Seismic Vulnerability Assessment In Vernacular Houses:

The Rapid Visual Screening Procedure for Non Engineered Building with Application to Java Indonesia

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ABSTRACT

Vernacular houses or known as non-engineered houses in fact are still the most inhabited buildings in this world, especially in developing countries. Many developments have been done, mostly by the occupants themselves, in various ways in order to follow the needs along to the capability of the people. Unfortunately, not all developments were relied on the real necessities, and some even lead to danger the user. In the other hand, least attention had been made by scholars, professionals, or even the authorities since the subject is vernacular, by mean can be devolved upon the people and considered as less important issue. This miss conception had been paid when it becomes a disaster, such as from an earthquake; when the houses are fail to give protection, instead its give a threat because of its deficiencies particularly in those countries that are allocated in high seismic zone such as Java Island.

Under seismic hazards, vernacular houses have various behaviors from most to least capability of resisting such hazard, which is related to architectural and structural system. Many methods for examining seismic vulnerabilities for building have been proposed through the structural analysis procedures which could be only done by competent engineers, other simpler survey procedures were also developed by the rapid visual screening for investigating building probabilities from the risk. However, almost all of these evaluations were intended for well defined-engineered buildings in structural point of view. None of them was applicable for form-typology-related evaluation such as vernacular buildings which are very different in many aspects. This research deals with the assessment of vernacular house development by the influence of natural disaster of earthquake. The aim of this research is to examine the seismic vulnerability level of the houses by developing a specific-applicable simple procedure, to be applied for Javanese vernacular houses.

A method based on FEMA 154, Rapid Visual Procedure had been adapted for Javanese vernacular house circumstances. To achieve this, a quantitative study based on computer simulation had been done for various types the houses, and a full performance comparison has been utilized. Post quake field finding were used to support the examination. Field applications were also taken in order to confirm the procedure and to discover the level of vulnerability. The result shows that the level of seismic risk in vernacular houses can be assessed by a certain method adopted from available well-defined procedure. Proper adaptation regarding the local seismicity and building practices turned the procedure become applicable for Javanese vernacular houses. Unfortunately, the vulnerability level of those houses, especially the new houses after the May 27th 2006 earthquake, is not as ideal as expected before, and this can be associated to the mixed technique in building practice between old and new. In other side, some original traditional (unmodified) houses were proved to have better performance under the earthquake Hazard. These findings on vulnerability trigger a new thinking for the more suitable alternative of the future of Javanese houses.

Keywords: Javanese vernacular houses, reconstruction of Javanese houses, seismic risk assessment, rapid visual screening procedure

ÖZ

Özellikle gelişmekte olan ülkelerde, geleneksel ya da bir başka deyişle bir profesyonel tarafından şekillendirilmemiş konutlar, halen dünyayı en çok işgal eden konut tipidir. Bizzat kullanıcılar tarafından, sürekli değişime uğrayan farklı ihtiyaçların karşılanabilmesi amacıyla bu konutlara yönelik birçok çözüm üretilmiştir. Ancak, bu çözümler her zaman gerçek ihtiyaçları karşılamaya yönelik düşünülmemesi bir yana, hatta bir kısmı kullanıcı hayatını dahi tehlikeye sokmaktadır. Öte taraftan, araştırmacılar, uzmanlar ve yerel yönetimler de konuya gerekli önemi göstermemiştir. Bu duyarsızlığın bedeli, özellikle Java adası gibi deprem riski daha yüksek olan bölgelerde, konutların yetersizliklerine bağlı olarak korunaklı birer mekan olmaktan öte hayatı tehdit eden unsurlara dönüştüğü deprem gibi olası bir felaket durumunda oldukça ağır ödenmektedir.

Geleneksel konutlar, olası kuvvetlerine karşı, mimari ve strüktürel tiplerine bağlı olarak farklı önem ve düzeylerde dayanıklılık sergilemektedir. Binaların sismik kırılganlığını incelemek için sadece yetkili mühendisler tarafından yapılabilecek strüktürel analiz sistemiyle birçok yöntem önerilmiştir. Binaların deprem tehditi altındaki risk olasılıklarını araştırmak için ayrıca hızlı görsel tarama ile geliştirilmiş daha basit inceleme yöntemleri de ortaya konulmuştur. Ancak, strüktürel açıdan bu değerlendirmelerin bütününe yakını mühendislik açısından iyi tariflenmiş binaları hedeflemiştir. Hiçbiri geleneksel konut gibi birçok yönden çok farklı olan biçim-tipoloji ilişkili değerlendirme için uygulanabilir değildir. İşte, bu çalışma, bir doğal afet olan deprem etkisinde gelişecek geleneksel konutun değerlendirilmesini ele alır. Bu araştırmanın amacı, tüm geleneksel Javanese konutlarına uygulanabilecek belirgin-uygulanabilir basit bir yöntem geliştirerek, konutların sismik kırılganlık seviyelerini değerlendirmektir.

Geleneksel Javanese konut şartlarına uygun olarak, FEMA 154'ü temel alan Hızlı Görsel Tarama Yöntemi uyarlanmıştır. Bunu başarmak için, farklı konut tiplerini kapsayacak şekilde, bilgisayar destekli simulasyon bazlı nicel bir çalışma yapılmış; ve tam bir performans karşılaştırmasından faydalanılmıştır. İncelemeyi desteklemek için deprem sonrası alan bulguları da kullanılmıştır. Kırılganlık düzeyini ortaya çıkarmak ve yöntemi doğrulamak için alan uygulamaları önemli olmuştur. Sonuçlar, geleneksel konutlardaki sismik risk seviyesinin mevcut iyi tanımlanmış yöntemlerden uyarlanmış belirli bir metotla değerlendirilebileceğini göstermiştir. Yöntem, yerel sismik bilginin ve inşaat tekniklerinin uygun adaptasyonu ile yukarıda bahsi geçen kullanım için uygulanabilir hale gelmiştir. Ancak, Javanese konutlarının kırılganlık seviyesi, özellikle 27 Mayıs 2006 depremi sonrası inşa edilen yeni konutlarda, önceki konutlardan beklenildiği gibi ideal düzeyde olmamıştır; ve bunun nedeni eski ve yeni inşaat sistemi arasında kalmış karışık inşaat tekniğine bağlanabilir. Öte yandan, kimi özgün (değişikliğe uğramamış) geleneksel konutların deprem kuvvetleri altında daha iyi performans gösterdiği kanıtlanmıştır. Kırılganlığa dair bu bulgular, Javanese konutlarının geleceğine yönelik, daha uygun bir alternatife dair yeni düşünceleri tetiklemektedir.

Anahtar kelimeler: Geleneksel Javanese konutları, Javanese konutlarının yeniden inşaası, sismik tehlike değerlendirilmesi, hızlı görsel tarama yöntemi

DEDICATION

Dedicated to my beloved family for all their endless love;

My Wife Ergi, and My Sons Sena and Wira

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LIST OF ABBREVIATIONS

ATC………………………………………………………. Applied Technology Council

BAPPENAS.................................... Badan Perencanaan dan Pembangunan Nasional /
National Planning and Development Agency

BMG…………. Badan Metrologi dan Geofisika / Metrology and Geophysics Bureau

BS……………………………………………………………………… Basic Score

BSH……………………………………………………….. Basic Structural Hazard

BSI………………………………………………………..British Standard Institute

BSM……………………………………………………….. Basic score modifier

BV……………………………………………………………….Basic vulnerability

CAPSS…………………………………. Community Action Plan for Seismic Safety

DCR……………………………………………………… Demand-Capacity Ratio

DEPKES………………………... Departemen Kesehatan / Ministry of Public Health

DFTW………………………………………………………Dome for the World

DFTW………………………………………………………Dome for the World

DPMs………………………………………………..Damage Probability Matrix

DVA……………………………………………..Detailed vulnerability assessment

EERI…………………………………….. Earthquake Engineering Research Institute

EMS……………………………………………….. European Macro-seismic Scale

FEMA…………………………………….. Federal Emergency Management Agency

IAEE	International Association for Earthquake Engineering
IAI	Institute Architect of Indonesia
IBC	International Building Code
IS	Index Seismicity
JPDPA	Japan Building Disaster Prevention Association
JRF	Java Reconstruction Program
LBA	Lembaga Bantuan Arsitektur / Architectural Advices Commission
LFRS	Lateral force resisting system
MAE	Mid-America Earthquake
MCE	Maximum credible earthquake
MMI	Modified Mercalli Intensities
MS	Magnitude Scale
NATO	North Atlantic Treaty Organization
NEHRP	National Earthquake Hazards Reduction Program
NICEE	National Information Center of Earthquake Engineering (India)
NRCC	National Research Council of Canada
NZDC	New Zealand Code
PAM	Preliminary assessment methodologies
PMFs	Performance Modification Factors
PU	Pekerjaan Umum / Public Work
RC	Reinforced concrete

RSP	Rapid Screening Procedure
RVS	Rapid Visual Screening
S	Structural score
SAP	Structural Analysis Program
SERC	Structural Engineering Research Center
SVA	Simplified vulnerability assessment
UBC	Uniform Building Code
UII	Universitas Islam Indonesia
UNDP	United Nation Development Program
UNIDO	United Nations Industrial Development Organization
UN-OCHA	United Nations Office for the Coordination of Humanitarian
URM	Unreinforced masonry
USGS	United States Geological Survey
VS	Vulnerability scores
WHO	World Health Organization

Chapter 1

INTRODUCTION

Initial work by accessing all aspect related to the vernacular house, the Javanese vernacular houses, earthquake, the risk, and the vulnerability, will be highlighted. All relevant data related to these categories is assessed in order to collect significant study for the background of the study.

1.1 Java and Seismic Risk

Figure 1-1: Java May 27th, 2006 Earthquake Affected Area (www.mapsofworld.com)

Southern Java Island of Indonesia is one of the highest risk areas from earthquake disaster in the world. Some aspects generated firstly; it stands close to intersection of two most active continental plates: Eurasian and Australian which about 20 earthquakes rock various parts of Indonesia every day, leading to a total of about 7,000 subterranean movements each year (Furne W.2000). Secondly; it is very high density population with total area of 138.793,6 km2 with inhabitants of 124 million (density level 979/km2).

Most of them about two-third are living in many types of non-engineered or vernacular housing where the contemporary houses were mostly built with less consideration to the earthquake risk. Thirdly; the people mostly have less awareness in earthquake threat and technical capabilities limitation to construct suitable houses since it was long time since big destructive earthquakes occurred in 1867 and 1943.

1.2 Java and the May 27th 2006 Earthquake

The May 27th 2006 Java earthquake has destroyed thousands of buildings that result so many loss of life. Although it was only shaking in 59 seconds with magnitude of 5.9 (BMG) or 6.3 (USGS) Richter scale, 6,060 people were killed and a further 63,305 injured (WHO, 2006). 302,868 houses were also destroyed or damaged beyond repair, with another minor damage to a further 252,909 houses (BAPPENAS 2006a). This left 1.6 million people homeless (UN-OCHA, 2006). The ground motion intensity was high and more intense than comparable earthquakes elsewhere. Even if all building were designed to resist seismic forces according to the code, they would have suffered unexpectedly high levels of damage (Elnashai AS, *et.al*, 2007). Eight districts in the Yogyakarta and Central Java Provinces suffered extensive damage; most of them were housing sector (figure 1-2). The destroyed houses were located mostly in the area near the epicenter, the southern rural region of these provinces. These areas are also known where the Javanese vernacular houses were mostly settled.

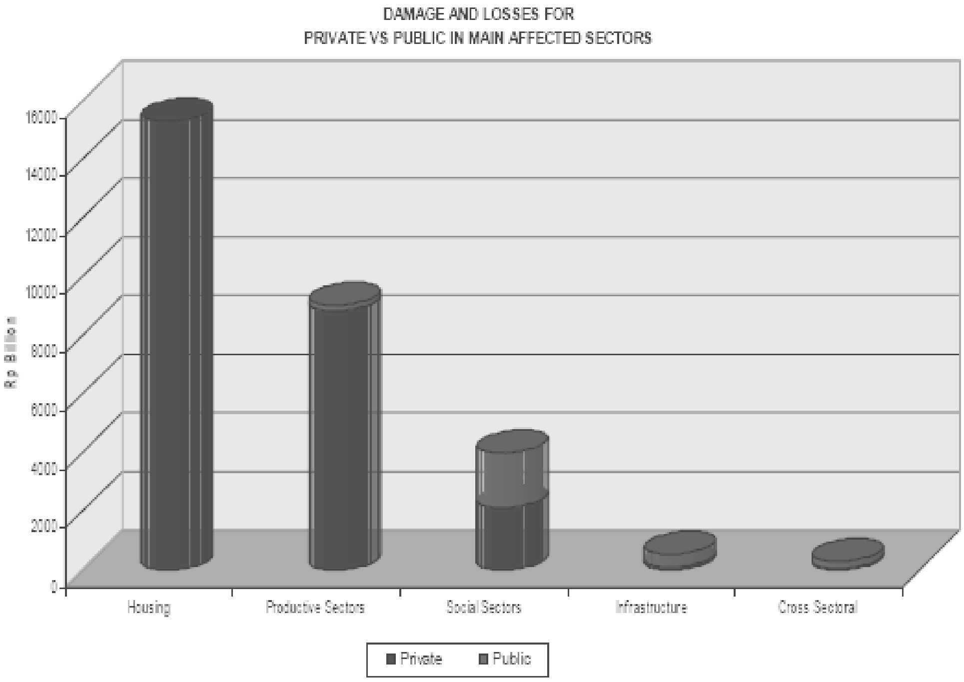


Figure 1-2: Private-Public Damage Sectors (BAPPENAS 2006a)

Soon after implementation of emergency period, Indonesian government supported by various relief organizations had redeveloped the destroyed area with reconstruction program. The program was the most successful action in term of time needed to rebuild 279.000 houses and to restore 253.000 others within two year (JRF, 2008). There were Eighty-five agencies who participated within the UN-OCHA humanitarian-cluster system redevelopment and 546 international and local organizations recorded as delivering assistance (UN-OCHA, 2007). Budget confirmed allocated and distributed 5.4 trillion Rupiah (580 million USD) (JRF, 2008) and more than 4000 specialists have contributed for helping the people in reconstructing the damaged region (Kimpraswil, 2007).

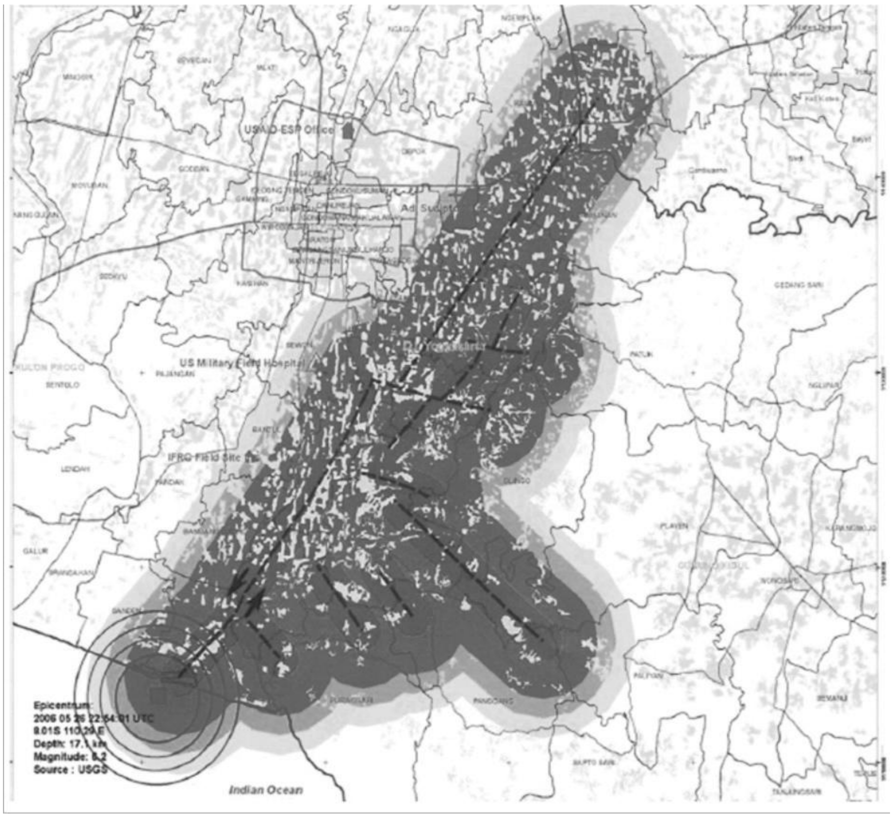


Figure 1-3: The affected areas of the May 27th, 2006 earthquake in Java (BAPPENAS 2006a)

The earthquake turned to catastrophe, primarily not because of the magnitude itself, but rather the level of intensity ground amplification caused by the proximity to the epicenter and soil condition, the lack of seismic-preparedness for buildings, and the limitation of the people’s awareness and understanding of earthquake (Idham, N *et.al*, 2010a). Thousand houses were destroyed and the most problem was how to provide the people with the more safety one. It was almost impossible to relocate the people to new place in the island since the scarcity of empty land might create more problems in the future. Indonesian government then focused on reconstruction program by developing earthquake resistant houses, conserving and strengthening the damages, and spreading earthquake risk awareness to the people in the affected areas.

Figure 1-4 : Collapsed Houses; Brick wall bearing construction and wooden frame structure

1.3 Post Earthquake Development on Javanese Houses

In order to be less vulnerable to the quake, the proposed models for the houses were mostly based on the conventional structural systems for earthquake protection, completely new structural system, and even completely strange structure. The new built houses range from the simple light wooden structure (IAI-LBA-UII, 2006, PU, 2007), the brick-concrete frame structure (Sarwidi, 2006; Widodo, 2007; PU, 2007), to the ‘teletubbies house’ concrete-shell dome structure (DFTW, 2007).

Figure 1-5: Some Results of Reconstruction House Program

Post earthquake development in the affected areas somehow shows that vernacular houses were suddenly stopped and changed with newer method and technique. This was completely inconsistence with some neighbor areas where old-vernacular ways are still used and maintained, even though there are also in high risk from earthquake from some aspects. This condition then followed by mixed development application in term of the way the people construct their houses. Many information regarding new safety house and traditional techniques then seems to blend up for the house development application.

Figure 1-6: Some varieties in detail of New Reconstruction Houses

From these circumstances, the direction of future development especially in the vernacular houses still could not be assured. This problem has a great significant impact in the future since related to the people safety in high seismic risk area. The previous catastrophe should not happen twice if the people could react consequently. The general background related to the initial problem shown in figure 1-7.

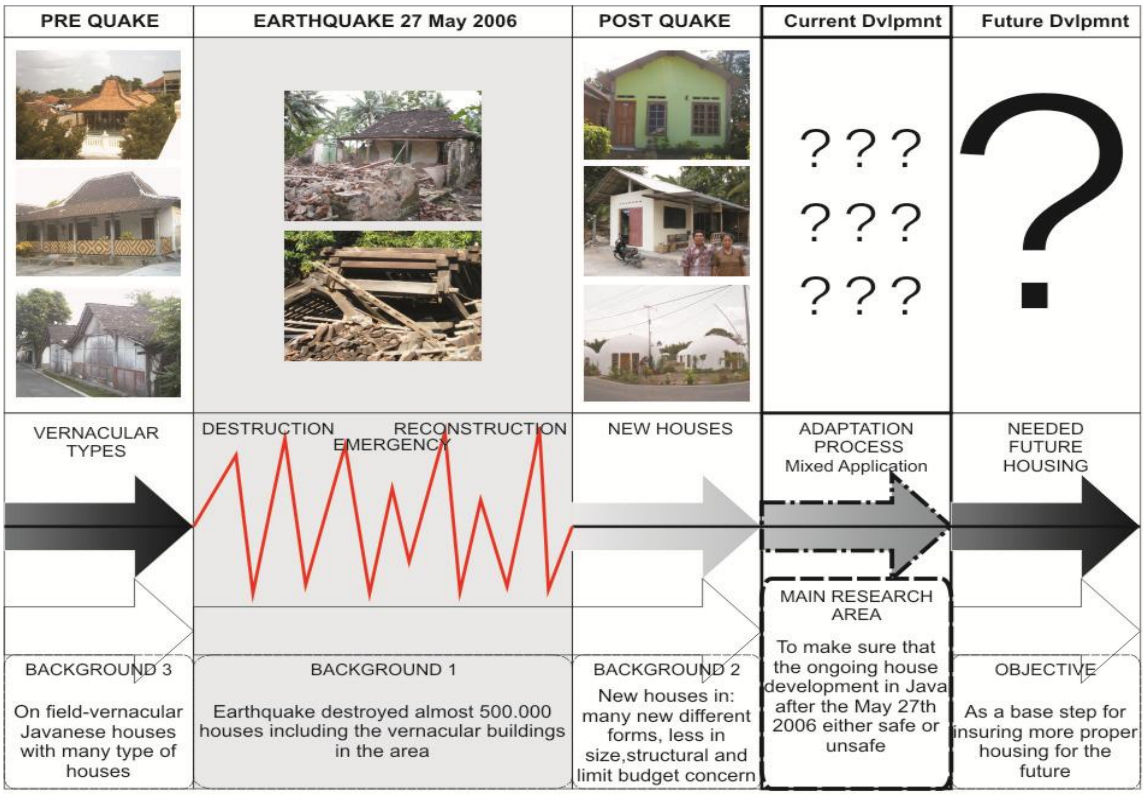


Figure 1-7: Research Main Problem Chart

1.4 Problem Statement and Objectives

Through the history, the vernacular Javanese houses development is directly affected by external factors such as using different material, new technique, and even different form of the building. This was as impact of the Javanese character that tends to keep their tradition by respecting and adapting the changes in order to keep them-selves up-to-date (Ronald, A 1986; Suseno, FM, 1988). As a result, there are several types of vernacular houses found in Java trying to follow the traditional, modern, or both principles. In sense of architectural typology, this has rose wide variation of the houses and enriching housing alternatives, but in the other hand, unfortunately, the qualities of the houses become divergence or not equal in many aspects. Furthermore, not every part of the different houses is compatible each other and not every later development is always suitable for the houses. All these occurrences could lessen the house qualities.

In the case of Javanese vernacular house development in the post earthquake is somehow as a combination, or precisely as mixed up, of continuation of the traditional way, the imported technique, and the new methods of reconstruction program after the May 27th 2006 earthquake. Since the character of the houses is different, *e.g.*; the traditional houses was mostly built by wooden materials and modified by masonry walls later, while the newer houses by brick wall with reinforced concrete (RC) frame, the mixed application has triggered the uncertain quality of building safety to the earthquake. Based on this circumstance, evaluation on seismic vulnerability level of Javanese vernacular houses is unquestionably needed.

Some procedures to examine seismic vulnerability where merely based on engineering point of view actually exist, but none of them are applicable directly for this particular use of evaluation. Most of building practice done by engineers put more their attention in ‘formal’ or well-defined in engineering term rather than in ‘informal’ type of building such as non-engineered house so-called as vernacular architecture. This became the main concern related to how, in fact, almost 90 percent of earthquake fatalities and casualties in most developing countries (Kenny, C., 2009) were associated to house failures which was mostly as a form of vernacular houses. This is even shocking enough when we deal with such very high seismically country like Indonesia, where two-third of building population are vernacular (Kusumastuti, D., *et.al,* 2008) but very least consideration, if ever, had been done for this special purpose.

Vernacular houses, however, though mentioned as non-engineered building, it is still following the rule of building’s engineering. To deal with earthquake threat; the law of forces and its properties will still work according to structural principles of the building. Fortunately, beside it will not as complicated as engineered building case, basic principles in building vulnerability assessment can be adopted and adapted for vernacular houses case. For this reason, it is more practical to deal with adaptation of seismic risk assessment from available method rather than developing the new one from the beginning. By this way, a suitable procedures considering most contextual aspect could be the most possible study to achieve the method.

This study thus aimed to evaluate the seismic vulnerability level for Javanese houses after the May 27th 2006 by proposing the appropriate examination in seismic vulnerability assessment. Adapted procedure for the simplest and easy but optimal use was examined and developed regarding the local consideration. By this study, the appropriate method for seismic vulnerability could be obtained and the level of Javanese vernacular vulnerability to the earthquake can be decided. For the further expectation, after considering all results of the study, seismic risk in Javanese houses could be reduced by more definite safe housing development in the future. This general illustration can be shown in figure 1-8.

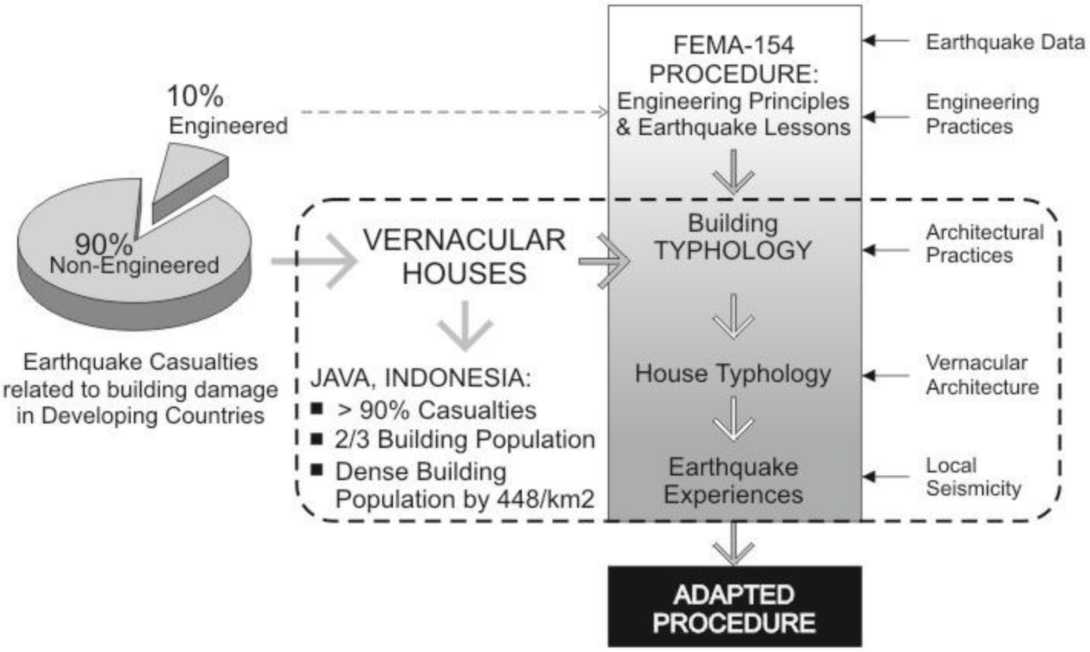


Figure 1-8: The field of study, the background, and the problem

1.5 Previous Studies

The earthquake phenomena might occur in any potential area located surrounding the continental edges but earthquake disaster was only take place in the area where people and the environment were not well prepare to. The seismic vulnerability is specific study related to seismic risk as the potential or probability of a loss in the of earthquake occurrence. Even the loss refers to broad concept as result of damaged environment; the buildings are still the main causal factor. Seismic risk analysis is also not only the matter of technical term but related to its acceptability, relative to social norms, and to other priorities (Scawthorn, C 2008). The existence of specific condition should be as the important vulnerability factor consideration. However, to tie the technical and social aspects is somehow not easy to be done, especially if we deal with some distinctive people, traditional people and vernacular building. Traditional buildings are placed with consideration of believes rather than in relation to physical sense (Hawkes 1996). This is also the main issues in vernacular architecture, while technology may progress; architecture does not necessarily do so (Rapoport, 1969).

Seismic vulnerability assessment was proposed since the US Federal Emergency Management Agency (FEMA) published their FEMA 154 (FEMA 1988a, accompanied by FEMA 155 (FEMA 1988b) and renewed in 2002 by Rapid Visual Screening (RVS) procedure, a vulnerability tool without involving any structural analysis or mathematic calculation. RVS is simply visual screening method to classify the building either safe or has potential risk from earthquake and need further detailed structural examination. This simple survey method then has gained its popularity and soon followed by some similar procedures that had been adapted by Sucuoglu, H and Yazgan, U (2003) in Turkey for their application, then by Sinha, R and Goyal, A (2004) proposed for Indian condition, also other scholars like Vallejo, C.B for vulnerability assessment in Philippines or De Masi (2006) for Thailand purpose. Numerous researchers were also having efforts in the field from many countries related to the earthquake such as from Japan, New Zealand, Canada, and Greece. RVS is literally called “visual examination” but actually the buildings are mostly categorized on the material used for structural system rather than using the form-typology of the building. Since the targeted RVS is structural system of the building, this procedure are applicable for a well defined building or term as engineered buildings but rarely used for non-engineered or vernacular building.

1.6 Research Methodology

In order to evaluate the seismic vulnerability level, some procedures in earthquake analysis related to building safety have been developed and successfully used. This study did not aim to develop a new but rather to adapt the available and most applicable one. The screening procedure of FEMA 154 is one of the most referred methods for Rapid Visual Screening (RVS) in seismic vulnerability. Based on FEMA 154, the Javanese RVS adopted the general procedure of grading system and adapted some criteria for Javanese house examination use.

To confirm the validity of the procedure adaptation, computer software for building performance under earthquake load model condition has been utilized. In order to have value level in vulnerability grading system, different type of Javanese houses have been examined according the form of the houses and the variation of detailed construction in the houses. The data gathered from the field after the earthquake related to damaged and collapsed houses were also used as supporting information for the examination from factual occurrence point of view. From this procedure, the RVS grading system can be approved and ready to be applied for the Javanese houses case.

After the RVS specific for the Javanese house developed field application was done in order to confirm the procedure liability and to examine the level of seismic vulnerability in the area where destructed earthquake of 27th May 2006 was occurred in Java. Hundreds data mainly from the affected field were gathered in order to have significant picture of the vulnerability of the recently new built houses in the area. By this method, both procedure confirmation and its usage have been examined. Figure 1-9 illustrates the outline of this methodology.

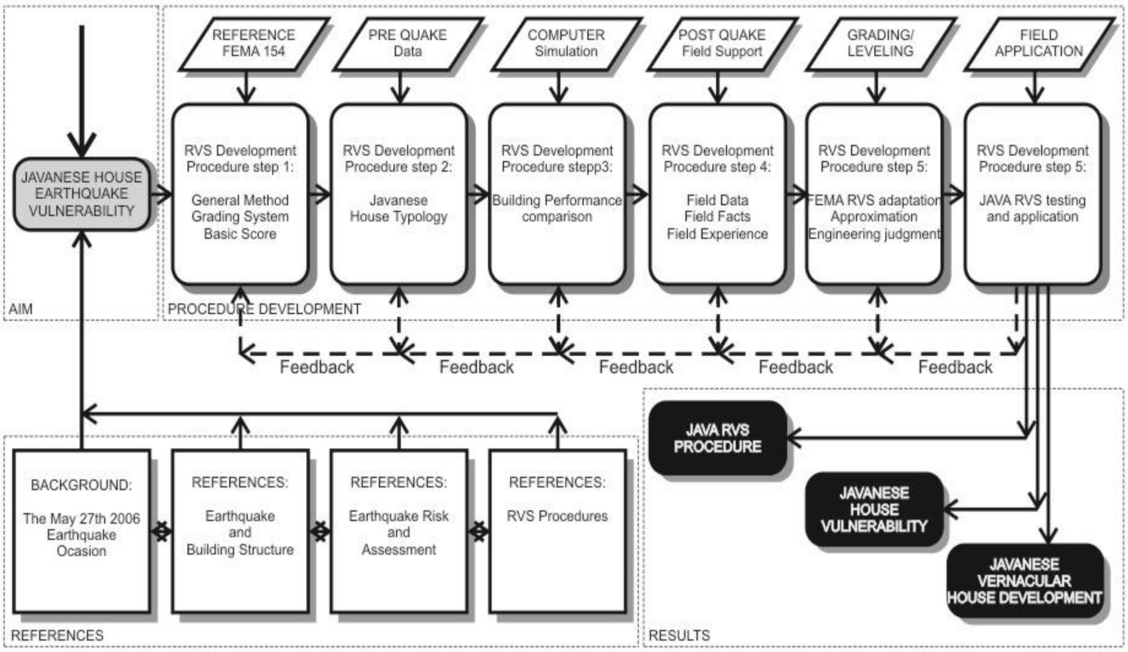


Figure 1-9: Methodology Procedure of the Research

1.7 Scope and Limitation of Study

This study is focused on modified-vernacular Javanese houses in order to resolve actual problem in safe house development after the May 27th 2006 earthquake. However, the Javanese vernacular houses in general could not be neglected as important aspect for the development. As a result of thousand year of adaptation from natural and social factors, traditional houses as part of vernacular houses in fact still affect both for concept and technique application in the field. For this reason, comparison study between all the vernacular houses is still essential. The result of this comprehensive study will open many possibilities in the future development and gives chance for re-orienting the best house policy of the government in Indonesia.

This study on vernacular Javanese architecture is only discussing the house performance related to the earthquake impact according to the previous local seismic data. The focus of the study is the seismic risk assessment of vernacular architecture by visual appearance of the buildings for Javanese houses case using RVS procedure. The comparison between the performance of the houses is the main key for precede the study. For this purpose, qualitative studies were ranged from vernacular architecture typology, the Javanese houses, earthquake risk, and structural damage probability from the earthquake. Even structural analysis was done by computer software in order to support the examination; this study is not the scope of quantitative or detailed structural analysis. Quantification on the building structure discussion done in this research is as initial figure which will always need to be re-evaluated based on actual seismic impact occurrences time-by-time adaptation. The deeper individual detailed performance analysis is beyond of this study as a following step in structural analysis.

1.8 Thesis Structure

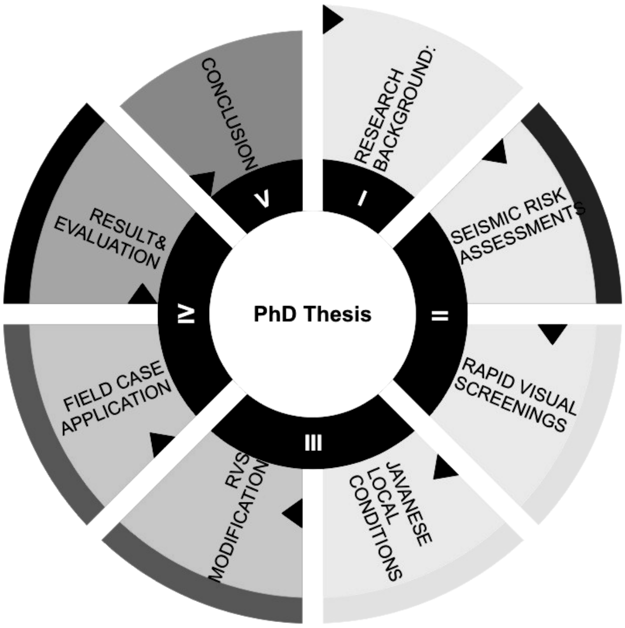


Figure 1-10: Thesis Body Chart

In order to achieve these aims some steps are organized in this thesis. Three early steps discuss for the RVS development issue and two others for Javanese houses vulnerability level issue. The whole process is shown by chart (see figure 1-9). All these segments are written in five chapters structured bellow:

Step1

The first step is focused on initial work by accessing all aspect related to the vernacular house, the Javanese vernacular houses, earthquake, the risk, and the vulnerability. All relevant data related to these categories is assessed in order to collect significant study for the background of the study.

Step2

The second step is to concentrate on seismic risk and vulnerability by assessing the existing procedures and references. By this step, the full understanding of seismic risk and its evaluation philosophy, and special study focuses on the rapid visual screening for earthquake vulnerability had been obtained. Some methods in visual screening were assessed in order to define the proper and appropriate procedure for the proposed method in the study.

Step3

The third step then to develop the specific vulnerability procedure for vernacular house assessment. This step has adapted the existing procedure for this specific purpose started by studying the vernacular Javanese house typology, identifying the aspects of structural performance of the houses, simulating the structural performance for each type, grading the significant aspects, and modifying the assessment procedure.

Step4

The result procedure from the third step then applied for the vernacular house object in area of the 2006 earthquake of Java. Some samples are taken for vulnerability level according the proposed method. The results were analyzed in term of how the level of the risk could be recognized and how the mitigation could be proposed for the promoting the level of building safety in vernacular house in Java.

Step5

Conclusion and suggestion based on the result of all previous assessment is served as the final result of this study. The summary of result correlated to problem and method proposed in the beginning of the thesis is focus to be concerned as result of the study. These five steps fulfill the purpose of this research.

Chapter 2

EARTHQUAKE, BUILDING VULNERABILITY, and THE EXAMINATION

The second chapter is theoretical base studies which are ranged from earthquake, seismic risk, and vulnerability examination procedure. The seismic risk and its evaluation philosophy, and special study focused on the rapid visual screening for earthquake vulnerability are the most emphasized. FEMA RVS and some similar methods in visual screening were assessed in order to define the proper and appropriate procedure for the proposed method.

2.1 Earthquake and Its Effects

Earthquake is ground shaking resulted by the rapid release of energy in the Earth's layer which can be initiated from different resources, e.g., displacement of the layer, volcanic activities, and by artificial explosions such as mines or karsts. However, most big earthquakes are recognized as the symptoms of active tectonic movements that occur predominantly on known plate boundaries. This plate movements are considered as divergent (rift zones), convergent (subduction zones) and transform zones (transcurrent horizontal slip).

