthquake size relating local earthquake phenomena to a certain level of predefined scale, evaluation of intensity mostly depends on how well the survey is designed and on time surrounding situations of the responding personals. To come up with this conditions, we carefully designed survey sheet which consists of necessary questionaries such as location, abnormal behavior of animals, location and degree of damage inside house, movements of households, changes in ground surface, type of architectural structures, pattern of vibrations, etc. The survey is, then, carried out through either mailing survey sheet or telephone calls. Target area of this survey covers whole South Korean region including Cheju island and Uleung Island and 2 locations per kun, which is a Korean local government unit, are selected as target location of this survey. For the locations close to the epicenter we visited to confirm damages associated with this earthquake in detail. Among those target survey locations, they responded from 262 locations throughout the country and they consist the data base we analyzed in this study, and it seems to be the largest data base obtained as yet in such kind of study.

3. Data Analysis

3.1 Evaluation of Intensity

Effects of earthquakes are known to be very much dependent upon the environments of the locations and personal characters. Thus, there can be numerous variety of descriptions on the phenomena associated with earthquakes. To evaluate those various phenomena into finite number of categories as intensity levels, some systematic scale is required. One of the most commonly used intensity scale is the MMI(Modified Mercali Intensity) scale in which all the possible earthquake phenomena are categorized into 12 intensity levels. In this study, we adapted this MMI scale in the evaluation of intensity. Most frequent descriptions appeared in this survey are as follows; felt of severe vibrations, vibration started with sound similar to thunder, ground motions similar to ocean waves, frightening of animals, shut down of electricity, distortion or movement of part of architectural structure, swinging or fall down of things on wall or shelf, fracturing of walls, detachment of tiles from the wall or ceiling, rupture of fence, and etc. In addition, other phenomena such as rock falls on land slope, fall off of gypsum board of office ceiling, felt of extreme horror, difficulties in standing due to severe vibration, and etc. are also reported.

Actual MMI intensity scale lists all the possible descriptions for each intensity level so that there can be situations having ambiguities in assigning specific intensity level. To avoid such ambiguities and make consistent evaluation, among the descriptions listed in MMI scale, we selected several representative descriptions that can represent most clearly each intensity level. They are listed in Table 1 and used to evaluate intensities in this study. Here, 'swinging of things attached on ceiling or wall' is used as the most typical criterion of intensity III, while we assigned intensity IV if vibration is felt inside building, but not outside.

Table 1 Representative descriptions of MMI scale used in this study

Intensity	Descriptions
II	felt by just a few people inside building
III	felt by some people inside building swinging of hanging objects
IV	felt by the most people inside building swinging of small objects difficult to feel outside building
V	felt by all people outside builng as well as inside shaking of whole building (sounds like thunder) breaking, fall aside, or fall down of objects movement of light objects
VI	many people frightened difficulties in walking fracturing or detachment of walls of weak building fall down or movement of heavy objects
VII	difficulties in standing felt by driver most walls are fractured or detached fall down of weak fence
VIII	felt threatnening by everybody difficulties in driving change of water level of well partial rupturing of common building rupturing of ground or slope severe movement of heavy objects

One of the most frequent and typical phenomena reported in this survey is the sound similar to thunder almost at the same time that vibration started. This phenomenon is reported from the locations as far as 200km apart from the epicenter indicating rapid vibration of building due to the sudden arrival of strong seismic energy shock causes the sound. We regarded this phenomena as vibration of whole building, that is a typical phenomenon of intensity V. In case of intensity VI, the discriptions such as "difficulties in walking" and "minor movement of light objects" are used as key criteria. Descriptions such as "suffer from difficulties even in standing straight", "fractures with some cavity of wall", or "fall down of weak fence" are the most typical descriptions of intensity VII. It is not quite certain, since the epicenter is located at a sparse population, but there may be some chance of intensity VIII within the regions of intensity VII.

