Master of Science in Engineering

Seismic Risk Assessment for Architectural Heritage considering Historical Data

by

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Abstract

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The disaster prevention researches about seismic hazard has significantly increased due to huge casualty of human-beings and property damage since the 2010 earthquake in Haiti and the 2011 earthquake in Japan. Although the occurrence of earthquake is relatively low in Korea, preparation is required due to increase frequency and scale of earthquake. However, available researches on earthquake prevention are mainly focused on modern architecture involved in Casualties.

This research is focused on earthquake disaster. Earthquake characteristic is unpredictable and damage of earthquake widespread and destructive. So most countries located in earthquake hazard area protect building, infrastructure and life. In Korea, It is located in adjacent areas of plate boundary that is dangerous area about earthquake. That`s why protection about earthquake is needed in Korea.

Architectural heritage have a lot of benefits such as historical value and academic value. That`s why It should be preserved from any dangerous factor especially natural disaster. In Korea, preparations for earthquake are only focused on building and infrastructure and research scope on the prevention of architectural heritage is yet to be reached.

Effective preparations against earthquake build system. It helps manage process because of lack of manager. So this research is proposed risk assessment process and system framework for effective preparations.

In this research, seismic risk assessment and building system for management of architectural heritage is aimed. Seismic risk of architectural heritage was calculated using a data from soil investment and a fatigue factor calculated by historical earthquake data and maintenance records both from architectural heritage. Seismic risk is suggested on the basis of four levels, and system for managing architectural heritage about earthquake through GIS is built.

Keywords: Architectural Heritage, Earthquake, Risk Assessment, Build System, Seismic Risk.

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Chapter 1. Introduction

This chapter presents the research objective, research scope and method. Also, the end of this chapter, main research process is described with research process figure.

1.1 Research Background and Objective

Recently, environment change issue has emerged though whole world and natural disaster such as flood, snowfall and earthquake is increased due to environment change. Haiti and the Great East Japan earthquake occurred at 2010, 2011 had led to loss massive wealth and casualties, and caused to increase the attention for earthquake damage.

In Korea, cycle of earthquake occurrence is longer and repetition rate of earthquake is lower than marginal state due to located on active continental margin of the Eurasian plate. However, Korea cannot be seen to be safe in earthquake disaster because of 50 active faults (Kim, 2011). Cycle of earthquake occurrence and earthquake magnitude is increased in Korea. That is why Korea government is preparing for earthquake though legislation to protect building. However it is hard to keep a rule of the original form preservation in case of architectural heritage if there is not sufficient preparation because earthquake damage is bigger than other disasters and legal regulatory and protection is insufficient than modern architecture. So National Research Institute of Cultural Heritage conducted geotechnical assessment for protecting architectural heritage from 2009 to 2012.

Geotechnical assessment that was conducted by National Research Institute of Cultural Heritage has a limitation that is difficult to manage and react in case of earthquake disaster because it is hard to seize the risk level for the earthquake disaster of architectural heritage, require Geotechnical knowledge to architectural heritage manager and low usability.

This research is aim to conduct seismic risk assessment to complement limitations previously stated and build system to base on seismic risk assessment.

1.2 Problem Statement

As mentioned above, earthquake causes a huge damage in human society. So many countries prepare a natural disaster and specific countries that located in earthquake risk area put a lot of effort to prepare for earthquake disaster.

In Korea, modern architectures have to design to resist earthquake magnitude about 6 and main government buildings have been measured by National Emergency Management Agency. However, architectural heritage cannot protect from natural disaster especially earthquake. Architectural heritage is needed to protect because it have a historically unique value and that’s why descendants have a duty to preserve. So the problems of management architectural heritage from earthquake that this research would solve are as follow:

1) Architectural heritage originality should be protected from any dangerous situation. Especially, earthquake is powerful disaster to damage building structure even architectural heritage. However there is insufficient preparation in Korea.
2) One main problem is architectural heritage manager shortage. In case of non-specified architectural heritage, they cannot be protected and managed and have been neglected. So there need systematic management system to efficient management and protection.
3) The existing system for protect from earthquake damage is only target to modern architectural. The system for architectural heritage is required because architectural heritages have unique characteristic.

1.3 Research Process

This research confines type of disaster to earthquake. The frequency of earthquakes is low and the strength of the earthquake is weak in Korea. But earthquake have an unpredictable nature and it caused serious damage when earthquake occurs. Management of architectural heritage manager

To assess earthquake risk, lots of data is required. So earthquake data is used from NECIS (National Earthquake Comprehensive Information System) and architectural heritage data is used from National Research Institute of Cultural Heritage. But there is a lot of Architectural heritage in Korea. So this research confines heritage located in Seoul Buyeo and Gyeongju that is judged to have high earthquake risk. Figure 1-1 shows process of research.

1) Establish concept of seismic risk and select a factor that can be standard to assess seismic risk in preceding studies about architectural heritage. There are a lot of methods to assess seismic risk. Architectural heritage have unique characteristic. So assessment process of architectural heritage considers that. So this research assesses earthquake risk using general method.

2) Factors selected step 1 is calculated for seismic risk assessment. That process comes out architectural heritage fatigue. Assess seismic risk using PGA (Peak Ground Acceleration) and architectural heritage fatigue.

3) Propose system framework based on seismic risk assessment and build architectural heritage management system for seismic risk. Various researchers insist necessity of system for earthquake detection to protect

earthquake damage. In Korea, The National Emergency Management Agency made real-time earthquake detection and assessment system. However it cannot protect architectural heritage because of low data and lack of awareness of the importance about heritage. That`s why This research propose system framework for architectural manager to protect heritage.

4) Validation seismic risk assessment using system based on historical data.

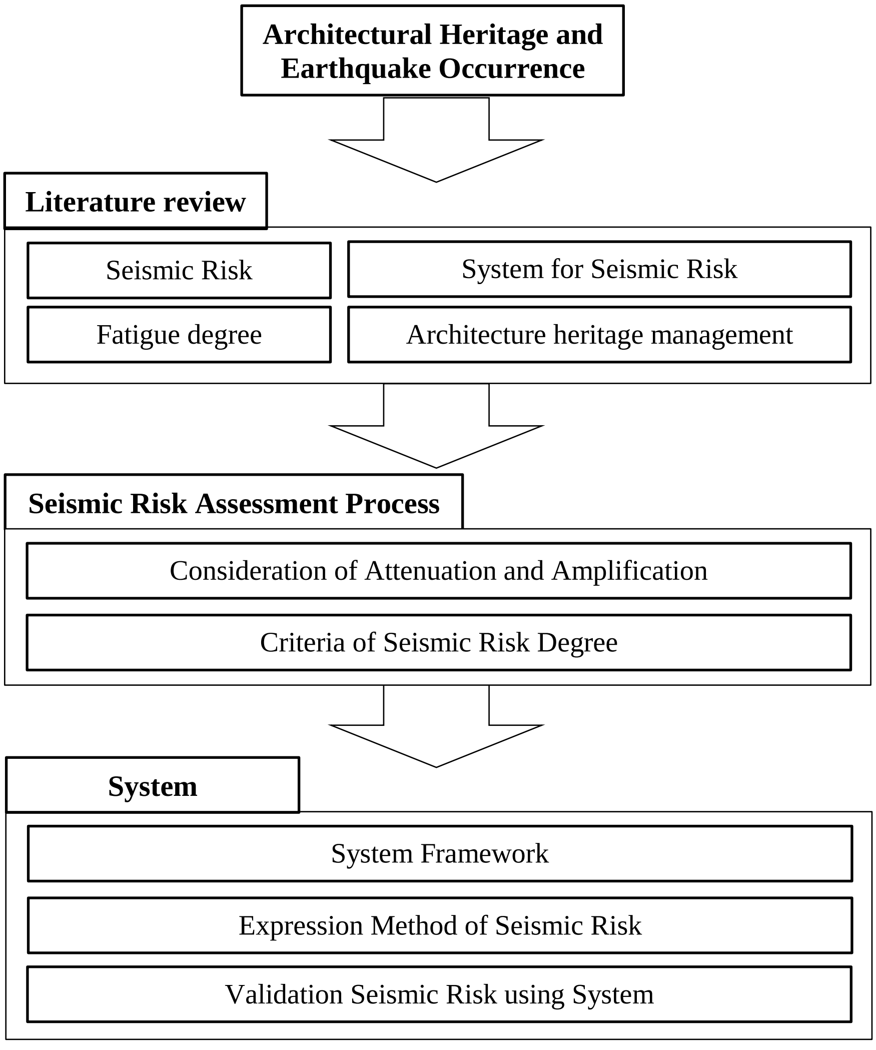

Figure 1-1. Research Process

Chapter 2. Literature Review

To calculate seismic risk for architectural heritage and build system for management by architectural heritage manager, this chapter discusses concept of the seismic risk and how to calculate seismic risk. Next, this research proposes system framework and expression method.

First, the base concept of seismic risk assessment is understood through a literature review. Second, to calculate seismic vulnerability, concept of architectural heritage fatigue is explained through a literature review and is used for calculating seismic risk assessment. Finally introduce the system framework which is used to manage architecture heritage about earthquake.