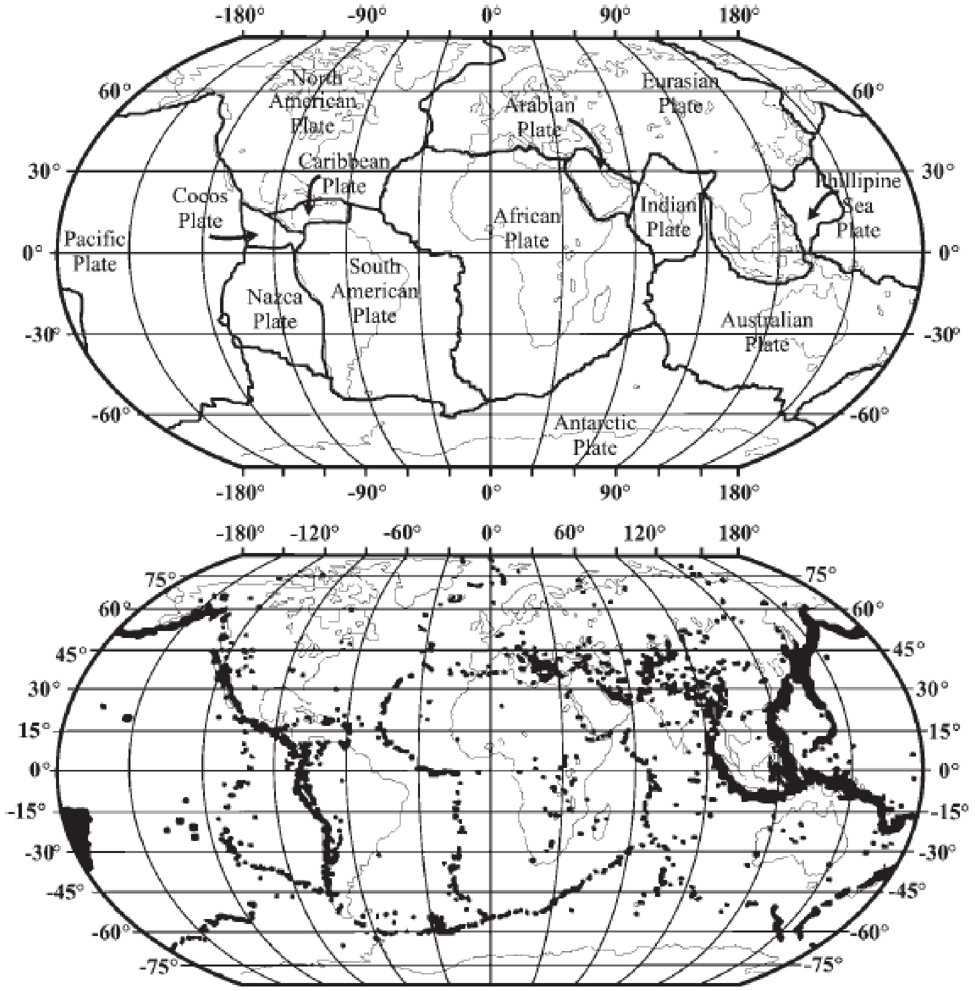


Figure 2-1: The seismic belt and earthquake distribution in the world (Elnashai, AS and Di Sarno, 2008)

Based on the continental drift theory, the lithosphere or earth's outer plate is separated into 15 rigid plates, both for continental and oceanic layers. 'Seismic belts' is the plate borders, where earthquakes often occur. The Circum-Pacific *Ring of fire* and Eurasian belts *Trans-Alpide belt* are the most seismically active (Scawthorn, C. 2006; Elnashai, AS. and Di Sarno, L 2008). The 1994 Northridge (California), the 1995 Kobe (Japan) and the 2010 Chile earthquakes occurred in the Circum-Pacific circle which stretched from New Zealand, New Guinea, Eastern Indonesia, the Philippines, Japan, the west coast of North America, and the west coast of South America. Other big earthquakes such as The Indian Ocean earthquake of 26 December 2004, the Kashmir earthquake of 8 October 2005, and the Java earthquake of 27 May 2006 and 17 July 2006 were generated by the active Eurasian belt which is spread along the northern part of the Mediterranean Sea, Central Asia, the southern part of the Himalayas and Indonesia. For this reason, Indonesian territory in this regard has high earthquake occurrence since it has both the most seismically active seismic belts.

Earthquake generates ground motion if its seismic wave reaches the earth's surface. Seismic ground motion is caused by two sorts of elastic seismic waves: body and surface waves. Body waves which are travel through the Earth's interior layers include longitudinal or primary P-waves (*push wave*) and transverse or secondary S-waves (*shock wave*). P-waves travel faster between 1.5 and 8 kilometers per second while S-waves are slower around 50% to 60% of the speed of P-waves (Elnashai, AS. and Di Sarno, L 2008). Velocities of common transverse waves throughout the ground for selected materials are as 60 for sand, 100 for reclaimed sand, 250 for clay, 600 for gravel and 1000 for tertiary rock in meters per second (Erdey, C,K. 2007). This difference used by seismologist to locate the epicenter or hypocenter of quake. The time the S-waves arrive, the magnitude of ground shaking will be recorded by seismographic diagrams. P-waves are seismic waves with less damage potential. In other hand, S-wave causes both vertical and horizontal movement which will affect more. Surface waves also known for their long duration. They are possibly to cause rigorous damage to structural systems under earthquakes. Amplification will intensify the shaking at the surface caused by wave's interference on certain local topography condition.

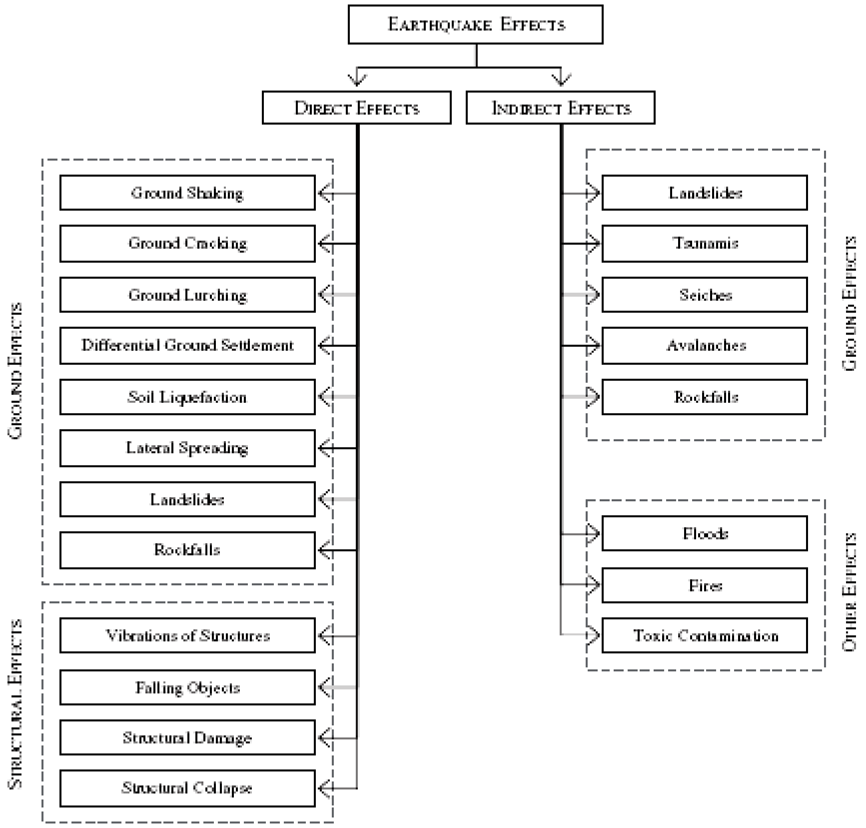


Figure 2-2: Earthquake effects (Elnashai, AS. and Di Sarno, L 2008)

Once reached the earth's surface, earthquake wave transforms to energy which will affect the human environment. Earthquake effects in general can be direct or indirect as shown in table 2-2.

2.2 Building Structure and Architecture Concept

Building structure is the media to deliver building load to the ground in order to support its architecture concept. A well-built structure should have ability to anticipate a load from any direction so the deformation should be minimized. Load in building structure in general is generated from nature and human activities. Load can be differentiated as: dead load (or static load, all building parts including structural, mechanical, utility system etc), live load, (or dynamic load, as result of building function including user and their utensils) external load (or natural load, come from wind, snow, rain, flood, earthquake etc), construction load (load considered in the construction process load such as tools and worker work in the building), and other additional loads. In order to keep building still upright, building condition should be maintained as equilibrium state and stable.

All loads transform to the building structure as energy which has properties as quantity unit and direction called forces. Forces in building should be in the equilibrium state, by means every force resulted from many loads in the building should be countered by internal building force to the opposite direction so the balance state can be achieved. Force can be distinguished as normal, moment, and shear. Normal forces are forces that have equaled entity in the same line but in opposite direction while moment force works in different direction that create rotation, and shear happen if the lines are different in the opposite way for producing translation. Equilibrium means that the building in stable condition, neither in rotation or translation.

2.3 Earthquake and Building Structure

If strong earthquake causing high ground motion occurs under a building, it sets the building in trembling from its foundation transfers throughout the rest of building in complicated way. This dynamic displacement of the soil where building located causes lateral and vertical force on the building. Lateral movements are the most damaging effects on the buildings. Vertical forces due to shaking are usually less significant (Hamburger, R and Scawthorn, C 2006), yet for buildings located near to the epicenter. While buildings are traditionally built for gravity or vertical loads, earthquake bring horizontal force by certain acceleration will destroy the building. The vertical gravity effects and the lateral effects combinations of the of earthquakes will cause overturning moment of the building (see figure 2-3).

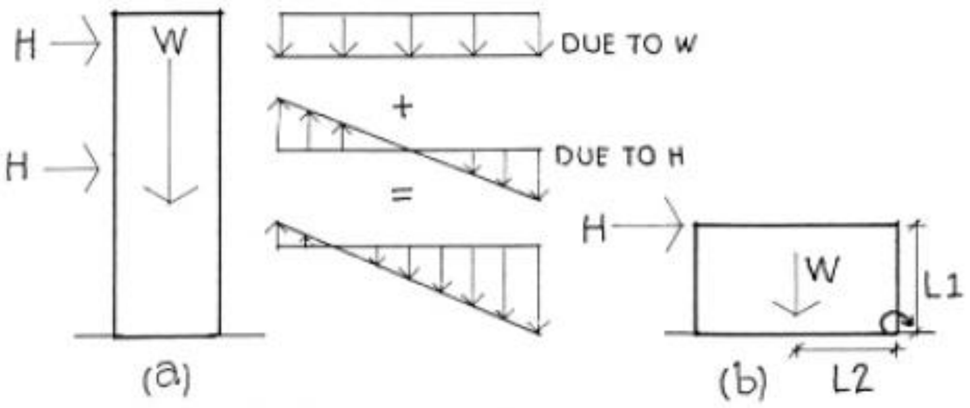


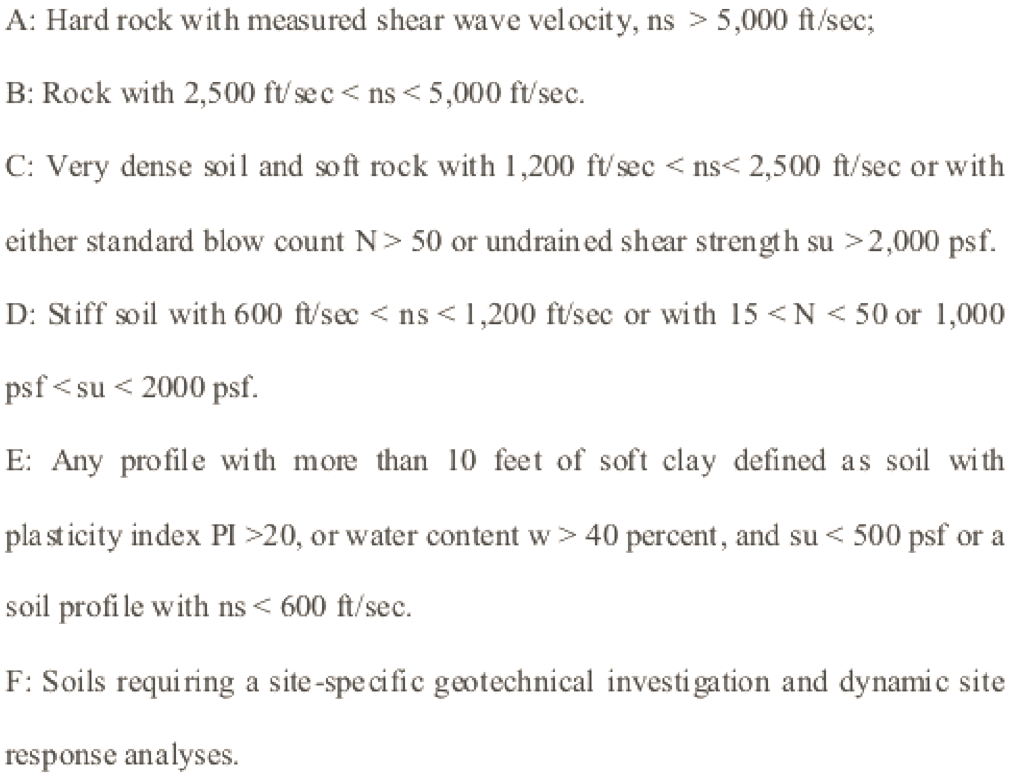
Figure 2-3: Effect of horizontal and vertical loads combination. Net overturning moment = (H x L1) – (WxL2). (Ghaidan, U., 2002)

The main properties of earthquake movement in buildings are the duration, amplitude and frequency (Ghaidan, U., 2002). Long time movement or duration will affect more to the material and structure endurance under the stress in the shaking building. The amplitude is related to the strength of movement while frequency shows the number of shaking in time or the amount of full cycles of vibration resulted by the wave in every second. Earthquake frequency is determined by the distance of its hypocenter the epicenter or the depth.

Buildings will response to the ground motion correspondingly in particular frequency as its natural frequency. Shorter building will have higher natural frequency and vice versa. Shorter building with a high natural frequency has a shorter natural period and a taller building with a low frequency has a longer period. This natural frequency and period could in resonance situation where the building and the earthquake have same level of its. The effect of resonance will magnify the movement and force. The resonance period about 0.1 to 6 second between ground and building will have significant impact. In this case, the short or rigid building will be affected more in high frequency earthquake while low frequency earthquake will influence more for tall or flexible buildings.

Ground shaking from earthquake can be described firstly as single shake in homogenous hard soil with wave cycle period less than 0.2 second and small amplitude about centimeters. Secondly then medium shake about 20-30 second long by 0.5 to 6 second cycle period and medium amplitude less than 20 cm. Thirdly as slow ground shaking about 5 minutes with more than 6 second cycle period with varied directions as result of soft soil with amplitude about 30 cm (after Krisnanto, E., *et.al* 2009).

Beside the resonance, magnification of earthquake energy is also caused by soil type in the area. Soft soil will deliver the wave speed less than hard rock and the energy turns into movement in the ground. Thus create the amplification of earthquake power to the higher ground acceleration. Soil types or class used for the evaluation are referring to FEMA 310 (FEMA 1998) as follows:



A: Hard rock with measured shear wave velocity, ns > 5,000 ft/sec;

B: Rock with 2,500 ft/sec < ns < 5,000 ft/sec.

C: Very dense soil and soft rock with 1,200 ft/sec < ns< 2,500 ft/sec or with either standard blow count N > 50 or undrained shear strength su > 2,000 psf.

D: Stiff soil with 600 ft/sec < ns < 1,200 ft/sec or with 15 < N < 50 or 1,000 psf < su < 2000 psf.

E: Any profile with more than 10 feet of soft clay defined as soil with plasticity index PI >20, or water content w > 40 percent, and su < 500 psf or a soil profile with ns < 600 ft/sec.

F: Soils requiring a site-specific geotechnical investigation and dynamic site response analyses.

2.4Structural Failures from Earthquake

High seismicity regions may experience many earthquakes every day. However, structural damage does not usually occur until the magnitude approaches 5.0. Structural damage in general is a result of soil problems, structural shaking and secondary causes (Yashinsky, M., 2006). Failure in building during earthquakes is commonly due to the inability of building parts to work as system in resisting lateral forces (Elnashai, AS. and Di Sarno, L., 2008). Building failure, in this case, is not only resulted from main structural system but also secondary element that easily deformed under the earthquake shaking.

Otani, S., (2004), listed some aspects causing building failure faced to earthquake including; structural damage associated with system faults, damage in structural members, and quality of workmanship and materials. The faults related to the building structure are:

-**Heavy structures**

High mass or heavy building using adobe and reinforced concrete house will attract bigger inertial forces under an earthquake because the amplitude of inertia is comparative to the structure mass.

-**Period of vibration**

The short period building structure will have more cycles of swinging. This type of building structure is commonly high vulnerable to damage except using stronger resistance system. A wave period range less than 0.5 to 1.0 s will create the high acceleration amplitude of ground movement, and then will decrease up to the end of shaking periods. For this reason, in short period structures, the acceleration response is generally large because it is corresponding to the inertia forces caused by the mass.

-**Strength and deformation capacity**

The failure of the building could be avoided in members that support vertical load carrying system by avoiding brittle materials. If not, then the higher strength must be granted and the mass of the construction should be reduced. A high deformation capacity can be built into weak structural members in order to delay the collapse. This will work even after significant structural damage.

-**Progressive collapse**

Brittle failure may effect on the other structural members in similar mode. The building will collapse starting in the floor where a brittle member has failed. As a result both because of the reduction of lateral resistance and loss of vertical load carrying capacity, it will causing further failure which is called as progressive brittle failure of vertical members.

-**Concentration of damage**

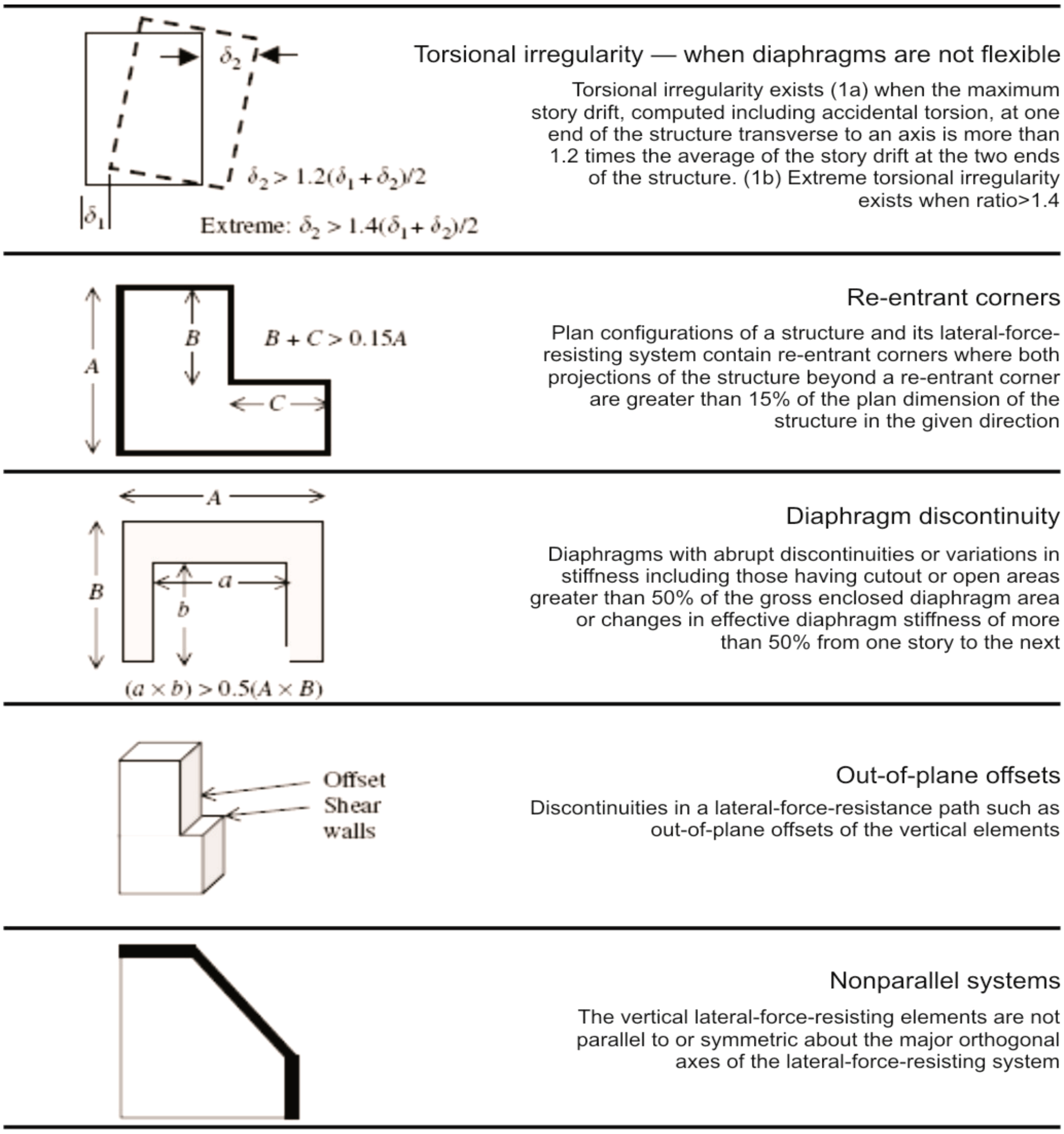
The failures of vertical load carrying members of a story will usually resulting collapse of the building. Higher strength connection between those vertical members is needed instead horizontal members in order to address the damage to the horizontal members so vertical members will be protected and building will be delayed for further collapse.

-**Vertical irregularities**

Earthquake deformation used to happen in particular issues such as the flexible and or weak story. It will create damage which further to lead deformation in vertical members and resulting to collapse of the building. This weak story known as soft story which is unfortunately broadly used in commercial and residential building at the ground floor is common in vertical irregularities.

-**Horizontal irregularities**

Horizontal irregularity such as in plan could create asymmetrical structure arrangement which leads the uniformity load between the center of mass. This will causes torsional vibration under earthquake loading. More damage will be expected higher in building part member that have more distance from the center of mass.



Torsional irregularity — when diaphragms are not flexible

Torsional irregularity exists (1a) when the maximum story drift, computed including accidental torsion, at one end of the structure transverse to an axis is more than 1.2 times the average of the story drift at the two ends of the structure. (1b) Extreme torsional irregularity exists when ratio>1.4

Re-entrant corners

Plan configurations of a structure and its lateral-force-resisting system contain re-entrant corners where both projections of the structure beyond a re-entrant corner are greater than 15% of the plan dimension of the structure in the given direction

Diaphragm discontinuity

Diaphragms with abrupt discontinuities or variations in stiffness including those having cutout or open areas greater than 50% of the gross enclosed diaphragm area or changes in effective diaphragm stiffness of more than 50% from one story to the next

Out-of-plane offsets

Discontinuities in a lateral-force-resistance path such as out-of-plane offsets of the vertical elements

Nonparallel systems

The vertical lateral-force-resisting elements are not parallel to or symmetric about the major orthogonal axes of the lateral-force-resisting system

Figure 2-4: Plan Irregularities in FEMA 368 (after Hamburger, R and Scawthorn, C., 2006)

-**Contribution of nonstructural elements**

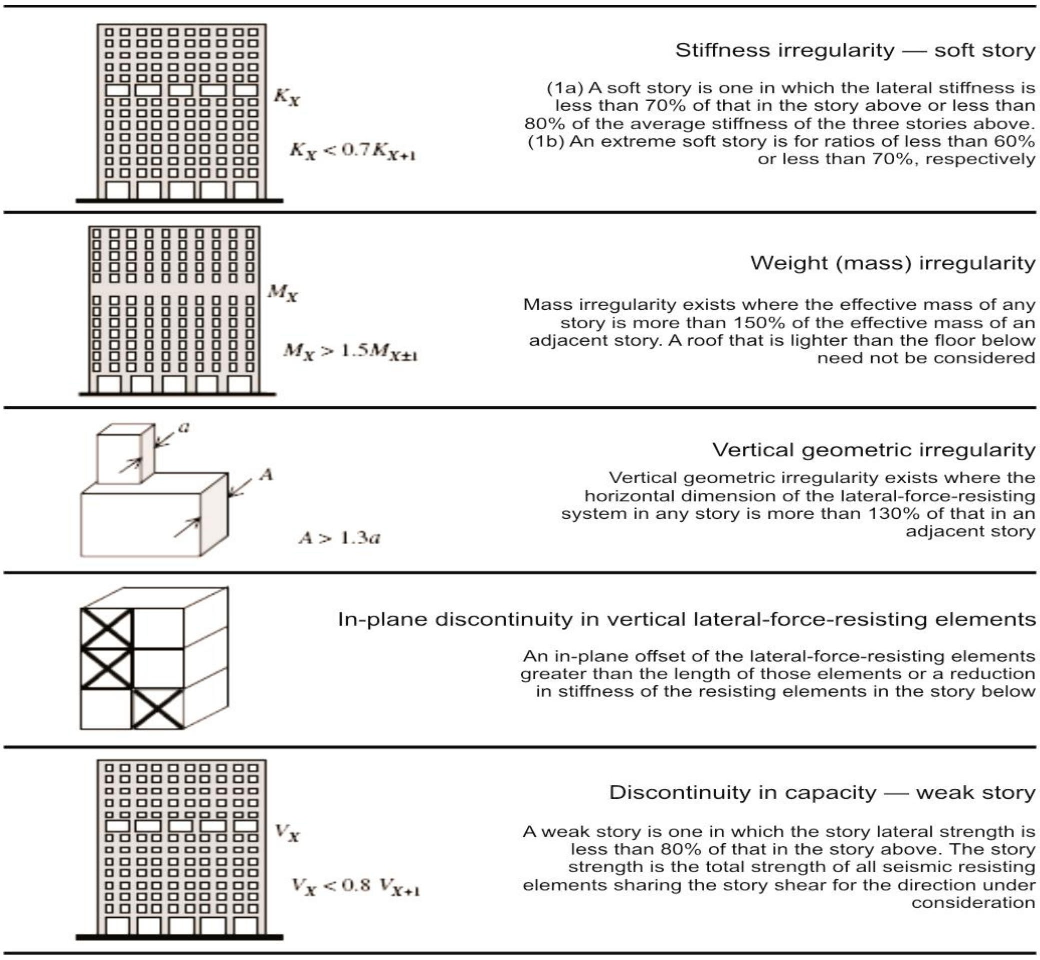
Non structural element such as wall can contribute significant stiffness to the system. If this element is not well located in balance position, irregular stiffness or even torsion, can failure of the system.

-**Pounding of adjacent buildings**

Improper or to near distance of adjacent buildings could cause pounding when earthquake occurs. Pounding will damage both structure of the buildings.

- **Deterioration and age**

Age and or destructive environmental circumstances will deteriorate structural materials and directly decreases the seismic performance capability of a building.



Stiffness irregularity — soft story

(1a) A soft story is one in which the lateral stiffness is less than 70% of that in the story above or less than 80% of the average stiffness of the three stories above. (1b) An extreme soft story is for ratios of less than 60% or less than 70%, respectively

Weight (mass) irregularity

Mass irregularity exists where the effective mass of any story is more than 150% of the effective mass of an adjacent story. A roof that is lighter than the floor below need not be considered

Vertical geometric irregularity

Vertical geometric irregularity exists where the horizontal dimension of the lateral-force-resisting system in any story is more than 130% of that in an adjacent story

In-plane discontinuity in vertical lateral-force-resisting elements

An in-plane offset of the lateral-force-resisting elements greater than the length of those elements or a reduction in stiffness of the resisting elements in the story below

Discontinuity in capacity — weak story

A weak story is one in which the story lateral strength is less than 80% of that in the story above. The story strength is the total strength of all seismic resisting elements sharing the story shear for the direction under consideration

Figure 2-5: Vertical irregularities in FEMA 386 (after Hamburger, R and Scawthorn, C., 2006)

-**Foundation**

Foundation can have a failure commonly because of landslides, liquefaction, fault shatter, compaction of soils, and differential movements.

-**Architectural Elements**

Architectural or non structural elements can reduce the structural system such as wide openings, heavy roof tanks, etc.

Inconsistency in plan and elevation are commonly used in building such as vertical discontinuities as sidestepping and offsetting which will lead concentrations of stress. Asymmetry in plan and elevation change the transfer of load from the upper structure to the foundations which will result to unwanted stress disturbance or concentrations, and torsional effects. The completely open first floor without wall will cause soft storey which lead to collapse of the structural. FEMA 368 (FEMA, 2001) listed the complete plan and vertical irregularities as in table 2-4 and 2-5.

2.5 Structural Damage and Building Performance

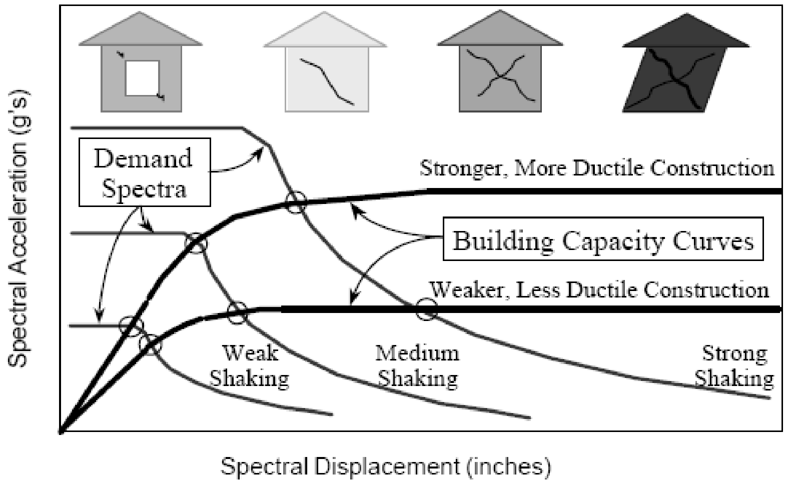


Figure 2-6: Example Intersection of Demand Spectra and Building Capacity Curves (FEMA, 2003)

Potential seismic hazards could result on building damage and loss. Building damage is the resulted physical condition correlated to the earthquake loading while building loss is impact of the damaged building such as casualties, economy, shelter, etc. Building properties in particular will define damage and loss significance. For this reason, buildings are classified in terms of, structural system, building type or even function. The aspect of seismic zone location, design period and use of functions differ building performance.

Capacity curves and fragility curves are the two main aspects for the functions of damage in ground tremor (FEMA, 2003). The capacity curves are examined regarding on engineering principles that illustrate the nonlinear behavior of building types. All aspect related to the potential damage including structural system, nonstructural components but sensitive to drift, and nonstructural components sensitive to acceleration will be considered in the fragility curves. The curves distribute damage between four physical damage states: Slight, Moderate, Extensive and Complete.

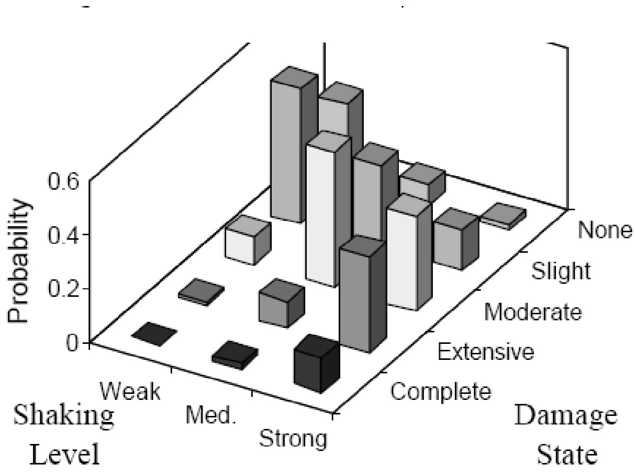


Figure 2-7: Example Damage-State Probabilities for Weak, Medium and Strong Shaking Levels (FEMA, 2003)

Regarding to the earthquake intensity, the figure of spectral acceleration of ground motion of earthquake can be intersected. Higher acceleration in earthquake will always associated to bigger displacement of the building. Stronger and more ductile structure will displace less than weaker and less ductile one (see figure 2-9). The probability related to the shaking level and damage state then can be seen in figure 2-10 where the stronger the earthquake, the higher damage level is expected.

Damage level is also amplified by the soil condition. Relation between the whole aspects from structural capacity, spectral displacement, soil class, and the damage probabilities can be resumed in figure 2-11. Slight, moderate, extensive, and complete damage are generally as result of structural performance, earthquake intensity level, and soil condition. Structural performance will be taken into account around 25 percent worth (FEMA, 2003), while soil can amplify the vibration up to 50 percent for soft-weak soil type (FEMA, 1988b).

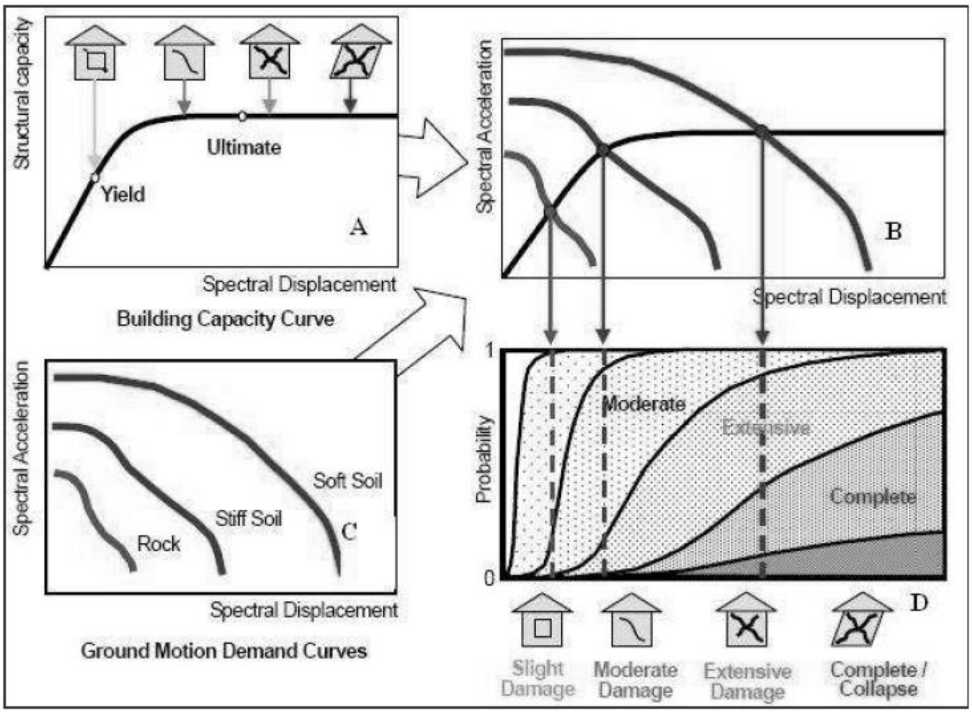


Figure 2-8: Schematic Diagram Damage Assessment method (Gulati, 2006, after Buyukozturk and Gunes)

2.6 Structural Principles for Building in Earthquake Area

The main aim for earthquake safety building is not to prevent the collapse, but to protect the people inside of the building. Though 100% earthquake-proof building technically can be constructed, but practically is rarely realized because of economical and functional reason. Thus, demand/capacity principle in building performance under seismic load is used and the philosophies of earthquake resistant building are:

- Under minor and frequent shaking; the main structural members of the buildings should not be damaged but non-structural member can have repairable damage.
- Under moderate and infrequent shaking; the members of main structural system can have repairable damage but the other parts which is non-structural member can experience repairable damage.
- Under major and rare shaking; the major structural members may be have rigorous damage but the building must still stand.

Stiffness, Strength and Ductility are the most important aspects to deal with earthquake-response of structures (Elnashai, A.S., and Di Sarno, L., 2008). Stiffness means the capability of an element or a group of element of building to defy buckling under the load of earthquake. Strength is the ability of a part or group of building parts to resist the load. Ductility is the ability part or assembly of parts to deform further than the elastic limit.

Under the regular-small earthquake, stiffness is the most significant parameter in building. Structures have adequate stiffness if can resist undergoing large deformations with minimum disruption from damage for uninterrupted use limit state. Strength related to demand and capacity of the structure. Relationship between structural damage limit and strength is if the accumulative stresses bigger than its capacity, structural components failure will take place. Strength is examined to manage the level of inelasticity in the intermediate but rare earthquake. This is the way how damage can be managed with minimum repair costs. By this way, structure will have sufficient strength in order to limit the damage. Ductility is related to collapse avoidance under the big but infrequent earthquake. Ductile structure will capable to well deform into the inelastic manner without significant loss of resistance to dead load actions. By this way, disruption from earthquake is accepted but loss can be minimized both for human life and properties.

Stiffness, strength and ductility of building are influenced by some factors including material, member, connection, structural system properties used by building. In general, masonry and concrete building are stiffer and those from wood and steel are more ductile. Wall based structure is stiffer and frame based one is more ductile. In term of strength, reinforced concrete building has the higher capacity since it combine optimum arrangement of reaction to the incoming force or load. The high stiffness is a subject of deformation because it will draw more loads come to structure. The maximum capacity will be reached early in stiff elements in building compare to flexible. Stiff system such as reinforced-concrete frame is even proven as the most vulnerable to earthquakes compare to all structures (Erdey, C.K., 2007). For this reason it is not suggested to be applied for big earthquake.

Earthquakes will impact as lateral forces which is comparative to the weight of the structure and other part in the building. The heavier the building the more lateral force will be expected to the building. Heavy building such as masonry building has greater impact force. For this reason, along to its stiffness, masonry building is only suggested to be constructed in low seismicity area. While, in the other hand, light-elastic wood or steel can be used in high seismicity. Building stiffness and ductility related to lateral force is also can be associated with the weight of the material used. In this case, reinforced concrete frame combined by brick wall is also less ductile than steel and wooden frame.