3.2 Iso-seismal Intensity Map

Figure 1 displays the intensity distribution and isoseismal contour lines based on the data we obtained as above. Each contour line represent boundary between intensities of both neighboring side. Inside the region bounded by contour lines, maximum intensity is shown inside and minimum intensity is less than that by amount of level 1. In general, since intensity simply reflects superficial phenomena at particular location which can be affected by various factors such as site geological characteristics, structure and materials of building, and personal sensitivity, etc., some degree of uncertainties are inherent in the evaluation of intensity. As such, intensity distribution is appeared as somewhat scattered in Figure 1, nevertheless, it shows a general trends of diminution of intensity as epicentral distance increases with some lateral inhomogeneities. In Gyonggi area and western part of Choongnam area, it shows quite homogeneous intensity distribution, while at intensity V and part of intensity IV region some local heterogeneities are developed. This heterogeneity is particularly prominent in the intensity V and IV regions. The cause of local variations of intensity distribution is not easy to understand. However, it may fall into one of following two categories. First, the scatter of intensities might be the results of the inherent uncertainties as mentioned above. Considering the evaluated intensities are based on the local phenomena that can be considerably affected by the various environmental factors at the location, it is not surprising that intensity can be ill determined by amount of level 1. Second, we can consider the heterogeneous anelasticity as a cause of local variations of intensities. However, it has been pointed out that maximum ground motion amplitudes experience little anelastic attenuation out to distances of about 150km for earthquakes of intensity less than VII(Hutton and Boore[5], Joyner and Boore[6], Alsaker et al.[7]). They showed that within those distances, geometrical spreading plays major role for the attenuation of seismic energy rather than intrinsic anelasticity of the local medium. However, recalling the observations by Hanks and McGuire[8] that, up to this distance range, most significant incipients of maximum amplitude of ground motion is bodily shear wave, anelastic attenuation can cause the local intensity variations if enough short period body waves, which are sensitive to the small size local heterogeneities, are present in the seismic wave. In all, we can say the small scale local variations does not bear significant implications. However, it is worthwhile to notice one of the overall feature appeared in the Figure 1 is that the trend of intensity change is little bit slower to the south-west direction(line A) and faster to the north-south direction(line B). This might reflect some differences in geological environment. The direction of line A approximately coincide with the trend of Ocheon Tectonic Zone which is known to be suffered from severe tectonic deformations. While to the direction of line B Gyongsang sedimentary basin, known to be one of the largest basin in Korea, and Yangsan Fault system, again most prominent fault system in Korea, are located at the southern part of the line. Larger scatter and rather rapid gradient of intensity change are observed along this line, and this can be interpreted in terms of those geological complexities and characteristics of the region.

Most outstanding feature appeared in this intensity map is that the felt area is surprisingly large compared to those of other similar size earthquakes in Korea. Intensity maps for the 1996