2.1 Seismic Risk

Seismic risk is generally calculated using seismic vulnerability and seismic hazard (Musson, 2000; Altan, 2004; Carreno, 2007). Seismic risk is multiplied by seismic vulnerability and seismic hazard.

Seismic Hazard expresses geotechnical data that is represented condition of ground though Geotechnical site investigation. Seismic Vulnerability expresses considering various factor such as type of building, location and so on. Results of National Research Institute of Cultural Heritage's researches (2009; 2010; 2011; 2012) are belonging to Seismic Hazard.

Researches about Seismic Vulnerability need lots of time and capital because of complexity due to consider a variety of variables (Lourenco, 2006) and a number of that is relatively less than seismic hazard research because of same reasons. However, researches about Seismic Vulnerability need to use to make establishing measures and preparedness for post-earthquake (Gueguen, 2007). Lourence(2006) and Gueguen(2007) propose simplification method to solve complexity problem that calculate seismic vulnerability.

In case of architectural heritage, they have unique characteristics unlike modern architecture. So there need to simplification method about seismic vulnerability to calculate seismic risk.

2.2 Architectural Heritage Fatigue

There need to seize characteristics of architectural heritage to calculate a seismic vulnerability but need lots of time and capital because of unique characteristics (Feilden, 1987). So this research utilizes architectural heritage fatigue to replace seismic vulnerability.

Architectural heritage fatigue is conjugated from fatigue concept in architectural structure, especially material engineering (National Research Institute of Cultural Heritage, 2011). Architectural heritage fatigue assumes one constant building in structure. This assumption is a step of simplification method that was proposed from National Research Institute of Cultural Heritage's research in 2011. 5 Structure is assumed, stone, wooden, masonry, historic site and RC/SRC. This research adds criteria to historic site from previous research. Equation 2-2 is about architectural heritage fatigue.

$$\text{Architectural Heritage Fatigue} = \sum[a \times \sum(M \times Nm) + b(S - Rs) \times (100\% - R)] \qquad (1)$$

M : Magnitude

Nm : Number of earthquake occurrence

S : Number of structure damage

Rs : Number of repair and maintenance

R : Recovery rate

a : scale factor for earthquake according to the structure

b : scale factor for repair and maintenance

Recovery rate is applied when architectural heritage was repaired and scale factor adjusts the figures. Detail of recovery rate is described figure 2-1

Figure 2-1. Recovery Rate of Architectural Heritage Fatigue

Category	Recovery rate	Category	Recovery rate
Improvement	50%	Restore/Reinforcement	40%
Dismantling repair	70%	Roof repair	40%
Rafters Maintenance	5%	Move and build	50%
Square/ angle rafter	10%	Reconstruction	100%

2.3 Architectural Heritage Management over Seismic Hazard

The architectural heritage is being managed in accordance with municipal and provincial ordinance. However, due to the fragmentary administrative management, execution and lack of manpower, sometimes their original form might get damaged (No, 2006; Moon, 2009). Therefore National Research Institute of Cultural Heritage proposed the necessity of systemized management and maintaining techniques in order to protect Architectural heritage, and started geotechnical evaluation targeting the architectural heritage from 2009 to 2012. And also, the precise structure evaluation of architectural heritage is being conducted through 'Safety management for architectural heritage and correspondence to calamity & structure standards study (2014).

The basic knowledge on geotechnique is required for the architectural heritage managers to understand the geotechnical evaluation conducted by National Research Institute of Cultural Heritage. And also, the precise structure evaluation is basic information required for the correspondence to calamity, but there is a defect that it requires much time and costs to figure out the indigenous characteristics of the architectural heritage. There are so many threats of calamity and disaster while the structure evaluation on several architectural heritages of architecture is conducted. Therefore, we aimed 3 objectives in this research.

First, while analyzing earthquake risks, we will support the decision on the selection of architectural heritage which are required to be managed and repaired. Secondly, we will set up the earthquake risk evaluating system for the systemized management. Thirdly, we will see the earthquake risk intuitively and utilize real time information on earthquake calamity so that we will improve its usability by helping those managers to correspond the calamity.

2.4 Commercialized Seismic Risk Assessment System

Collection and analysis of earthquake data using seismology, computer and sensor is needed to Systematic earthquake disaster preparedness. Building system that can be estimate seismic risk and manage by integrating the technique mentioned above has been suggested as effective disaster mitigation measures about earthquake (Baek, 2003; Niyatake, 2006).

U.S and Japan that are studied actively in progress about earthquake are operating system called HAZUS(FEMA, Federal Emergency Management Agency) and DIS (NIBS, National Institute of Building Science) and they use the systems for establishing earthquake disaster prevention (Han, 2013). However, the systems is hard to apply to other regions because it focus on prevention for their countries

So National Emergency Management Agency built a system called Earthquake Disaster Response System for preparing earthquake. Earthquake Disaster Response System apply a seismic fragility functions for Korea (Jung, 2011). Figure 2-2 and 2-3 represent assessment process of Earthquake Disaster Response System and organizing data.

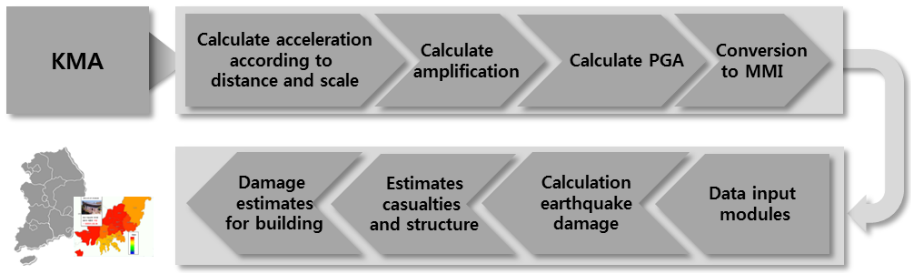

Figure 2-2. Process of Earthquake Disaster Response System

Figure 2-3 Earthquake Disaster Response System Organizing Data

Category	Material	Category	Material
1st Project	Ground data	2nd Project	Sewer facilities
	Detail ground data		Power facilities
	Architecture list		Communication facilities
	Population		Emergency medical facilities
2nd Project	Road facilities		Evacuation facilities
	Water supply facilities		Transport facilities
	Gas facilities		-

As Figure 2-3 shows, the building that is possible responses from earthquake disaster using Earthquake Disaster Response System is modern architecture and data for calculating degree of earthquake damage is not unsuitable to architectural heritage. That makes it hard to establish recovery measures and identify earthquake damage when earthquake occurs. So the system preparing earthquake in case of Korea is required. (Architectural heritage)

2.5 Summary

In this chapter, seismic risk assessment method is explained and current status of architectural heritage management in Korea and how seismic risk assessment is used in other countries. In these reasons, risk assessment is required and system using risk assessment should be made in Korea.

Limitation of architectural heritage research for seismic risk is that there is a lots of factors and cannot find general model. So this research uses general method that assesses seismic risk to simplify factors. To simplify assessment process, architectural heritage fatigue is fixed to fit this research and used. Process of calculation that assesses seismic risk assessment is statement chapter 3.

Chapter 3. Evaluation of Seismic Risk on Architectural Heritage

In this chapter, we will describe the computation process on earthquake risk focused on architectural heritage.

3.1 Evolution of Seismic Risk on Architectural Heritage

In order to compute the earthquake risk, we used architectural heritage fatigue for seismic vulnerability, and in case of seismic hazard, we used PGA(Peak Ground Acceleration) considering amplification.

Here, the scale factor is used for applying architectural heritage fatigue into weight. The architectural heritage fatigue is the element which can be replaced with seismic vulnerability. But as it is estimation used for computing the fatigue, there might be an error. Accordingly, in this research, we applied the architectural heritage fatigue into PGA value with weight through correction figure.

The figure of seismic risk is shown in this equation because the figure shows the risk at the condition level of the architectural heritage in GIS, so that the managers can recognize its risk intuitively.

The historic earthquake data used in the process of computing the architectural heritage fatigue are from data provided by NECIS. These data include the earthquake occurrence records since last 500years, so with these data we can compute all the architectural heritage fatigue. Architectural heritage, their repair and calamity records are sourced research result of

National Research Institute of Cultural Heritage.

The result calculated from assessment equation is simple figure which is same as geotechnical evaluation result conducted by National Research Institute of Cultural Heritage. The managers may feel limitation to recognize the condition of the architectural heritage as it is in simple figure. In order to solve this problem, we set up the damage standard for each architectural heritage, and showed recognizable level by using the earthquake risk figure derived from the assessment equation and through comparison. The explanation about the level is given in 3.3.

3.2 Ground Attenuation and Amplification

The phenomenon of the amplification and the attenuation is considered according to the movement of vibratory ground motion in order to figure out the effect of the earthquake at the location of architectural heritage.