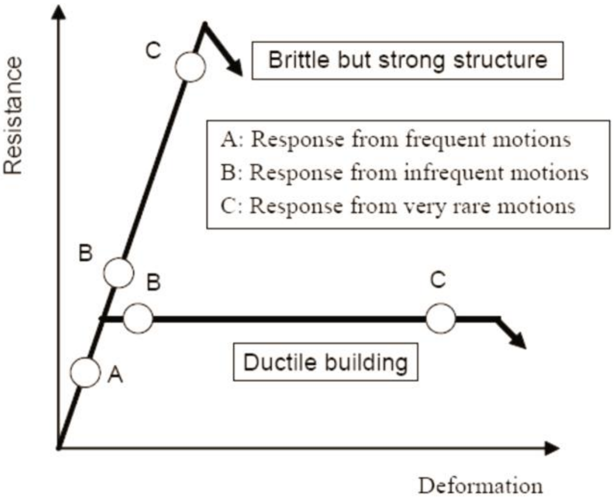


Figure 2-9: Response difference between brittle-strong and ductile building (Otani, S., 2004)

Most engineered structures are not designed to completely proof to earthquake but only to prevent collapse (Otani, S., 2004, Yashinsky, M., 2006, Scawthorn, C., 2006). Nevertheless, even very strong and compacted mass building can create a failure in earthquake shake (Erdey, C.K., 2007). The aim is not only to save money, but also because stronger structure will attracts larger forces. For this reason, most structures are designed to have sufficient ductility to survive an earthquake rather than maximizing the strength. This means that elements may yield and deform but they will be strong in shear and continue to support their load during and after the earthquake.

Both lateral and vertical loads should be considered for earthquake resistant building in order to achieve seismic force resisting systems. Forces should be directed from one place down through the structural system and end up in the foundations. To attain safe transfer of the seismic forces to the ground, undisturbed path between structural components to transfer load is essential. Dead and lateral loads should be directed in a continuous route throughout both the horizontal and vertical elements of structures before dumped to the base ground. Building structures prepared for dead load only will have least capability to resist lateral-horizontal forces. Insufficient lateral resisting systems and connections will disturb the load line and the building will easily to be damaged under the earthquake.

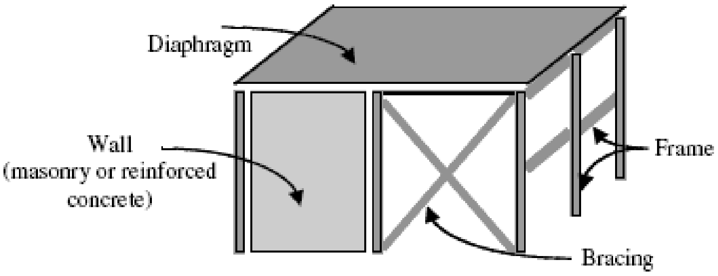


Figure 2-10: The elements of lateral force resisting system of building (Hamburger, R and Scawthorn, C (2006),

The lateral force resisting system principle is important in securing the structure to the ground. The system will either resist or accommodate the displacements caused by earthquake forces parallel to them (Hamburger, R., and Scawthorn, C., 2006). For this reason, the system should be prepared for both horizontal directions.

Furthermore, Eurocode 8 guide the principles for conceptual earthquake resistance design are should follow (BSI, 2005):

-**Structural simplicity**

Characterized by using undisturbed-smooth and direct pathways in transmitting the earthquake load.

-**Uniformity, symmetry and redundancy**

Uniformity in plan, vertical appearance, distribution of masses, and a symmetrical layout of structural elements

-**Bi-directional resistance and stiffness**

Building structure should have capability to resist lateral-horizontal forces for every direction

-**Torsional resistance and stiffness**

The most important components to defy the seismic load should be distributed not far away from the building envelope.

-**Diaphragmatic behavior at storey level**

Floor and roof systems should be presented stiff enough by proper connection to the vertical structural systems in order to resist any lateral forces.

-**Adequate foundation**

The foundations and its connection to the superstructure should unitized the building as a whole when is subjected to a seismic forces.

2.7 Seismic Risk and Vulnerability

Earthquake killed about 10,000 people from the year 1900 to 1999; three major earthquakes in Bhuj India (7.9 MS), El Salvador (7.6 MS) and Arequipa, Peru, (8.4 MS) resulted at least 26,000 casualties in 2001; then in 2003 the Bam, Iran (6.6 MS) with more than 26,000 death; and in 2004 Sumatra, Indian Ocean (9.3 MS)resulted more and 280,000 deaths; the Kashmir earthquake of October 8th 2005 caused over 85,000 people and the Java earthquake May 27th 2006 killed more than 6000 people (USGS, 2006). Over the century (108 - year period), fatality because of earthquakes was more than 1.8 million. Some reports have discovered that building collapses contribute more than 75 percent of earthquake dead during the previous century (Elnashai, A.S. and Di Sarno, L., 2008).

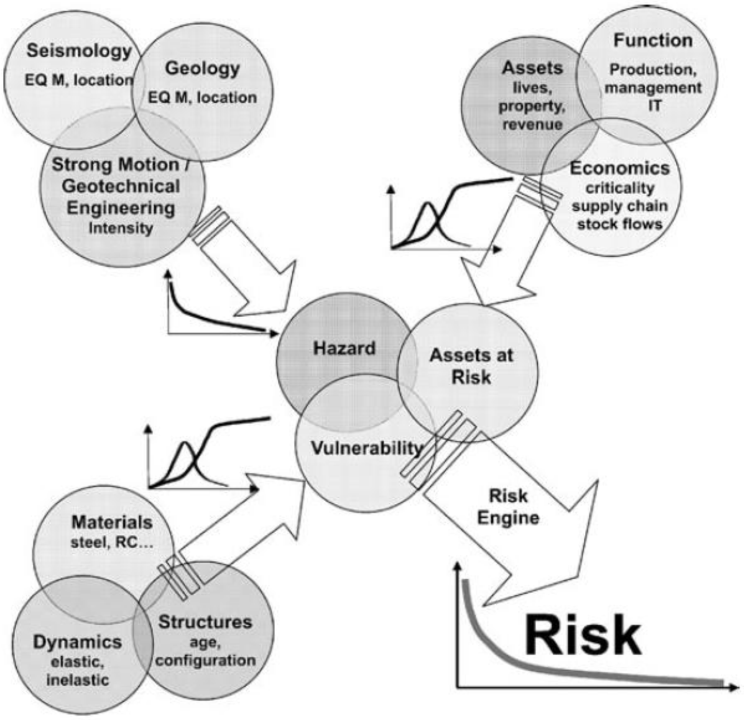


Figure 2-11: The Element of Seismic Risk (Scawthorn, C., 2008)

Earthquake is natural phenomenon and not always causing a disaster. Only the object that has potential weakness can transform the event to become catastrophe. This potential weakness is called seismic risk which is related to the loss possibility under an earthquake occurrence. This probability is the mixture of three general aspects which are the earthquake hazard, the assets at risk, and the vulnerability of the assets (Scawthorn, C., 2008).

Seismic risk analysis should be assorted from entire aspects and not the matter of technical examination but also have to be assessed in term of its adequacy to public customs, and to other aspects. Vulnerability, in the other hand, is the probability of built environment lost because of the hazard. The more vulnerable, the higher probability in failures expected from the earthquake. Structural vulnerability is the building damage possibility of complete or parts of a building that are required for physical support when subjected to an intense earthquake or other hazards.

The building structure seismic vulnerability is the probability of damage by ground motions in a particular intensity (Calvi, G.M., *et.al*, 2006). Structural vulnerability will parallel to the level of the damage level expected from an earthquake, yet dissimilar with the level of building safety. High vulnerability means low safety and vice versa.

2.8 Seismic Vulnerability Assessments

Many earthquakes have resulted widespread losses both life and properties. Identification of that seismic vulnerability of buildings in the populations is an extremely needed in the seismic risk reduction of the area in order to find the probability of damage for particular building type due to earthquake occurrence. The procedure for vulnerability evaluation can be categorized into two; empirical and analytical while combination of the two can be used as hybrid methods.

Earthquakes were always threatening the building surrounding the area where it is happened but the attempt to inspect and giving a certain level of warning, or in this case, we call vulnerability, is started just about 30 years ago. The earthquake vulnerability evaluation of buildings for massive building population had been initially conducted in the beginning of 70’s (Calvi, G.M., *et.al*, 2006). Some various methods had been used as a ‘very technical matter’ either using empirical (Damage Probability Matrices, Vulnerability Index Method, Continuous Vulnerability Curves, Screening Methods) or analytical (Analytically-Derived Vulnerability Curves and DPMs, Hybrid Methods, Collapse Mechanism-Based Methods, Capacity Spectrum-Based Methods, Fully Displacement-Based Methods, and General Evaluation of Analytical Methods). All these methods are generally abbreviated engineering analyses, requiring a trained engineer and access to the structural drawings. Only a few rapid visual screening methods have been found to exist and have had widespread practical application.

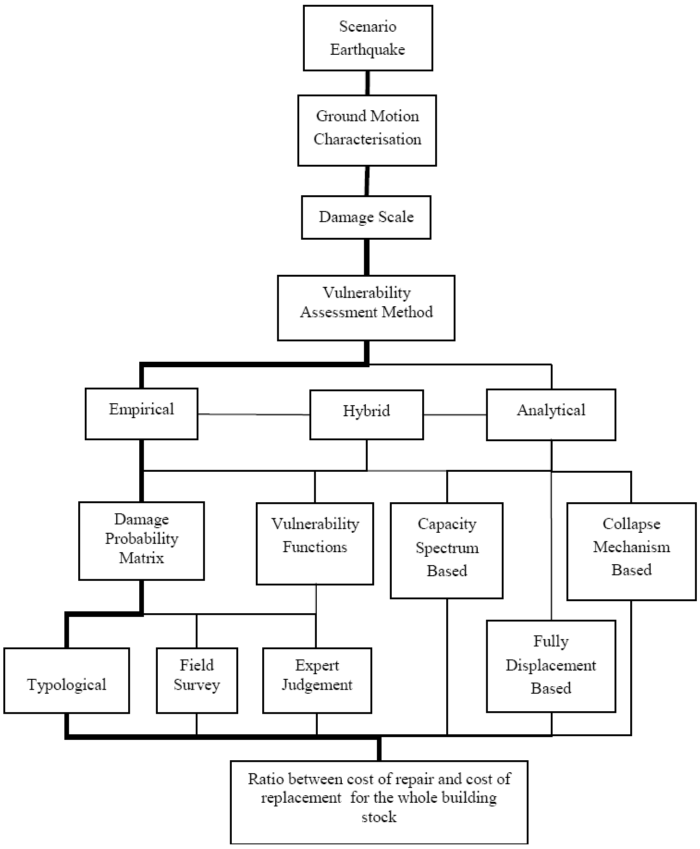


Figure 2-12: Earthquake Vulnerability Assessments (Calvi, G.M., *et.al*, 2006).

The estimation reviewed for seismic vulnerability is done under many aspects including earthquake resistance system of buildings, the record of past earthquake damage, the application of construction technique, the typology of building, the seismicity area, the building samples, the detailed survey of chosen buildings, and the building database about its qualitative and quantitative aspects (Sinha, R. and Goyal, A., 2004). The qualitative method that approximates structural scores for buildings is known as Rapid Screening Procedure (RSP) while the quantitative analysis covers demand-capacity (DCR) computation.

2.9 Screening Procedures for Earthquake Vulnerability

FEMA 310 (FEMA, 1998) recommends three level processes for the seismic evaluation of present buildings by enhancing detail analysis and considering the level of safety. There are Tier 1, Tier 2 and Tier 3 procedures. Tier 1 is the screening phase for potential deficiencies and expected behavior to recognize its compliance. Tier 2 is evaluation process for sufficiency of lateral-force-resisting system performs restricted by basic linear analysis technique. Tier 3 is detailed evaluation phase for buildings that have deficiencies identified in Tier 2 for advanced evaluation.

In general, based on their level of complexity, seismic vulnerability examination procedures are grouped in three types (Sinha, R. and Goyal, A., 2004):

1. Rapid visual screening (RVS) or Level 1 (Tier 1) procedure. This procedure needs only visual evaluation and small additional information known as “Walk down Evaluation” which is not involve any numerical analysis. Its aim is to verify the main concern levels of buildings that need further detailed examination. The procedures in FEMA 154 (FEMA, 1988), FEMA 310 (FEMA, 1998) Tier 1 and the similar procedure adapted by Sucuoglu and Yazgan (2003) are model of this procedure.

2. Simplified vulnerability assessment (SVA) or Level 2 (Tier 2) procedure. This procedure is also known as Preliminary assessment methodologies (PAM) which needs simple engineering analysis. This method should be regarded on the data from visual screening and structural documents or on-site measurements both for structural and nonstructural elements. The procedures by FEMA 310 (FEMA, 1998) Tier 2, Yakut, *et.al,* (2003) are the examples of this method.

3. Detailed vulnerability assessment (DVA) or Level 3 (Tier 3) procedure. This procedure requires detailed analysis (mostly by computer software) which is like to or even more complicated than that needed for designing a new building. This method is suggested for all important and emergency buildings. The procedures proposed in FEMA 356 (FEMA 2000), EUROCODE 8 (BSI, 2004), Park and Ang, (1985) are some of third level assessment procedures.

Beside the three methods above, simpler and more approximate procedure for vulnerability assessment as called as ‘Level 0 procedure’ was also proposed but not suggested because the procedure was completely non-technical and could be even give more risk.

2.10 Rapid Visual Screening (RVS) Assessment

Rapid Visual Screening (RVS) or Rapid Screening Procedure (RSP) is intended for recognizing potential-dangerous buildings in the particular field, without performing detailed examination or involving structural computations. This method utilizes a scoring system to identify the main structural system related to lateral load-resisting mechanism (FEMA, 1988a). Building elements that change the seismic performance is also considered as modifying factor for the final score. All evaluation started from collecting information to giving decision are done at the building site in short time.

The RVS procedure was prepared for a wide-ranging user starting from building officials to private-sector such as building owners to decide which are expected to have adequate seismic performance and which are decided seismically dangerous and should be examined more in detail.

The outcome from rapid visual screening can be applied for diverse applications as part of the earthquake disaster risk supervision program as clearly mentioned by Sinha, R. and Goyal, A., (2004):

1. To identify whether the building needs further detailed evaluation in seismic vulnerability or not.
2. To level the probability a seismic vulnerability in one area or city for further seismic treatment.
3. To prepare the seismic risk supervision agenda of a city or a society.
4. To plan building safety assessment in the post-earthquake condition.
5. To develop information system related to seismic vulnerability related to regional rate and prioritization for redevelopment.
6. To recognize retrofitting and or reinforcement for collapse prevention in a particular building.
7. To enhance awareness amongst the people concerning seismic vulnerability of buildings.

The RVS procedure can be used both for rural and urban areas. Since the method was based more on engineering principle rather than others, city building is more applicable compare to the rural one. Furthermore, the construction and structural system could be more easily to be examined by visual observation. For this reason, rural buildings where vernacular building mostly found have less compatibility for RVS application and results for rural areas may be very low. It is therefore preferable that the RVS methodology be used for non-standard (or non-engineered) constructions in rural areas only with some adaptation (Sinha, R. and Goyal, A., 2004).

2.11 The RVS Methodologies

The aim of the RVS procedure is generally to examine seismic vulnerability level of a buildings population based on the cut-off rate as a level either have accepted or my hazardous and should be studied further in detail. Some methodologies had been proposed based on earthquake data or analytical approaches. A method developed in US by FEMA (FEMA 154) is well known and became a main reference for application in some countries outside US by some modifications.

2.11.1 FEMA 154 RVS

A procedure for rapid visual screening (RVS) was first proposed by Federal Emergency Management Agency in FEMA-154 on 1988 for identifying, recording, and ranking buildings that are probably seismically dangerous in the US (FEMA, 1988a) which was further modified in 2002 (FEMA 2002) to facilitated new technological improvement and also experience-lessons from previous earthquake hazards (1990s). RVS procedure has been broadly used in many other countries after some adaptations related to the local condition.

FEMA RVS utilizes a methodology which is started with examining the main structural system and the use of materials in the building with a score based on basic structural hazard (BSH), and modifying by optional condition in the building which will modify the score (as PMFs or performance modification factors).

2.11.2 Basic Structural Hazard (BSH)

Structural hazard score is a measure of the probability of major seismic damage to the building. Major damage is taken to be direct physical damage being 60% or greater of the building value in FEMA 155 / ATC 13-1985 (FEMA, 1988b). The determination of the Basic Structural Hazard score is

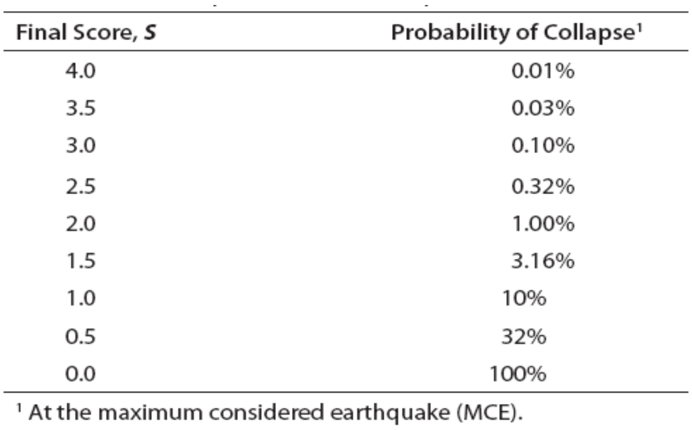
Basic Structural Hazard Score= -log (probability of damage >= 60%)

If the probability of damage exceeding 60%, given value for the building site, is, for example, .001, then the Basic Structural Hazard score is 3. If the probability is .01, then it is 2, so on. The final score as structural score 'S' is calculation (subtraction) of basic score (defined by main system and material) and modification aspect found as PMFs.

S (Structural score) = BSH (Basic Structural Hazard) + PMFs (Performance Modification Factor)

FEMA-RVS scores range from 0 – 4 which are based on logarithmic calculation explained above. Low 'S' score means that the building is vulnerable and needs for further detailed analysis. Oppositely, a high 'S' score shows that the building is probably safe for earthquake threat. FEMA 154 suggested for cutoff value is typically as 2.0, which means 1 percent chance of collapse at ground shaking "two thirds of the 2% probability of exceedance in 50-year peak ground accelerations for the seismicity region of the county in which the building is located".

Table 2-1: Calculated probabilities of collapse versus final score, S. (Wang, Y. and Goettel, K.A., 2007),

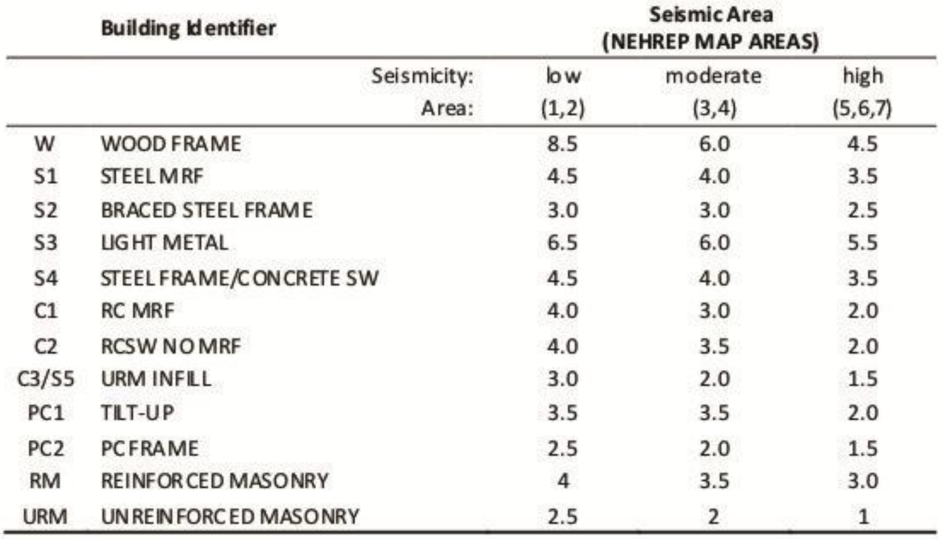


Final Score, *S*	Probability of Collapse[1]
4.0	0.01%
3.5	0.03%
3.0	0.10%
2.5	0.32%
2.0	1.00%
1.5	3.16%
1.0	10%
0.5	32%
0.0	100%

[1] At the maximum considered earthquake (MCE).

BSH is assigned for each building type and represent the expected average of a similar building in major damage related to the seismic area building located. The various building type according to FEMA 154 (FEMA1988) and FEMA 155 (FEMA1988b) seen in table 2-1. The table illustrate BSH score for a variety of building types originally suitable to state of California then modified to Non-California building in general as 3 level of seismicity which is high, medium and low (table2-2). These rates have been decided in order that the seismically good building has a higher value, and a weak and dangerous building has a lower value.

Table 2-2: Basic Structural Hazard (BSH) Scores for all Building Classes and NEHRP Areas (FEMA, 1998b)

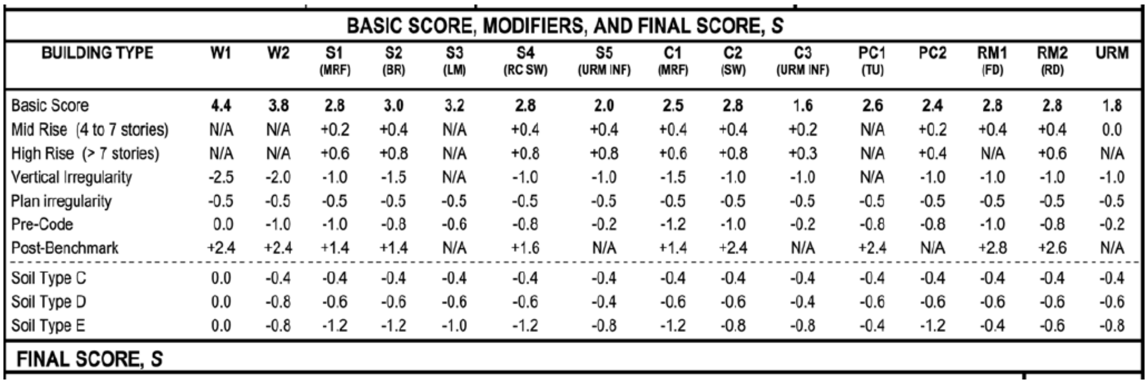


Building Identifier		Seismic Area (NEHREP MAP AREAS)		
	Seismicity:	low	moderate	high
	Area:	(1,2)	(3,4)	(5,6,7)
W	WOOD FRAME	8.5	6.0	4.5
S1	STEEL MRF	4.5	4.0	3.5
S2	BRACED STEEL FRAME	3.0	3.0	2.5
S3	LIGHT METAL	6.5	6.0	5.5
S4	STEEL FRAME/CONCRETE SW	4.5	4.0	3.5
C1	RC MRF	4.0	3.0	2.0
C2	RCSW NO MRF	4.0	3.5	2.0
C3/S5	URM INFILL	3.0	2.0	1.5
PC1	TILT-UP	3.5	3.5	2.0
PC2	PC FRAME	2.5	2.0	1.5
RM	REINFORCED MASONRY	4	3.5	3.0
URM	UNREINFORCED MASONRY	2.5	2	1

2.11.3Performance Modification Factors (PMFs)

The seismic performance of a building could be modified by many factors to be dissimilar from the regular. These factors, called as ‘irregularity’, are essentially related to important difference from the ordinary structural performance. A set of Performance Modification Factors (PMFs) are deducted from BSH in order to find a final structural score ‘S’. PMFs considers all important aspects such as floor number, construction quality, irregularities in vertical or plan in the structural system, soft storey, pounding, cladding, soil/ground condition and ambience (FEMA, 1988a). All those aspects can harmfully affect a seismic performance of a building.

Table 2-3: Basic score and Modifiers (PMFs) used by FEMA RVS for high seismicity (FEMA, 2002)



BASIC SCORE, MODIFIERS, AND FINAL SCORE, *S*

BUILDING TYPE	W1	W2	S1 (MRF)	S2 (BR)	S3 (LM)	S4 (RC SW)	S5 (URM INF)	C1 (MRF)	C2 (SW)	C3 (URM INF)	PC1 (TU)	PC2	RM1 (FD)	RM2 (RD)	URM
Basic Score	**4.4**	**3.8**	**2.8**	**3.0**	**3.2**	**2.8**	**2.0**	**2.5**	**2.8**	**1.6**	**2.6**	**2.4**	**2.8**	**2.8**	**1.8**
Mid Rise (4 to 7 stories)	N/A	N/A	+0.2	+0.4	N/A	+0.4	+0.4	+0.4	+0.4	+0.2	N/A	+0.2	+0.4	+0.4	0.0
High Rise (> 7 stories)	N/A	N/A	+0.6	+0.8	N/A	+0.8	+0.8	+0.6	+0.8	+0.3	N/A	+0.4	N/A	+0.6	N/A
Vertical Irregularity	-2.5	-2.0	-1.0	-1.5	N/A	-1.0	-1.0	-1.5	-1.0	-1.0	N/A	-1.0	-1.0	-1.0	-1.0
Plan irregularity	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
Pre-Code	0.0	-1.0	-1.0	-0.8	-0.6	-0.8	-0.2	-1.2	-1.0	-0.2	-0.8	-0.8	-1.0	-0.8	-0.2
Post-Benchmark	+2.4	+2.4	+1.4	+1.4	N/A	+1.6	N/A	+1.4	+2.4	N/A	+2.4	N/A	+2.8	+2.6	N/A
Soil Type C	0.0	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
Soil Type D	0.0	-0.8	-0.6	-0.6	-0.6	-0.6	-0.4	-0.6	-0.6	-0.4	-0.6	-0.6	-0.6	-0.6	-0.6
Soil Type E	0.0	-0.8	-1.2	-1.2	-1.0	-1.2	-0.8	-1.2	-0.8	-0.8	-0.4	-1.2	-0.4	-0.6	-0.8
FINAL SCORE, *S*															

2.12Turkish RVS:

The Turkish RVS procedure was originally developed by Sucuoglu, H. and Yazgan, U. (2003) which uses a two-level seismic risk assessment method for low to mid rise less than 8 stories with regular reinforced concrete buildings. A data of 477 damaged buildings surveyed after the 1999 Düzee earthquake had been utilized for the procedure which was on the basis of statistical correlations. The first survey level is conducted from the sidewalk by trained observers through walk-down visits and extended by structural parameters measured by entering into the ground storey in the second level. The acquired data is then processed for calculating a risk score for each building.

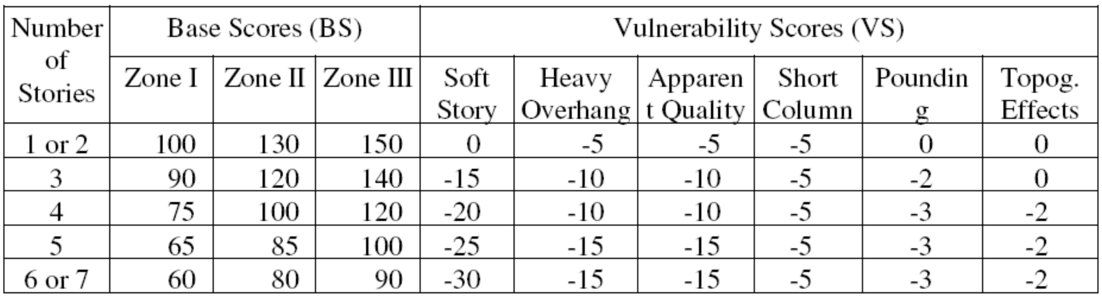
This method has some similarities with FEMA RVS in FEMA-154 (FEMA, 1988a) except the grading method they used. Because it was believed that most residential building do not match to the necessities of modern seismic design and construction rules, Turkish-RVS method is proposed to provide a more report of seismic risk for the mid storey buildings constructed by reinforced concrete in Turkey. The damage enlarges almost linearly with the number of stories.

The seismic performance score *PS* is calculation of the base scores (*BS*), the vulnerability scores (*VS*), and the vulnerability score multiplies (*VSM*) using equation:

$$\mathbf{PS = (BS) - \Sigma\ (VSM) \times (VS)}$$

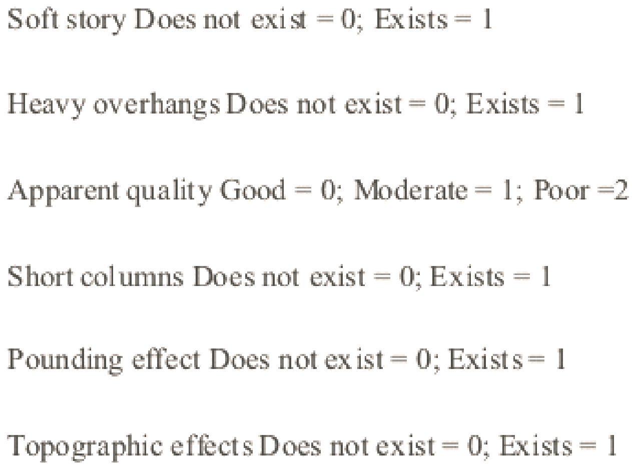
The base scores BS, is given first with respect to the number of floor and the intensity zone. Then base score is reduced for every vulnerability parameter that is observed or calculated.

Table 2-4: Base Scores and Vulnerability Scores for Concrete Buildings in Turkish-RVS (Ozcebe, G., *et.al*)



Number of Stories	Base Scores (BS)			Vulnerability Scores (VS)					
	Zone I	Zone II	Zone III	Soft Story	Heavy Overhang	Apparent Quality	Short Column	Pounding	Topog. Effects
1 or 2	100	130	150	0	-5	-5	-5	0	0
3	90	120	140	-15	-10	-10	-5	-2	0
4	75	100	120	-20	-10	-10	-5	-3	-2
5	65	85	100	-25	-15	-15	-5	-3	-2
6 or 7	60	80	90	-30	-15	-15	-5	-3	-2

The important of every building vulnerability limitation is examined by statistical method, based on the Duzce database. The results are then approximated to the restrictions because of the limitation of data such as topography, pounding, and soft story problem, and engineering judgment was used. The Vulnerability Parameters *(VSM)* are (Sucuoglu, H. and Yazgan, U., 2003):



Soft story Does not exist = 0; Exists = 1

Heavy overhangs Does not exist = 0; Exists = 1

Apparent quality Good = 0; Moderate = 1; Poor =2

Short columns Does not exist = 0; Exists = 1

Pounding effect Does not exist = 0; Exists = 1

Topographic effects Does not exist = 0; Exists = 1

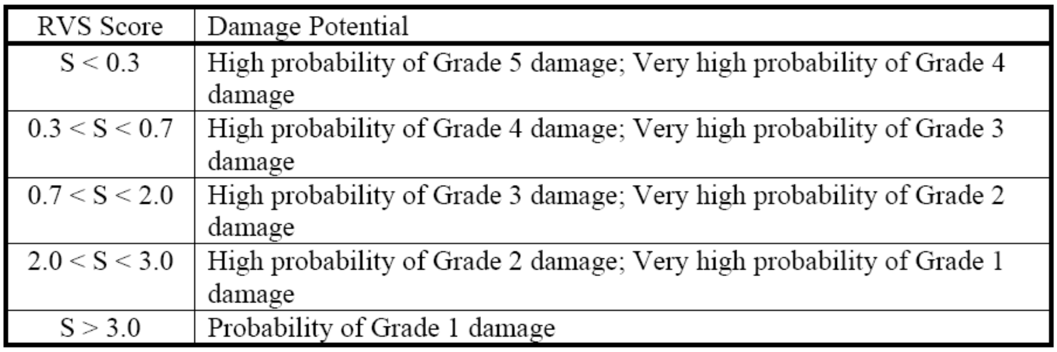
The final score of Turkish RVS therefore literally have a range between less than zero to 100. In order to grade the building, a group of building then classified from PS≤30, 30<PS≤60, 60<PS≤80, 80<PS≤100, and 100<PS. The first two groups are considered as high vulnerable and need a further more technical investigation.

2.13 Indian RVS

The assessment proposed by SERC Report (Structural Engineering Research Center) using a rapid assessment method level 1 as a customized FEMA 154 method considered the Indian situation. The detailed Level 2 Structural Analysis is proceed out if the grading method used is if the accumulated structural score is higher than 1. The method is very similar to FEMA 310–Tier 1 technique (Rai, D.C.).

Sinha, R and Goyal, A, (2004) proposed RVS in India by dividing the buildings into the categories: masonry buildings, RC buildings, steel buildings, and timber buildings. Based on the seismic resistance the vulnerability categorization has been proposed refer to the European Macro-seismic Scale (EMS-98) which defines building damage to be in Grade 1 to Grade 5.

Table 2-5: Expected damage level as function of Indian-RVS score (Sinha, R and Goyal, A, 2004).



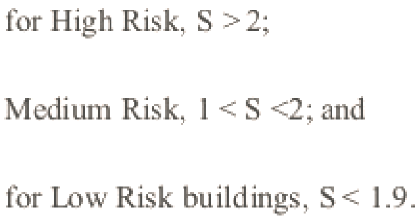
RVS Score	Damage Potential
$S < 0.3$	High probability of Grade 5 damage; Very high probability of Grade 4 damage
$0.3 < S < 0.7$	High probability of Grade 4 damage; Very high probability of Grade 3 damage
$0.7 < S < 2.0$	High probability of Grade 3 damage; Very high probability of Grade 2 damage
$2.0 < S < 3.0$	High probability of Grade 2 damage; Very high probability of Grade 1 damage
$S > 3.0$	Probability of Grade 1 damage

Other efforts in India towards developing rapid visual screening methods proposed by Sudhir K Jain et al for assessment of buildings in Gandhidham & Adipur, and Arya, A.S, (2008) for the development of RVS method in Indian condition without quantifying by a certain scoring system.

2.14 Other Applications of RVS

2.14.1 Philippine RVS

Philippine RVS use the modification of the Federal FEMA 154 by use slightly different quantification "cut off" technique (Vallejo, C.B,). If FEMA 154 using 0-4 for final score with 2 as cut off by means under 2 is unacceptable grade, the Philippine RVS defines risks by the S scores as:



for High Risk, $S > 2$;

Medium Risk, $1 < S < 2$; and

for Low Risk buildings, $S < 1.9$.

2.14.2Thailand RVS

Thailand also developed Rapid Assessment framework by modification of FEMA 154 for their Rapid Visual Screening (RVS) method for determining probable seismic hazards by considering additional part of building (DeMasi, T., *et.al,* 2006). This procedure is also using only qualitative procedure without quantifying or giving certain level with no grade is given.

2.14.3 New Zealand Code (NZDC)

NZDC New Zealand also has their rapid assessment procedure which is based on a visual screening method of FEMA 154. The method works from external screening of the building and continued with further structural assessment inside building by performing detailed examination if required (Rai, D.C). This code renewed by NZSEE 2006 which recommends a two-stage seismic performance evaluation of buildings (Srikanth, T., *et.al,* 2010). The Initial Evaluation Procedure (IEP) involves making an initial assessment of performance of existing buildings against the standard required for a new building, which is defined as ‘percentage new building standard’.

2.14.4 The Japanese (JPDPA 2001)

The Japanese procedure (JPDPA 2001) is based on seismic index (IS) for total earthquake resisting capacity of a storey which is estimated as the consequence of basic seismic index based on strength and ductility indices, an irregularity index, and a time index. The evaluation is based on very few parameters and lacks clarity regarding ranking of buildings based on a scoring or rating system.

2.14.5 Balkan UNIDO Vol. 4

Procedure performed by United Nations Industrial Development Organization (UNDP/UNIDO 1985) which scrutinize the present structure for the good structural concept aspects, strength needed in the elastic condition, acceptable deformability and the ductility levels. Good, acceptable and unclear are structures categorization depend on the quality of their concept and layout. (Rai, D.C)

2.14.6 Euro Code 8

Euro Code 8 procedure is the confirmation of the seismic resistance of an existing damaged or undamaged building from the effect of both non-seismic and seismic actions, for the period of its particular lifetime and usability. Examination and redesigning existing structures may be taken for modify the building based on safety-factors (Rai, D.C)

2.14.7 Canada (NRCC 1993)

RVS method in Canada by National Research Council, NRCC 1993, is based on a seismic priority index which accounts for both structural and nonstructural factors including soil conditions, building occupancy, building importance and falling hazards to life safety and a factor based on occupied density and the duration of occupancy (Srikanth, T., *et.al,* 2010).

2.15 Summary

Earthquake is a natural phenomenon which will occurs in surrounding continental plates. Circum Pacific *ring of fire* and Eurasian belts *trans-Alpide belt* are the most seismically active in the world and have created severe big earthquake through history. Earthquake becomes a disaster when human environment is affected. Buildings are account for 75% for victim’s fatalities causing by earthquake.

Building has different capacity facing to earthquake regarding its structural system, element arrangement, and material quality. Experiencing from previous occurrence, based on the failure of the buildings, some guidance and code have been released.

Strength of the building is not the sole aspect related to earthquake shaking. Other properties of building as stiffness and ductility are the most important aspect considered to refuse or dissipate the shake. Heavier building will act more rigid while lighter tend to elastic. Masonry and RC buildings are known for structural rigidity, heavy weight structure and tend to have stiffness that relatively limited while wooden or steel buildings are identified as flexible structure, light weight, and more ductile. Heavy rigid structure is not suggested for high seismicity area.

The other important principles for building in order to retreat earthquake shake is also related the design which is based on simplicity, compactness and regularity. Any complicated and irregularity found in building will contribute the weakness of the building and increase the vulnerability. Unfortunately, this principle seems to contrast with the architectural design which tends to proceed on the opposite direction.

Rapid Visual Screening Procedure, RVS, is the useful preliminary tool to examine seismic vulnerability by predicting the potential or expected damage on targeted building in specific area. RVS is basically as a first part of other level of further structural examinations. Although the procedure used is very simple, without involving any structural analysis and calculation, the RVS procedure-result solely give the important information which is definitely useful for authority and owner to decide the building either acceptable or not for seismic risk expectation. Furthermore RVS procedure can be a simply practical tool for the building authorities to give further attention and needed precaution for safety of the people.