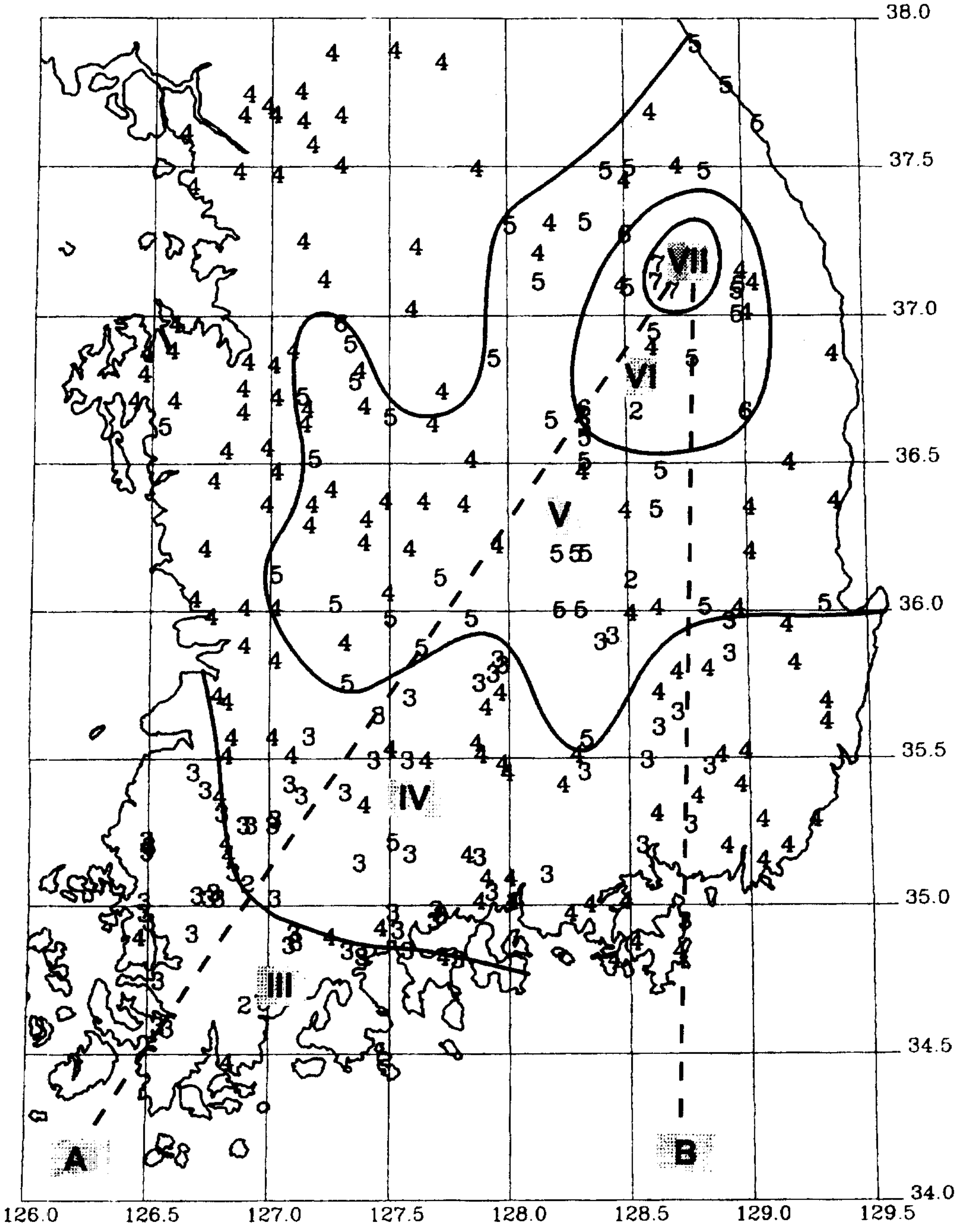

Figure 1 Iso-seismal intensity map of the 13 December 1996 Yeongweol earthquake.