If there is no seismological observatory system, we should compute earthquake acceleration indirectly by considering the phenomenon of decreasing vibration in accordance with the distance from the seismic center. In this research, we used the formula of earthquake attenuation of "Program development for drawing up the seismic hazard" conducted from National Institute for disaster prevention in 2000. The given equation 3-2 is the attenuation formula used in this thesis, and the figure 3-1 shows the coefficient applied in the formula.

$$ln\mathrm{a} = c_0 + c_1 M - c_2 ln\sqrt{r^2 + 10^2} - c_3\sqrt{r^2 + 10^2} \qquad (2)$$

a : maximum ground acceleration

M : size of the earthquake

r : distance from the seismic center

Figure 3-1. Coefficient of Attenuation Formula

(National Institute for Disaster Prevention, 2000)

Attenuation formula	Coefficient				Standard deviation
	C_0	C_1	C_2	C_3	
Ⅰ	0.4854	1.2	-0.8416	-0.0061	0.8036
Ⅱ	0.5577	1.2	-0.8587	-0.0062	0.7629
Ⅲ	5.0244	0.5442	-1.0020	0.0	0.1

The next is a process of considering the phenomenon of ground amplification. The ground amplification is the phenomenon that size of the vibration occurred by earthquake is affected by soils above the bed rocks (Idriss, 1990; Seed, 1976). The result of the equation 3-2 is the ground acceleration of rock mass, so we should consider the phenomenon of amplification in order to figure out the actual effect of earthquake on the architectural heritage. We utilized the geotechnical evaluation result from National Research Institute of Cultural Heritage and the research of Idriss (1990). Figure 3-2 is a graph showing the research of Idriss (1990)

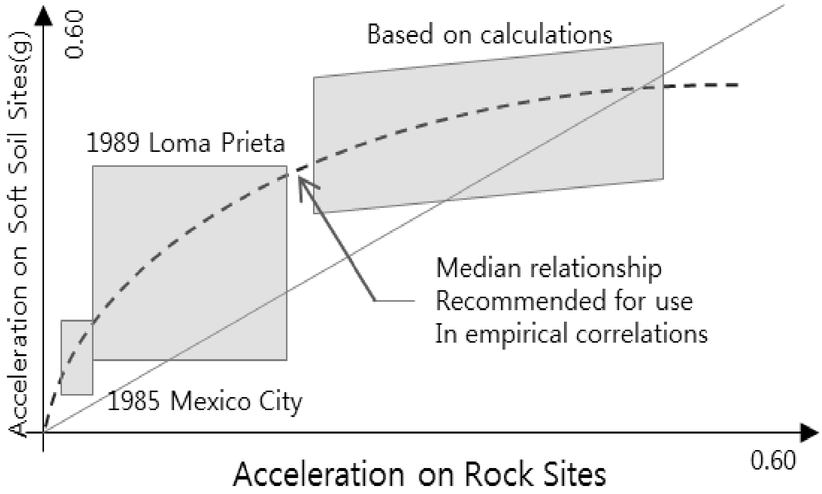

Figure 3-2. Peak Ground Acceleration in Soft Rock (Idriss, 1990)

The dotted line in the figure 3-2 implies the degree of amplifying vibration of rock mass.

However, all graph of ground acceleration cannot be obtained. Using some of the data, It will get approximate graphs each architectural heritage such as figure 3-2. The approximate graph can be shown in figure 4-2. The more data is collected, the more accurate graph is made. This research considers soft rock that is weak about earthquake and hard rock is directly delivered to architectural heritage.

3.3 The level of Seismic Risks

Similar vibration causes different reaction and degree of damage on different cultural architecture. The result of evaluation process of risks explained earlier is in simple figure like the geotechnical data. The numerical information may deaden the accessibility of amateurs and certain degree of understanding is required. Accordingly, in this research, we set up seismic risk into the condition and the stage of architectural heritage. There are 4 stages: safe, warning, dangerous and emergency. At the stage of safe and warning, it shows that there is no damage yet. But in comparison with safe stage, the managers should make proper confirmation at warning stage as its criteria is just 10% less than the dangerous stage. At the dangerous stage, the original form of architecture starts getting damage, and lastly at emergency stage, its original form is seriously destroyed.

Figure 3-3. Degree of Seismic Risk

Category	Description	color
Safety	Architectural heritage is safety from earthquake	Blue
Caution	Architectural manager need to check condition of heritage	Yellow
Danger	The damage to architectural heritage (minor)	Red
Emergency	The huge damage to architectural heritage Maybe more than half-defeated	Black

The pertinent stages are displayed on GIS, and for the purpose of intuitive recognition of the user, each stage are displayed in different color. Blue implies safe stage, yellow implies caution stage, red implies danger stage and black implies emergency stage.

In order to distinguish the risk stage of architectural heritage, we need a certain standard to judge their condition. Therefore, we utilized the results of research which conducted behavior test about architectural heritage vibration. Figure 3-4 given below shows that research.

Figure 3-4. Peak Ground Acceleration to damage to architectural heritage

Category	Acceleration	Researchers	Research names
Thatch	0.25g	Choi I.G (2002)	Estimation of historical earthquake intensities and intensity-PGA relationship for wooden house damage
	0.6g		
Tile house	0.12g	Seo J.M (1997)	Experiment seismic performance of traditional house
	0.3g		
Beacon Hill	0.28g		
	0.36g		
Pagoda	0.15g	Kim J.G (2001)	Dynamic behavior test to Ssanggyesa temple pagoda
	0.26g		
Masonry	0.35g	Kim M.H (2004)	Dynamic behavior test to unreinforced masonry
	0.45g	Kim H.C (1998)	Analysis and Evaluation of crack on the second floor masonry about seismic loads
RC/SRC	0.374g	Jung S.H (2010)	Seismic Behavior Analysis of non-seismic RC Frame with nonlinear dynamic analysis
	0.6g		
Walls	0.26g	Maeng S.W (2001)	Shaking table tests and evaluation of historical earthquakes of intensity about Seongcheop model
	0.38g		
Historic Site	0.25g	Harry (1931)	Modified Mercalli
	0.5g		
Cheomseongdae	0.15g	NRICH (2010)	Basic research about earthquake flood disaster risk assessment for Architectural Heritage in Seoul
	0.285g		

The stage will be decided by comparing the seismic risk level and the result of pertinent researches.

3.4 Results of Seismic Risks Assessment

In this research, process of seismic risk assessment is proposed. Real architectural heritage data from National Research Institute for Cultural Properties is input to the process and the results are blow figures.

The figure 3-4 and 3-5 shows the result arranged on the basis of the cultural assets materials derived from the system. In these images the distribution status of architectural heritage according to the degree of earthquake, and figure 3-6 shows the distribution of architectural heritage fatigue