RVS was originally the advanced version of previous simple method of vulnerability used for simple masonry building in California (FEMA, 1988b). The method was upgraded for other type of building since there are thousands others need to be examined roughly. Up to a decade ago, the seismic vulnerability for engineered building was mostly done by a complicated structural analysis and time consuming that should be done by competent engineer. This was an obstacle for vulnerability assessment since the subject buildings are in big number and not all of them really need that such examination. FEMA 154 has proved that the simple analysis in RVS as a main instrument to decide the vulnerability level of buildings in certain area in the first stage has been used broadly and efficiently for thousand of buildings in US.

In the field application, the RVS procedure was not without deficiency. Wang, Y and Goettel, K.A., (2007) claimed the insufficiency of FEMA RVS for overvalue the level of risk for places with under average ground motions and undervalue risk for locations with above average ground motions, the combined RVS score modifiers in final scores in some cases are off limits since could resulted a negative value, substantially overcorrect for soil effect, and the logarithmic relationship between final scores and the probability of collapse makes RVS results somewhat difficult to interpret, especially for less technical users. However, all these lacks could be resolved by some modification and adaptation regarding local or special use.

Some procedures for RVS have been proposed by several countries following the original method release by FEMA 154. The RVS of Turkey, India, Japan, Philippine, and other countries are slightly different in both in method and scoring system compare to FEMA-RVS though the general procedure itself is similar. This difference in RVS is a result of the local consideration including seismicity condition and building practice in the area. Score can be meaningful as explanation of percentage of expected damaged building (as in FEMA 154), as a level in order to positioning the vulnerability itself by certain groups (Indian RVS based on EMS 1998), as a result of basic structural computation value in certain seismic zone (Turkish RVS), or just as a simple score for low, medium and high by a certain points (Philippine RVS and others). However, though the main aim for the RVS is to classify the buildings either accepted or need a future detailed examination or suspected in high vulnerability, it can not to be applied for every case. For the Javanese houses subject, none of RVS method above could be applied directly since the buildings are different, especially if we deal with the vernacular houses. For this reason, modifying the method is the most convenient way and FEMA RVS as the original concept came from is the most appropriate one.

Using RVS procedure has advantages and opportunities, since it minimizes the complicated examination and the application is simply and widely open for public use. Before going to higher level of examination, this first judgment is meaningful for building categorization since the main structural system and building irregularities that modify the seismic performance are identified. However, RVS examination itself is not for global building. It needs the local consideration regarding seismicity and building technique in the area need to be assessed. It also needs to follow technological development for updating the tools. For this reason, RVS method is still widely open subject to be discussed.

Chapter 3

ADAPTATION of RAPID VISUAL ASSESSMENT for JAVANESE HOUSES

After the RVS philosophy is studied in previous chapter, this chapter is aimed for developing the specific vulnerability procedure for Javanese vernacular house assessment. The adaptation of the existing procedure for this specific purpose started by studying the vernacular Javanese house typology, identifying the aspects of structural performance of the houses, simulating the structural performance for each type, grading the significant aspects, and modifying the assessment procedure.

3.1 The Assessment Application and Non-Engineered Houses

As mentioned in FEMA 154 (FEMA, 1988a, 2002), the target group of Rapid Visual Screening (RVS) assessment is broad application, especially for building population in urban area where building types range from simple to complicated form and structure. This advanced usage was actually as result of the development of 'classic' rapid visual screening for masonry building vulnerability from the earthquake (FEMA, 1988b). Starting from the 90's, the non-masonry buildings then have the simpler examination for seismic vulnerability as the procedure proposed by FEMA 154. However, the recent procedure is totally aimed for advanced buildings or *engineered buildings* where not all of the buildings need a completed-detailed structural examination from earthquake in tier 2 or tier 3 as mention in FEMA 155

(FEMA, 1988b). The main purpose is to classify either the building need or not to the next step of structural evaluation.

Rural houses, which we know mostly as non-engineered building or vernacular houses, nevertheless have a great significant number especially those in developing countries. The level of vulnerability of these simple houses is believed even higher than that found in engineered building. This was proved since the history such as Dec. 22, 856 Damghan, Iran killed 200,000; Aug. 9, 1138 Aleppo, Syria, fatal earthquake took lives of the people more than 230,000. In Jan. 23, 1556 the most deadly earthquake in history in Shaanxi province, China with more than 830,000 people killed; earthquake at Quetta Pakistan killed 30,000–60,000 people in May 30th, 1935. Earthquake destroyed cities and villages in Caspian Sea northwest Iran area with magnitude 7.7 SR in June 21st, 1990 and more than 50,000 people dead. And also December 26th, 2004 Sumatra, Indonesia, magnitude 9.0 earthquake, off the west coast of Sumatra, caused a tremendously powerful tsunami in the Indian Ocean that hit 12 Asian countries, killing at least 225,000 and leaving millions homeless (infoplease.com). It was the deadliest tsunami in history. Most of these great earthquakes victims were found in rural area.

Some scholars also acclaimed rural houses which are built from masonry building types constructed using local materials cannot be assessed by RVS methodology since their seismic vulnerability level is already known to be very high. For this reason, those house do not require visual screening to provide information regarding their structural performance (Sinha, R. and Goyal, A., 2004). However, an effort related to define the actual level of vulnerability even needed more since it will affect the life significantly. Unfortunately, although we already know that these vernacular buildings have a big threat from earthquake risk, the appropriate consideration given to the buildings is even less.

On the other hand, the traditional-vernacular houses in some countries are also well-known for their ability to deal with earthquake. Tropical traditional houses which built from light wooden frame are believed have strong structural capacity under the earthquake. However, a big number of structural failures of the traditional houses from past earthquakes (i.e.; Sumatra 2004 and Java 2006) trigger the question on how all these vernacular houses can be categorized in certain group for their level of seismic vulnerability.

3.2 The Scope of Adaptation of the Assessment

Assessing the seismic risk of vernacular houses means using a certain procedure similar to a rapid visual screening method where only need visual examination of these simple buildings without going further to any structural analysis. The main purpose of the assessment is to categorize the population of building rapidly. Detailed analysis cannot be performed for big population of building for short time period. Only by result of the rapid assessment leads further examination clearly.

Since the vernacular buildings are simple by means of structural form and access to inspect the inner part of the building, the procedure should take into account the interior condition of the houses. By this method, further examination such as tier 2 or tier 3 can be preceded more easily, if needed. For this reason, a modification of rapid visual assessment is not only in the context of the local seismicity and building practice, but also in the scope and method of examination. Visual examination by categorizing building types is more practical rather than merely based on building structure. Thus, form typology or architectural type is initial aspect to pursue the other examination in building vulnerability.

3.3 The Use of the Assessment

The assessment procedure is proposed for seismic vulnerability of specific non-engineered building or vernacular houses limited to the Javanese house both old and new type after catastrophic event of the Java May 27th , 2006 earthquake. The houses range from traditional houses constructed from wooden frame; wooden frame combined by brick-masonry wall; to the various arrangements of reinforced concrete (RC) frames of post earthquake houses. However, since the form of the houses especially post earthquake type can be found outside of Java Island as well, the procedure proposed might be useful for the recent vernacular house type in Indonesia and for houses in developing countries in general.

3.4 The Javanese House Typology

Traditional building forms in Javanese houses are mainly based on five types of roof configuration, from the simplest to the most complex; *Panggangpe, Kampung, Limasan, Joglo* and *Tajug* (Ismunandar, 1993; Prijotomo, 1984; Dakung, 1981) and18 variants differences (Idham, N., *et.al* 2010b). However, three types (*Kampung, Limasan* and *Joglo*) are the most common. The first one of the five roof configurations, *Panggang-Pe*, is mostly used for temporary construction, and the last one, known as *Tajug* is only used for religious buildings such as mosques, temples and graves (Idham,N., 2006). The other type, which is known as 'modern' as modern-vernacular (contemporary type different than the traditional types) is also exist even widely used in Java. Modern-vernacular type is simpler in form compare to the traditional houses. RC with brick wall is famous building materials for the modern-vernacular type. All these type since they were constructed by people themselves, considered as vernacular houses in Java.

Based on time period, form of Javanese house then can be categorized in five groups; pure traditional, old culture, new culture, reconstruction house, and foreign culture (Idham, N, *et.al* 2010b). This categorization is useful for examination of the houses related style and building materials used (figure 3-1).

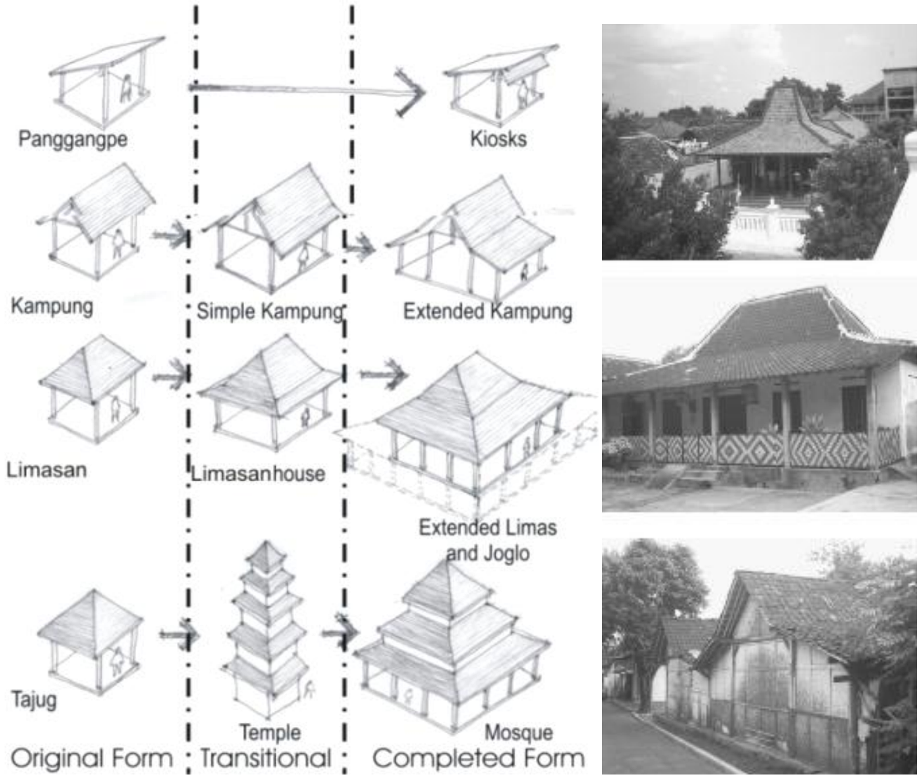


Figure 3-1: Traditional Javanese building forms and house typology (*Kampung, Limasan* and *Joglo*) (Idham, N. and Aksugur, E., 2006)

3.4.1Pure Tradition

Traditional houses known as *Joglo*, *Limasan*, and *Kampung*. All main structural system members are constructed with wood, including hardwood, coconut palm tree wood, or bamboo. The use of wooden planks or woven bamboo was a common material used for walls, wooden tiles or thatch also was used for roof construction, but it is not any longer.

Figure 3-2 Original Javanese *Joglo*, *Limasan*, and *Kampung* types with clay roof tiles and wooden materials ranging from hardwood to bamboo (Idham, N., *et.al*, 2010b)

Houses are relatively large and are composed of more than one unit depending on the wealth of the owner. However, these types are rarely built for new houses nowadays although they are still exist belong either to a rich owner, who still wishes to maintain his/ her status/ position in the towns and cities, therefore constructs the classic *Joglo*, or to villagers who live in remote area and require simpler wooden housing (see figure 3-2). In relation to the earthquake, these houses proved to be safer as a result of the use of lightweight materials, thus providing a more flexible structural system (figure 3-3).

Figure 3-3: Survived Javanese traditional house *Joglo* after the May 27th earthquake

3.4.2 Old Culture

The old culture and new culture are terminologies first used by Boen (2006) to distinguish between the Dutch colonial era and the post independence-modern technique used in housing construction in Indonesia. The term ‘Old culture’ refers to the colonial era when houses were built using predominantly a thick weight-bearing wall system and burned clay roof tiles for roofing. In respect of the vernacular housing, this technique was adopted for constructing Javanese housing by replacing the wooden wall and roof with a brick masonry wall and clay roof tiles.

Traditional houses constructed by newer materials was popular for the Javanese since the people had the opinion and judgment that brick- walled houses are related directly to the wealth of the owner. In recent times, we can still easily find these houses throughout Java Island (figure 3-4). Unfortunately, the use of low quality heavy bricks for the construction of the bearing wall was one of the main reasons for the collapse of houses during the earthquake. It is also believed to a main causal factor for the high number of fatalities.

Figure 3-4: Old Culture houses Javanese *Limasan* and Javanese *Kampung* with masonry bearing wall structure (Idham, N., *et.al*, 2010b)

3.4.3 New Culture

New culture type is used for contemporary or modern-vernacular type houses. Brick wall combined with a reinforced concrete (RC) frame structure is the common structural system of the houses. Ceramic roof and floor tiles are other important materials used. The size of the houses is mostly smaller than the two types described above (pure tradition and old culture types).

Figure 3-5: New Culture types: Combined hipped roof, hipped roof, and gable roof with a reinforced concrete frame structure (Idham, N., *et.al*, 2010b)

The form of the new culture type construction is also simpler. This type of housing was developed sharply between the 80’s -90’s when Portland cement and steel bars started to be widely used (figure 3-5). Unfortunately, a mixed application of the old and new was widely practiced. During or after the earthquake, many houses were collapsed or badly damaged as a result of weak connections and poor or quality of both the materials and the construction methods used (figure 3-6). The use of heavy material, which was applied also for the older houses, resulted in high numbers of casualties and fatalities.

Figure 3-6: Sample of Destructed houses from the 2006 earthquake; pure traditional, old culture, and new culture (Idham, N., *et.al*, 2010b)

3.4.4 Reconstruction House

Reconstruction houses were built after the 2006 Java earthquake. They are constructed mostly using brick walls and a more complete reinforced concrete confining/framing system. Since the majority of collapsed houses had been rebuilt within a limited time and budget, it was common practice to build a very simple, small house using a simple construction form, known as a core house (figure 3-7). These core houses vary in size (e.g. 18 -20 square meters). People have to extend the core houses according to their needs and financial budget. In one case study of this issue Ikaputra (2008) found that almost all core houses had been extended by up to 97.22%.

Figure 3-7: Reconstructed Houses: An ordinary - reinforced concrete frame structure and the unusual domed or shell-shaped structure

3.4.5 Foreign Culture

The strange reconstruction houses as a shell- shape or domed house was also built in the affected area (see figure 3-7) built by a DFTW (Dome for the World) donor. Seventy-one new units of this type were built to replace the destroyed village of

Nglepen. The house is 7 meters diameter with a total area about 38 square meters and constructed using a shell-shaped concrete structure (Saraswati, T., 2007). There is no internal bathroom or WC facility. A communal toilet is provided by the developer for every 12 units.

3.5 Brick wall - RC Construction and the Houses Development

The load bearing brick-wall construction has been used widely as preferred house construction system together with timber frame. Originally, since the beginning of history, the Javanese house was built by local material such as wood and bamboo. Tropical nature offer many high quality wood such as teak wood and ebony wood. These woods are known for their strength and long lasting application both for interior and exterior. Nevertheless, light weight materials are best for flexible or even moveable structure. Wooden house was seems the original and appropriate shelter to the people.

However, the arrival of the Dutch colonial since 17th century brought their influence by introducing their ‘traditional material’ brick to the Javanese (Prijotomo, 1996). Although brick and rock material was used before, yet for non residential building. Later on, the brick house then even has been used as a symbol of social status of family of the owner for Javanese, (Koentjaraningrat, 1984). Since then, bricks became the most popular material for constructing a house and brick-wall house are found everywhere till recent time. Unfortunately, the brick was used as masonry construction with the use of very weak mortar. This technique was adopted from the most economical way by the Dutch which was never facing earthquake in their country.

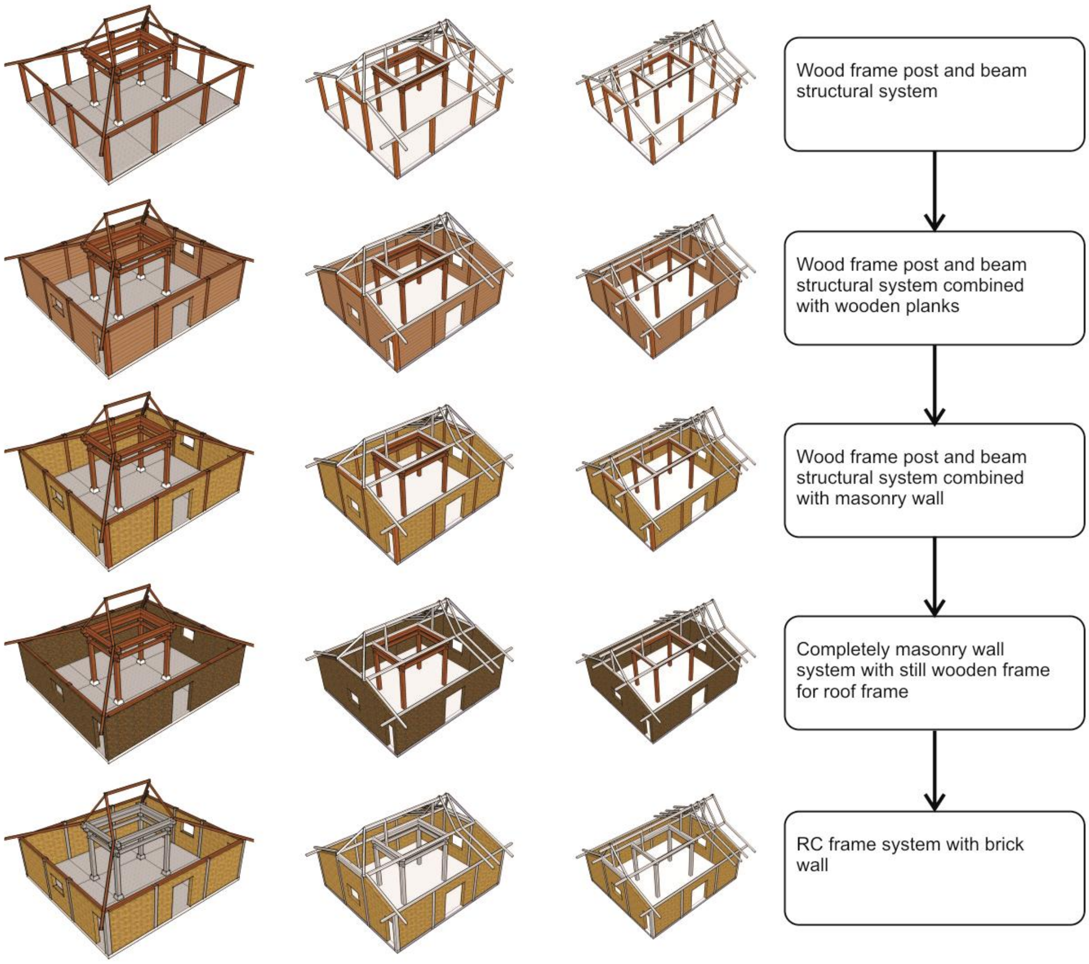
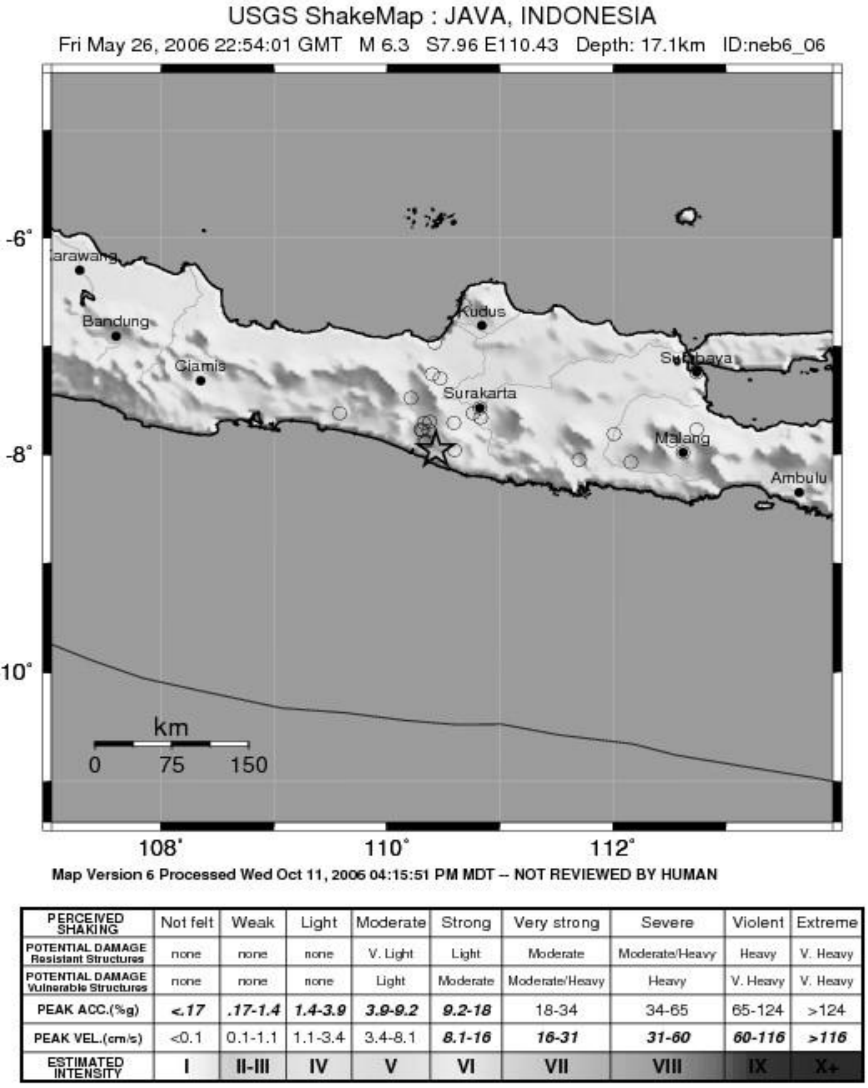


Figure 3-8: The change of Javanese house quality affected by different material applications

Throughout the economical development in Java, the use of brick wall combine with concrete as main material for houses has increased and became the most popular material in the current era (figure 3-8). Concrete material is known for its ability for high compression but low tension strength. Reinforced concrete (RC) was developed by using steel-bar strengthening in high tension part of structural members such as beams and columns. Despite the RC building is the most vulnerable house to the earthquake (Erdey, C.K., 2007), it offers a number of advantages: inexpensive and easy to form. It can be easily constructed by available local materials since stone and sand aggregates are abundant in Java. The process needed to construct is simple and could be done by less skilled worker and simpler tools compare to other advance materials such as steel and even wood. The use of RC even lately has replaced some materials in Javanese house including wood which has different properties, (e.g., RC application for roof frame that supposed to be wood can be found easily in Java). Unfortunately there is few distinction application for construction both materials RC and wood in the sense of material properties. This circumstance thus became one of the most reasons to suspect uncertainty of vulnerability level of the houses in Java. Even after new house construction in post the May 27th 2006 earthquake.

3.6 The May 27th, 2006 Earthquake and Its Affect to the Houses



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE Resistant Structures	none	none	none	V. Light	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy
POTENTIAL DAMAGE Vulnerable Structures	none	none	none	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy	V. Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
ESTIMATED INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Figure 3-9: the May 27th, 2006 Java Earthquake Intensity (earthquake.usgs.gov)

The earthquake struck at 5:54 local time on May 27, 2006. The magnitude was 6.3, and the location coordinates were 7.962S-110.458E, with a focal depth of 10 km (6.2 miles) (USGS 2006). The distance from the epicenter was 20 km SSE of Yogyakarta which was severely affected and 455 km ESE of Jakarta. The intensity felt in the most affected area was up to IX MMI (figure 3-9).

The maximum acceleration for every direction maximum was 0.262g EW, 0.270g NS and 0.243g Vertical. This was amplified by soft soil contained in Yogyakarta area for about 3.5g in vertical acceleration. The highest amplification was about 5.0 for the EW component. The maximum horizontal ground motion accelerations PGA are 0.49g and 0.41g for Bantul and Yogyakarta City, respectively (Elnashai A.S., *et.al*, 2007).

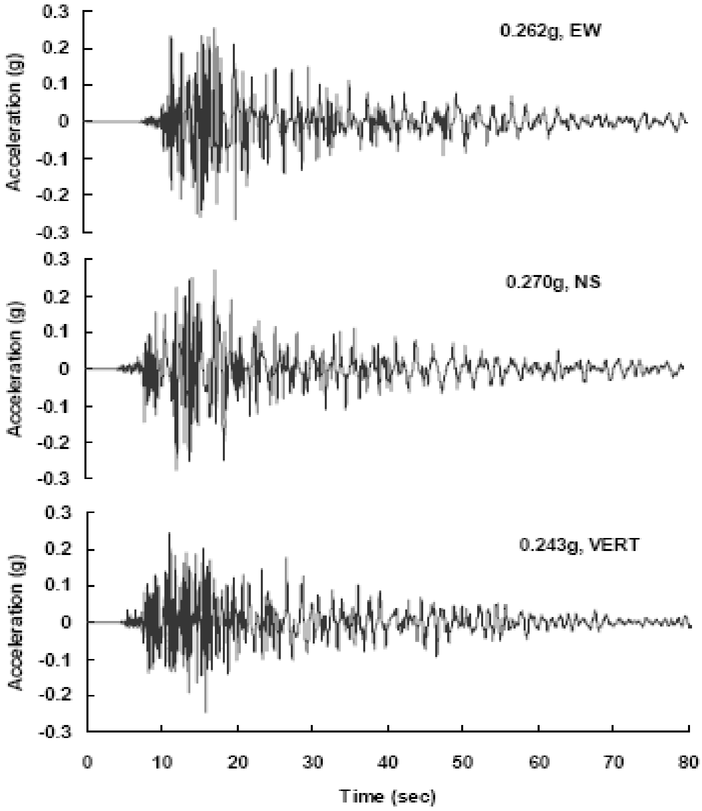


Figure 3-10: the May 27th, 2006 Java Earthquake Acceleration (Elnashai A.S., *et.al*, 2007)

MAE reported that the earthquake was very destructive, even beyond the prediction by the standard. The building spectra or shaking response from the building was beyond the expectation (see figure 3-11). In engineering point of view, there is no surprise that the number of destructed buildings was very high both for engineered and non-engineered types. However, the strength of earthquake was not the solely factor affecting the high number collapsed houses in Java. The less quality of the houses was also suspected as one of the most important issues related to the catastrophe. For this reason, learning from the damages after earthquake is also important in order to understand the weaknesses of the buildings since earthquake damage is “the mother of earthquake engineering” (Boen 2001). Damages represent the true expression and give a good opportunity to learn structural performance of buildings during an earthquake.

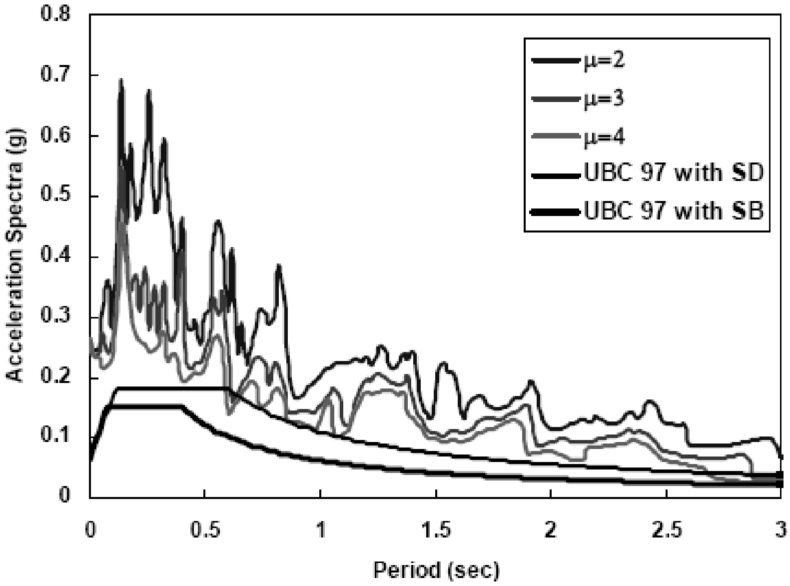


Figure 3-11: The May 27th, 2006 Java Earthquake Acceleration Spectra compare to a standard code (Elnashai, *et.al* (2007))

Javanese houses were rigorously affected by the earthquake, more than 7 percent of the house population damaged in the six affected areas and in some villages in the most destructed area, about 70-90 percent of the houses were totally collapsed (EERI 2006, BAPPENAS, 2006a) (figure 3-12,13). Beside the unusual seismic data above, the factors causing the failure of Javanese house can be affected by: the epicenter proximity, the geological formation, high density level, and weak construction of the houses (Idham, N, *et.al* 2010a)

Figure 3-12: The destroyed masonry thick walled (old culture) (Boen, 2006)

Figure 3-13: The destroyed masonry thin walled with RC frame (new culture) (Boen, 2006)

3.6.1 Epicenter Proximity

The epicenter was relatively very close and shallow to the object of Javanese houses. It was located in the Opak river estuary around 20 km from Yogyakarta with shallow depth (figure 3-14). It means that the source of the quake was on the site of the houses (Bantul district of Yogyakarta). The magnitude would have less meaning if the proximity to the epicenter is also less by means far away from the energy resource. Some other earthquakes actually stroke later such as the 7.0 SR West Java Province on September 2, 2009 with the epicenter distance 195 km from Jakarta and

46.2 km depth under the sea (USGS 2009a). In this case, it was causing casualties ‘only’ 57 fatalities and 300 injured from about 10000 damaged houses. This earthquake was also felt from Yogyakarta and Central Java but it has no effect or little, if any, to the buildings. The other earthquake occurred in November 13th with 5.4 SR magnitude 360 km away from Jakarta and 41 km depth (USGS 2009b). The last quake had no any casualties and building damage. Intensity scale such as MMI was more useful in measuring the effect earthquake to the buildings since it based on the impact in the area. If the 2006 Java earthquake has VIII-IX, while the September 2, 2009 west Java earthquake only VI-VII.

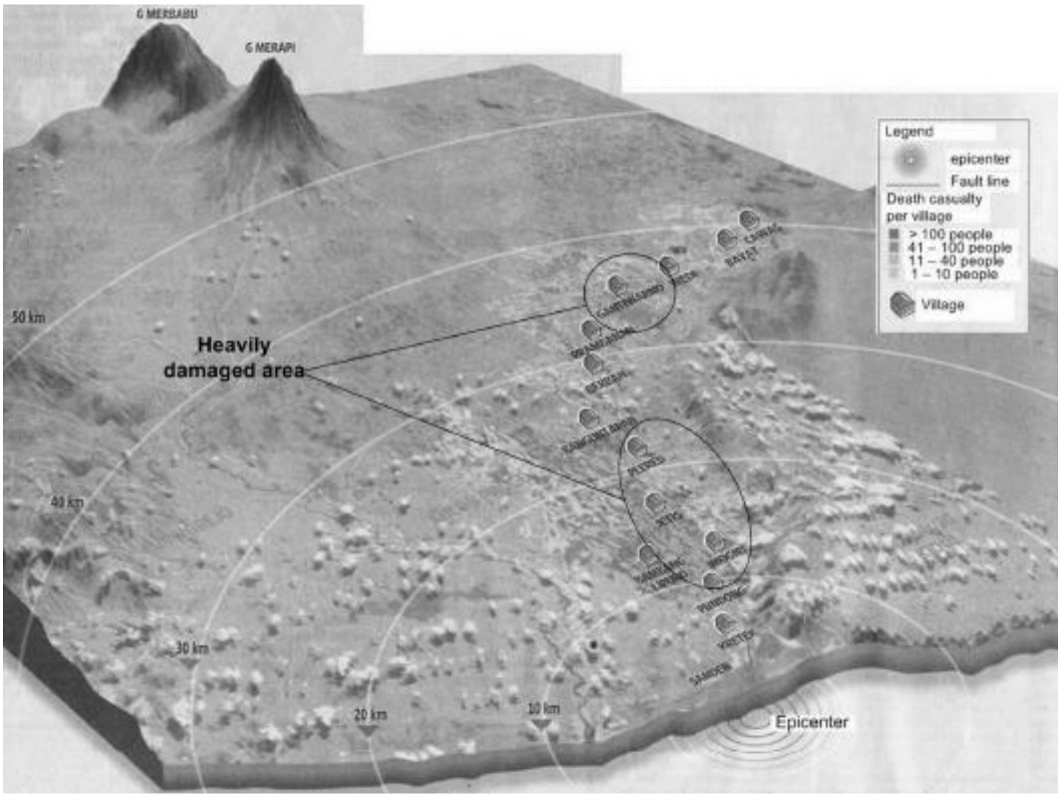


Figure 3-14: The most affected areas alongside Opak river (EERI after Kompas, 2006)

3.6.2 Geological formation

The local geological formation of the sites amplified earthquake effect to the buildings. Instead of spreading to the surrounding site in radial way, the May 27, 2006 Java earthquake had different effect in some areas related to the local geological condition. Relatively soft soils easily magnify shear waves transfer from the hypocenter. MAE recorded that horizontal peak ground accelerations in the region was 0.20~0.34g and vertical ground motion was estimated from structural collapse back-analysis at 0.18~0.30g which was categorized very high (Elnashai A.S., *et.al*, 2007). As a result, buildings located near river lane were affected more. From the 2006 earthquake data, the nearer area of the epicenter, Gunung Kidul has less effect since the ground is more rigid constituted from limestone. In other hand, farer area as Klaten Regency with most wet agricultural soil has more collapsed houses. Unfortunately, as a consequence of agricultural land, Bantul and Klaten have sit on soft soil and will have more threat from earthquake disaster compared to surrounding areas. The wet areas stretched from Bantul to Klaten are also known as Opak vault (see figure 3-15).

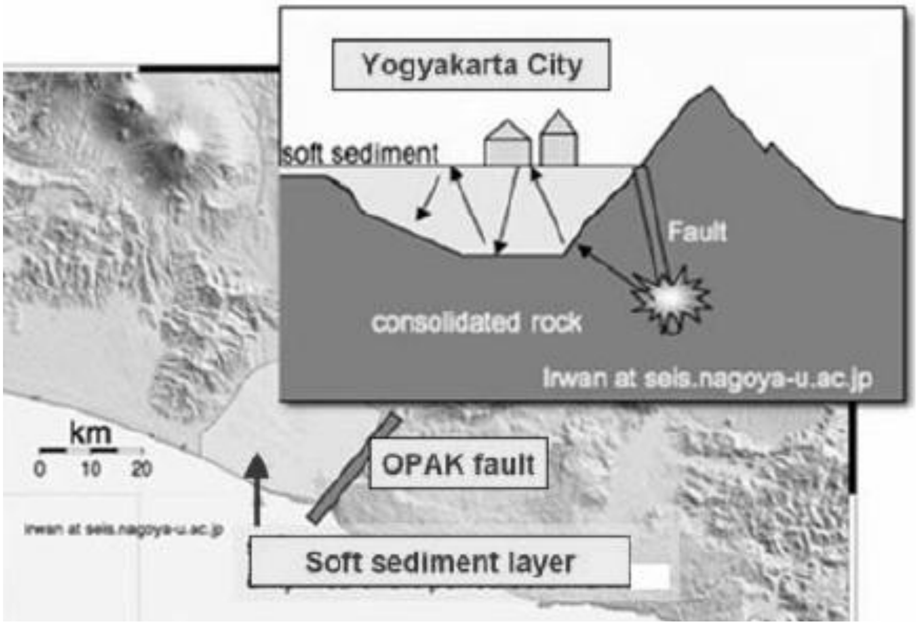


Figure 3-15: Soil profile in Yogyakarta area (MAE/ Elnashai A.S., *et.al*, 2007 after BMG)

3.6.3 Population Density Level

The affected areas have very high density of houses. Java Island in general is the densest population in the world by 979/km². Among of them, Bantul district where collapsed houses were high is the densest area in Java with population of 831,955 living in 226,777 houses in 506.85 km² area or 1641.4/km² of inhabitants and 447.4 houses in every km² (DEPKES, 2007). When the 2006 earthquake stroke, 148,440 out of 218,345 houses (67.9%) in Bantul were non inhabitable or badly damaged and collapsed (BAPPENAS, 2006a).

3.6.4 Structural System of the Houses

The houses structures were very weak and built without earthquake consideration. According to Boen (2006), the houses collapsed from Java 2006 were mostly built by masonry either with or without reinforced concrete confined-frame. However, most of the deaths and injuries were mainly caused by the collapse of unreinforced masonry buildings (EERI, 2006) (see figure 3-16). The weak masonry was the main factor to collapse of the building while for the newer with reinforced concrete; improper connection is the most aspect of structural failures. The most salient damage features of non-engineered buildings according to MAE were (Elnashai, A.S., *et.al*, (2007) :

1) Failures at corners of walls and at doors and window openings
2) Roof system sliding off the supporting walls
3) Shear, flexural or combined cracking of masonry brick walls
4) Failures at connection regions between roof, wall and foundations

Figure 3-16: The most destructed houses by weak unreinforced masonry wall (EERI 2006)

According to EERI (2006), the Javanese houses can be divided into three general categories in structural system; unreinforced masonry, confined (framed) or partially confined masonry, and timber frame. Unreinforced masonry, URM, were found mostly for old houses which constructed mostly before 90's and constructed by unframed brick masonry walls with pitched or hipped timber truss or bamboo and finished with roof terracotta tiles. After 90's, fully or partially framed masonry used in newer houses which are built by reinforced concrete frame, brick wall, solid concrete block or stone masonry in cement mortar walls. Upper part uses pitched or hipped timber or bamboo roofs which are finished by ceramic tiles. Wood frame were less used instead some masonry walls are applied more. The detailed structural system as follows (refer to EERI, 2006; Boen, 2006);

Unreinforced Masonry: This type of house was most used in the area and unfortunately most of them were highly damaged. URM failures were related with poor quality materials and lack of wall integrity in the transverse direction of lateral forces: no mechanical connection linking the top of the wall and the roof or floor, and inadequate lateral strength due to a lack of reinforcement. In older houses there was no steel reinforced concrete for almost main structural element in the houses. Fired clay bricks were constructed in masonry system only using clay mortar or weak cement-sand-lime mortar.