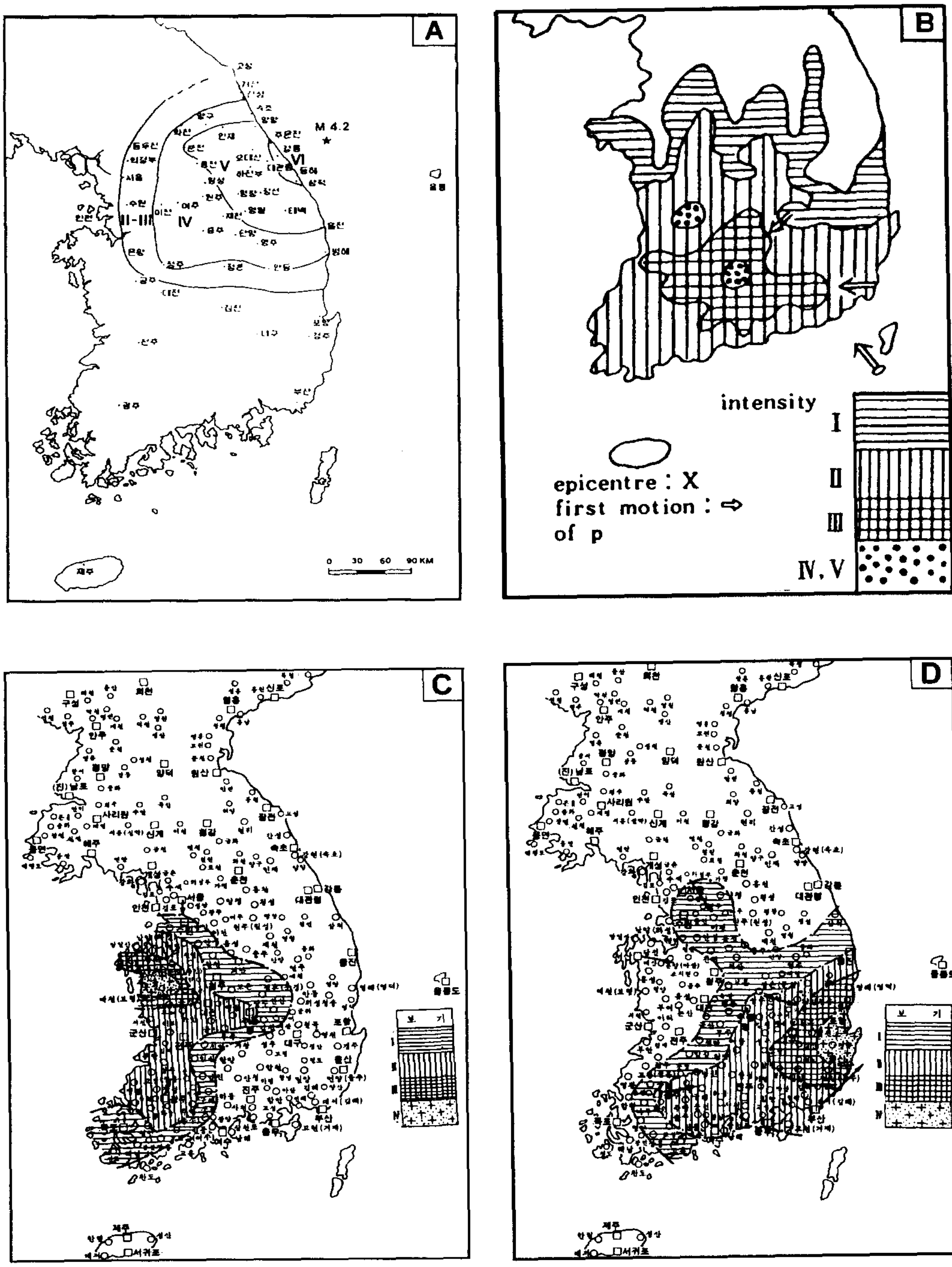

Figure 2 Iso-seismal intensity map for the 1996 Donghae event(A; from Kyung[1]), 1936 Ssanggye-sa event(B), 1978 Hongsung event(C), and 1981 Pohang event(D), respectively.

Donghae event(Kyung[2], M=4.5), 1936 Ssanggyesa event(Lee[10], M=5.0), and 1981 Pohang event(M=4.5) are displayed in the box A, B, C, D, of Figure 2, Here JMA intensity scale is used except Donghae event, where MMI scale is used. JMA intensity I, II, III, and IV can be compared with MMI intensity II, III-IV, V, and VI-VII, respectively. As is shown in those figures, Yeongweol event is clearly distinguished from the other events by the remarkably larger felt area for most of intensity level. Notice the felt area of intensity II is distributed over the whole South Korea for the Yeongweol event, while they are confined only to a part of South Korea for other events. The average radius of felt area of intensity larger than V for Yeongweol event is found to be 131km which is substantially larger than 90km of Ssanggyesa event and 40km of Hongsung earthquake. The cause of the discrepancies may stem from the following 3 types of categories; ill determination of magnitude, heterogeneity of anelasticity, and finally differences in stress drop at the focus. However, the target area of the intensity maps is exactly coincide, we can rule out the second category of the cause of felt area discrepancies. Meanwhile, it is quite plausible to expect the epicenter of Yeongweol event and the 24 January 1996 Donghae event share the common focal environment, then, the first category becomes most probable. However, still there remains some possibility that the third category can be the cause of the discrepancy. If this is the case, the focal depth would be much deeper than reported one since deeper focal depth usually accompanies higher stress drop(Kanamori and Anderson[11], Evernden[12]) and stress drop and amplitude of ground motion have some linear relationship(Hanks and Mcguire[8], Boatwright[13]).

3.3 Magnitude Estimation from the Felt Area-Magnitude Relationship

Hanks[14] showed that magnitude of earthquake is linearly dependent upon the felt area of some level of intensity, and derived relationships between magnitude and felt area for each intensity level using earthquakes of Eastern North America and Western North America, respectively. We used the relationships for Eastern North America, whose tectonic environment is intraplate type similar to Korea, to estimate the magnitude of this event. Although, this result, of course, may be not much reliable than those from instrumental records, it seems to be worthwhile to attempt when not appropriate instrumental data is available as is in Korea. We measured average radius of felt area and then, area of the region for each intensity is computed(Table 2). From the diagram showing the relationship for stable continental intraplate earthquake we determined corresponding magnitude for each intensity level, which are shown in Table 1.