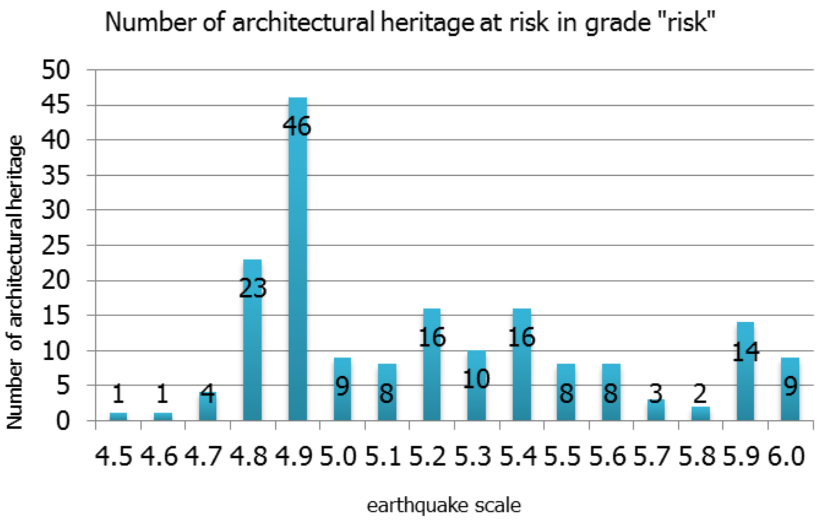

Figure 3-5. Architectural Heritage about ‘Risk’ Degree

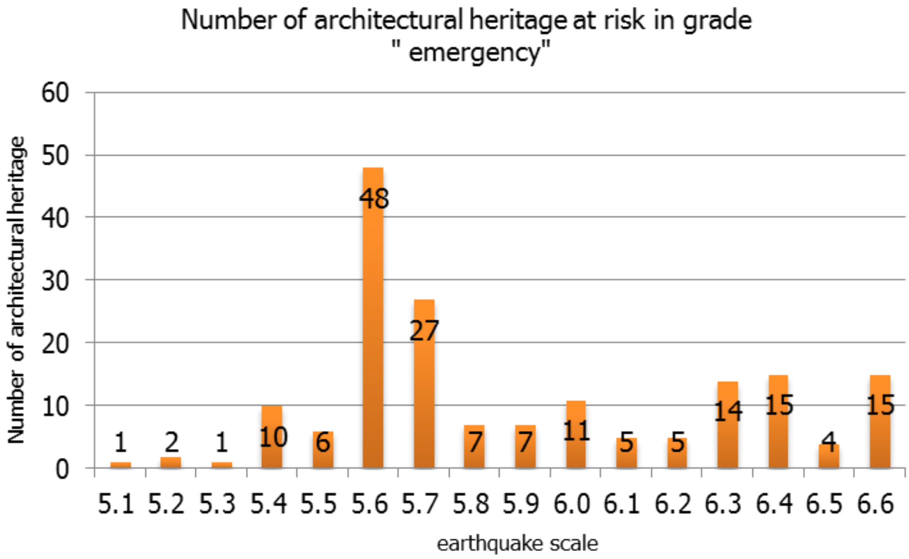

Figure 3-6. Architectural Heritage about 'Emergency' Degree

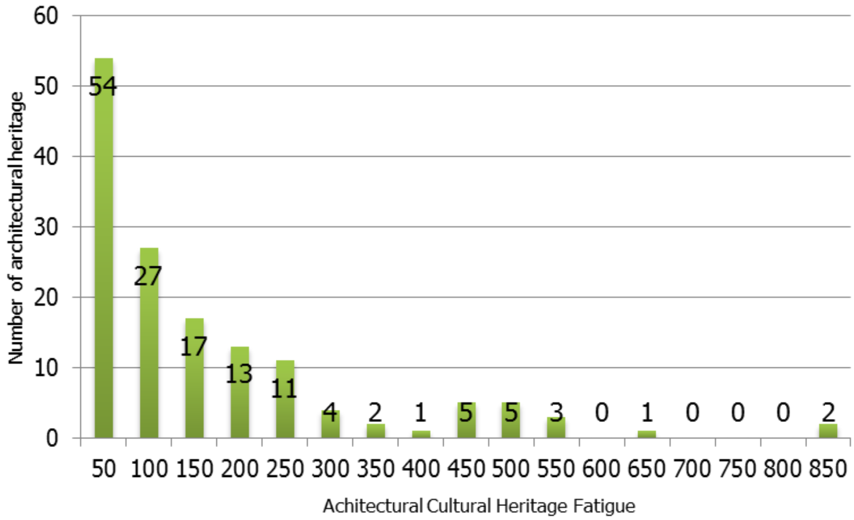

Figure 3-7. Architectural heritage Fatigue Distribution

(1) The dangerous stage in which the architectural heritage get direct damage is in the range from 4.5 to 6.0 degree and approximately 80 architectural heritage got damaged by 5.0 degree earthquake which available degree in our country. The emergency stage in which original form of the architectural heritage gets damage is in the range of 5.1 to 6.6 degree.

(2) The result after the computing the fatigue of the architectural heritage located in historic cities showed low fatigues as the conservative process had been applied, however, the result showed that 첨성대 and 경주남산성 have comparatively larger fatigue as they have no conservative background.

This results help to decide to protection policy for architectural heritage against the earthquake and manage for architectural heritage. To validate process and results of seismic risk assessment, actual earthquakes occur. So this research uses system for validation.

3.5 Summary

This chapter is explained that calculate seismic risk assessment and results. Assessment method is explained and how to calculate for architectural heritage. In Korea, earthquake magnitude over 5 is rare. That`s why most of architectural heritage can be preserved from past to now but earthquake can occurs anytime because of Korea located in plate boundary adjacent areas. From now, architectural heritage should be protected from any dangerous factor that can be damage to architectural heritage. The result can help admission policy and preserve architectural heritage through awareness.

Chapter 4. Seismic Risk Assessment System

This chapter includes system frame work for evaluation of seismic risk and verification of system through historical earthquake records.

4.1 Composition of System Input Data

The data forming database are historical earthquake, basic information on architectural heritage, repair and calamity background, information on ground weight of architectural heritage fatigue and countermeasure against calamities and the data required for seismic risk are historical earthquake, repair and calamity background and information on ground.

(1)Basic Information on Architectural Heritages

It is based on the information of architectural heritage provided from the website of Culture Heritage Administration. The relevant information is linked with ground database. This database includes data conducted in National Research Institute of Cultural Heritage. This data is the result of a field study on the basis of a seismic design from 1000 to 2400

ex) Name of the architectural heritage: 정혜사지십삼층석탑

Location: Kyeongjoo

Type of the architectural heritage: stone pagoda

Ground information: 0.251, 0.345

(2) Historic Earthquake Record

Historic earthquake data consists of date of occurrence, its location and its degree. We utilized location data of historic earthquake and classified by each cities. If an earthquake information is created in the weather center, it is automatically classified by cities and it saves the such information in the historic earthquake database.

ex) Date of occurrence : 1832.11.23

GPS: 35.86, 129.20

Degree: 5.3

Location: Kyeongjoo

(3) Repair record of Architectural Heritage

The repair information of each architectural heritage is saved in the text, therefore, it is difficult to use in the system. So we arranged the repair records on the basis of 8 types repair which is given in the table 1.

Ex) Name of the architectural heritage: 정혜사지십삼층석탑

Location: kyeongjoo

Type of the architectural heritage: stone pagoda

Date of repair: 1921.01.05

Type of repair: dissolution and repair of roof

4.2 System Framework

The system framework for the management of architectural heritage of architecture is shown in figure 4-1. The system consists of input, data process and output.

The input part consists of historic earthquake, ground information, repair-calamity background, basic information on architectural heritage, weight of architectural heritage fatigue DB. The earthquake data is fed in 2 ways: 'earthquake data of user random' and 'earthquake record at real time from weather center. The former is composed for the simulation of earthquake and latter is for the real time correspondence.

Data processing part consists of 'architectural heritage fatigue computing module', 'maximum ground acceleration computing module' and 'evaluating risks module'. Explanation of each module is as follow.

(1) Architectural Heritage Fatigue Computing Module

The architectural heritage fatigue is computed from this module by using the repair-calamity background and historic earthquake. The record earthquake classified by each cities and of repair and calamity on architectural heritage are calculated on the yearly basis. The fatigues calculated on this basis is added each other and during this process, its recovery rate is applied. The fatigue is saved in 'basic information database of the architectural heritage', and once the earthquake occurs or repair & calamity occur, it automatically recomputed the architectural heritage fatigue.

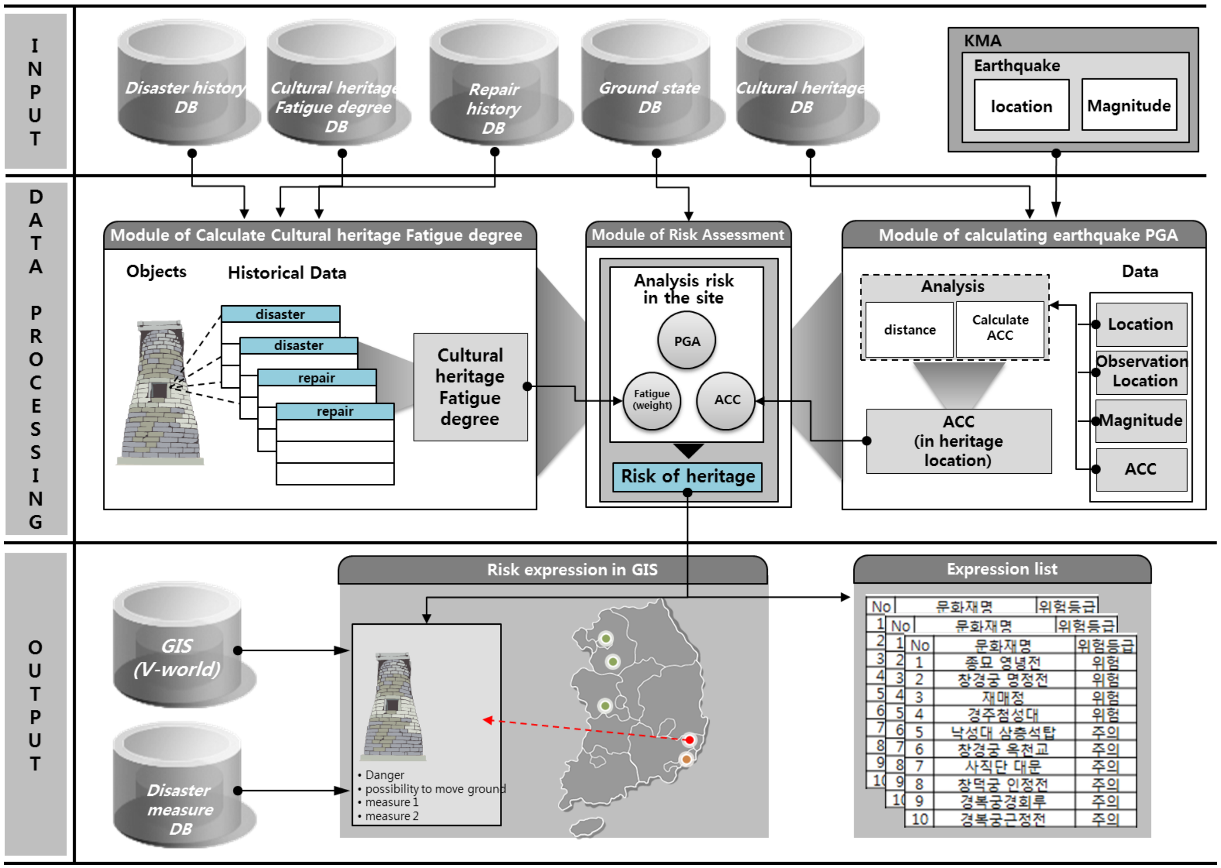

Figure 4-1. Seismic Risk Assessment and Management System Framework for Architectural Heritage

(2) Maximum Ground Acceleration Computing Module

The data is entered in 2 ways from this module. This is simply a difference of input method; the processes of management on the data are same. In this page, we explain with the example of using the earthquake records in real time at the weather center.