The thickness of the walls in the old masonry houses were approximately 25 cm wide, built with full brick bonding. The bricks used in the oldest houses were commonly bigger than the new one with (25 x 11 x 4cm) compare to (22 x 11 x 4 cm). Because of shorter brick, full brick wide bonding is not possible, so common practice transitioned to a 17 cm wide bond in which two bricks were laid in the plane of the wall and one brick turned on its side.

Framed or partially framed masonry: Some new houses built by framed (confined) masonry houses performed perfectly because of their connected-reinforced concrete columns and beams both at below and top part of the wall. Frame system as columns and beams were typically casted after the masonry wall was built, by this method, the thickness of column and wall is the same which is commonly about 10 to 11cm. Small reinforcing steel was generally used by 6 or 8mm in diameter with stirrups ranging from 3 to 6mm in diameter and interval around 15 to 20 cm.

Although confined masonry houses performed fairly well, many collapsed or were severely damaged, for various reasons (based on Boen, 2006):

1) Connection failure because of weak-improper construction between reinforced concrete columns and beams, and between columns and masonry walls. In the heavily damaged houses, typical weak reinforcement was commonly found in the joint with a poorly made hook.

2) Thin brick wall which is commonly constructed by one layer of wall and weak confined in its frame has created less strong performance under the lateral forces. This was used to be applied in newer houses which use a half-brick wide wall (12-13 cm with plaster, 10-11cm without). The height of wall is usually over 3 m tall with gables in 1–2 m more. In most cases, gable masonry was without framed properly or un-tied strongly to the roof construction. Connection between gables was also not commonly used. Damage and failure to masonry gable walls were extensive throughout the affected area no matter new or older houses with and without reinforced concrete ring beams.

3) Incomplete of frame by the nonappearance of plinth and ring beams. Careless construction in newer houses by using only concrete columns but no plinth or ring beams was common.

4) Weak connections between main part of house (column and wall) with roof. Using different materials such as column steel and timber beam which functioned as a ring beam in some cases or wooden column with brick wall had weaken the structural integrity since the properties of materials are different. Both older and new houses were found to have a mix of structural systems, in which part of the roof load was carried by timber posts combined by masonry.

5) Heavy roof structure by using reinforced concrete trusses. This type of roof structure is easily found in newer houses and proven to contribute the heavily failure of the houses. Some houses have an open frame (no shear wall) for functional reasons such as for store or garage.

Figure 3-17: The destructed modern-vernacular type of Javanese Houses (Elnashai, A.S., *et.al*, 2007)

3.7 The Javanese Houses Considered for Rapid Visual Evaluation

From the explanation above, the Javanese houses need to be examined and categorized mainly from traditional, old culture and new culture (modern-vernacular types including post earthquake houses). Typologically, the first and second are mostly using the three similar form of Javanese traditional house types; *Joglo, Limasan,* and *Kampung* while the modern-vernacular types are using any other form.

In term of material used for structural system of the houses, traditional houses are known for wooden materials while old culture for brick-masonry and modern-vernacular type for brick wall with RC frame. These form typology and material categorization are the main aspect which used for the main structural examination purpose. Board application in combination of architectural form type and the use of material has produced the variation of buildings. For the purpose of the Java RVS method development, this house variation had defined the initial examination of the procedure (table 3-1).

Table 3-1: The main house variation in typology and material-structural system

	Joglo	**Limasan**	**Kampung**	**Modern-Ver**
Wood Frame	Joglo Wood	Limasan Wood	Kampung wood	Modern wood
WF brick infill	Joglo Infill	Limasan Infill	Kampung Infill	Modern Infill
Masonry	Joglo masonry	Limasan Msry	Kampung Msry	Modern msry
RC Frame	Joglo RC	Limasan RC	Kampung RC	Modern RC
RC Frame+Brick	Joglo RC brick	Limasan RC brick	Kampung RC brick	Modern RC brick

3.8 Structural System Evaluation

The aim of this evaluation is to examine the Javanese houses performance under the May 27th, 2006 earthquake in Java. In this study, spectral response analysis as well as Time history analysis based on the earthquake data applied for the Javanese house models has been performed.

3.8.1 Evaluation Methods

The computer simulation of SAP 2000 was used to examine the structural behavior under earthquake movement for every type of the house models. Non-linear static procedures by utilizing the maximum response of the maximum ground motion effects and frequency (response spectra) was used primarily (as mentioned in FEMA, 2005). The method examines the effects of ground motion excitations on the structures by measuring the intensity of the motion. Response spectra is used for a generic ground motion, to analysis the building response in order to estimate the maximum displacement or pseudo velocity or acceleration of the structure during a given earthquake.

House models of *Joglo, Limasan, Kampung,* and Modern-vernacular types were prepared based on the common condition in the field both for type and materials used. Plan, elevations, sections, and some necessary details have been prepared. The module of 9 x 8.5 m2 (*Joglo* and *Limasan*), 8x7.5 m2 (*Kampung*), and 6 x 9 m2 (Modern-vernacular) were applied for the average of the wall of 3 and inclined to 5 m high. Wood frame was sized 12 x 12 cm2 for external columns, 16 x 16 m2 for internal columns, 8 x 12 cm2 for beams, 8 x 16 cm2 for main beams, and 5 x 10 cm2 for rafter. RC confine was use for 15 x 15 cm2. RC was assumed for 2500 kg/m3, brick for 2000 kg/m3, wood for 700 kg/m3 and roofing for 2000 kg/m3. Lateral load was modeled regarding the actual forces of the earthquake (see following explanation). The basic properties of the material are shown in table 3-2 below.

Table 3-2: Material Properties used in the simulation

Element Type Form	**Element Type Modeling**	**Modulus of Elasticity E (Gpa)**	**Poisson's Ratio J**
brick	solid	13	0.2
column, beam	frame	wood(12) concrete(20)	(0.5)(0.2)

3.8.2Earthquake Parameters

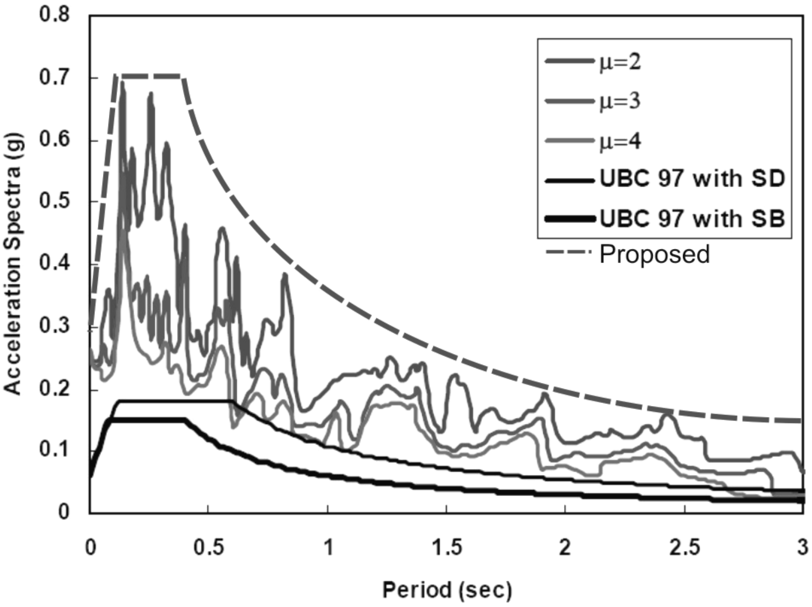


Figure3-18: Demand Spectra Proposed after the May 27th, 2006 Java Earthquake (after Elnashai, M.A., *et.al* 2007)

In order to have a proper simulation, the May 27th 2006 Java earthquake properties including duration, amplitude or the level of displacement, velocity and acceleration, and also frequency data were identified and used for shaking parameter. Data were gathered from some resources including BMG, USGS and MAE (Elnashai, M.A., *et.al*, 2007) was inserted to the computer software to generate the actual movement simulation to the objects. The response spectra used here was according the May 27th 2006 Java earthquake. It showed that the maximum affect should be considered in earthquake simulation is even 3 to 4 times higher compare to the international code (UBC) used (see table 3-18). Time history method was also utilized in order to support the result of study.

3.8.3Building Performances Principles

As mentioned in previous chapter, building in general is not constructed for totally earthquake-proof. Though the technology is available, for economical and practical reason, 100 percent earthquake-resistant is unnecessary. Only some important facilities need to be built somehow resistant from earthquake. The most consideration related to the seismic risk on building is people safety. Building may be damaged or even collapsed, but the people should be secured from the occasion. Common buildings are expected damaged in some degree under the earthquake. The levels of damage expected thus become very important to be defined.

Building damage levels according to HAZUS (FEMA, 2003) are stated as slight, moderate, extensive, and complete. These levels are taken from the building capacity curve, known also as a pushover curve, a chart of building performance under the lateral forces. As acceleration applied to the building, displacements will occur. In some degree, building starts to have limit on the process. Curve is defined by two control points: the "yield" capacity, and the "ultimate" capacity. The yield capacity characterizes the strength of the building from lateral forces and to be considered for design strength while the ultimate capacity represents the top limit strength of the building when the whole structural system has reached a maximum reaction. In other word, yield is ideal condition and ultimate is the condition that building is going to collapsed.

Regarding the damage states, HAZUS had defined the three level of building performance which are Immediate Occupancy (IO), Life Safety (LS), and Collapse Prevention (CP) (see figure 3-19). IO is the condition where the building related to slightly, while LS is for medium, and CP is for extensive damage. A maximum allowed damage could be decided depending on which safety level should be considered. For emergencies purpose, IO should be taken while others may LS.

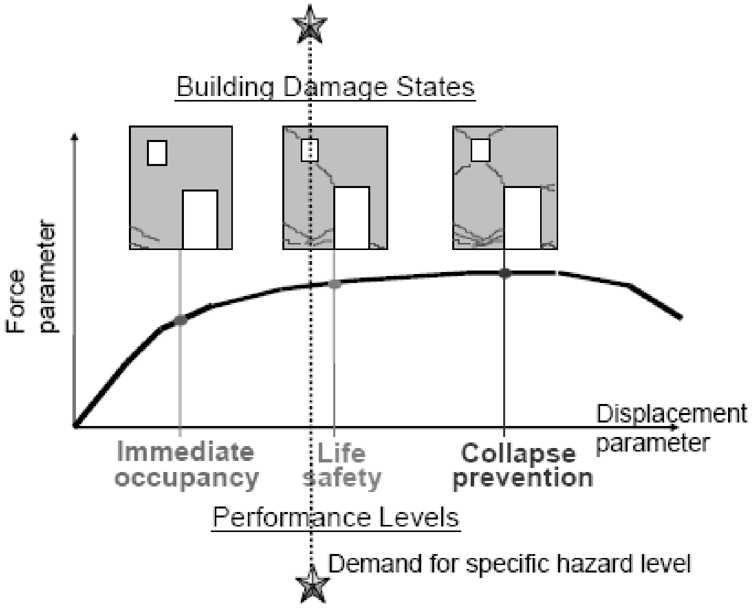


Figure 3-19: Performance Based Criteria

In order to define the level of accepted damage level, building capacity curve is correlated to other aspects such us fragility and demand spectra figure (see figure 3-20). Fragility curve represents the probability displacements among the least to the most fragile level, while demand spectra decide in what displacement accepted from ground movement (acceleration) level. If maximum tolerable damage is putted in all figures, correlation among these charts will appear. For the moderate damage, fragility curve shows the moderate level in high probability under quake, and demand spectra shows the higher acceleration will need less displacement or stronger and more ductile building. 60 percent destructed is considered as the major damage as limit state for life safety (FEMA, 1988b).

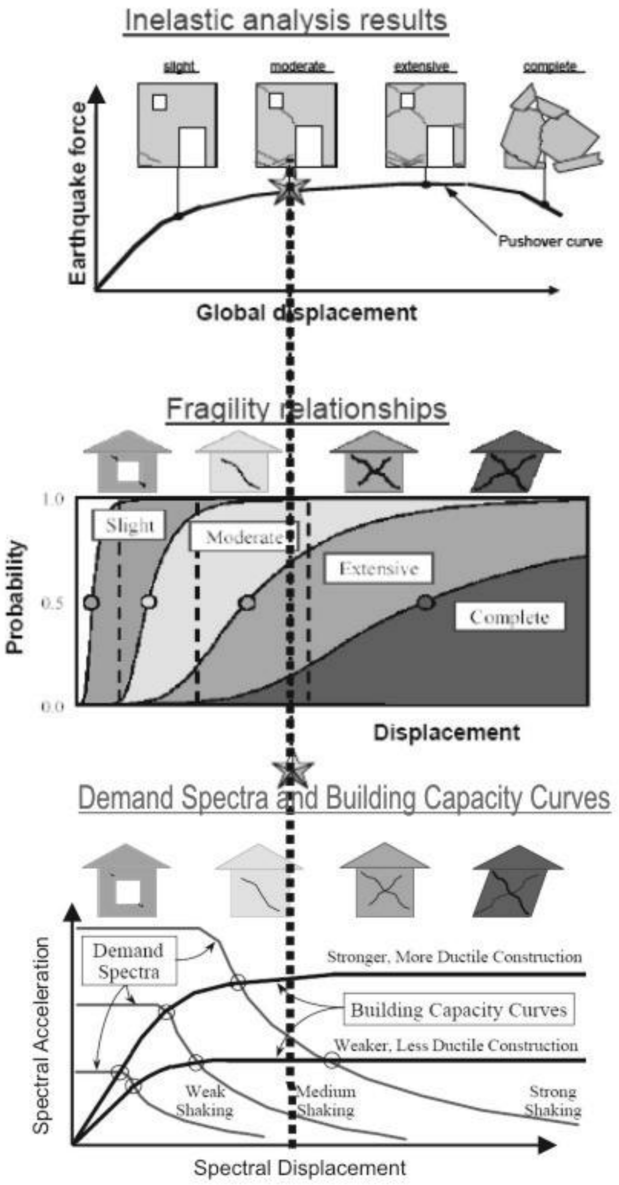


Figure 3-20: Building Capacity, Inelastic analysis, Fragility curve, and Demand Spectra relationship

3.8.4Building Simulations Results

This simulation firstly defined comparison of structural capacity level of the house types as general behavior of the houses under the actual lateral stress. Secondly, it discovered the weaknesses from irregularities aspect in each house type. House performance comparison produced by the simulation is used to support the adoption of Basic Score (BS) of house type while irregularities result used for supporting the adaptation of Performance Modification Factors (PMFs). BS and PMFs then used as main functions to calculate the level of earthquake vulnerability of Javanese house.

From the earthquake spectrum simulated to houses, first main category results are forces applied in frames both for different house types and the structural systems variations. The second important figure is the level of stresses applied in the wall applicable for walled houses. Frame and wall are the most determinant factor both for supporting and collapsing the houses. Most Javanese houses use the frame and wall system both from light and heavy materials. Totally wood frame and wall was the original of traditional house while modern-vernacular was by brick-RC confined and wood frame for roof. This was followed by some variation of the houses (see figure 3-21).

Frame examination was done by focusing the level of the forces applied in the house columns as the most significant element supporting the houses. Wall examination was completed by discovering the maximum stress in the brick and masonry walls. Wall aspect is important related to its role for supporting the roof and the frame itself if applied together. Furthermore failing heavy wall even could provoke the level of damage or even could causing fatality.

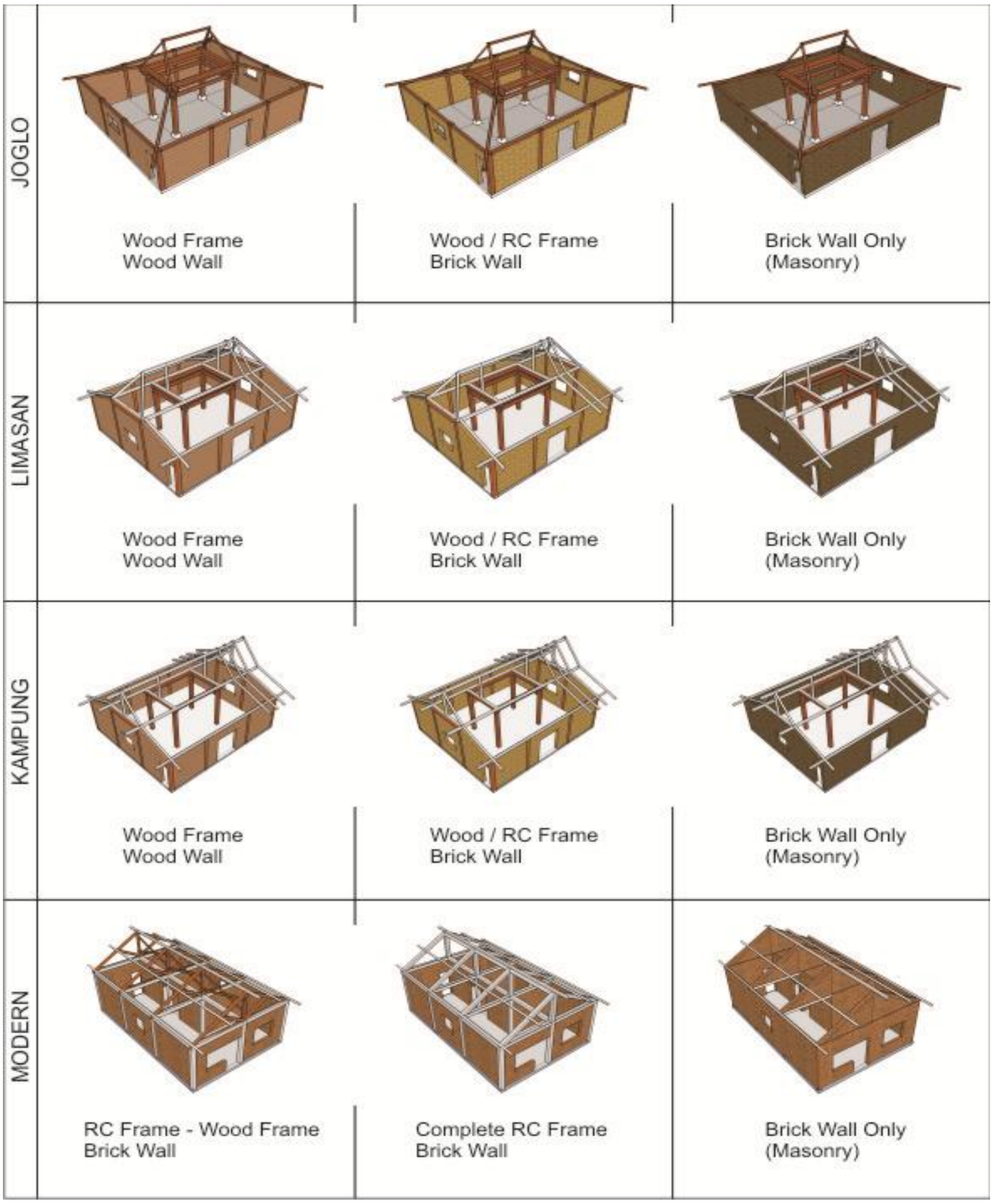


Figure 3-21: the Most found building types and structural systems

Frames perform differently between wood and RC. For this reason, both are examined bellow. In wood frame, *Joglo* and Modern-vernacular type show have less loading for axial, moment and shear while *Limasan* medium, and *Kampung* higher (see figure 3-22). These results are reasonable since Joglo has more rigid frame in the center and lower outside frame compare to the traditional others. Modern-vernacular house also has less force since the truss used is rigid and columns are more compacted. However, modern-vernacular type is rarely constructed by totally wood frame but RC frame is used more instead. For this purpose, RC frame were also examined. The result is, unfortunately, Modern-vernaculra type by complete RC frame both columns and roof frames, received very high loading and significantly higher compare to others. *Joglo* has the lowest followed by *Limasan* and *Kampung* (see figure 3-23).

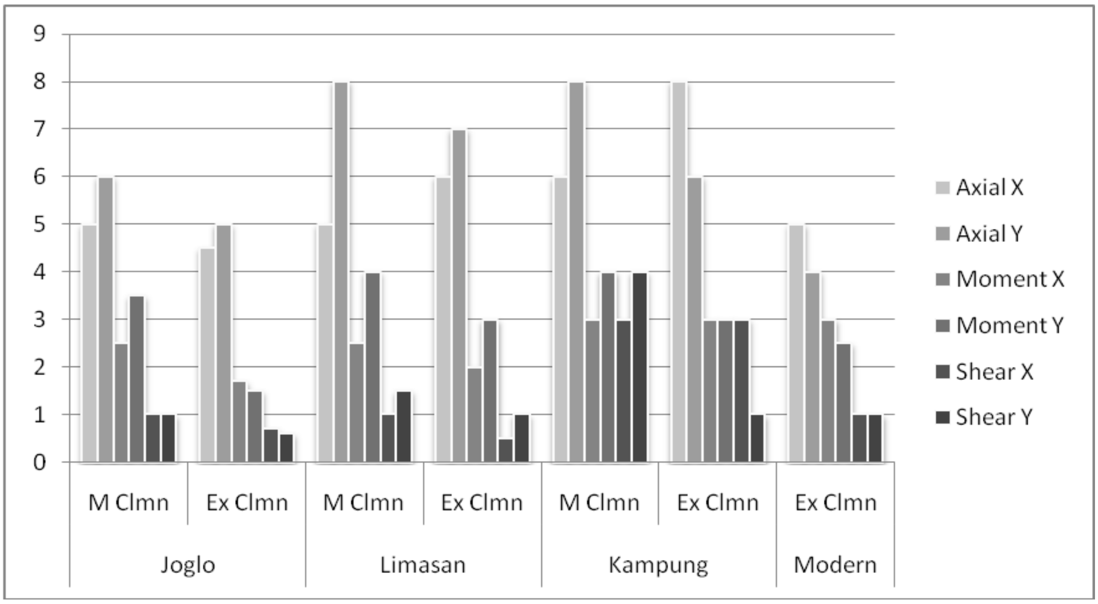


Figure 3-22: Combined forces resulted from four Javanese houses types by wood frames (in Ton)

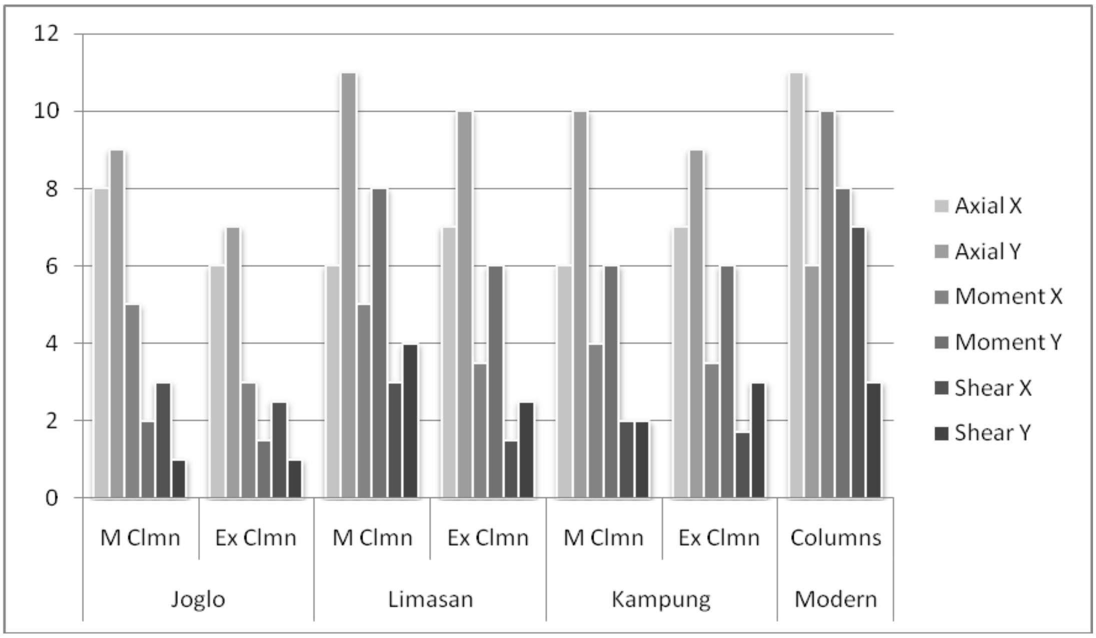


Figure 3-23: Combined forces resulted from four Javanese houses types by RC frames (in Ton)

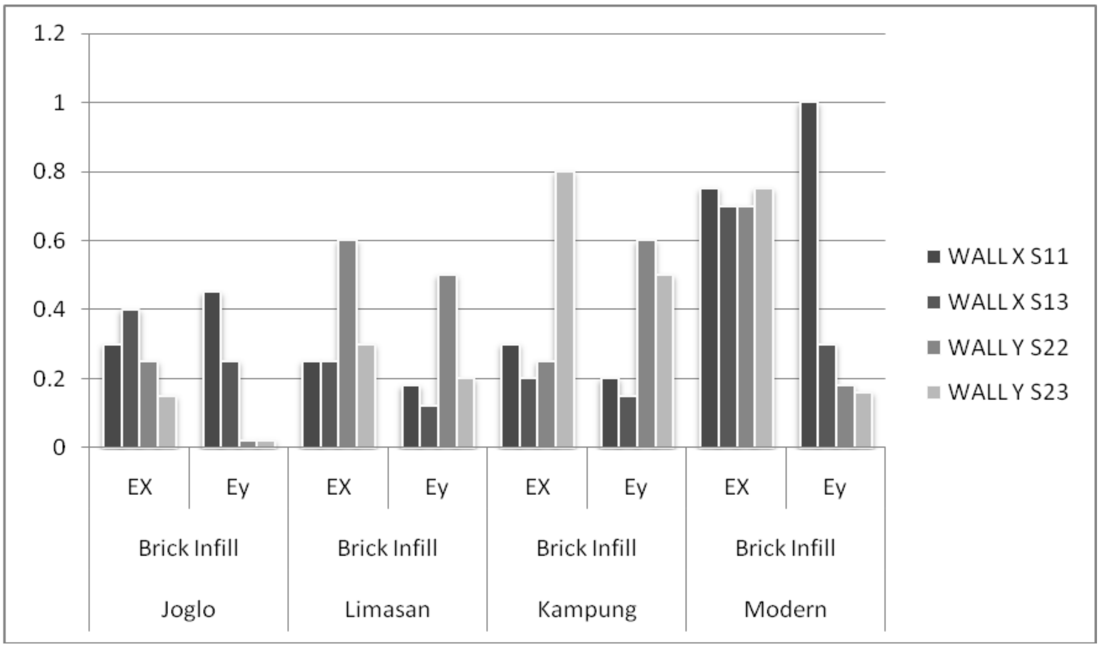


Figure 3-24: Comparison of stresses in brick infill walls between type of structures of the house (in Mpa)

The examination regarding level of the stress on the wall had been done for infill brick wall, masonry bearing wall, and RC frame brick wall. These three figures are important to define the influence of the wall for contributing the performance of the houses. Since walls were blamed for contributing the damages and casualties in the earthquake. Despite to the structural system type, the wall examinations show that heavy brick wall had high level of stress since it has high mass which trigger to accumulating the lateral force of the quake. This is the reason that masonry wall bearing house is not suggested to be constructed in the high seismic area. Comparing the masonry wall in the houses, *Kampung* has least performance compared to *Limasan* and *Joglo* (figure 3-25). Even if combined with frame, especially RC frame, the brick wall had the highest stress (see figure 3-26). This was the reason of why most *Kampung* and Modern-vernacular type house were badly damaged and collapsed in the May 27th 2006 earthquake.

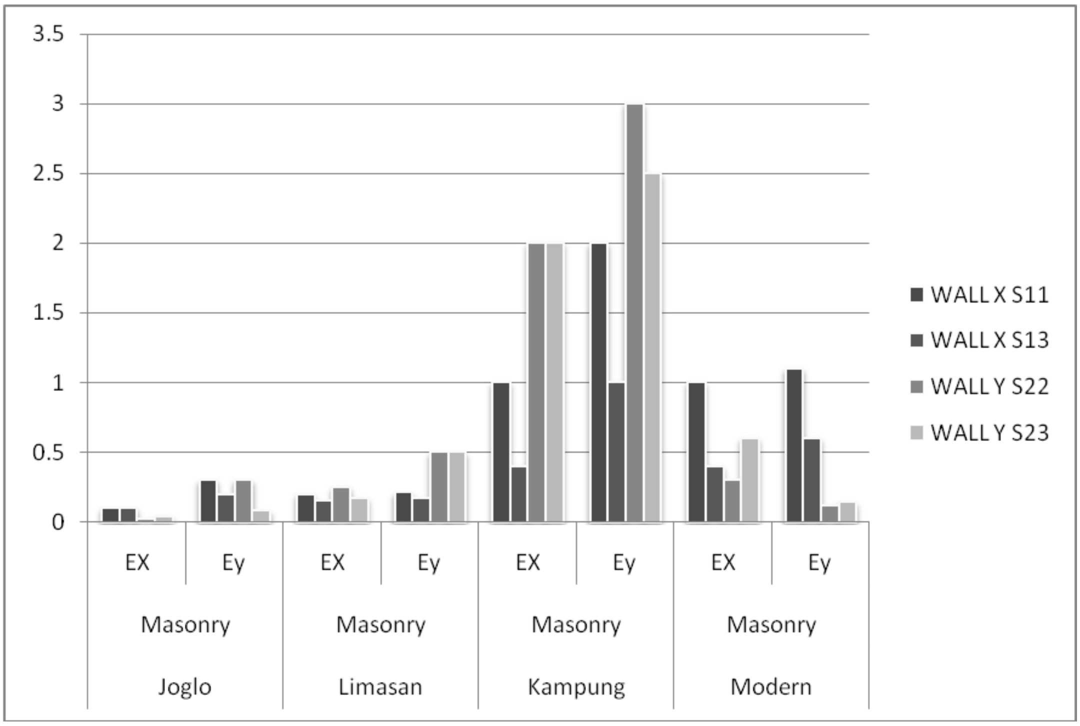


Figure 3-25: Comparison of stresses in masonry walls between type of structures of the house (in Mpa)

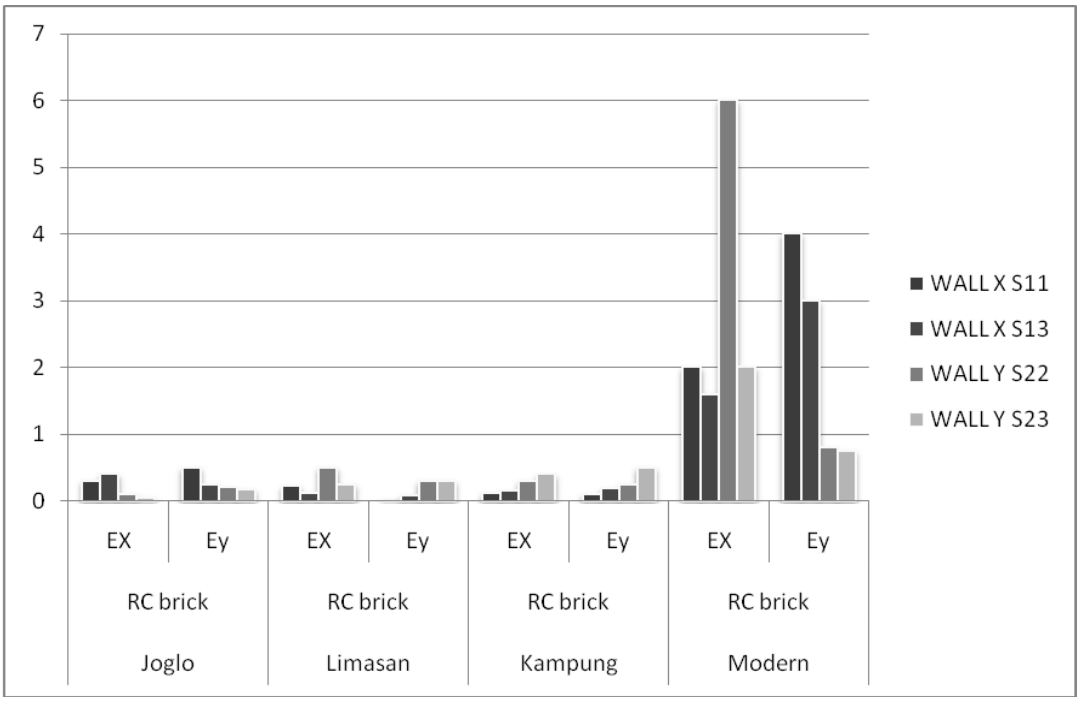


Figure 3-26: Comparison of stresses in RC brick walls between type of structures of the house (in Mpa)

3.9 The Houses Performances

The simulation results confirmed the predictions concerning the behavior of the models under seismic action; the stress distribution as well as the stability of the forms for each case can be discussed as follow:

3.9.1The Traditional House Evaluation

The four main columns in the central space for the three houses are the main structural properties of the houses. These main columns traditionally have main function to support the main space of the house in the central area of the building. The columns have a significant role in supporting the dead load of the building and acting as a 'core' of the house. Many studies consider only on these main four column *saka guru* and claimed as the main part of the houses to diver the earthquake force (Prihatmadji, Y.P., 2007; Maer, B.W., 2008).

Figure 3-27: The remain standing four main columns *Saka Guru*

If the outer frame is weaker than the central part of the building, rotation effect will great under earthquake loading. It is worsted by less or no horizontal-structural connection between external and internal columns as in traditional houses which only use roof's diagonal beam and rafters. Thus, the most vulnerable part of the houses is actually in this envelope structure rather than in the main columns. In other word, the structure will easily damage or even collapse if outer structure is weak. Field experience have proved that some houses were still standing within four main columns while the external parts were completely collapse since the outer structure constructed by weak supporting system such as masonry (figure 3-27). In an earthquake load, the wall could collapse while the wooden frame still left in position. The failures of weaker parts are not distributed to the main structure. The elements of the building structure can deformed independently while simultaneously collaborating. However, this was better compare to modern-vernacular building which is without internal column. Once structure fail, the whole houses is in danger for life safety.

If we compare the general performance among the traditional houses of *Joglo, Limasan,* and *Kampung,* the first is better than the second, and the second better then the third type. It was approved by both computer simulation and post-earthquake experience. *Joglo* has several advantages in the main columns that more rigid and outer frame or wall is shorter compare the others. The most complete *Limasan* house is also has similar performance since the houses is surrounding by lower frame/wall. Consideration then goes to the bigger size of house with similar (even less) size of frame members. This was worsted by heavy wall which will affect more in the quake. The other type of *Limasan,* which is more common, has taller wall and frame in both sides of the house. This higher part as frame or wall will react more (more displacement) from lateral forces. For this reason the performance of *Limasan* below the *Joglo. Kampung,* has the least performance since the frame is simplest. Though the four main columns are used, the less horizontal member has made the frame ductility is less. Higher frame or wall in both sides is also one of most characteristic of the houses. Again, if heavy wall used in this weaker-taller frame, the impact of lateral forces will be the worst.

3.9.2 The Modern-vernacular House Evaluation

The structural system of modern-vernacular type is completely different with the three traditional houses. Four main columns in the center is not used anymore, instead, external columns is more dominant. The performance of modern-vernacular type could be same as *Joglo*, as long as built completely by wooden frame in proper technique (see again the computer simulation result). Unfortunately, the modern-vernacular wooden house is very rarely found in the area. The use of truss for roof frame has opened the possibility to eliminate the inner columns. Thus problem appears related to ‘strong beam – weak column’ phenomena where column will be easily damaged from lateral loading and house will be easily collapsed (more reaction/displacement on the column rather than on the beam). This disadvantage is found in weak support column or masonry wall house with wooden truss frame. For this reason, ring beam applied on top of the envelope wall is important in order to keep the column in its position. This is common practice for RC frame house with wooden frame in the roof.

However, the use of RC frame has somehow been exaggerated. The house which is completely built by RC frame with brick wall both for main and roof structure can be easily found even for the post earthquake houses. This brought the performance under the earthquake has jumped to the lowest one. Heavy RC material altogether with massive brick wall gives more thrust to the frame and high displacement will occurs. Confine RC which is common by 15 x 15 cm2 most probably would not accommodate the load and the houses will easily collapse (see figure 3-28).

Figure 3-28: Damages on modern-vernacular type of the houses constructed by masonry and RC frame

3.9.3The Performance Comparison

By considering the results of all cases, it can be shown that the house performance under earthquake from high to low level will be listed from *Joglo*, *Limasan*, *Kampung,* and Modern-vernacular type. This arrangement presumes that the houses follow the original structural system as wood for traditional houses, and RC with wooden roof frame for the modern-vernacular type. The variation of the structural system should be considered as the change in the performance, e.g., the *Joglo* will not always better than the others once found that this house use other than wood for main structural system, and so on.

3.10 Performance Modifier Aspects Related

Main aspects considered due to building vulnerability analysis are structural and non structural point of views. Regarding FEMA 154, the non structural aspects are related to location of the building, soil condition, and neighborhood while structural aspects are including storey number, vertical irregularity, horizontal irregularity, and code applied. For this purpose of analysis, structural aspect is related to structural lacks, deficiencies, or irregularities such as main and roof structure irregularities and the quality of building materials while the non structural aspect is related to the location and the soil condition which is given by local data.