The results are remarkably consistent for intensity IV to VI, M=5.4, while for intensity VII, magnitude is measured to be 5.8 possibly due to the small number of intensity VII data. When we use the relationship for the Western North America, the magnitude is measured as large as 7.0 which is hardly acceptable. This result, however, may be a supporting evidence that tectonical environment of Korea is that of continental intraplate as Eastern North America.

Table 2 Radius and area of felt area for each intensity level, and corresponding magnitudes estimated

Intensity	Average radius (km)	Logarithmic area (km^2)	Magnitude
IV	270	5.3	5.4
V	135 90[1] 40[2]	4.7	5.4 5.0 5.0
VI	46	3.8	5.5
VII	15	2.7	5.8

(1) 1936 Ssanggyesa event
(2) 1978 Hongsung event

3.4 Attenuation Formula

As mentioned earlier, with intensity map only, it is very difficult to assess the local attenuation variations in detail. However, if we are considering larger scale, typically greater than 100km, surface waves begin to play important role in general, then the intensity map such as Figure 1 can be effectively used to analyze gross attenuation properties. In Figure 1, we already noticed there exist two trends of attenuation, slower to the south-west direction and faster to the north-south direction. To obtain reasonable attenuation relation -ship, we started with the following formula representing intensity I in terms of magnitude M and epicentral distance Δ;

$$I = a + bM + c\log(\Delta) + d\Delta \quad (1)$$

Here, a, b, c, and d are constants to be determined by aregression procedure. We applied a multi-variate linear regression procedure to determine both c and d simultaneously. For this, we selected 11 and 10 intensity data along the line A and B, respectively. After this, we obtained following attenuation formula for both line A and B substituting the formula obtained above into the formula, given by Trifunac and Brady,[15]relating ground acceleration a in terms of intensity,

$$\log(a) = 0.3\, I + 0.014.$$

Attenuation formula along the line B;

$$\log(a) = 0.278M - 0.555\log\Delta - 0.00156\Delta + 1.532 \quad (2)$$

Attenuation formula along the line A;

$$\log(a) = 0.278M - 0.575\log\Delta - 0.00114\Delta + 2.660 \quad (3)$$

These two equations represent two extreme cases of attenuation of this event. In the above equations, the coefficients of the third term in the righthand side of equation reflect the anelastic attenuation and it appears to be much 50% larger for the line B than for the line A indicating faster energy attenuation to the north-south direction. Although, more reliable and detailed attenuation formulae can only be obtained through sufficient number of instrumental data, above equations give us fundamental insights on the attenuation properties in Korea.

4. Discussion and Conclusion

The Yeongweol earthquake occurred at 13 December 1996 is one of the largest earthquake in Korea during this century. In that sense, we consider the result of investigation on this earthquake bears significant implications. In particular, the location and time of this earthquake is so close to the 24 January 1996 Donghae earthquake, which is a very unusual case in Korea, that it has special implications on the present seismicity of this region.

First, the felt area of this earthquake is remarkably large compared to those of the similar size of earthquakes in Korea, which indicates either magnitude or depth of the earthquake is ill determined or both. Assuming the focal depth is correct, the estimated magnitude based on the felt area, M=5.4, is found to be much higher than reported value 4.5. This should be clarified by further investigations based on high quality instrumental data in the following studies.

Second, the pattern of intensity distribution is found to show some degree of local and regional heterogeneities. Considering the size of this earthquake, the regional heterogeneity bears more significant implications on the attenuation properties in Korea. We delineated two lines of heterogeneity trends, slower to the SW direction, which roughly coincide with the Ogcheon Tectonic zone, one of the most prominent tectonic feature, and slower to the NS direction passing through the Gyeongsang Basin and Yangsan Fault system.

Third, we derived attenuation formula, which is one of the fundamental input information in the assesment of seismic hazard analysis, for both SW direction and NS direction to account for the regional heterogeneity in South Korea.

Finally, in the evaluation of intensity we did not take the effect of site conditions and structure of building into account mainly due to the poor responses on this subject by the people who joined in this survey.

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