Such records are sourced from the webpage, and for the better efficiency of system the information is renewed at every 10 minutes. By using the location data of earthquake center, basic information on the architectural heritage and by using the attenuation formula given in 3.3, we calculate the distance between the architectural heritage and earthquake center.

In order to consider the phenomenon of ground amplification, the graph shown in figure 4-2 is created from the system at each architectural heritage. And for this purpose more than one field ground survey data is used. On this research, we used 2 ground data which are saved in the basic information database of architectural heritage.

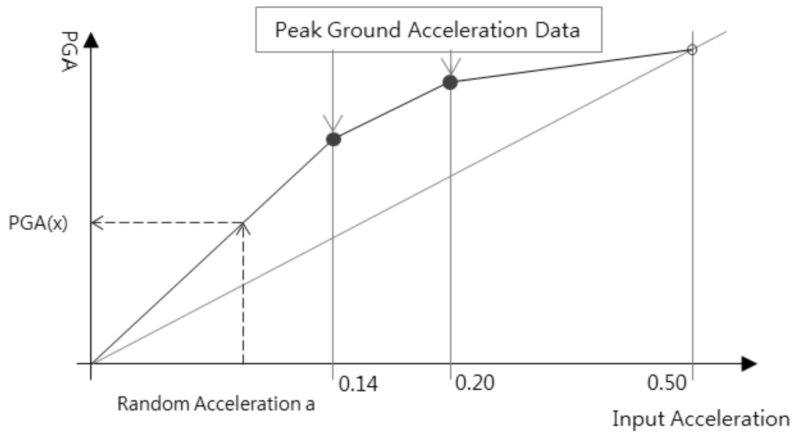

Figure 4-2. Utilization of Peak Ground Acceleration Data

We created straight line with 3 parts by using 2 ground data. On the basis of earthquake acceleration, we utilize the graph and compute the ground acceleration.

(3) Evaluating Risks Module

From this module, we evaluate the seismic risk by using the architectural heritage fatigue and maximum ground acceleration which are derived from other two modules. Formula 3 is applied here and the risks are computed after getting the result. By using the types of architectural heritages saved in the basic information DB of architectural heritage, we print out the damage criteria of architectural heritages. Through this output and by comparison with the level of the seismic risk, the risk stages are decided.

Lastly the output has a role of expressing the seismic risk evaluated from the module through GIS to the managers. We used V-world which is web-GIS for the user's accessibility. Different risk rate are decided to different architectural heritages and its outputs are in the icon form. In the next page, the method of expressing seismic risk is explained.

4.3 Method of Expressing Seismic Risk

Basically the seismic risk rate is the method of expressing the risk for each architectural heritage. The user of the system which is the result of this research can figure out and cope with the risks through 3 types of risk expressing method. Figure 4-3, 4-4, 4-5 shows the seismic risk expressing method system.

(1) Method of Expressing the Expected Risks on the Basis of Real Time Information

In this system, we receive the real time earthquake information from the weather center. By using such information, the expected risks can be computed and expressed to the users. From that system they can see the expected risks expressed on the basis of the real time information from weather center through the clause 'real time risks'. The information on earthquake is transferred at every 10 minutes, and such information is used according to the needs and the time period. During this process the system is set up to express the highest risk rate out of every earthquake.

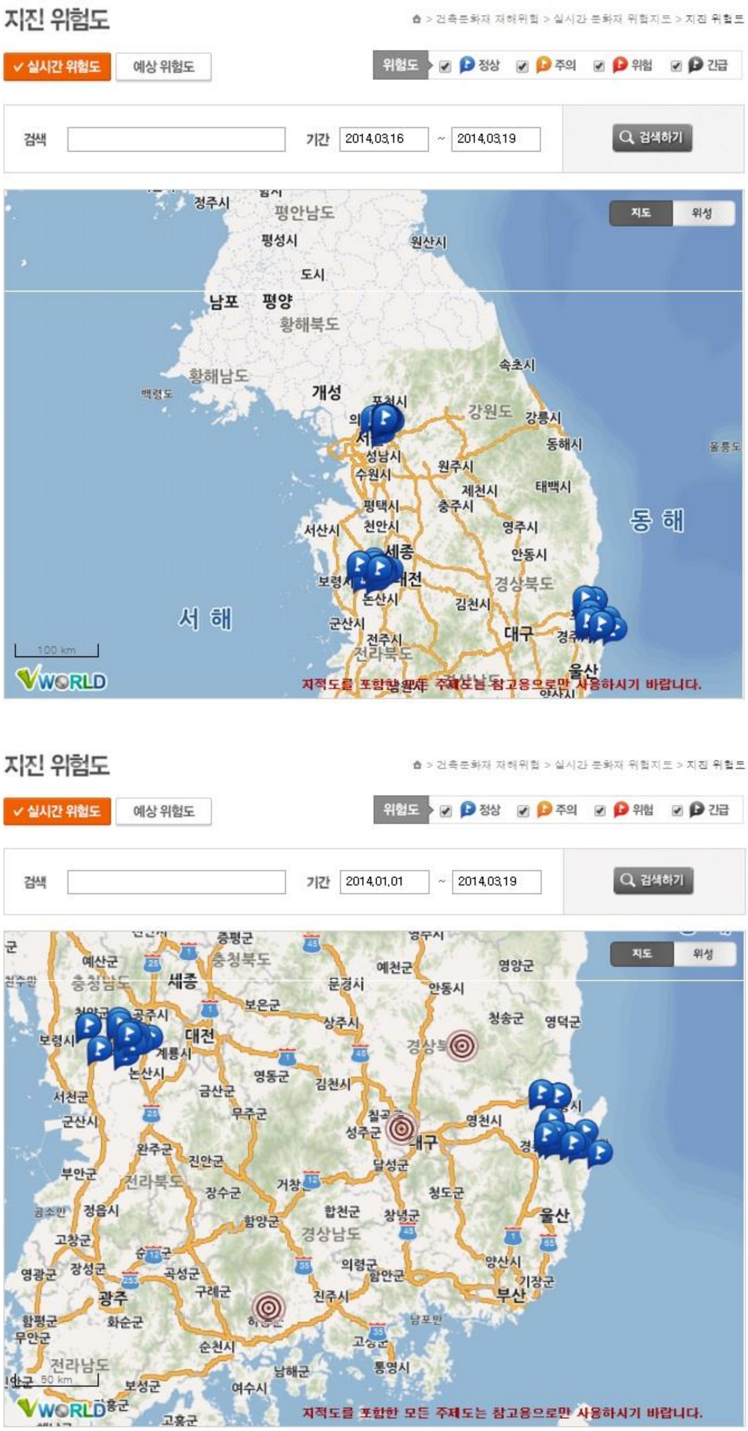

Figure 4-3. Risk Expression Method based on Real-Time Data

(2) Risk Expressing Method through Virtual Earthquake Occurrence

The risk expressing method through virtual earthquake occurrence is a simulation method that we assume that there is an earthquake in order to get the report of the damage.

The user can select one of the options from 'expectable risk' and launch the virtual earthquake. He/she should choose a location in GIS, and enter the degree of the earthquake so that he/she can understand the seismic risk on that particular architectural heritage. The circular part in figure 4-4 shows the earthquake selected by the user.