Based on field experiences after past earthquake and since the buildings are relatively simple compare to those targeted by FEMA, the vertical and horizontal irregularity is not taken directly as in FEMA 154. Instead, roof and main structural systems are more applicable to the single floor-tropical house (with high inclination roof part) which was proved as damage sources. Main structure and roof structure irregularity of the houses have direct significant impact to the building under lateral forces and will be considered as main aspect in building performance modifiers. Approved by damages in the May 27th 2006 earthquake, most aspects need to be considered in Java RVS including:

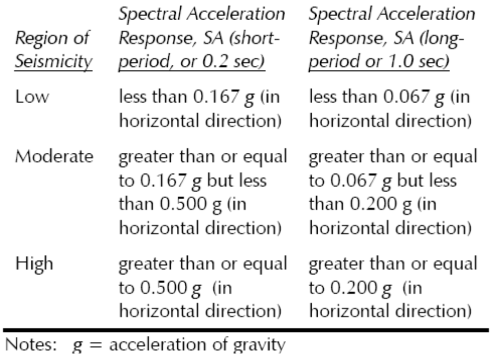
3.10.1 Seismic zone

Figure 3-29: Map of Seismic Zone in Indonesia (Kementrian PU Indonesia, 2010)

Seismic designs in Indonesia consider the International Building Code (IBC, 2000) which implements spectral hazard maps for 2% probability of exceedance in design time period of 50 years (2500 years return period of earthquakes). Seismic zone in Indonesia has been developed by the latest seismic data up to recent year of 2010 after consideration some of the enormous earthquakes such as the 2004 Aceh Earthquake by 9.0–9.3 MS which was followed by big tsunami, the 2005 Nias Earthquake with 8.7 MS and the 2006 Yogyakarta Earthquake in 6.3 MS to establish parameters of seismic hazard by maximum credible earthquake magnitude (MCE) (Irsyam, M., *et.al*, 2008). Two sets of maps are presented. One set presents contours of MCE, 5% damped, elastic spectral response acceleration at a period of 0.2 s, termed SS. The second set presents contours of MCE, 5%damped, elastic spectral response acceleration at a period of 1.0 s, termed S1.

Indonesian seismic zone consist of 15 areas of seismicity which is started from < 0.05 g to the maximum range > 1.2 g (figure 3-29). From the map, Java Island itself has the spectral acceleration response between 0.2 - 1.0 g. According to FEMA 310, the area is mostly located between medium and high seismicity since 0.3 to 0.8 g is the most zone found in the island (table 3-2). Only small part of the island have below and upper the range. Northern part of the island has lower seismicity while southern part higher.

Table 3-3: Regions of Seismicity with Corresponding Spectral Acceleration Response (FEMA, 2002)



Region of Seismicity	*Spectral Acceleration Response, SA (short-period, or 0.2 sec)*	*Spectral Acceleration Response, SA (long-period or 1.0 sec)*
Low	less than 0.167 *g* (in horizontal direction)	less than 0.067 *g* (in horizontal direction)
Moderate	greater than or equal to 0.167 *g* but less than 0.500 g (in horizontal direction)	greater than or equal to 0.067 *g* but less than 0.200 g (in horizontal direction)
High	greater than or equal to 0.500 *g* (in horizontal direction)	greater than or equal to 0.200 *g* (in horizontal direction)

Notes: *g* = acceleration of gravity

3.10.2 Microzonation Map

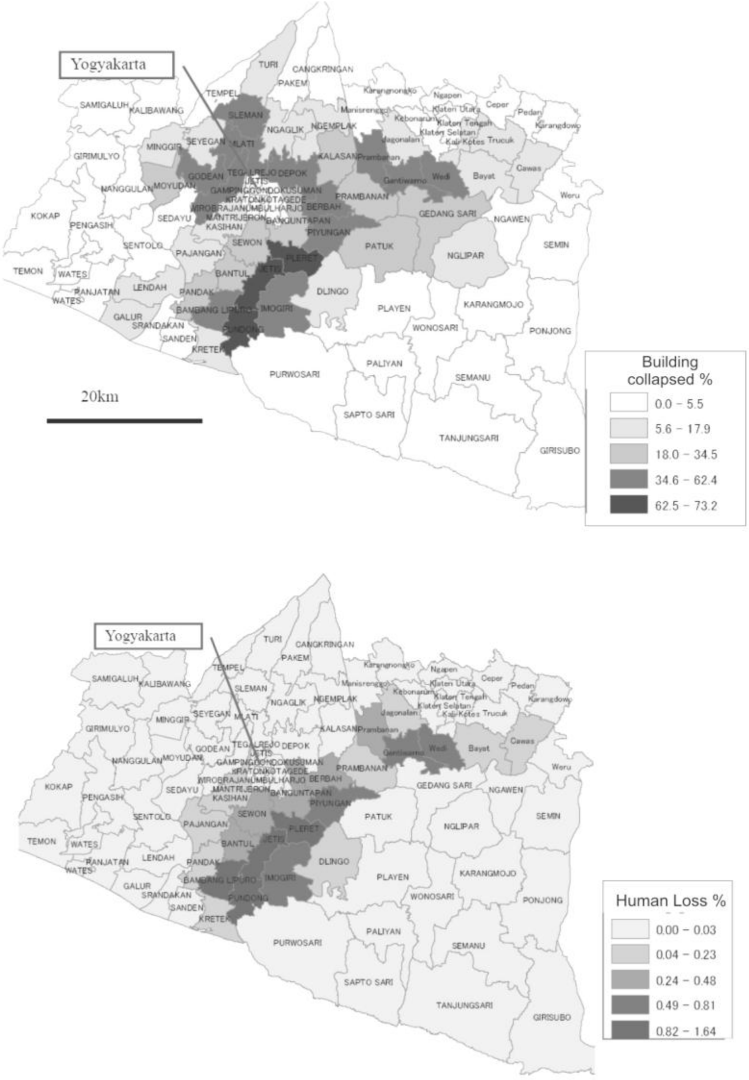


Figure 3-30: Building collapsed and Human loss maps in the 2006 earthquake (Murakami, H, *et.al* 2008)

Seismic zone map is meaningful for the purpose of figuring the seismic risk in general especially if it covers a wide area like the case of Indonesian territory. However, to categorize the building and the population in the exact seismic location should use the smaller detailed called microzonation map. The map has detailed information in bigger scale map in a certain area. It can be used as initial information for seismic design, land use management, and even for estimation of the potential for liquefaction and landslides. Microzonation map is ideally produced as result of study in acquire ground motion constraint e.g. acceleration, amplification factor and response spectra at the earth surface (Irsyam, M., *et.al*, 2008). Yet, the empirical data from previous earthquake(s) is also useful to categorize the level of suspected area. From the May 27th 2006 earthquake, Bantul and Klaten were the most affected area with the highest number of collapse building found. The secondary affected such as Sleman and Yogyakarta regency (figure 3-30).

In fact, not all the districts above have identical zone. Karnawati, *et.al*, (2008) found after the May 27th 2006 earthquake that some area in the districts have higher risk according the geological condition. Opak fault below the areas is great significant aspect for the most tectonic-risky lane above. Sub district such as Pleret, Imogiri, Pundong, Jetis, Piyungan are the extremely high area, while Bambanglipuro, Pandak, Kretek are the high, and Bantul and Sewon are the moderate one (see figure 3-31).

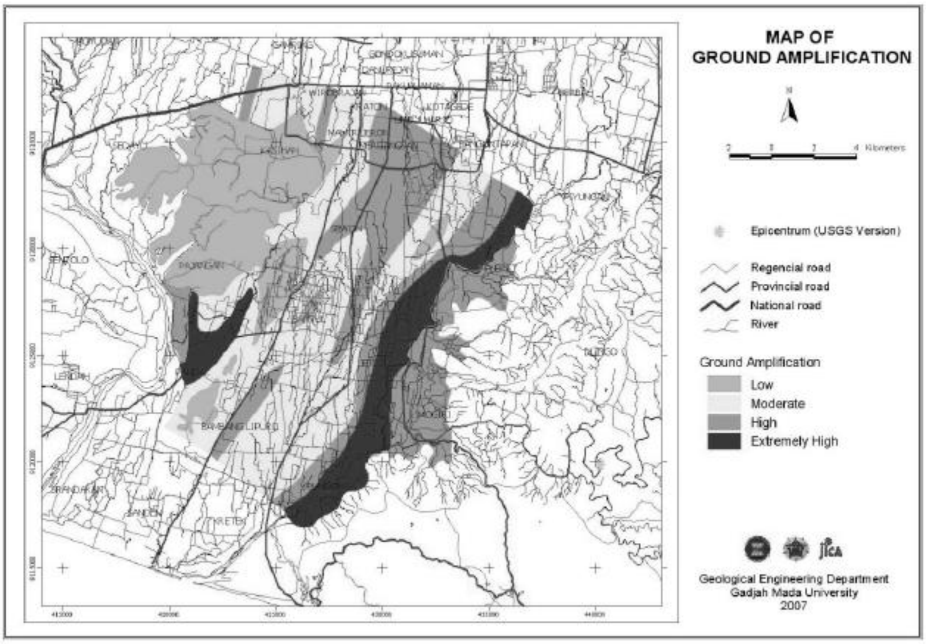


Figure 3-31: Microzonation Seismicity from Ground Amplification Map of Bantul (Karnawati, *et.al*, 2008)

3.10.3 Soil condition

The soil type found generally for site of the houses in Java especially in the land of Yogyakarta province according to FEMA 310 are mainly from C, D, and E class as hard, medium, and soft soil while A and B rarely used for house site and mostly found in the mountainous-hard-rock ground while class E only use non building purposes.

3.10.4 Main structure irregularity

Here is the study from the 2006 earthquake experiences. Though it is not fully empirical by means of statistical data availability and usage, it still as "the mother of earthquake examination" to the buildings since the analytical studies can be used to recognize the weakness and adventages of the building.

The main structure means the system structure used for main building under roof structure. It is used for space function where the most activities are done inside. In tropical countries, for environmental reason houses are built with two important parts of building which are the main and the roof structures. The roof structure is mostly constructed in high inclination even the height is sometimes more than used for the main-under structure. Main structure irregularity will directly affect the vulnerability of the house since this part of building support the people inside and the roof above. The irregularities of the main structure can be: missing column(s), no envelope wall, heavy wall, thin wall, wide opening, and complex plan.

Missing Column(s):

Column in single story building is mostly practical column as frame located between conjunctions of two or more walls. In some case especially in modern-vernacular type houses, column is easy to absent because of complicated room arrangement or just because of additional room with similar or different material. Missing column will directly decrease the compactness of the building (See figure 3-32).

Figure 3-32: Missing column sample and the sample result from earthquake

Incomplete Frame or No beam:

It was commonly found that using a PC column without following by horizontal frame or beam. Without beam tie, frame then act not as a frame anymore since there is no unity in reaction to the quake (see figure 3-33).

Figure 3-33: House sample without beam and the result from earthquake

No Envelope Wall:

For tropical house, the absence of outer wall is practical to be used for eliminating the humidity in the room. The wall surrounding even though not as a main structural element will increase the rigidity of the building (figure 3-34).

Figure 3-34: Traditional house with and without envelope wall after earthquake (right photo: Maer, B.W., 2008)

Heavy Wall:

Heavy wall here is pointed to masonry wall that to be used in traditional way without sufficient column, anchor to the column, or to the wooden frame (figure 3-35)

Figure 3-35: Masonry heavy wall failures

Thin Wall:

In contrary, thin wall is also suspected to the weakness of building, especially the traditional masonry houses that suppose to be has a thick wall to bear the weight of the roof (figure 3-36).

Figure 3-36: The result of thin and weak masonry wall usage after earthquake

Wide Opening:

Wide opening for window or door between two vertical frames will decrease the support to the building rigidity. It also will be easy damaged and collapsed during a quake. This opening was mostly used for kiosk or garage door (figure 3-37).

Figure 3-37: Wide opening house and the result sample after earthquake

Complex Plan:

The original complex plan in Javanese house was only found in bigger houses belong to the richer people but found to be popular later. Plan for the houses are started by simple compacted square shape but later modified by additional part of the houses such as kitchen, garage, bathroom or new sitting room. As a result, many types of plan are now used for the Javanese houses. Faced to the quake, plan will affect the performance of structure and only compact-simple plan can perform well (figure 3-38).

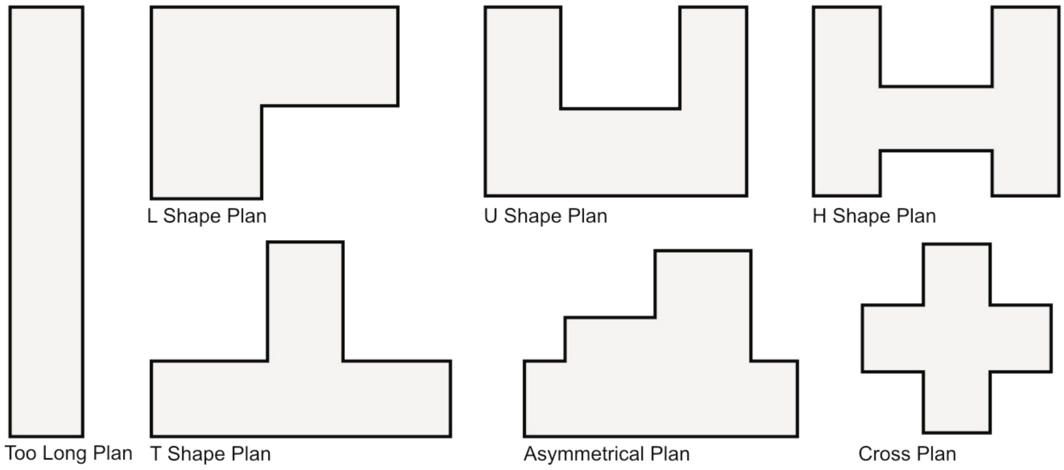


Figure 3-38: Irregularities of complex Plan

3.10.5 Roof structure irregularity

The important of roof structure is covering the main building and room function below. Irregularity of the structure will affect for collapsed the roof part and hit the user inside. Irregularity of roof structure can be: incomplete structural member, heavy PC frame, complicated roof frame, and cantilever roof.

Incomplete structural member:

Figure 3-39: Incomplete frame for roof structure and its failure after earthquake (right photo: Boen, 2007)

Just like main structure, incomplete member in roof structure will create non-compacted roof system. The most neglected frame of the roof is commonly found for inclined tie beam (figure 3-29). However, completely unframed or the absence of horizontal beam are also found frequently in the houses (figure 3-30).

Figure 3-40: Supported-heavy roof frame and failure of unsupported framed or the absence of horizontal beam in between of gable roof (right photo: EERI, 2006)

Heavy PC frame:

Using PC frame actually has been suggested due to the price of wood but exaggerated use of PC in less supported frame is always dangerous. Since the frame is heavy, the potential collapsed is high (figure 3-41).

Figure 3-41: Heavy roof frame and its failure after earthquake (right photo: EERI, 2006)

Complicated Roof Frame:

Complicated frame means the use of combined roof structure together between different material such as masonry, RC, and wood as a main structural system.

Since the material properties is different between wood, brick and RC, the unity reaction to the earthquake will absence (figure 3-42).

Figure 3-42: Complicated roof frame and result the failure after earthquake (right photo: Boen, 2007)

Cantilever Roof

No column or hanged roof was unusual used in old vernacular Javanese house but later applied for main entrance terrace or protecting the door and window in new type of the houses. Most of cantilever roof are constructed from RC. Since it has free column below, cantilever then is broadly used by the people. Unfortunately, under the earthquake movement the combined moment force of heavy PC is great while the reinforced bar inside mostly did not consider the lateral force. As result, many cantilever roofs failed in earthquake.

3.10.6 Material and construction appearance

The appearance of material and construction can affect the firmness and ductility of the houses. Age and maintenance level of building will affect directly the appearance which is directly affect the strength and endurance of material to support the weight and force of the building. Natural material such as wood has limited lifetime compare to RC. However, unprotected masonry and steel are also susceptible to shorted lifetime usage in building structure. Some wooden structures were found collapsed in the May 27, 2006 Java earthquake. One of the reasons was the deterioration of old or untreated wooden frame, especially in the connection where most suspected failure came from (see figure 3-43).

Figure 3-43: Connection failure of old and less maintained wooden structure

3.11 Javanese House RVS Development

In general, method for grading system in Java RVS is based on FEMA RVS procedure, proved by the computer simulation and supported by the field experience. Basic scores related the main structural system had referred FEMA standard (ATC 13). Adjustment on the method had been achieved by some adaptation related to the local building practices.

3.11.1 FEMA Procedure Adoption

FEMA RVS had taken all important necessities to the procedure development. Even the procedure was originally for screening building in California up to pre-1988, it had been expanded to building in other area on the scope of nationwide in US. This means that the method itself is already as common procedure which can be applied everywhere throughout the country which has differences in term of seismicity and building practice. Development was also updated with recently seismic and technology from 1988 to 2002. For this reason, FEMA-RVS method is referred for Java RVS.

However, to apply the procedure directly for the houses in Java is not suitable. Even the general procedure may used for the grading phase from Basic Structural Hazard (BSH) to Performance Modifiers (PMFs) and the final score (S), the detail aspects such as the building type and it's particular performance are not identical. Since the procedure is proposed for a specific type of building, which is vernacular house, some adjustments are needed herein. The method for adjustment itself might be based on quantitative or qualitative method depends on availability of the data and references. Due to lack of data and quantitative-qualitative exchange complexity, even judgment and approximation based on engineering-logical reason and or references had been used for certain aspects as used as well in FEMA 154. For this reason, all studies above are needed to be accounted in the grading examination.

3.11.2 Score Meaning and Procedure

The final score of FEMA RVS is the result of subtraction of Basic Score (BS)/Basic Structural Hazard (BSH) by some Performance Modifying Factors (PMFs) from certain structural type in definite seismic location. BS in FEMA 154 is the range of structural type of building which is concluded from 12 types (FEMA, 1988a) or 15 types (FEMA, 2003). PMFs are modification aspect suspected for weakness of the buildings. As mentioned before, the classification of the houses in Java is easier and more practical based on form type rather than structural system used. Since this RVS is developed based on the typological form, three steps scoring system is proposed which involves Basic Score (BS), Basic Structural Modifying Score (BSM), and Performance Modifying Factors (PMFs). BSM is adjustment score for the structural type of the building. Final score S, is generated by calculation of BS which is modifying by BSM and PMFs according the equation:

$$\mathbf{S = BS \pm BSM - PMFs}$$

The Basic score describe a rate for a type of building as the negative of the base 10 logarithm of the possibility of damage (D) more than 60 percent of total building value for specific Effective Peak Acceleration (EPA) loading (reflecting seismic hazard) as:

$$\mathbf{BS = - \log_{10}[Pr(D \geq 60\%)]}$$

For example, a BS score of 2.0 means that is the level of the probability of damage more than 60 percent of building value for the particular building considered earthquake is 10^{-2} or 0.01 by means a 1% chance of collapse. Sixty percent is accepted as major damage, the level where many structures are tend to be razed more than renovated because it begins to threat life safety to the occupants. Determined collapse probabilities at the MCE related to final scores in general are between 0.0 and 4.0 (table 3-3). The higher score is considered for less vulnerability or high acceptability and vice versa.

Table 3-4: FEMA RVS score and Probabilities of collapse predicted in Maximum Considered Earthquake

Score	Damage Probability ≥ 60%
4	0.01 %
3	0.1 %
2	1 %
1	10 %
0	100 %

This FEMA RVS scoring system procedure is followed since it has a meaning in its score rather than merely a grouping level. The most important meaning for FEMA score is it gives score the building related both for the population and the individual condition. Some other known RVS scores used different approach applied for scoring system such as Turkish RVS grading score between 0 – 100 (related to percentage of direct probability to be damaged in single building only) or Indian RVS score for 1 – 5 (related to damage level of single building under earthquake, as refer to Euro code). By the method, FEMA score then should be considered by the level of cut off which is flexible rather than fix since it related to the building population. The benefit of this flexible method is that the jurisdiction of the buildings under examination could define the actual cut off or limit to predict the expectation of vulnerability level. Furthermore, for individual purpose, FEMA score still has significant meaning since it then correlated with the individual performance defined by basic score and performance modifiers found in the building under examination.

3.11.3 Basic Score Adaptation

To decide the level of probability of damage more than 60 percents for a type of building or structures in particular ground motion is complicated study because of inadequate data or methods currently available even by FEMA themselves. FEMA was asking from engineering expert opinion in order to deal for damage level and building types (FEMA 1988b). Moreover, computational techniques of earthquake-proof improvement cannot cover whole aspects such as construction principles, suitable construction methods and workmanship (Arbabian, 2000). For this reason, approximation, smoothing, or rounding in some aspects were also taken without losing the main idea of the structural principles. Regarding to this matter, Java RVS has been developed with some approximation for adjustment in the procedure.

According to main material use for the houses, wood, masonry, and RC are commonly used. Though the detailed structure of the building might be not exactly identical with those have been examined by FEMA 154, the definition of simple wood building (W1), unreinforced masonry (URM), and concrete frame-brick wall infill (C3) are the closest to the main building typology based on the material used in Java. These three main materials are then referred as the main aspect to define the basic score of the houses. FEMA’s score putted wood in the highest rank following by RC and masonry building. Structural simulation run for the Javanese houses had also confirmed the rank of the material variations. Based on scoring system proposed by FEMA 154 and proved by the computer simulation, basic score proposed for the three types of building regarding the main materials in the three different seismic zones can be followed in table 3-4 below:

Table 3-5: BS for FEMA 154 1988 versus 2002 and Initial adaptation

	FEMA 154 (1988)			FEMA 154 (2002)			Initial Adaptation		
	Low	Medium	High	Low	Medium	High	Low	Medium	High
Wood	8.5	6	4.5	7.4	5.2	4.4	**8**	**6**	**4**
Masonry	2.5	2	1	4.6	3.4	1.8	**3**	**2**	**1**
RC	3	2	1.5	4.4	3.2	1.6	**4**	**3**	**2**

In order to apply FEMA scoring system, adaptation of the score was taken from FEMA 154 1988 and 2002 edition. The older and newer scores are compared with the consideration that the score might be adjusted due to certain reasons, mainly after another great earthquake incident (e.g. After Loma Prieta California earthquake 1989 and Northridge Loas Angeles earthquake 1994). The meant score ranges are: wood 4 – 8, masonry 1 – 4, and RC 2 – 4. Applied to the Java RVS, some adjustment is required based on the simulation and previous field experience such as that masonry houses was always lower than concrete frame quality in Java. For this reason, initial score for masonry ranges from 1 – 3, while RC started from 2 – 4, and wood run from 4 – 8. If cut off value is in middle as 2, it can be assumed that without considering the performance modification PMFs, complete structural system of wood is always accepted for all seismic zones, masonry is only for low seismicity zone, while RC is accepted for medium and low zones.

Figure 3-44. Destroyed traditional masonry house with remain four wooden columns standing (photo: BAPPENAS, 2006b)

After considering all circumstances including computer simulation and field data, instead of completely RC frame, RC main frame combined by wooden roof frame in Javanese house was commonly used for single floor house. This puts the RC frame - wooden roof frame is better than completely RC frame. Completely RC frame then considered as has ‘roof structure irregularities’ to be accounted in PMFs later. This was proved by some RC frame houses were still standing after the earthquake. Score ranges from 3 to 5 are applicable for this house type. Modification was also done for masonry type of structure where used in traditional house types. Regarding the previous similar reason, some masonry houses which uses traditional type (mostly *Joglo* and *Limasan* types), were still found standing with some degree of damage. Since the traditional houses uses the four main columns inside, the masonry then roles not as completely bearing wall for the houses. This is the reason to increase masonry performance used by the traditional houses of *Joglo* and *Limasan* which will be used in BSM (see figure 3-44).

3.11.4 Javanese Houses Basic Score

For the Javanese houses, BS will be applied regarding the main typology of the houses which are *Joglo, Limasan, Kampung* and modern-vernacular type. All these houses are considered as vernacular houses as result of non-engineered construction though one called modern type. 'Modern' in this case refers to the form typology and main material used (mainly RC frame) which is cannot be categorized as the traditional of the three. This typological form base is very important in order to categorize the buildings by a visual assessment. For the purpose of visual screening, it will be easier by recognizing the form type rather than the type of material used in the building. Another reason for investigating the building typology first rather than others is that the Javanese houses are always related to the form classification rather than others. The people used to mention the houses regarding the form type such as *Joglo, Limasan,* and *Kampung.*

BS for the Java RVS is purposed to refer the original vulnerability level of the houses as they were built in the original way. In this case, the three of traditional types will have wooden post and beam covered by wooden plank wall, while the modern-vernacular type will has RC frame-brick wall and wooden roof frame as an initial consideration. The disparity of the houses according the different use of material for main structure as found in the field will be accommodated by BSM, while the alteration of detailed house configuration and construction will be considered as PMFs. BSM is intended to modify the houses in the proper level score after considering the main material used in the structure. PMFs are aimed for second modifier for some irregularities and external factors of the houses.

By adopting the FEMA 154 (showed in table 3-3 above), the vulnerability level of wooden structure building ranges from 4 in high to 8 in low seismicity zone. Computer simulation had examined that the *Joglo* has the highest level of wooden structural strength to earthquake followed by the *Limasan* and the *Kampung*. Adjustment was done for the lowest type of *Kampung* since it has some inefficiency in its frame which was confirmed by the high forces found in the simulation. For this reason, *Kampung* type might be started from 3 instead of 4 although uses wood for its main structural system. The modern-vernacular type has RC score which was discussed before. By the adjusted distribution, score will be obtained as table 3-5 below.

Table 3-6: Basic score of Javanese Houses according to the original material use

Seismicity/House type	Joglo	Limasan	Kampung	Modern-Ver
Low	8	7	6	5
Medium	6	5	4	4
High	5	4	3	3

3.11.5 Javanese House Basic Structural Modifying Scores and Basic Vulnerability Scores Adaptation

Basic Structural Modifying Scores (BSM) modification for the Javanese houses accounts for the possibilities of the houses which are constructed from different material application. Every type of the houses will have two other disparities beside the original one. Thus the *Joglo, Limasan,* and *Kampung* will have masonry and RC variations while the modern-vernacular type will have option in wood and masonry. This arrangement was decided from the factual structural disparity in the field that the *Joglo, Limasan* and *Kampung* are not anymore developed only by the original material supposed to be used; wood. In the other hand, the modern-vernacular type might be constructed from wood as safety concern to the earthquake, or in the opposite direction; by masonry as a limitation of owner's economic background or building knowhow of the people.

The aim of BSM application is to set the houses in its actual performance level. By this procedure, misinterpretation of which structural level of the houses will be obliterated, and misconception about the ideal state of the traditional houses to earthquake will be corrected. In other words, the *Joglo, Limasan* and *Kampung* are not always better than the modern-vernacular type of the houses and vice versa without going to examine the structural system used. This is very important to the people's understanding related to the prejudgment that the traditional houses are either better or lesser compare to other type of houses.

To obtain the actual score of vulnerability or Basic Vulnerability (BV), BS should be subtracted by BSM and the result should be related to its category. For example; the *Joglo* house should be scored by 4, 3, 2 instead of 8, 6, 5 for low to high seismicity as discovered that the houses constructed by masonry. The BV, BS and BSM scores relationship then listed in table 3-6 below.

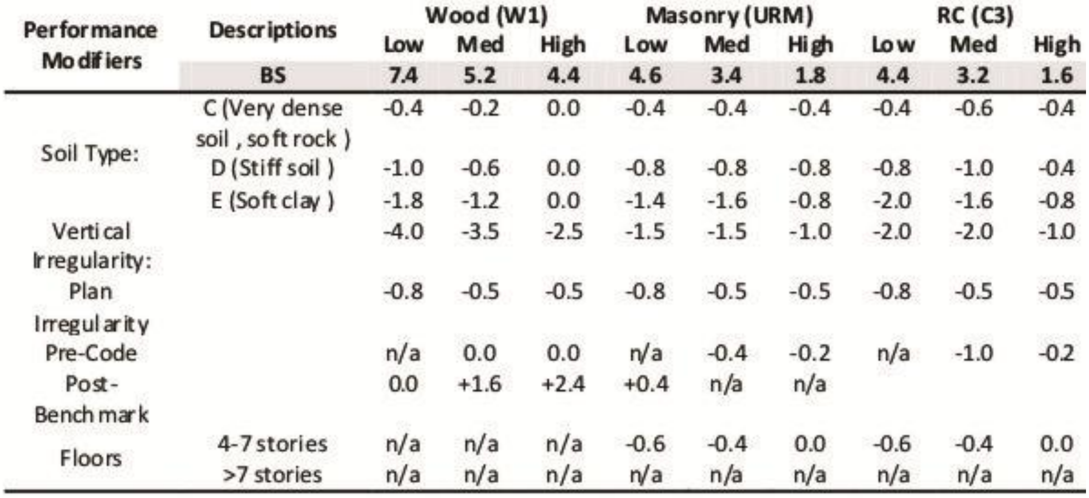
Table 3-7: BV, BS and BSM score possibilities for every type of Javanese Houses

	Joglo			Limasan			Kampung			Modern-ver		
	Low	Med	High	Low	Med	High	Low	Med	High	Low	Med	High
BS	**8**	**6**	**5**	**7**	**5**	**4**	**6**	**4**	**3**	**5**	**4**	**3**
Wood	x	x	x	x	x	x	x	x	x	+3	+2	+2
Masonry	-4	-3	-3	-3	-2	-2	-3	-2	-2	-2	-2	-2
RC Frm	-3	-2	-2	-2	-1	-1	-1	x	x	x	x	x
BV												

FEMA 154 used many aspects account for PMFs including Vertical and Plan irregularities, soil types, floor number, pre code and benchmark. Vertical and Plan irregularities was considered in every aspect e.g. soft storey, short column, etc for 1988 version but altered by its representation found in the building by the 2002 version. Floor number aspect is used only for modifying multi level floor building. Benchmark and Pre-code is aimed for tuning the building by specific code where and when building has been built. Building appearance quality is not scored anymore in the last version. Scores for every PMFs of wood, masonry and RC building are shown in table 3-7.

For adaptation to Javanese purpose, some modification is needed. Using FEMA's PMFs directly to the proposed procedure is unacceptable since the target object is different. The most possible aspect related to the Javanese house is vertical and plan irregularities, and then soil condition as a base for examine the location. Building appearance will be listed in order to accommodate the level of deterioration causing by age or maintenance level aspect. The others can be neglected since they are only applicable for more complex buildings and conditions.

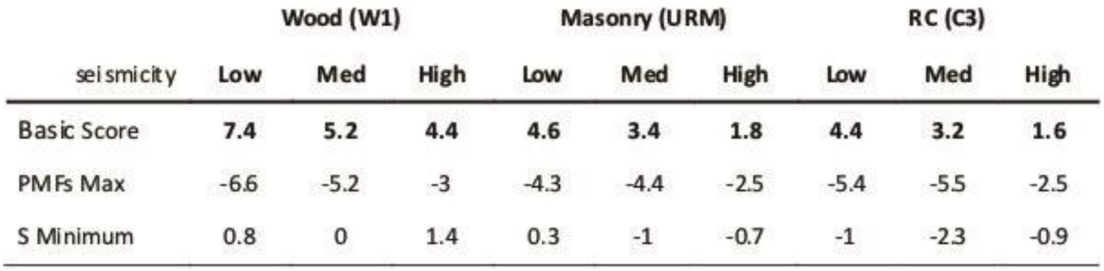
Table 3-8: Performance Modification Factors PMFs in FEMA 154 (2002)



Performance Modifiers	Descriptions	Wood (W1)			Masonry (URM)			RC (C3)		
		Low	Med	High	Low	Med	High	Low	Med	High
	BS	7.4	5.2	4.4	4.6	3.4	1.8	4.4	3.2	1.6
Soil Type:	C (Very dense soil , soft rock)	-0.4	-0.2	0.0	-0.4	-0.4	-0.4	-0.4	-0.6	-0.4
	D (Stiff soil)	-1.0	-0.6	0.0	-0.8	-0.8	-0.8	-0.8	-1.0	-0.4
	E (Soft clay)	-1.8	-1.2	0.0	-1.4	-1.6	-0.8	-2.0	-1.6	-0.8
Vertical Irregularity:		-4.0	-3.5	-2.5	-1.5	-1.5	-1.0	-2.0	-2.0	-1.0
Plan Irregularity		-0.8	-0.5	-0.5	-0.8	-0.5	-0.5	-0.8	-0.5	-0.5
Pre-Code		n/a	0.0	0.0	n/a	-0.4	-0.2	n/a	-1.0	-0.2
Post-Benchmark		0.0	+1.6	+2.4	+0.4	n/a	n/a			
Floors	4-7 stories	n/a	n/a	n/a	-0.6	-0.4	0.0	-0.6	-0.4	0.0
	>7 stories	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

PMF scores applied in FEMA are range from – 4 (vertical irregularities URM) to +2.8 (benchmark for RM1). These PMF scores as result of engineers prejudge in order to give some negative value due to the weakness of the building. Linear scoring method was used which was aimed for a simple scoring system. However, despite the simplicity of the result and the process, this system delivers confusedness in term of logical understanding (Wang, Y. and Goettel, K.A., 2007). This argument is proven by some negative result of final score which is not acceptable for such scoring (see table 3-8).

Table 3-9: BS, minimum PMFs and Final scores in FEMA 154



	Wood (W1)			Masonry (URM)			RC (C3)		
seismicity	Low	Med	High	Low	Med	High	Low	Med	High
Basic Score	**7.4**	**5.2**	**4.4**	**4.6**	**3.4**	**1.8**	**4.4**	**3.2**	**1.6**
PMFs Max	-6.6	-5.2	-3	-4.3	-4.4	-2.5	-5.4	-5.5	-2.5
S Minimum	0.8	0	1.4	0.3	-1	-0.7	-1	-2.3	-0.9

Another reason to modify PMFs scoring system is that this Java RVS examination is based on form-typology rather than structural as in FEMA 154. Since the basic score will easily to jump from one to another type of structure which will shift the level of score itself by BSM mention before, a fix score modifier will not applicable. Instead, a subtraction by percentage level expected from building damage causing by PMFs will be applied for the BSM result. For this reason, PMFs are stated as result of percentage rather than similar as used in BS and BSM. The effectiveness of using this method can also be proven by FEMA’s PMFs percentage to the basic score which is has a specific range in every aspect i.e., vertical irregularities for wood building will lessen from 25 to 35 percent while roof irregularities from 20 to 25 percent and so on. Another advantage using percentage in PMFs is that the weaknesses of building could be read independently from total score, BS and BSM. Since the range of BS is for 1 – 8 (lowest score is masonry as 1 and wood structure is highest score as 8), PMFs ranges from 0 – -100 percent, the formula of final score then modified as:

$$\mathbf{S} = \sum_{n=1}^{8} \mathrm{BV}n + \left(\mathrm{BV}n \,.\, \frac{\mathrm{PMFs}}{100}\right)$$

Where:

BV = BS – BSM
PMFs = 0 to -100

S is final score for vulnerability, BV is basic vulnerability score which is as result of basic score BS subtractions by basic score modifier score BSM. Theoretically, final score S ranges from 0 to 8, but for field application purpose, range 0 – 4 is the ideal consideration related to the seismicity area and the possibility level of PMFs.

3.11.6 Javanese Houses Performance Modifying Factors

As mentioned before that the aim of performance modifying factor is to tune in the individual weakness found in the building. The PMFs are related to the prediction of damages related to the insufficient condition both for structural and non-structural aspect of the building. Unlike the basic score which more related to the damage probability, the PMFs are subjected to the expected behavior of the building under earthquake caused by incompleteness, deficiency or irregularities. Apart from environmental aspect, building should be configured, detailed, and constructed well (Szakats, G., 2006). These are related to three main aspects which are structural system and configuration, construction technique, and material chooses. Each aspect is assumed to have equal contribution to the building performance, thus, in general one third should be taken into account for the performance deficiency. In order to simplify the aspects as discussed before, the first and second aspect then converted to

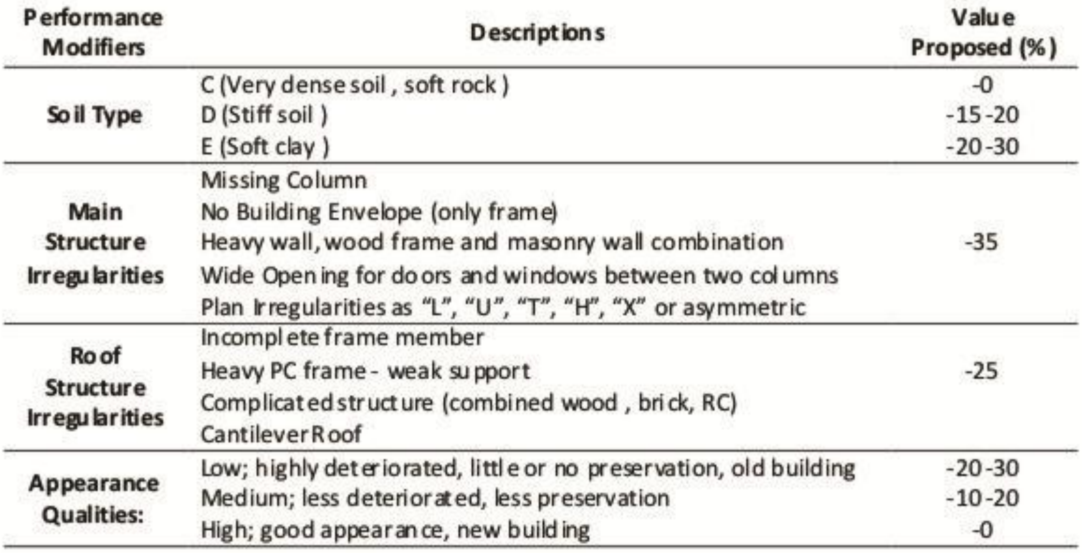
Main Structural Irregularities and Roof Structure Irregularities while material quality in general can be examined by Appearance Qualities. Soil condition had been considered as environmental seismic aspect.

Soil type according to seismic wave amplification aspect accounts for 20 to 50 percent from medium stiff soil to soft-weak soil (FEMA, 1988b) or 12 to 50 percent (IAEE, 2004). However, from the May 27th 2006 earthquake, it was very little associated with the failure of foundation on the soil. Since the buildings are mostly single floor, thus the effect of soil to the foundation is less compare to multi storey buildings. Based on this reason, the percentage then needs to be lessened. On the other hand, since the general character of soil is compiled by sediment surrounding by rock on the mountains, significant level should be still considered for the soil. For this reason soil ranges from 15 to 30 percent (from hard to soft types) associated to performance of the building under earthquake.