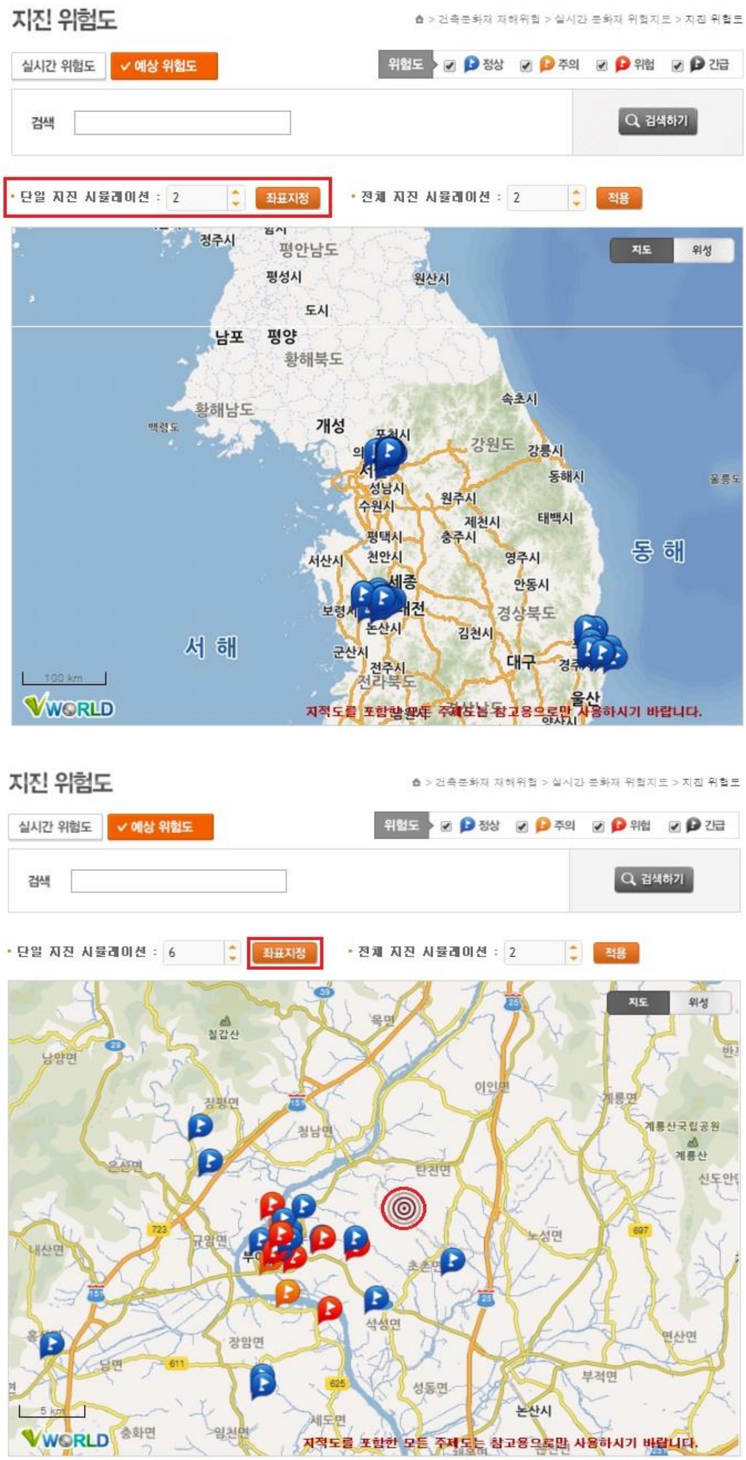

Figure 4-4. Risk Expression Method though Virtual Earthquake Occurrence

(3) Risk Expressing Method Targeting Entire the Architectural Heritages.

This expressing method is a method that we apply a certain standard to all the architectural heritages so that we can confirm the risks.

The user selects the expectable risks and then understands the risks on all the architectural heritage. In this particular method, which is unlike the virtual earthquake occurrence method, we do not have to select the location in GIS, therefore, we only need to enter the degree of the earthquake. In this method we apply the same earthquake condition to all the architectural heritages so that we can check whichever is required to be repaired and managed. This helps the architectural heritage managers to make decision about repair and preservation of those heritages.

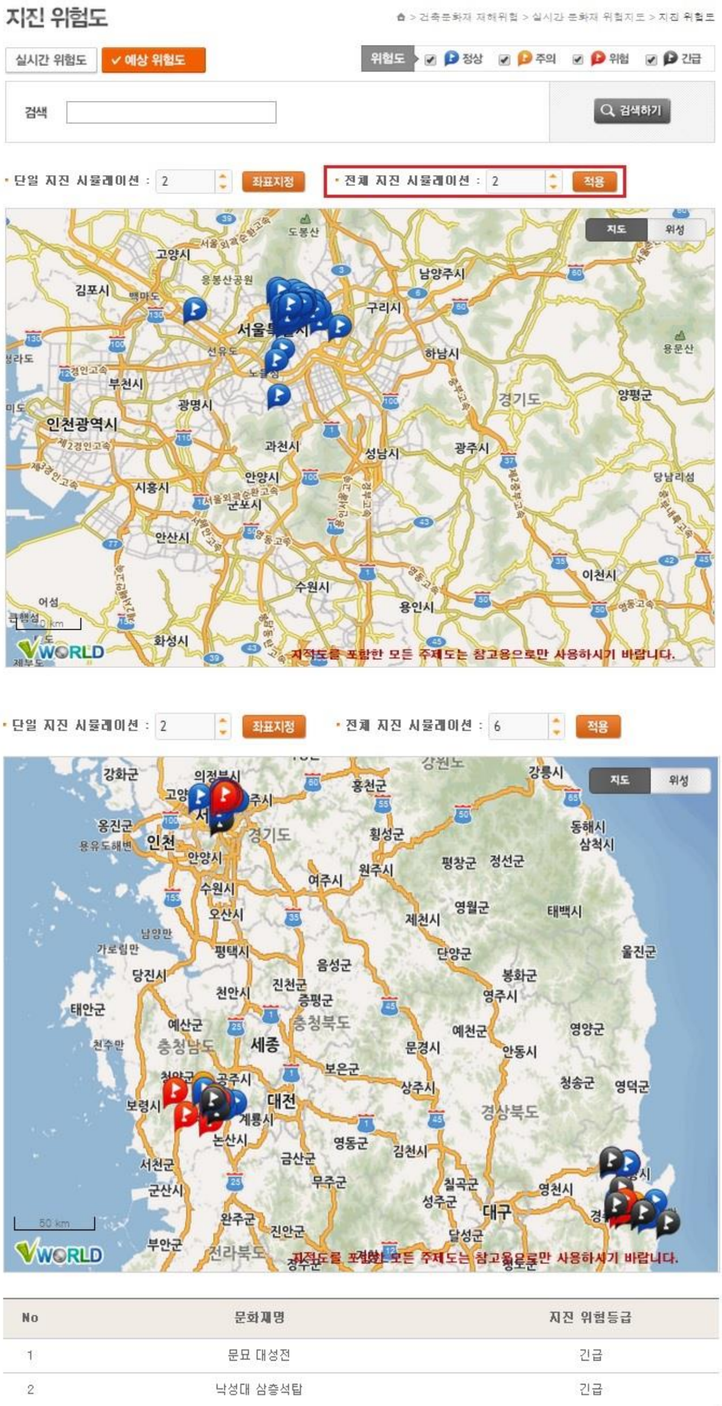

Figure 4-5. Risk Expression Method that Entire Architectural Heritage

4.4 Validation of Risk Assessment using System

We validated risk assessment using the system on the basis of the background of the architectural heritages damaged by the historic earthquake. Figure 4-6 given below shows the case of the architectural heritage damaged by the historic earthquake.

Time	Location	Contents	Magnitude	scale
1036. 7. 17 / 靖宗 2. 6. 21(戊辰)	35.8 / 129.2	Facilities near south stair and downside door of Bulguksa was collapse and Seokga paragon was almost collapse (Bulguksa 서석탑중수형지기묵서지편)	Ⅷ	6.4

Figure 4-6. Historical Damage Record about Architectural Heritage

For the purpose of validation, we applied above case by using the risk expressing method through virtual earthquake occurrence. Figure 4-7 shows the result after using the mock earthquake.

Figure 4-7 Expression Result using Virtual Earthquake Occurrence

In the figure 4-7, the architectural heritage with star mark indicates dangerous stage and the heritage in the rectangular box indicates emergency stage. From the expressed result and the historic record, we validated the Validation of the system through the comparison with the damage case caused by the earthquake. From the result of the system, we can see that the architectural heritages located in bulkuksa are in emergency stage. The comparison result showed the condition similar to the result recorded in 서석탑중수형지기묵서지편 which state that 'the several facilities were destroyed and stone pagoda were almost destroyed which. Seismic risk assessment process has validation from that result.

4.5 Verification of System Usability

There is the figure 4-8 that users estimate the system. Evaluation Factors are 8, and conducted a survey to 6 users that are working at National Research Institute for Cultural Properties.

Figure 4-8. Results of the Proposed System

Evaluation Factors	Experts						Average
	A	B	C	D	E	F	
Accessibility	3	4	4	4	3	3	3.50
Convenience	2	3	5	3	3	4	3.33
Findability	3	4	4	3	3	4	3.50
Usefulness	4	3	5	3	4	3	3.67
Availability	3	3	4	4	3	3	3.33
Aesthetics	3	3	2	2	3	2	2.50
Interaction & Feedback	4	4	3	3	3	4	3.50
Satisfiability	3	3	4	3	4	3	3.33
Total							3.33

Each Factor can get degree 0 to 5. Aesthetics is low than other factor but it is problem in design of system. Average of estimation result is 3.33. Overall, it is judged that the system has usability for actual user.

Chapter 5. Conclusions

The existing earthquake calamity researches and objects were targeted on modern architectures and the domestic researches on cultural assets tended to historicity and scholarity etc. But the research on calamity and prevention has been increased as there was huge degree of earthquake recently. Some evaluation on seismic risk were carried out from National Research Institute of Cultural Heritage in order to protect cultural assets, however, that particular evaluation was on the basis of geotechnical data so it produced a result showing low efficiency and accessibility. The system which was developed by National Emergency Management Agency is still being continuously enhanced and reinforced. But the current system does not treat the architectural heritage as objects to be managed, so there is a limitation to handle the earthquake calamity. Therefore, in this research, we evaluated and indicated the seismic risk on the basis of the ground, conservation and earthquake calamity information so that it is directly noticeable. Finally, the system is development on the basis of the risk evaluation.

The system has been enhanced so that managers can administer the cultural assets properly. If we utilize the risk evaluation and management system which is the result of this research, it will help them to select the architectural heritage which is need to be enhanced, and prepare for the calamity. And also the real time computed seismic risk sourced by weather center might be helpful for corresponding the calamity and restore the cultural assets. The list of architectural heritage computed by the utilization of seismic risk is also helpful for the efficient decision making.

In this research, there is an advantage of efficient management on architectural heritage. But it has some limitations too. Firstly, the points, that the architectural heritage were classified on certain standard, and that the study was on the basis of advanced research in which the behavior test had been conducted, do not show the exact risk standard. And also, architecture such as rampart which is in huge range might cause some errors.

Accordingly, in order to evaluate precisely, we need more research on earthquake damage. If, hereafter, a behavior test research accomplishes and more of concrete plans to prevent calamities are added, then it will be helpful for precise evaluation of seismic risk and for prevention of earthquake calamity.

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국 문 초 록

2010년 아이티 지진과 발생한 2011년 일본 지진으로 인해 막대한 인명 및 재산피해가 발생했고, 이로 인해 지진에 대한 관심과 지진재해 방재 연구가 증가했다. 국내의 경우 지진의 발생빈도는 상대적으로 낮지만, 그 규모 및 횟수가 증가하고 있어 대비가 필요하다. 현재 지진재해 방재에 관한 기존 연구는 인명피해가 연관되어 있는 현대 건축물에 초점이 맞춰져 있었다.

따라서 본 연구에서는 지진의 불확실한 특성과 지진 발생 시 미치는 영향을 고려하여 자연재해 중에서 지진을 연구범위로 설정했다. 언급한 지진의 특성으로 인해 많은 국가들에서 지진에 대해 대비하고 있으며, 특히 한국은 판 경계에 위치하고 있기 때문에 지진에 대해 대비해야 한다.

위험요소로부터 대비가 필요한 건축물 중에서 건축문화재는 역사적 가치 및 학문적 가치를 가지고 있기에 중요하다. 그러나 한국에서는 사회기반시설 및 국가중요시설에 대해서 대비를 하고 있을 뿐, 아직 건축문화재 방재 측면까지 확대되지는 않았다. 또한, 효과적인 지진 방재를 위해서는 시스템 구축을 통한 과정이 필요하다. 이에 지진위험도뿐만 아니라 이를 활용한 시스템의 프레임워크를 제안했다.

본 연구에서는 건축문화재를 대상으로 지진 재해 피해 예방을

위한 위험도 평가 및 관리 시스템 구축을 목적으로 한다. 내진 설계기준으로 조사된 개별 건축문화재의 지반 데이터와 역사지진 및 문화재의 보수기록을 이용한 건축문화재의 지진취약도 산정을 통해 지진 위험도를 산출했다. 이를 총 4단계의 기준으로 제시했으며, 이를 GIS에 표출하여 관리자가 건축문화재를 지진재해에 대해 관리 할 수 있는 시스템 구축했다.

주요어: 건축문화재, 지진, 위험도평가, 관리시스템

학 번: 2014-20553

Appendix

Name of heritage	Factor	contents
불국사다보탑	Specify type	국보
	Specify number	제20호
	Location	경상북도 경주시 진현동 15-1 불국사
	Latitude	35°47'24""
	Longitude	129°19'57""
	Architectural heritage fatigue	246
	Danger magnitude	4.9
	Emergency magnitude	5.4
Name of heritage	**Factor**	**contents**
불국사연화교칠보교	Specify type	국보
	Specify number	제22호
	Location	경상북도 경주시 진현동 15-1 불국사
	Latitude	35°47'23
	Longitude	129°19'56
	Architectural heritage fatigue	257
	Danger magnitude	5.1
	Emergency magnitude	5.6
Name of heritage	**Factor**	**contents**
석굴암석굴	Specify type	국보
	Specify number	제24호
	Location	경상북도 경주시 진현동 891 석굴암
	Latitude	
	Longitude	
	Architectural heritage fatigue	205
	Danger magnitude	5.8
	Emergency magnitude	6.2
Name of heritage	**Factor**	**contents**
분황사석탑	Specify type	국보
	Specify number	제30호
	Location	경북 경주시 구황동 313 분황사
	Latitude	35°50'27""
	Longitude	129°14'2""
	Architectural heritage fatigue	247
	Danger magnitude	5.2
	Emergency magnitude	5.6

지진	홍수	태풍	화재	재난유형별 할증계수		◇	▲△
1.000	1.000	1.000	1.000				

이 항목은 세부 할증계수를 조절하는 부분입니다. 재해유형별 상호 파괴력 차이를 조절할 수 있으며, 구조에 따라 특정 재해에 강하고 취약함을 수치로 조절할 수 있습니다.

구조유형별 재난별 할증계수

						회복률	
목조	지진	1.000	석조	지진	1.500	개수/수축	50%
	홍수	1.000		홍수	0.500	해체보수	70%
	태풍	1.000		태풍	0.400	서까래	5%
	화재	2.000		화재	0.850	주녀/사래	10%
조적조	지진	2.000	RC조 SRC조	지진	0.500	보강/복원	40%
	홍수	1.200		홍수	0.100	지붕해체	40%
	태풍	0.850		태풍	0.200	이건	50%
	화재	0.250		화재	0.100	재건	100%

시대구분		시대																																	
		왕조	태조							정종		태종																					
		년도	1392	1393	1394	1395	1396	1397	1398	1399	1400	1401	1402	1403	1404	1405	1406	1407	1408	1409	1410	1411	1412	1413	1414	1415	1416	1417	1418	1419	1420	1421	1422	1423
지해연표	지진	등급																																
		횟수																																
	홍수	등급								2	3	2			4			5		5				2					2			1	2	
		횟수								1	1	1			2			1		1				1					1			1	2	
	태풍	등급																																
		횟수																																
	화재/기타	등급																																
		횟수																																
문화재명/년도별재해규모			0	0	0	0	0	0	0	2	3	2	0	0	8	0	0	5	0	5	0	0	0	2	0	0	0	0	2	0	0	1	4	0

구조1	구조2	구조체결점	밀폐여부	입면상 개구부 비중	시대	입면구성	최종 재건	문화재명/년도별재해규모	
석조	목재트러스	화강석마할력	밀폐	소	일제강점기	전면벽체	1938	가회동 이준구 가옥	
목조	목조	목재일체화	반개방	중	일제강점기	벽체 및 창호	192?	가회동 한씨 가옥	
목조	목조	목재일체화	반개방	소	조선후기	벽체 및 창호	1867	경복궁근정전	◀ 신축 5 25 29
목조	목조	목재일체화	반개방	다	조선후기	창호	1865	경복궁자경전	
목조	조적조	목재일체화	밀폐	다	조선후기	벽체 및 창호	1888	경복궁집옥재	
목조	목조	목재일체화	개방	다	조선후기	-	1867	경복궁 경회루	◀ 신축 4
목조	목조	목재일체화	밀폐	다	조선후기	창호	1926	경희궁숭정전	
목조	목조	목재일체화	밀폐	다	조선후기	창호	1873	경복궁 향원정	
목조	목조	목재일체화	개방	다	조선후기	2면벽체	1616	경희궁흥화문	
목조	목재트러스	긴결철물	밀폐	중	대한제국	벽체 및 창호	1907	구공업전습소본관	
조적조	목재트러스	시멘트몰탈	밀폐	중	대한제국	벽체 및 창호	1907	구대한의원본관	
조적조	조적조	시멘트몰탈	밀폐	소	조선후기	벽체 및 창호	1890	구러시아공사관	
RC벽식	-	일체식	밀폐	소	일제강점기	벽체 및 창호	1931	구서울대학교본관	
목조	목조	목재일체화	반개방	중	조선후기	벽체 및 창호	1867	경복궁 근정문 및 행각	◀ 신축 5 25 29
조적조	목재트러스	시멘트몰탈	밀폐	소	조선후기	전면벽체	1884	기기국번사창	