Structural system of the house is the most associated aspect related to the firmness level in building performance under seismic risk. An irregularity, nonexistence, or incompleteness of one part of the system will trigger to the whole system of the building. Mezzy, M,, *et.al,* (2004, after SEAOC) wrote that vertical and plan irregularities is considered for 30 percent variation of the horizontal dimension at any story. This can be assumed that any vertical irregularity found in the building will be accounted for providing about 30 percent deficiency in building performance since the area correlated to the weight of the building.

From past earthquake experiences, incomplete or partial confined masonry has proved to be as major aspect up to 60 percent damage (Chile 1939 and 1985, both were 7.8 magnitudes; see: (Brzev, S., 2009). Similar to Chile case, for Javanese house under the May 27th 2006 earthquake; 70 to 90 percent of building populations were damaged and for both unreinforced and partial masonry population was about 80 percent. It was believed that almost all unreinforced masonry houses were damage severely nearly to 100 percent while confined either partial or complete were destructed in some different levels. For these reasons, incomplete structural system altogether with main supporting system in single floor building (main roof system) will take responsible up to 60 percent. For practical purposes, 35 and 25 percent was divided for main and roof structural system.

Table 3-10: The Performance Modifier factors found in the Javanese Houses



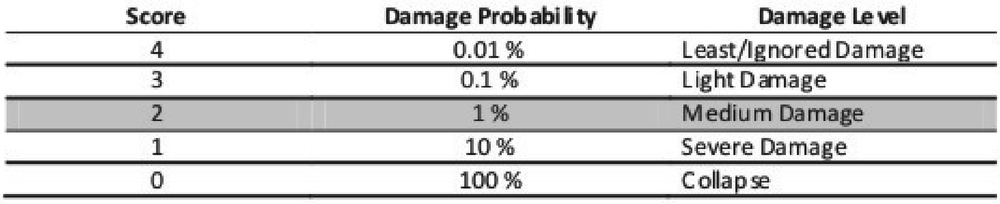
Performance Modifiers	Descriptions	Value Proposed (%)
Soil Type	C (Very dense soil , soft rock)	-0
	D (Stiff soil)	-15-20
	E (Soft clay)	-20-30
Main Structure Irregularities	Missing Column No Building Envelope (only frame) Heavy wall, wood frame and masonry wall combination Wide Opening for doors and windows between two columns Plan Irregularities as “L”, “U”, “T”, “H”, “X” or asymmetric	-35
Roof Structure Irregularities	Incomplete frame member Heavy PC frame - weak support Complicated structure (combined wood , brick, RC) Cantilever Roof	-25
Appearance Qualities:	Low; highly deteriorated, little or no preservation, old building	-20-30
	Medium; less deteriorated, less preservation	-10-20
	High; good appearance, new building	-0

The level of quality of the material and construction used in the building is also another important aspect to the building performance. Although everything is done in proper system but built by low quality material, or material already deteriorated (e.g., for wood), the system will easily affected by external force. Poor joint is also other issue related to this discussion. However, the correlation between deteriorated materials and seismic safety has not been studied in detail (CAPSS, 2009), but the experts had all observed examples of buildings with weakened structural capacity due to material deterioration. Matsuki, S., *et.al*, (2006) in his research in bridge discovered that 30 percent quality lower after found some deterioration in concrete structure. For specific non-engineered houses, Shaw, R., *et.al*, (2004) discovered from his respondents that the damages under earthquake were 31 percent because of material usage and 26 percent was correlated to its quality. After considering all these cases, 30 percent maximum will be given for material or appearance quality (see table 3-9).

3.11.7 Damage Level and Cut-off Criteria Relationship

From examination above, the damage probabilities are categorized from score 0 to 4 even though the level of certain building might be more. Beside it has probability meaning as explained before, the score of 0 – 4 is also considered as building damage range from completely damaged (collapsed/100 percent probability) to least affected. Correlation between damage probability and predicted damage level thus is shown as in table 3-10.

Table 3-11: Correlation between Score, Damage Probability, and Predicted Damage Level



Score	Damage Probability	Damage Level
4	0.01 %	Least/Ignored Damage
3	0.1 %	Light Damage
2	1 %	Medium Damage
1	10 %	Severe Damage
0	100 %	Collapse

Cut-off is the limit level where building could be categorized as ‘accepted’ or ‘need the further detailed investigation’ group. This categorization is not means as a fixed point. The jurisdiction where the buildings located could decide different cut-off based on certain safety level consideration such as emergency facilities or based on the population since the probability score is related to the amount of the population. The main aspect to decide cut-off is Life Safety (LS) level which means building under earthquake loading has to has enough ability to support itself from further dangerous damage that threat the safety. Certain facilities need even more than LS move to Immediate Occupancy (IO).

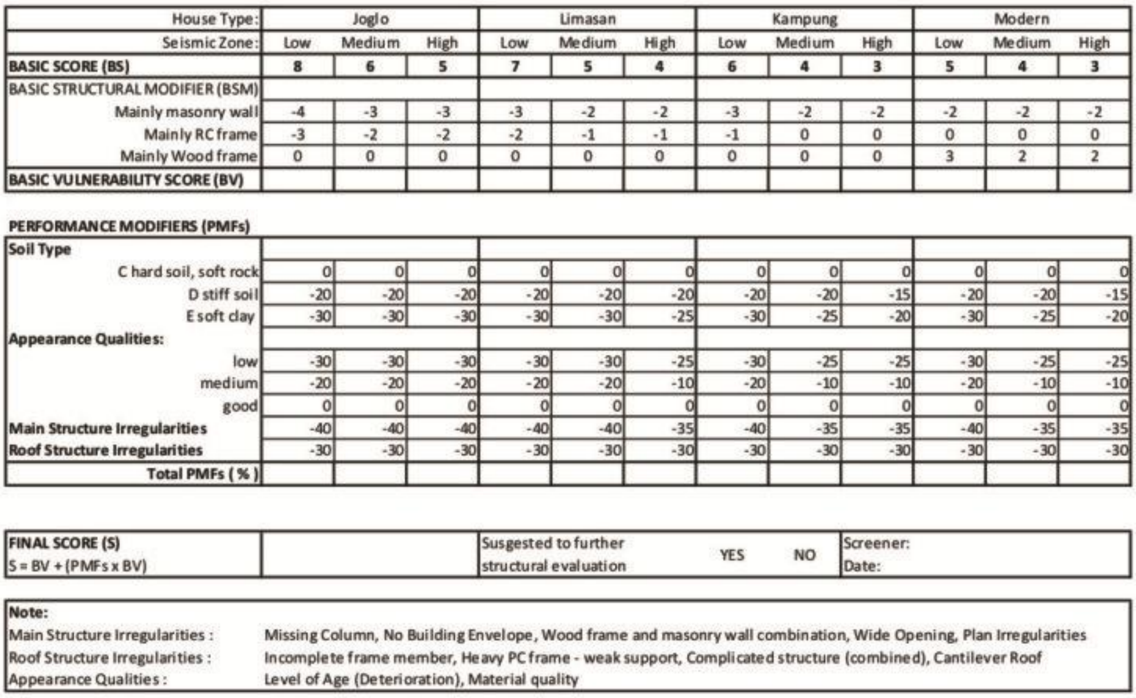
For Javanese purposed in this study, based on FEMA suggestion, cut-off 2 by means 1 percent probability to have more than 60 percent damaged is accepted. Somehow this figure is very low since using 1 percent value, but if the population of the building is high (e.g., 20,000 population in one sub-district) the cut-of 2 is somehow reasonable for maximum 200 houses expected damaged more than 60 percent. Regarding damage level, score 2 means to be predicted in Medium Damage which is accepted for Life Safety support.

3.12 Javanese RVS

From all examinations above, the Javanese RVS comes in two main charts (see table 3-11). The first chart is for defining Basic Vulnerability Score (BV) by adapting Basic Score (BS) from the type of the houses. Basic Structural Modifier (BSM) is an option for adapting the basic score by any structural system alteration found in the sample house.

The second chart is aimed for tuning the building according to the weakness found for decreasing the performance as Performance Modifying Factors (PMFs). Soil type, Appearances qualities, Main and Roof structure Irregularities are the general modifier aspects applicable on the building which come in percentage. This proportional system is proposed for more logical and practical use in modifying the basic performance by some negative qualities found in the houses. Unlike FEMA 154 that has positive value modification (e.g., for post code building, benchmark, etc), instead, all scores here come in negative value (for decreasing the level of the building because of its deficiency(s) only).

Table 3-12: the Javanese RVS chart



House Type:	Joglo			Limasan			Kampung			Modern		
Seismic Zone:	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High
BASIC SCORE (BS)	**8**	**6**	**5**	**7**	**5**	**4**	**6**	**4**	**3**	**5**	**4**	**3**
BASIC STRUCTURAL MODIFIER (BSM)												
Mainly masonry wall	-4	-3	-3	-3	-2	-2	-3	-2	-2	-2	-2	-2
Mainly RC frame	-3	-2	-2	-2	-1	-1	-1	0	0	0	0	0
Mainly Wood frame	0	0	0	0	0	0	0	0	0	3	2	2
BASIC VULNERABILITY SCORE (BV)												

PERFORMANCE MODIFIERS (PMFs)

Soil Type												
C hard soil, soft rock	0	0	0	0	0	0	0	0	0	0	0	0
D stiff soil	-20	-20	-20	-20	-20	-20	-20	-20	-15	-20	-20	-15
E soft clay	-30	-30	-30	-30	-30	-25	-30	-25	-20	-30	-25	-20
Appearance Qualities:												
low	-30	-30	-30	-30	-30	-25	-30	-25	-25	-30	-25	-25
medium	-20	-20	-20	-20	-20	-10	-20	-10	-10	-20	-10	-10
good	0	0	0	0	0	0	0	0	0	0	0	0
Main Structure Irregularities	-40	-40	-40	-40	-40	-35	-40	-35	-35	-40	-35	-35
Roof Structure Irregularities	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30
Total PMFs (%)												

FINAL SCORE (S) S = BV + (PMFs x BV)		Susgested to further structural evaluation	YES	NO	Screener: Date:

Note:
Main Structure Irregularities : Missing Column, No Building Envelope, Wood frame and masonry wall combination, Wide Opening, Plan Irregularities
Roof Structure Irregularities : Incomplete frame member, Heavy PC frame - weak support, Complicated structure (combined), Cantilever Roof
Appearance Qualities : Level of Age (Deterioration), Material quality

3.13PMFs Score Verification

Beside Basic Vulnerability Score (BV), the role of PMFs is also important to decide either the building is accepted or not. In order to make sure that the chart will work for field usage, score verification for probability has been done to simulate the possible variations starting from least to the worst in PMFs. This method based on linear distribution based on the range of score (1 – 4) and cutoff selection as presumed as 2. For all possibilities of final score, symmetric distribution between under and upper cutoff 2 should be achieved (see table 3-12).

Table 3-13: House variety and possible combined PMFs scores for the Javanese RVS

COMBINED PMFs	Joglo			Limasan			Kampung			Modern		
	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High
Stiff soil	6.4	4.8	4	5.6	4	3.4	4.8	3.2	2.55	4	3.2	2.55
Roof Structure Irregularities	5.6	4.2	3.5	4.9	3.5	2.8	4.2	2.8	2.1	3.5	2.8	2.1
Main Structure Irregularities	4.8	3.6	3	4.2	3	2.6	3.6	2.6	1.95	3	2.6	1.95
Roof Structure Irregularities +Stiff Soil	4	3	2.5	3.5	2.5	2.2	3	2	1.65	2.5	2	1.65
Roof Structure Irregularities+Soft Clay	3.2	2.4	2	2.8	2	1.8	2.4	1.8	1.5	2	1.8	1.5
Main Structure Irregularities+Stiff Soil	3.2	2.4	2	2.8	2	2	2.4	1.8	1.5	2	1.8	1.5
Main Structure Irregularities+Soft Clay	2.4	1.8	1.5	2.1	1.5	1.6	1.8	1.6	1.35	1.5	1.6	1.35
Main Structure Irregularities+Medium Appearance+Soft Clay	0.8	0.6	0.5	0.7	0.5	0.8	0.6	0.8	0.9	0.5	0.8	0.9
Main Structure Irregularities+Low Appearance+Soft Clay	0	0	0	0	0	0.6	0	0.6	0.6	0	0.6	0.6

Accepted level from the PMFs will decrease (below 2) when combined PMFs are from the most important aspect such as "Main structure and Roof Structure irregularities". From the table, it can be assumed that, the chart will work starting from the least to the worst condition according to the linear value relation. PMFs in simpler-single aspect (e.g., "stiff soil" only) will not give any significant impact to the result level while combination from all aspects will have great impact and will reduce the building performance by resulting below cut off level. The complete figure for the combined PMFs shown in figure 3-45 below;

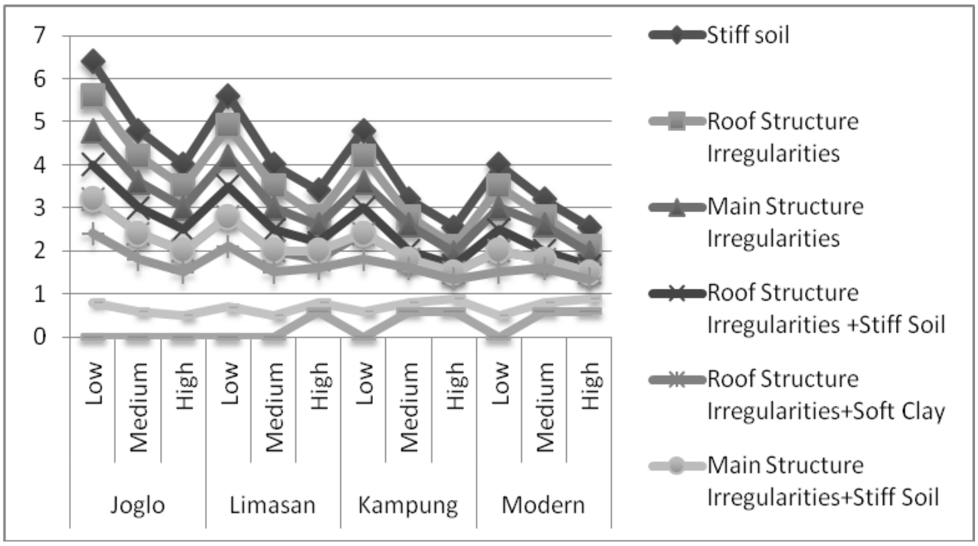


Figure 3-45: Houses performances and combined Possible PMFs in Java RVS

3.14 Summary

Rapid Visual Screening (RVS) modified for Javanese vernacular house could only be done by considering the all types of the houses found in the area. Since the form-type of the houses is widely accepted for categorizing the houses, examination based on this form type is the most suitable for the Java RVS rather than merely based on structural system type as used in FEMA RVS. In order to facilitate every type of the houses, the house typology are based on four types of the houses; *Joglo, Kampung, Limasan,* and Modern-vernacular house (or called 'modern' only in some part of this thesis).

Grading system referred from FEMA 154 is used to give the basic score of the houses. Adoption and modification of the grade was done in order to have an applicable method for Javanese houses. For further application, this initial adaptation should be always updated through time after time related to current seismicity condition and method development. Since this procedure is aimed for examining the probability in the population by concerning time limitation (rapid screening), there was no suitable method for exact qualitative-quantitative measurement used for grading system. The quality of the houses is only confirmed in range based on approximation and judgment in building structure principles. Furthermore, the comparison figure between types of the houses with their structural system performance herein is considered more rather than the focused examination of the houses since this screening system development is not aimed for detailed individual building. However, by structural performance analysis modeled for building under forces of the May 27th 2006 earthquake and support by post-earthquake data, this grading system capability is liable.

Chapter 4

FIELD APPLICATION

Field application had been done for two purposes; (1) for verification of the proposed procedure and (2) for examination of the earthquake vulnerability of Javanese houses. The first is aimed for qualitative examination by purposive sampling technique where samples were taken only from the left undestroyed houses found after earthquake for examining the houses quality-performance. The second is rather quantitative and probability sampling was applied for representing the houses in the population. Furthermore, since the method is propose for simple and massive application, in order to simulate the use of the procedure, data were gathered from the most affected area of Bantul by group of surveyor leaded and conducted by the author.

4.1 Java RVS Procedure Field Verification

4.1.1 Precedence Samples

This Java RVS development is aimed for examining all type of Javanese houses found in the area. Concerning on the vernacular houses, the form of houses and its structural system variation had been accommodated in the procedure. In order to verify its utilization, general comparison for various type and performance possibilities had been done in previous chapter. However, field examination finding is still needed to support the method. Purposive sampling was chosen in order to classify the performance of the houses which was undestroyed by the earthquake.

Samples from each type of the houses were taken representatively from the field. Since the left undestroyed houses in most affected area were rarely and hardly located, the method used for acquiring the sample was by chance (accidental sampling). To find the sample, searching was done through street surfing. Although this is not a probability sampling aimed for representing the population, the found houses could also give a rough image of the house's existence in the field.

4.1.2 Typological Performances and the RVS Examination

Four years after the catastrophe, it was not easy to find the original left undestroyed house after the earthquake in Bantul region. Everywhere were easily found new houses constructed after the quake. From the street surfing survey, few undestroyed houses examples were found. The houses range from little to severe damaged in some parts but still stand on its place and some has been reused by the owners/users. Among others, *Joglo* and *Limasan* types were relatively found more than *Kampung* or modern-vernacular houses. The samples found 8 for *Joglo,* 7 for *Limasan,* 2 for *Kampung,* and 4 for the modern type. From these numbers, the common views of the house performance of *Joglo* and *Limasan* types were more than *Kampung* and the modern types. In other word, *Kampung* and the modern types were most destroyed and very small numbered still exist although the house population was dominated by *Kampung* and the modern types in pre-earthquake time.

After applying the RVS procedure on the samples, the figures of these houses show various performance of the houses. RVS scores are applied for both before and after the earthquake by identify the modified part done for reinforcement of the houses. Comparative examination about the scores and the aspects related to the modifying factors could be recognized. Furthermore, how the houses were affected by the earthquake also could be defined. By this way, comparison of the score according to the house and structural types could be proved more herein. The complete figure can be shown in table 4-1;

Table 4-1: RVS result applied for left undestroyed houses according to house types before and after the earthquake

Samples	RVS Score (pre-Earthquake)	RVS Score (post- Earthquake)	Affected and changed matters
Joglo 1	1.6	2.4	Masonry failure, changed to RC
Joglo 2	2	2*	Brick wall in filled failure
Joglo 3	4	4*	Wood Frame, None
Joglo 4	1.6	2.4	Masonry failure, changed to RC
Joglo 5	1.6	1.6*	Masonry failure
Joglo 6	1.6	2.4	Masonry failure, changed to RC
Joglo 7	1.6	2.4	Masonry failure, changed to RC
Joglo 8	1.6	2.4	Masonry failure, changed to RC
Limasan 1	1.6	2.4	Masonry failure, changed to RC
Limasan 2	1.6	1.6*	Masonry failure
Limasan 3	1.8	1.8*	Brick wall in filled failure
Limasan 4	1.6	2.4	Masonry failure, changed to RC
Limasan 5	1.6	1.6*	Masonry failure
Limasan 6	1.6	1.6*	Masonry failure
Limasan 7	3.2	3.2*	Wood Frame, None
Kampung 1	2.55	2.55*	Wood Frame, None
Kampung 2	1.8	1.8*	RC Failure, Low appearance, None
Modern 1	1.5	1.5*	RC Frame, Main irregularity, None
Modern 2	2.55	2.55*	RC frame, none
Modern 3	2.25	2.25*	RC frame, Medium Quality, None
Modern 4	2.25	2.25*	RC frame, Medium Quality, None

* no following strengthening had been applied

Beside the number of the houses, from the result, RVS scores for the houses pre and post earthquake are increased significantly after some strengthening applied to the houses. The houses which had less scored (under 2) had proven to be damaged severely. Only by certain treatment then the house is secure and life safety level could be achieved. This proves that Basic Score (BS) and Performance Modifying Factors (PMFs) altogether are work here.

Although affected severely in the earthquake, these houses were still standing but had some severe damage. This occurrence was found mostly from the *Joglo* and

Limasan houses case where had been examined to have higher performance compare to others. However, modifying performance such as using in filled brick wall or masonry bearing system of the houses had modified the score below cut-off value. For this reason, the score was below 2 (as assumed for medium damage level related to cut-off) while the one which use the original structure of wood and good appearance had no or very little effect and scored higher. Fortunately, the inner structural system by using main columns had helped the houses from further damage and collapse. Considering the level of damage, score between 1 and 2 would not result completely collapsed. Again, this is confirmed that damage level is correlated with the final score of this RVS.

Looking to the causing factors in every type of the left undestroyed houses, it can be resumed that infill brick wall in wood frame, masonry wall, and even brick wall in RC frame were the most causing factor to decrease the score almost for all cases. Some houses mostly *Joglo* and *Limasan* types were had higher change to survive with less modifying factors applied (e.g., better quality of masonry or brick wall in filled). This is understandable since frame performances as proved by computer simulation where the best to the least are *Joglo, Limasan*, *Kampung,* and Modern-vernacular type. The modern type results the least one since there is no main frame supporting in the middle of the houses. Once this type damaged from the quake in severe level, there is nothing left for load support inside. For others, the four main columns in the center of the house took responsible to bear the roof, if outer wall were damaged. For this reason, some *Joglo* and *Limasan* houses were still found in the area though being damage in some level.

4.2 Vulnerability Level Examination

4.2.1 Samples Gathered

In order to examine the level of vulnerability, the Javanese RVS procedure had been applied for population of building in ten sub districts most affected from the May 27th, 2006 earthquake in Bantul district (figure 4-1). These population of new houses constructed after the catastrophe, had been chosen in order to confirm their performance under the quake. This vulnerability screening procedure is needed for new reconstructed houses since these houses are still in high risk location. The others building population outside are considered as less risk and not as main target of this field study in vulnerability examination.

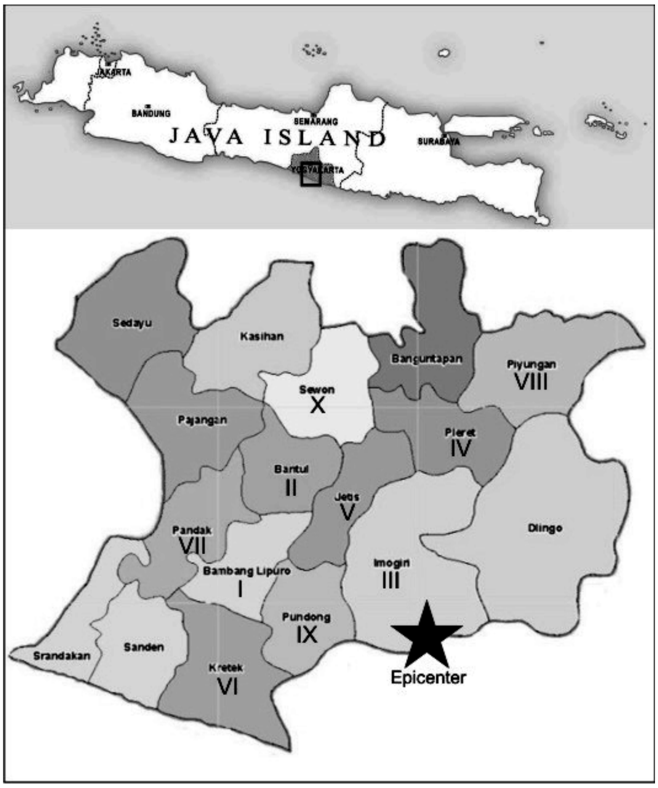


Figure 4-1: the ten most affected sub districts location in Bantul

The figure of Javanese house found outside the affected area from the quake are somehow similar to the houses were collapsed in 2006. Suppose that the similar earthquake occurs in that area, the damage result should not be far different from the

2006 catastrophe (see figure 4-2). Fortunately, these other houses are located in a distance such that the seismicity risk is less. For this reason, samples from outside area were only used as form reference in the previous discussion.

Figure 4-2: Similar *Kampung* type in Bantul before the earthquake (destroyed) and other area in Sleman after earthquake (undamaged)

Bantul district of Yogyakarta province is one of the most affected areas beside Klaten region in Central Java. From the two areas was comprised 72 percent of the total housing stock destroyed, and 95 percent of total fatalities and serious injuries occurred in these districts (LODIY, 2009). More than 50 percent of housing stock destructed in Bantul was uninhabited (see table 4-2). The ten most affected area then were taken as sample in order to examine the highest risk. 71.2 percent of total houses were destroyed uninhabited. In order to have trustworthy result, reliability has been defined by statistical method as high as possible about 95 percent by margin error less than 6 percent. The number of samples related to the population of building then decided according the equation bellow (Yamane, 1967):

$$\mathbf{n = \frac{N}{Nd^2 + 1}}$$

Where
n : samples number
N: population
d : margin error

Table 4-2: Statistical Data of Houses Affected by 2006 Java Earthquake in Bantul region (source: updated from BAPPENAS, 2006a/b, 2009)

No	Sub-districts	Total Houses*	Collapsed	Heavily Damaged	Lightly Damaged	Total uninhabited	% uninhabited **
1	BAMBANG LIPURO	12394	6587	2732	816	9319	75.19
2	BANTUL	17364	4708	7378	3295	12086	69.60
3	IMOGIRI	16072	5664	5353	4471	11017	68.55
4	PLERET	12349	8139	2322	1438	10461	84.71
5	JETIS	14493	11195	2532	655	13727	94.72
6	KRETEK	9573	1081	4665	2486	5746	60.02
7	PANDAK	13406	2886	5185	4065	8071	60.20
8	PIYUNGAN	13882	5514	4801	3135	10315	74.30
9	PUNDONG	10216	6793	1903	500	8696	85.12
10	SEWON	29366	8281	8496	6004	16777	57.13
11	BANGUNTAPAN	28013	5557	8232	7452	13789	49.22
12	DLINGO	9101	1377	3380	4720	4757	52.27
13	KASIHAN	27629	1790	4657	12103	6447	23.33
14	PAJANGAN	10282	1228	2216	2610	3444	33.50
15	SANDEN	9989	97	2052	4650	2149	21.51
16	SEDAYU	14372	243	1800	4591	2043	14.21
17	SRANDAKAN	9162	342	3054	3506	3396	37.07
	total	257664	71482	70758	66497	142240	55.20

**Based on year 2003 census statistical data (PODES 2003) by 12% growth assumption*

*** Ratio of total severe damaged houses*

292 random new houses samples data from assumed total population of 150000 houses in the most affected ten sub districts in Bantul area were taken according the RVS method. As its original procedure for rapid screening, only visual appearance could be considered. For Java RVS, inside house data is taken as possible in order to examine the total performance. User or owner participation to support data is assessed if the data could not be seen directly by the screener. Although outside appearance in RVS is enough to gather the required data on the procedure, however, since this Javanese RVS is deal with vernacular houses where simpler in form and structure, complete structural system needs to be assured. Accessing inside house is mostly needed since inside data are also considered as important aspect to decide the performance of the building.

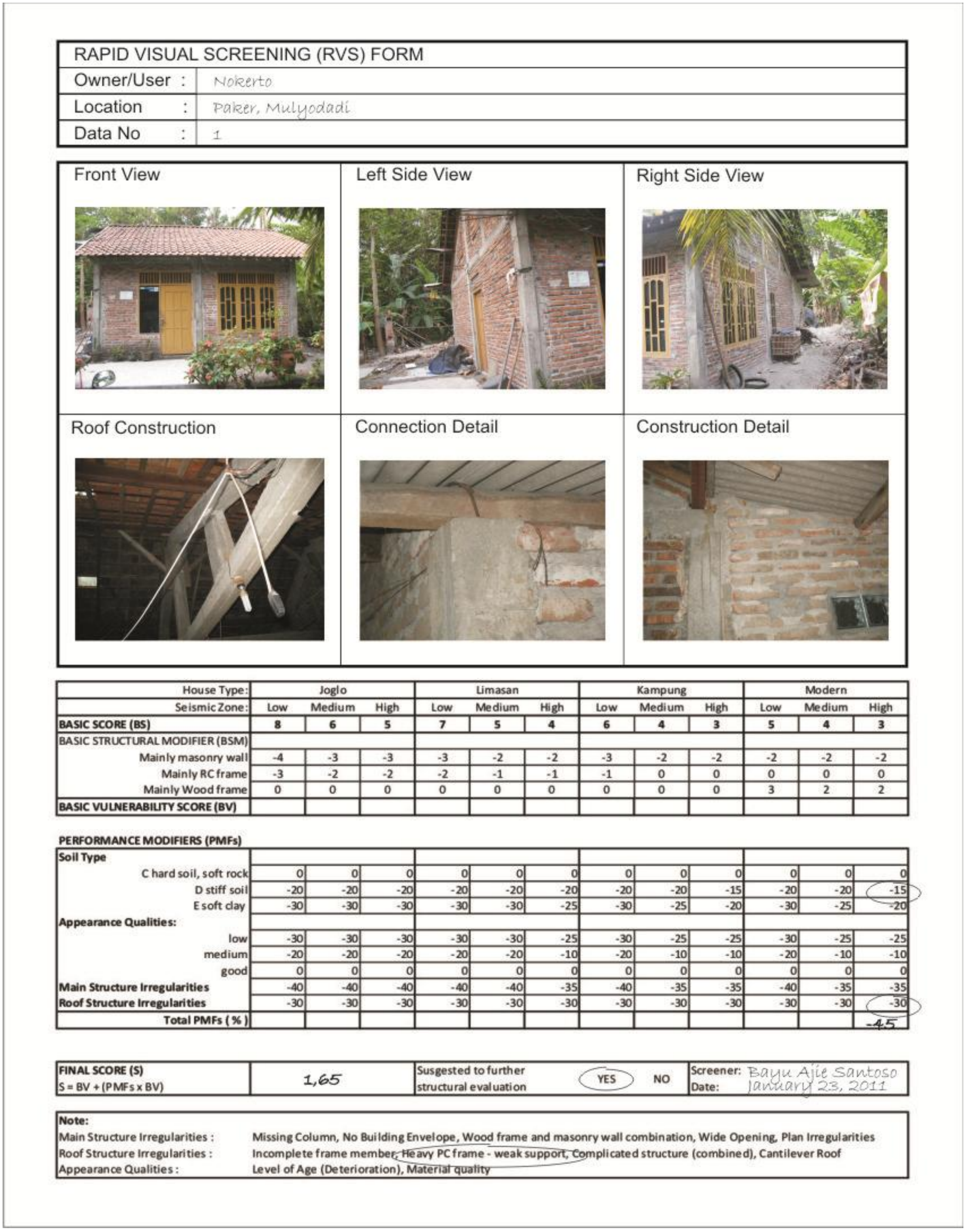
4.2.2 Data Assessment

In general, based on seismic map published by Indonesia government, all Bantul area are located in high seismicity area. According to the microzonation map (Karnawati, *et.al*, 2008), almost ten sub districts taken for sample population above are located in high seismicity area. Only two of them, which are Bantul and Sewon are located in medium seismicity (table 4-3). For this purpose of RVS examination, Bantul and Sewon then categorized both for high and medium, since the total destructed houses were high as happened as other eight districts. Comparison result from both high and medium seismicity will be evaluated later.

Table 4-3: Seismicity zone of study area and data gathered

No	Sub-districts	Seismic Zone Map	Microzotaion	Sample gathered
1	Bambanglipuro	High	High	30
2	Bantul	High	Medium	27
3	Imogiri	High	High	30
4	Pleret	High	High	33
5	Jetis	High	High	25
6	Kretek	High	High	27
7	Pandak	High	High	30
8	Piyungan	High	High	30
9	Pundong	High	High	30
10	Sewon	High	Medium	30
Total				292

For the purpose of RVS screening, a specific form has been prepared as Java RVS. This form consists three parts main information, which are general information about house owner or user and location, drawing or photograph of the sample house, and RVS chart for examining the house. All these information is printed in single sheet of RVS examination for all seismicity area (figure 4-3).



RAPID VISUAL SCREENING (RVS) FORM

Owner/User : Nokerto

Location : Paker, Mulyodadi

Data No : 1

House Type:	Joglo			Limasan			Kampung			Modern		
Seismic Zone:	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High
BASIC SCORE (BS)	**8**	**6**	**5**	**7**	**5**	**4**	**6**	**4**	**3**	**5**	**4**	**3**
BASIC STRUCTURAL MODIFIER (BSM)												
Mainly masonry wall	-4	-3	-3	-3	-2	-2	-3	-2	-2	-2	-2	-2
Mainly RC frame	-3	-2	-2	-2	-1	-1	-1	0	0	0	0	0
Mainly Wood frame	0	0	0	0	0	0	0	0	0	3	2	2
BASIC VULNERABILITY SCORE (BV)												

PERFORMANCE MODIFIERS (PMFs)

Soil Type												
C hard soil, soft rock	0	0	0	0	0	0	0	0	0	0	0	0
D stiff soil	-20	-20	-20	-20	-20	-20	-20	-20	-15	-20	-20	-15
E soft clay	-30	-30	-30	-30	-30	-25	-30	-25	-20	-30	-25	-20
Appearance Qualities:												
low	-30	-30	-30	-30	-30	-25	-30	-25	-25	-30	-25	-25
medium	-20	-20	-20	-20	-20	-10	-20	-10	-10	-20	-10	-10
good	0	0	0	0	0	0	0	0	0	0	0	0
Main Structure Irregularities	-40	-40	-40	-40	-40	-35	-40	-35	-35	-40	-35	-35
Roof Structure Irregularities	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30
Total PMFs (%)												-45

FINAL SCORE (S) S = BV + (PMFs x BV)	1,65	Susgested to further structural evaluation [✓ YES] NO	Screener: Bayu Ajie Santoso Date: January 23, 2011

Note:

Main Structure Irregularities :	Missing Column, No Building Envelope, Wood frame and masonry wall combination, Wide Opening, Plan Irregularities
Roof Structure Irregularities :	Incomplete frame member, Heavy PC frame - weak support, Complicated structure (combined), Cantilever Roof
Appearance Qualities :	Level of Age (Deterioration), Material quality

Figure 4-3: Java RVS applied to the field sample

To be able to fill the form, screener should double check to the structural system used both from outside and inside of the houses. If inside examination could not be done, e.g. because of already constructed by ceiling, information from the user or owner then should be gathered. Sketches or photographs are necessary to be attached on the form. Simple calculator can be used to determine the result of the RVS chart.

Any performance deficiency should be noted in the final part of the chart. By all these information, further detailed examination for earthquake vulnerability could be preceded.

4.2.3 Vulnerability Assessment Result

From the ten sub districts sample gathered in Bantul, the result figure is somehow as predicted before. Since the main new houses are mostly constructed by RC frame (RC confined) with the brick wall, the initial grades for the houses were already less. Unfortunately, many PMFs which are mostly caused by heavy roof without or less sufficient support are the main finding for the case. Because of these reasons, final grades for RVS are mostly low. Even more than 50% un-accepted houses are found in the area. The average non-accepted house is about 47.7. The complete figure of RVS result in the ten sub-districts in Bantul can be seen as follow (Table 4-4).

Table 4-4: Java RVS Result for New Houses in High Seismicity Ten Sub-Districts in Bantul

No	**Sub-Districts**	**Samples**	**Non Accepted**	**%**
1	Bambanglipuro	30	17	56.7
2	Bantul	27	10	37.0
3	Imogiri	30	6	20.0
4	Jetis	25	10	40.0
5	Kretek	27	18	66.7
6	Pandak	30	12	40.0
7	Piyungan	30	13	43.3
8	Pleret	33	13	39.4
9	Pundong	30	19	63.3
10	Sewon	30	20	66.7
	TOTAL	**292**	**138**	**47.3**

If two sub districts move to the medium seismicity, according to microzonation map, the figure of un-accepted house is still high about 16.7 percent of the sample. If house located in cut off value as 2 is taken in to consideration, the number is increase up to 56.7 percent (see table 4-5).

Table 4-5: Java RVS Result for New Houses considering Two Sub-Districts as located in Medium Seismicity

No	Sub-Districts	Samples	Non Accepted	Cut-Off	% Not Accpt	% Incl.Cut-Off
1	Bambanglipuro	30	6	2	20.0	26.7
2	Sewon	30	4	14	13.3	60.0
	TOTAL	**60**	**10**		**16.7**	**56.7**

4.3House Performance Evaluation

Heavy mass construction such as RC frame with brick wall in almost RVSs will put the houses always in less performance. Even though in this RVS, RC frame initial grade has been elevate higher compare to the FEMA 154, the result of RVS is still bellow expectation for the better new house after earthquake.

In other side, the traditional houses are also not always in better result especially if modification was done for the structure of the house. Since the brick walls are widely used for the wall, if located in high seismicity area, this type of house is also does not have any chance to get a better grade. Even some traditional houses in other areas are still use weak masonry wall without the frame as before. Once applied for the RVS, the masonry house will always below cut off level in high seismicity area since the masonry building is originally not suggested to be constructed in high risk in earthquake.

4.4 Summary

Comparing the building performances for seismic vulnerability applied for the Javanese houses left undestroyed both for pre and post earthquake condition concluded that the use of Java RVS has been proved. House quality related to form type and structural system had been evaluated through acceptable scoring system used in Java RVS procedure. This step is very important in order to confirm the procedure liability.

For vulnerability examination, Java RVS again gives confirmation that the procedure works in the field. 292 samples had been examined and unfortunately the result is below the general expectation that the new house will give significant protection to the people. The main aspect to the level of vulnerability in Javanese vernacular house is come from the building practice. As predicted before in this study, mixed application in material usage especially RC both for building type and structural system, has lessen the performance of the building.