					규모대비 위치 가속도		문화재 종류.1 기	종류.2 피	경고	긴급	문화재 피로도	경고규모	긴급규모							입력지진우
1	불국사다보탑	불국사	불국사	0.07663898	0.132840897	경주	석탑	석조	0.15	0.26	246	4.9	5.4	0.047	0.00174	0.00078	0.0007	0.54187	0.60852	긴급
2	불국사 삼층석탑	국유	경주시	0.07667312	0.132900069	경주	석탑	석조	0.15	0.26	245	4.9	5.4	0.085	0.00174	0.00142	0.00057	0.54187	0.60825	긴급
3	불국사연화교칠보교	불국사	불국사	0.09951215	0.172545747	경주	석교	석조	0.15	0.26	257	5.1	5.6	0.08	0.00134	0.00133	0.00078	0.54187	0.6115	긴급
4	불국사청운교백운교	불국사	불국사	0.09991056	0.173237544	경주	석탑	석조	0.15	0.26	248	5.1	5.6	0.08	0.00134	0.00133	0.00078	0.54187	0.60906	긴급
5	석굴암석굴	석굴암	석굴암	0.23519388	0.366774563	경주	조적(2층)	석조	0.35	0.45	205	5.8	6.2	0.07967	0.00153	0.00133	0.00069	0.54187	0.59741	긴급
6	신라태종무열왕릉비	국유	경주시	0.11544012	0.190745291	경주	비석	석조	0.2	0.32	475	5.2	5.7	0.074	0.0014	0.00123	0.00077	0.54187	0.67057	긴급
7	분황사석탑	분황사	분황사	0.1056022	0.180310867	경주	석탑	석조	0.15	0.26	247	5.2	5.6	0.081	0.00126	0.00135	0.00081	0.54187	0.60879	긴급
8	경주첨성대	국유	경주시	0.05791506	0.11003861	경주	첨성대	조적조	0.15	0.285	800	4.7	5.2	0.111	0.00185	0.00185	0.00043	0.54187	0.75862	긴급
9	경주구황리삼층석탑	국유	경주시	0.08560841	0.149504112	경주	석탑	석조	0.15	0.26	542	5	5.5	0.073	0.00138	0.00122	0.00078	0.54187	0.68872	긴급
10	월성나원리오층석탑	국유	경주시	0.10348447	0.177912113	경주	석탑	석조	0.15	0.26	346	5.2	5.6	0.077	0.00124	0.00128	0.00083	0.54187	0.63561	긴급
11	정혜사지십삼층석탑	국유	경주시	0.09750322	0.166348239	경주	석탑	석조	0.15	0.26	209	5.1	5.5	0.092	0.00139	0.00153	0.00071	0.54187	0.5985	긴급
12	감은사지삼층석탑	국유	경주시	0.07666752	0.132890365	경주	석탑	석조	0.15	0.26	548	4.9	5.4	0.06	0.00154	0.001	0.00075	0.54187	0.69034	긴급
13	월성장항리사지서오층	국유	경주시	0.07743725	0.134224558	경주	석탑	석조	0.15	0.26	540	4.9	5.4	0.07967	0.00153	0.00133	0.00069	0.54187	0.68818	긴급
14	무첨당	이지락	이지락	0.07528827	0.195391804	경주	기와집	목조	0.12	0.3	90	4.9	5.7	0.07967	0.00153	0.00133	0.00069	0.54187	0.56626	긴급
15	향단	이문환	이문환	0.1071309	0.271293675	경주	기와집	목조	0.12	0.3	163	5.2	6	0.063	0.00104	0.00105	0.00097	0.54187	0.58603	긴급
16	관가정	손동만	손동만	0.10787487	0.273619502	경주	기와집	목조	0.12	0.3	163	5.2	6	0.061	0.00103	0.00102	0.00098	0.54187	0.58603	긴급
17	경주포석정지	국유 및 공	경주시	0.14622796	0.381700024	경주	사적지	사지	0.26	0.6	379	5.4	6.2	0.098	0.00143	0.00163	0.00067	0.54187	0.64456	긴급
18	황룡사지	국유, 사유	경주시	0.14989776	0.376474034	경주	사적지	사지	0.26	0.6	485	5.5	6.2	0.074	0.00135	0.00123	0.00079	0.54187	0.67327	긴급
19	망덕사지	국유, 사유	경주시	0.11493234	0.338161084	경주	사적지	사지	0.26	0.6	446	5.2	6.1	0.082	0.00178	0.00137	0.00056	0.54187	0.66271	긴급
20	경주월성	국유, 사유	경주시	0.13954754	0.286877081	경주	성첩 균은	조적조	0.26	0.38	62	5.4	6	0.062	0.00181	0.00103	0.00062	0.54187	0.55867	긴급
21	경주임해전지	국유, 공유	경주시	0.10942441	0.271892734	경주	사적지	사지	0.26	0.6	451	5.2	6	0.118	0.00186	0.00197	0.0004	0.54187	0.66406	긴급
22	경주계림	국유	경주시	0.07716687	0.189990888	경주	기와집	목조	0.12	0.3	124	4.9	5.7	0.093	0.00146	0.00155	0.00067	0.54187	0.57547	긴급
23	경주남산성	국유, 사유	경주시	0.12141395	0.183020706	경주	성첩 균은	조적조	0.26	0.38	808	5.3	5.6	0.07967	0.00153	0.00133	0.00069	0.54187	0.76079	긴급
24	명활산성	국유	경주시	0.17889406	0.316002424	경주	성첩 균은	조적조	0.26	0.38	103	5.6	6.1	0.076	0.00141	0.00127	0.00075	0.54187	0.56978	긴급
25	경주나정	국유	경주시	0.07752653	0.226792424	경주	기와집	목조	0.12	0.3	167	4.9	5.8	0.055	0.00143	0.00092	0.00082	0.54187	0.58712	긴급
26	재매정	공유	경주시	0.05455121	0.136378027	경주	기와집	목조	0.12	0.3	621	4.6	5.4	0.102	0.00168	0.0017	0.00054	0.54187	0.71012	긴급
37	부여정림사지오층석탑	국유	부여군	0.08784314	0.151479155	부여	석탑	석조	0.15	0.26	125	5	5.5	0.103	0.00161	0.00172	0.00057	0.54187	0.57574	긴급
38	당유인원기공비	국유	국립부여박	0.11485903	0.190603657	부여	비석	석조	0.2	0.32	104	5.2	5.7	0.08591	0.00166	0.00143	0.00061	0.54187	0.57005	긴급
39	보광사대보광선사비	국유	국립부여박	0.11485903	0.190603657	부여	비석	석조	0.2	0.32	104	5.2	5.7	0.08591	0.00166	0.00143	0.00061	0.54187	0.57005	긴급
40	부여정림사지석불좌상	국유	부여군	0.09795998	0.17560198	부여	비석	석조	0.2	0.32	94	5.1	5.6	0.055	0.00195	0.00092	0.00057	0.54187	0.56734	긴급
41	부여장하리3층석탑	국유	부여군	0.08410429	0.146483597	부여	석탑	석조	0.15	0.26	30	5	5.4	0.094	0.00176	0.00157	0.00053	0.54187	0.55	긴급
42	무량사 오층석탑	무량사	무량사	0.10914647	0.188001988	부여	석탑	석조	0.15	0.26	36	5.2	5.7	0.083	0.00135	0.00138	0.00076	0.54187	0.55162	긴급
43	부여석조	국유	국립부여박	0.11372395	0.188504201	부여	비석	석조	0.2	0.32	125	5.2	5.7	0.08591	0.00166	0.00143	0.00061	0.54187	0.57574	긴급
45	대조사석조미륵보살입	대조사	대조사	0.12857956	0.201800776	부여	비석	석조	0.2	0.32	104	5.3	5.7	0.096	0.00148	0.0016	0.00066	0.54187	0.57005	긴급
46	무량사 석등	무량사	무량사	0.12170385	0.205029398	부여	석탑	석조	0.15	0.26	30	5.3	5.7	0.082	0.00121	0.00137	0.00083	0.54187	0.55	긴급
47	무량사극락전	무량사	무량사	0.08713038	0.228361813	부여	기와집	목조	0.12	0.3	19	5	5.8	0.085	0.00136	0.00142	0.00075	0.54187	0.54702	긴급
48	부여성흥산성	국유 및 사	부여군	0.18285346	0.318524848	부여	성첩 균은	조적조	0.26	0.38	92	5.6	6.1	0.089	0.00132	0.00148	0.00075	0.54187	0.5668	긴급
49	부여부소산성	국유	부여군	0.20073632	0.329914886	부여	성첩 균은	조적조	0.26	0.38	152	5.7	6.1	0.046	0.00139	0.00077	0.00086	0.54187	0.58305	긴급
50	부여능산리고분군	국유	부여군	0.11596162	0.442748092	부여	사적지	사지	0.26	0.6	96	5.2	6.4	0.092	0.00206	0.00153	0.0004	0.54187	0.56788	긴급
51	부여청마산성	국유, 사유	부여군	0.14692016	0.258438439	부여	성첩 균은	조적조	0.26	0.38	152	5.4	5.9	0.08591	0.00166	0.00143	0.00061	0.54187	0.58305	긴급
52	부여군수리사지	국유, 공유,	부여군	0.12307649	0.450917466	부여	사적지	사지	0.26	0.6	91	5.3	6.4	0.095	0.00194	0.00158	0.00044	0.54187	0.56653	긴급
53	부여나성	국유,사유	부여군	0.15134643	0.27367611	부여	성첩 균은	조적조	0.26	0.38	97	5.5	6	0.08591	0.00166	0.00143	0.00061	0.54187	0.56815	긴급
54	부여청산성	국유, 사유	부여군	0.14582937	0.254683318	부여	성첩 균은	조적조	0.26	0.38	166	5.4	5.9	0.08591	0.00166	0.00143	0.00061	0.54187	0.58685	긴급
55	부여석성산성	국유 및 사	부여군	0.14802524	0.262242738	부여	성첩 균은	조적조	0.26	0.38	138	5.5	5.9	0.08591	0.00166	0.00143	0.00061	0.54187	0.57926	긴급
56	부여쌍북리요지	공유	부여군	0.14476481	0.46232676	부여	사적지	사지	0.26	0.6	96	5.4	6.4	0.08591	0.00166	0.00143	0.00061	0.54187	0.56788	긴급
57	궁남지	국유,사유	부여군	0.13987579	0.479946839	부여	사적지	사지	0.26	0.6	51	5.4	6.4	0.07	0.00174	0.00117	0.00062	0.54187	0.55569	긴급
58	증산성	국유, 사유	부여군	0.14582937	0.254683318	부여	성첩 균은	조적조	0.26	0.38	166	5.4	5.9	0.08591	0.00166	0.00143	0.00061	0.54187	0.58685	긴급