Although the RVS itself is simple, it can be a quietly powerful tool for grading the seismic vulnerability since almost all aspects related to the building performance had been considered in its development. In order the keep procedure up to date, further modification and adaptation are still needed regarding the actual seismicity condition in the field.

Chapter 5

CONCLUSIONS and SUGGESTIONS

As result of the study, the Javanese RVS has been developed, and the method has been proven work in the field. This RVS modified in vernacular architecture is very important since the earthquake loss, related to this type of building, especially in developing countries was very high. The study will contribute in the risk mitigation from earthquake for those buildings which was relatively less considered.

5.1 Javanese Houses and Rapid Visual Development

It was broadly known that traditional architecture as a product of long time trial and error has ideality for its adaptation to the nature. Related to its ability to deal with the environment, it was believed that some architectural type of traditional architecture has the best answer to face the challenge. 'Javanese traditional house' as part of Javanese vernacular architecture was also believed as the best earthquake resistant building in the area. Unfortunately, the May 27th 2006 earthquake has different result from the expectation. Thousands of Javanese houses were heavily destructed and collapsed during the quake. This was mainly proofed because of the use of less appropriate material such as weak masonry and less performance RC confined-brick wall. This leaded to the re-questioning about the performance of the houses. Prejudgment of ideality of the traditional houses from the risk of earthquake should be assured since the structural type of the houses are not as found as the original structure as wood.

Modern-vernacular type of the RC houses, in the other side, has been widely built especially after the May 27th 2006 earthquake. This type of house was believed as most secure structure in modern way to answer the earthquake threat in the area. However, a far from miss-used application in the field, as common building knowledge, this heavy mass RC building without appropriate quality and quantity of the element is not the answer for accommodate seismic forces. Instead, to be less vulnerable, light mass and flexible structure should be used since its capacity to deal with the shaking. Furthermore, mixed application building technique in the field as result of people misinformation and misunderstanding regarding new and traditional way was widespread. This was trigger uncertainty in vulnerability level among the houses.

In order to be able to examine the level of vulnerability, FEMA 154 Rapid Visual Screening had been referred as adopted procedure for Java RVS. This option was chosen since FEMA RVS has several advantages in rapid screening such as practical usage and simplicity but rationality in engineering point of view. The method was also has been broadly used inside the US and known as one of the most referred one for earthquake vulnerability screening in other parts of the world.

Adoption and adaptation had been taken from FEMA RVS for the concept of screening procedure and grading technique according the Javanese houses environment. However, as the nature of qualitative and quantitative exchange regarding seismicity, building structure and its damage probability under earthquake loading, purely exact method was unavailable. For this reason, the background knowledge including local practice of building, which is vernacular architecture, is undeniably needed. Based on this circumstance, grading method for Java RVS had been done as quantitative-qualitative examination. By this method, an accurate grading system for Java RVS could be established.

However, developing the method in seismic vulnerability, should not as seen as one closed loop process. Updating the procedure according the new technology and current seismic activity should be achieved in order to have more accurate result of the method. For this purpose, the accurate data of earthquake activity and its correlation with the building and casualties is definitely very essential.

5.2 Vulnerability Level of Javanese Vernacular Architecture

Applied in the affected areas from the May 27th 2006 earthquake, Java RVS has result that new houses as result of reconstruction program after the quake has mixture performances from high to low level of vulnerability. Different application and variety of building technique applied in the field are the most causal factor for altering the building quality. It was understandable since the destruction was massive and the reconstruction processes were done by many autonomic institutions.

Unfortunately, as accumulative result, the levels of vulnerability in the ten most affected sub-district areas in Bantul are still high. According to the FEMA RVS method which is adopted in Java RVS, if cut-off is taken as 2 (which mean 1 percent probability in 50 year earthquake return period), the chance being more than 60 percent damage (uninhabitable) is about 47 percent in average. It is important to be emphasized that this Java RVS takes into account the population figure since it deals with the probability. If the building population in Bantul district alone is about

250,000 houses, 2500 houses is actually the maximum probability being damage. If sub-district population is about 15,000 houses, 150 of them only expected to be damaged. However, 47 percent in average thus mean more than 7000 expected will being uninhabitable damaged. This figure has no significant different from the May 27th 2006 earthquake occurrence that in average more than 50 percent was uninhabitable (see table 4-1).

Besides considering accumulative result, this Java RVS screening are also resulting individual level of vulnerability of a house. If 47 percent beyond cut-off 2, it means this 47 percent houses should be double check one by one. Every case is difference, in order to increase the performance under earthquake and decrease vulnerability level, specific reinforcement should be done. The result of Java RVS is as base step for further examination which means without RVS procedure, detailed assessment could not be done properly.

5.3 The Future of Javanese Vernacular Architecture

This Java RVS development and field application has proved that the performance of Javanese houses could vary through architectural and structural types. What we called as vernacular architecture in Javanese houses range from low to very high quality in sense of earthquake vulnerability level. It depends on the structural type used through the form typology of the houses.

In term of structural type, it is commonly known that lighter and flexible structural system has better response to the lateral forces. For this reason traditional way of construction by utilizing wood as main material still as better way to deal with earthquake. For using RC house together with brick wall is also accepted as long as the building has only minor performance modification. But for masonry house, there is no chance to survive from lateral loading. For this reason masonry is not suggested for house in high or even in medium seismicity area.

Based on the result of this research, it is time for reorienting the concept of the vernacular house in Java. Since the area is mostly has high to medium seismicity, using appropriate type of building structure along with architectural type is priority task. Unfortunately, looking back to the traditional way is not always convenience for some reasons such as trend of fashion and also budget limitation. However, all these aspects would not be equal to the cost of catastrophe resulted from wrong decision in house development.

After considering all results in this study, the author needs to emphasis that the product of this study which is the Javanese rapid visual screening proves to be the powerful and useful enough as one of important tools in seismic vulnerability assessment and deserve to be considered to be applied broadly in the field. Comprehensive comparison in vernacular house types in Java also confirms that the new development technique application do not always in parallel to the safety level of the people, instead, older-traditional ways has proven to be more suitable to the Javanese condition. Considering the safety issues related to the earthquake problem, this finding will alternate the direction of housing development in the future.

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APPENDIX

Appendix A: Earthquake Loading Simulation Result

A.1. Frame Load comparison in Wood Frame (Ton)

	Joglo		Limasan		Kampung		Modern
	M Clmn	Ex Clmn	M Clmn	Ex Clmn	M Clmn	Ex Clmn	Ex Clmn
Axial X	-5	-4.5	-5	-6	-6	-8	-5
Axial Y	-6	-5	-8	-7	-8	-6	-4
Moment X	-2.5	-1.7	-2.5	-2	-3	-3	-3
Moment Y	-3.5	-1.5	-4	-3	-4	-3	-2.5
Shear X	-1	-0.7	-1	-0.5	-3	-3	-1
Shear Y	-1	-0.6	-1.5	-1	-4	-1	-1

A.2. Frame Load comparison in Wood Frame-Brick Wall Infill (Ton)

	Joglo		Limasan		Kampung		Modern
	M Clmn	Ex Clmn	M Clmn	Ex Clmn	M Clmn	Ex Clmn	Ex Clmn
Axial X	-5	-6	-5	-6	-1.5	-3	-9
Axial Y	-4	-3	-3.5	-5	-1.5	-2	-3

A.3. Frame Load comparison in Masonry Bearing Wall (Ton)

	Joglo		Limasan		Kampung		Modern
	M Clmn	Ex Clmn	M Clmn	Ex Clmn	M Clmn	Ex Clmn	Ex Clmn
Axial X	-5		-3		-1.7		
Axial Y	-4		-3		-1.5		

A.4. Frame Load comparison in Completely RC Frame (Ton)

	Joglo		Limasan		Kampung		Modern
	M Clmn	Ex Clmn	M Clmn	Ex Clmn	M Clmn	Ex Clmn	Ex Clmn
Axial X	-8	-6	-6	-7	-6	-7	-11
Axial Y	-9	-7	-11	-10	-10	-9	-6
Moment X	-5	-3	-5	-3.5	-4	-3.5	-10
Moment Y	-2	-1.5	-8	-6	-6	-6	-8
Shear X	-3	-2.5	-3	-1.5	-2	-1.7	-7
Shear Y	-1	-1	-4	-2.5	-2	-3	-3

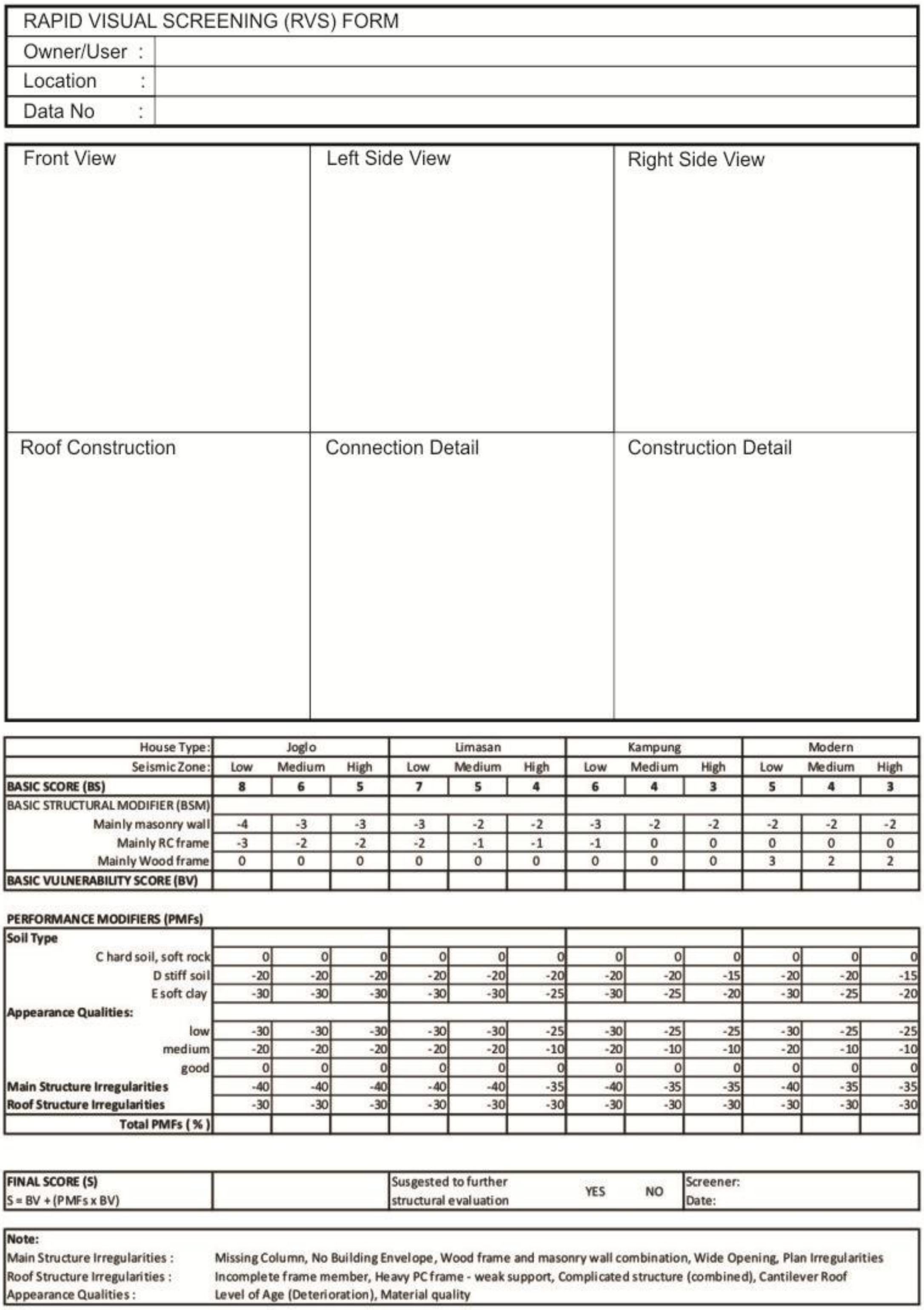
A.5. Frame Load comparison in Completely RC Frame-Brick Wall (Ton)

	Joglo		Limasan		Kampung		
	M Clmn	Ex Clmn	M Clmn	Ex Clmn	M Clmn	Ex Clmn	Ex Clmn
Axial X	-5	-2.5	-6	-7	-3	-1.5	-60
Axial Y	-6	-1	-5	-7	-4	-3	-17

A.6. Stresses comparison in walls (MPa)

House Types	Structural Type	Earthquake	WALL X		WALL Y	
			S11	S13	S22	S23
Joglo	Brick Infill	EX	0.3	0.4	0.25	0.15
		Ey	0.45	0.25	0.02	0.02
	Masonry	EX	0.1	0.1	0.02	0.04
		Ey	0.3	0.2	0.3	0.08
	RC brick	EX	0.3	0.4	0.1	0.05
		Ey	0.5	0.25	0.2	0.17
Limasan	Brick Infill	EX	0.25	0.25	0.6	0.3
		Ey	0.18	0.12	0.5	0.2
	Masonry	EX	0.4	0.35	0.75	0.5
		Ey	0.2	0.3	0.5	0.4
	RC brick	EX	0.22	0.12	0.5	0.25
		Ey	0.02	0.08	0.3	0.3
Kampung	Brick Infill	EX	0.3	0.2	0.25	0.8
		Ey	0.2	0.15	0.6	0.5
	Masonry	EX	0.2	0.15	0.25	0.17
		Ey	0.21	0.17	0.5	0.5
	RC brick	EX	0.12	0.15	0.3	0.4
		Ey	0.1	0.18	0.25	0.5
Modern	Brick Infill	EX	0.75	0.7	0.7	0.75
		Ey	1	0.3	0.18	0.16
	Masonry	EX	1	0.4	0.3	0.6
		Ey	1.1	0.6	0.12	0.14
	RC brick	EX	2	1.6	6	2
		Ey	4	3	0.8	0.75

Appendix B: Java RVS Form



RAPID VISUAL SCREENING (RVS) FORM

Owner/User :

Location :

Data No :

Front View

Left Side View

Right Side View

Roof Construction

Connection Detail

Construction Detail

House Type:	Joglo			Limasan			Kampung			Modern		
Seismic Zone:	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High
BASIC SCORE (BS)	**8**	**6**	**5**	**7**	**5**	**4**	**6**	**4**	**3**	**5**	**4**	**3**
BASIC STRUCTURAL MODIFIER (BSM)												
Mainly masonry wall	-4	-3	-3	-3	-2	-2	-3	-2	-2	-2	-2	-2
Mainly RC frame	-3	-2	-2	-2	-1	-1	-1	0	0	0	0	0
Mainly Wood frame	0	0	0	0	0	0	0	0	0	3	2	2
BASIC VULNERABILITY SCORE (BV)												

PERFORMANCE MODIFIERS (PMFs)

Soil Type												
C hard soil, soft rock	0	0	0	0	0	0	0	0	0	0	0	0
D stiff soil	-20	-20	-20	-20	-20	-20	-20	-20	-15	-20	-20	-15
E soft clay	-30	-30	-30	-30	-30	-25	-30	-25	-20	-30	-25	-20
Appearance Qualities:												
low	-30	-30	-30	-30	-30	-25	-30	-25	-25	-30	-25	-25
medium	-20	-20	-20	-20	-20	-10	-20	-10	-10	-20	-10	-10
good	0	0	0	0	0	0	0	0	0	0	0	0
Main Structure Irregularities	-40	-40	-40	-40	-40	-35	-40	-35	-35	-40	-35	-35
Roof Structure Irregularities	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30
Total PMFs (%)												

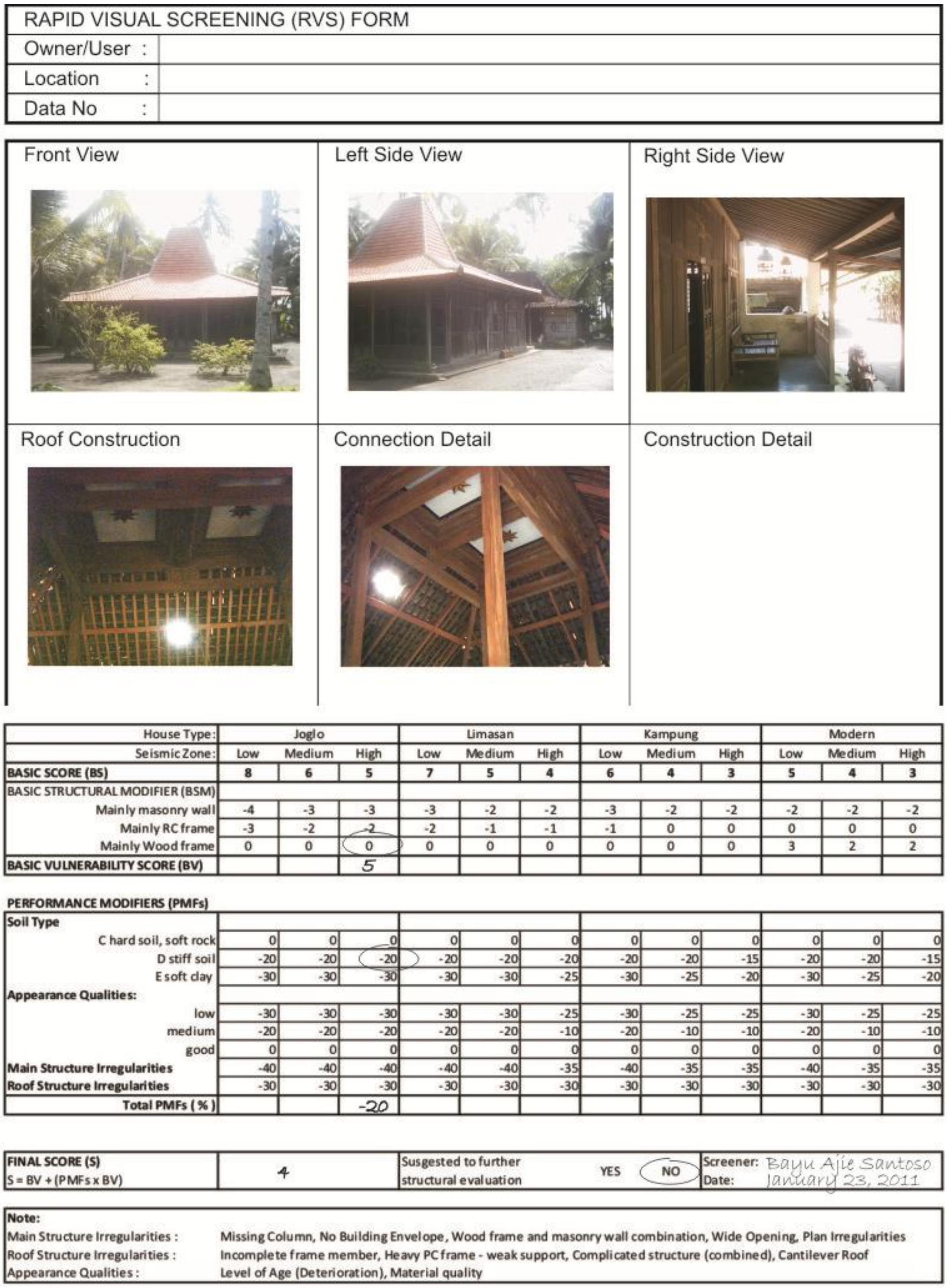
FINAL SCORE (S) S = BV + (PMFs x BV)		Susgested to further structural evaluation	YES	NO	Screener: Date:

Note:

Main Structure Irregularities :	Missing Column, No Building Envelope, Wood frame and masonry wall combination, Wide Opening, Plan Irregularities
Roof Structure Irregularities :	Incomplete frame member, Heavy PC frame - weak support, Complicated structure (combined), Cantilever Roof
Appearance Qualities :	Level of Age (Deterioration), Material quality

Appendix C: Precedence Study RVS Form Examples

C.1. 4 scorer *Joglo* before and after the earthquake



RAPID VISUAL SCREENING (RVS) FORM

Owner/User :

Location :

Data No :

Front View

Left Side View

Right Side View

Roof Construction

Connection Detail

Construction Detail

House Type:	Joglo			Limasan			Kampung			Modern		
Seismic Zone:	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High
BASIC SCORE (BS)	**8**	**6**	**5**	**7**	**5**	**4**	**6**	**4**	**3**	**5**	**4**	**3**
BASIC STRUCTURAL MODIFIER (BSM)												
Mainly masonry wall	-4	-3	-3	-3	-2	-2	-3	-2	-2	-2	-2	-2
Mainly RC frame	-3	-2	-2	-2	-1	-1	-1	0	0	0	0	0
Mainly Wood frame	0	0	[✓ 0]	0	0	0	0	0	0	3	2	2
BASIC VULNERABILITY SCORE (BV)			5									

PERFORMANCE MODIFIERS (PMFs)

Soil Type												
C hard soil, soft rock	0	0	0	0	0	0	0	0	0	0	0	0
D stiff soil	-20	-20	[✓ -20]	-20	-20	-20	-20	-20	-15	-20	-20	-15
E soft clay	-30	-30	-30	-30	-30	-25	-30	-25	-20	-30	-25	-20
Appearance Qualities:												
low	-30	-30	-30	-30	-30	-25	-30	-25	-25	-30	-25	-25
medium	-20	-20	-20	-20	-20	-10	-20	-10	-10	-20	-10	-10
good	0	0	0	0	0	0	0	0	0	0	0	0
Main Structure Irregularities	-40	-40	-40	-40	-40	-35	-40	-35	-35	-40	-35	-35
Roof Structure Irregularities	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30
Total PMFs (%)			-20									

FINAL SCORE (S) S = BV + (PMFs x BV)	4	Susgested to further structural evaluation	YES [✓ NO]

Screener: Bayu Ajie Santoso
Date: January 23, 2011

Note:

Main Structure Irregularities :	Missing Column, No Building Envelope, Wood frame and masonry wall combination, Wide Opening, Plan Irregularities
Roof Structure Irregularities :	Incomplete frame member, Heavy PC frame - weak support, Complicated structure (combined), Cantilever Roof
Appearance Qualities :	Level of Age (Deterioration), Material quality

C.2. 2 scorer *Joglo* before and after the earthquake

RAPID VISUAL SCREENING (RVS) FORM

Owner/User :	Ny Prawiro
Location :	Pleret
Data No :	2

Front View

Left Side View

Right Side View

Roof Construction

Connection Detail

Construction Detail

House Type:	Joglo			Limasan			Kampung			Modern		
Seismic Zone:	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High
BASIC SCORE (BS)	**8**	**6**	**5**	**7**	**5**	**4**	**6**	**4**	**3**	**5**	**4**	**3**
BASIC STRUCTURAL MODIFIER (BSM)												
Mainly masonry wall	-4	-3	-3	-3	-2	-2	-3	-2	-2	-2	-2	-2
Mainly RC frame	-3	-2	-2	-2	-1	-1	-1	0	0	0	0	0
Mainly Wood frame	0	0	0	0	0	0	0	0	0	3	2	2
BASIC VULNERABILITY SCORE (BV)			5									

PERFORMANCE MODIFIERS (PMFs)

Soil Type												
C hard soil, soft rock	0	0	0	0	0	0	0	0	0	0	0	0
D stiff soil	-20	-20	-20	-20	-20	-20	-20	-20	-15	-20	-20	-15
E soft clay	-30	-30	-30	-30	-30	-25	-30	-25	-20	-30	-25	-20
Appearance Qualities:												
low	-30	-30	-30	-30	-30	-25	-30	-25	-25	-30	-25	-25
medium	-20	-20	-20	-20	-20	-10	-20	-10	-10	-20	-10	-10
good	0	0	0	0	0	0	0	0	0	0	0	0
Main Structure Irregularities	-40	-40	-40	-40	-40	-35	-40	-35	-35	-40	-35	-35
Roof Structure Irregularities	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30
Total PMFs (%)			-60									

FINAL SCORE (S) S = BV + (PMFs x BV)	2	Susgested to further structural evaluation	YES [✓ NO]	Screener: Bayu Ajie Santoso Date: January 23, 2011

Note:

Main Structure Irregularities :	Missing Column, No Building Envelope, Wood frame and masonry wall combination, Wide Opening, Plan Irregularities
Roof Structure Irregularities :	Incomplete frame member, Heavy PC frame - weak support, Complicated structure (combined), Cantilever Roof
Appearance Qualities :	Level of Age (Deterioration), Material quality

C.3. 1.6 to 2.4 scorer *Joglo* before and after the earthquake

RAPID VISUAL SCREENING (RVS) FORM

Owner/User : Sugeng Rahardjo
Location : Pleret
Data No : 6

Front View

Left Side View

Right Side View

Roof Construction

Connection Detail

Construction Detail

House Type:	Joglo			Limasan			Kampung			Modern		
Seismic Zone:	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High
BASIC SCORE (BS)	**8**	**6**	**5**	**7**	**5**	**4**	**6**	**4**	**3**	**5**	**4**	**3**
BASIC STRUCTURAL MODIFIER (BSM)												
Mainly masonry wall	-4	-3	[✓ -3]	-3	-2	-2	-3	-2	-2	-2	-2	-2
Mainly RC frame	-3	-2	[✓ -2]	-2	-1	-1	-1	0	0	0	0	0
Mainly Wood frame	0	0	0	0	0	0	0	0	0	3	2	2
BASIC VULNERABILITY SCORE (BV)			2 / 3									

PERFORMANCE MODIFIERS (PMFs)

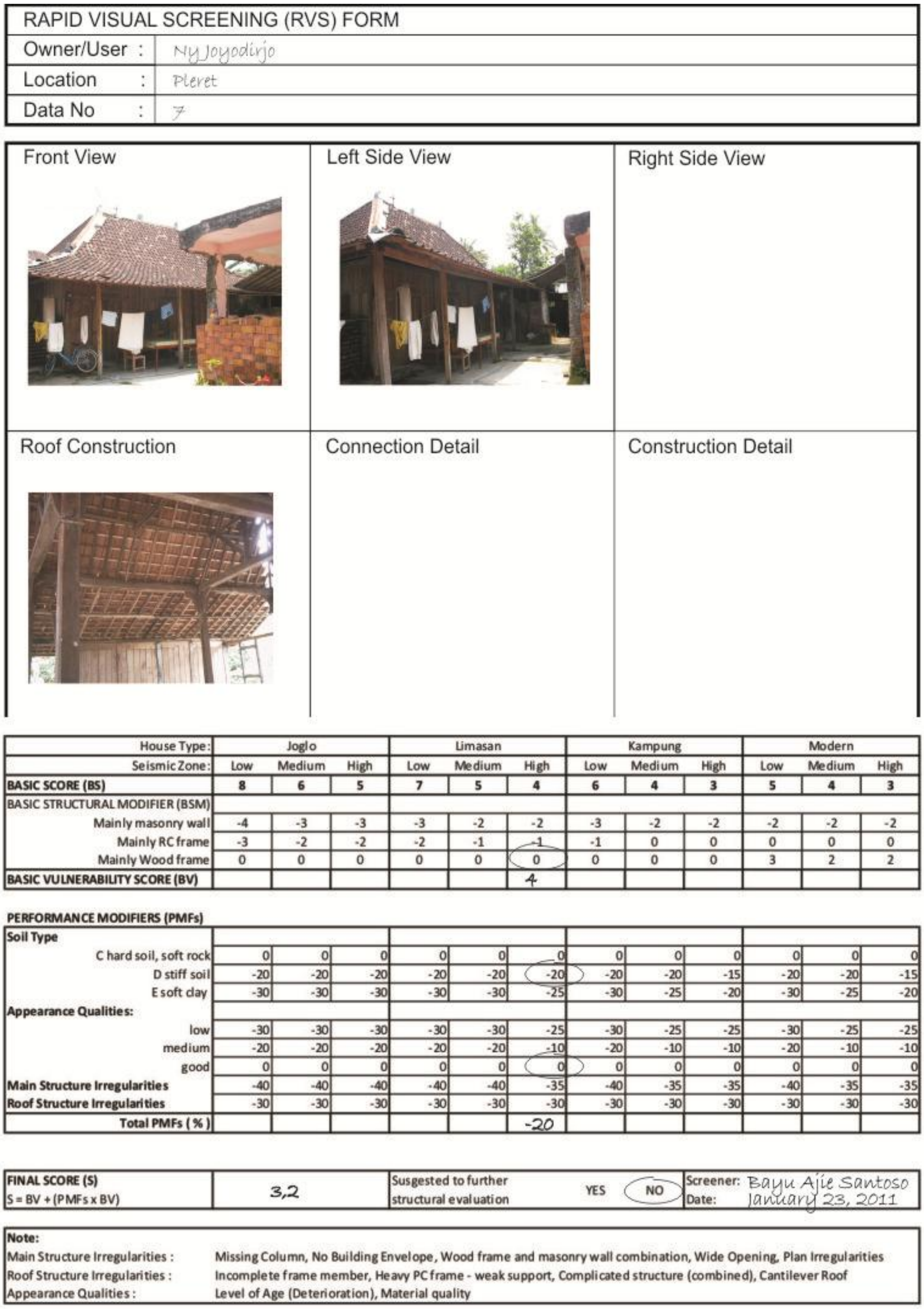
Soil Type												
C hard soil, soft rock	0	0	0	0	0	0	0	0	0	0	0	0
D stiff soil	-20	-20	[✓ -20]	-20	-20	-20	-20	-20	-15	-20	-20	-15
E soft clay	-30	-30	-30	-30	-30	-25	-30	-25	-20	-30	-25	-20
Appearance Qualities:												
low	-30	-30	-30	-30	-30	-25	-30	-25	-25	-30	-25	-25
medium	-20	-20	-20	-20	-20	-10	-20	-10	-10	-20	-10	-10
good	0	0	[✓ 0]	0	0	0	0	0	0	0	0	0
Main Structure Irregularities	-40	-40	-40	-40	-40	-35	-40	-35	-35	-40	-35	-35
Roof Structure Irregularities	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30
Total PMFs (%)			-20									

FINAL SCORE (S) S = BV + (PMFs x BV)	1,6 / 2,4	Susgested to further structural evaluation [✓ YES] [✓ NO]	Screener: Bayu Ajie Santoso Date: January 23, 2011

Note:

Main Structure Irregularities :	Missing Column, No Building Envelope, Wood frame and masonry wall combination, Wide Opening, Plan Irregularities
Roof Structure Irregularities :	Incomplete frame member, Heavy PC frame - weak support, Complicated structure (combined), Cantilever Roof
Appearance Qualities :	Level of Age (Deterioration), Material quality

C.4. 3.2 scorer *Limasan* before and after the earthquake



RAPID VISUAL SCREENING (RVS) FORM

Owner/User : Ny Joyodirjo

Location : Pleret

Data No : 7

Front View

Left Side View

Right Side View

Roof Construction

Connection Detail

Construction Detail

House Type:	Joglo			Limasan			Kampung			Modern		
Seismic Zone:	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High
BASIC SCORE (BS)	**8**	**6**	**5**	**7**	**5**	**4**	**6**	**4**	**3**	**5**	**4**	**3**
BASIC STRUCTURAL MODIFIER (BSM)												
Mainly masonry wall	-4	-3	-3	-3	-2	-2	-3	-2	-2	-2	-2	-2
Mainly RC frame	-3	-2	-2	-2	-1	-1	-1	0	0	0	0	0
Mainly Wood frame	0	0	0	0	0	[✓ 0]	0	0	0	3	2	2
BASIC VULNERABILITY SCORE (BV)						4						

PERFORMANCE MODIFIERS (PMFs)

Soil Type												
C hard soil, soft rock	0	0	0	0	0	0	0	0	0	0	0	0
D stiff soil	-20	-20	-20	-20	-20	[✓ -20]	-20	-20	-15	-20	-20	-15
E soft clay	-30	-30	-30	-30	-30	-25	-30	-25	-20	-30	-25	-20
Appearance Qualities:												
low	-30	-30	-30	-30	-30	-25	-30	-25	-25	-30	-25	-25
medium	-20	-20	-20	-20	-20	-10	-20	-10	-10	-20	-10	-10
good	0	0	0	0	0	[✓ 0]	0	0	0	0	0	0
Main Structure Irregularities	-40	-40	-40	-40	-40	-35	-40	-35	-35	-40	-35	-35
Roof Structure Irregularities	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30
Total PMFs (%)						-20						

FINAL SCORE (S) S = BV + (PMFs x BV)	3,2	Susgested to further structural evaluation	YES [✓ NO]	Screener: Bayu Ajie Santoso Date: January 23, 2011

Note:

Main Structure Irregularities :	Missing Column, No Building Envelope, Wood frame and masonry wall combination, Wide Opening, Plan Irregularities
Roof Structure Irregularities :	Incomplete frame member, Heavy PC frame - weak support, Complicated structure (combined), Cantilever Roof
Appearance Qualities :	Level of Age (Deterioration), Material quality

C.5. 1.8 scorer *Limasan* before and after the earthquake

RAPID VISUAL SCREENING (RVS) FORM

Owner/User : Sumadi
Location : Piyungan
Data No : 3

Front View

Left Side View

Right Side View

Roof Construction

Connection Detail

Construction Detail

House Type:	Joglo			Limasan			Kampung			Modern		
Seismic Zone:	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High
BASIC SCORE (BS)	**8**	**6**	**5**	**7**	**5**	**4**	**6**	**4**	**3**	**5**	**4**	**3**
BASIC STRUCTURAL MODIFIER (BSM)												
Mainly masonry wall	-4	-3	-3	-3	-2	-2	-3	-2	-2	-2	-2	-2
Mainly RC frame	-3	-2	-2	-2	-1	-1	-1	0	0	0	0	0
Mainly Wood frame	0	0	0	0	0	0	0	0	0	3	2	2
BASIC VULNERABILITY SCORE (BV)						4						

PERFORMANCE MODIFIERS (PMFs)

Soil Type												
C hard soil, soft rock	0	0	0	0	0	0	0	0	0	0	0	0
D stiff soil	-20	-20	-20	-20	-20	-20	-20	-20	-15	-20	-20	-15
E soft clay	-30	-30	-30	-30	-30	-25	-30	-25	-20	-30	-25	-20
Appearance Qualities:												
low	-30	-30	-30	-30	-30	-25	-30	-25	-25	-30	-25	-25
medium	-20	-20	-20	-20	-20	-10	-20	-10	-10	-20	-10	-10
good	0	0	0	0	0	0	0	0	0	0	0	0
Main Structure Irregularities	-40	-40	-40	-40	-40	-35	-40	-35	-35	-40	-35	-35
Roof Structure Irregularities	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30
Total PMFs (%)						-55						

FINAL SCORE (S) S = BV + (PMFs x BV)	1,8	Susgested to further structural evaluation [✓ YES] NO	Screener: Bayu Ajie Santoso Date: January 23, 2011

Note:

Main Structure Irregularities :	Missing Column, No Building Envelope, Wood frame and masonry wall combination, Wide Opening, Plan Irregularities
Roof Structure Irregularities :	Incomplete frame member, Heavy PC frame - weak support, Complicated structure (combined), Cantilever Roof
Appearance Qualities :	Level of Age (Deterioration), Material quality

C.6. 1.6 to 2.4 scorer *Limasan* before and after the earthquake

RAPID VISUAL SCREENING (RVS) FORM

Owner/User : Rahadi

Location : Piyungan

Data No : 4

Front View

Left Side View

Right Side View

Roof Construction

Connection Detail

Construction Detail

House Type:	Joglo			Limasan			Kampung			Modern		
Seismic Zone:	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High
BASIC SCORE (BS)	8	6	5	7	5	4	6	4	3	5	4	3
BASIC STRUCTURAL MODIFIER (BSM)												
Mainly masonry wall	-4	-3	-3	-3	-2	-2	-3	-2	-2	-2	-2	-2
Mainly RC frame	-3	-2	-2	-2	-1	-1	-1	0	0	0	0	0
Mainly Wood frame	0	0	0	0	0	0	0	0	0	3	2	2
BASIC VULNERABILITY SCORE (BV)						2 / 3						

PERFORMANCE MODIFIERS (PMFs)

Soil Type												
C hard soil, soft rock	0	0	0	0	0	0	0	0	0	0	0	0
D stiff soil	-20	-20	-20	-20	-20	-20	-20	-20	-15	-20	-20	-15
E soft clay	-30	-30	-30	-30	-30	-25	-30	-25	-20	-30	-25	-20
Appearance Qualities:												
low	-30	-30	-30	-30	-30	-25	-30	-25	-25	-30	-25	-25
medium	-20	-20	-20	-20	-20	-10	-20	-10	-10	-20	-10	-10
good	0	0	0	0	0	0	0	0	0	0	0	0
Main Structure Irregularities	-40	-40	-40	-40	-40	-35	-40	-35	-35	-40	-35	-35
Roof Structure Irregularities	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30
Total PMFs (%)						-20						

FINAL SCORE (S) S = BV + (PMFs x BV)	1,6 / 2,4	Susgested to further structural evaluation	[✓ YES] [✓ NO]	Screener: Bayu Ajie Santoso Date: January 23, 2011

Note:

Main Structure Irregularities :	Missing Column, No Building Envelope, Wood frame and masonry wall combination, Wide Opening, Plan Irregularities
Roof Structure Irregularities :	Incomplete frame member, Heavy PC frame - weak support, Complicated structure (combined), Cantilever Roof
Appearance Qualities :	Level of Age (Deterioration), Material quality

C.7. 1.6 scorer *Limasan* before and after the earthquake

RAPID VISUAL SCREENING (RVS) FORM	
Owner/User :	Ny Pawiro
Location :	Pleret
Data No :	5

Front View

Left Side View

Right Side View

Roof Construction

Connection Detail

Construction Detail

House Type:	Joglo			Limasan			Kampung			Modern		
Seismic Zone:	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High
BASIC SCORE (BS)	**8**	**6**	**5**	**7**	**5**	**4**	**6**	**4**	**3**	**5**	**4**	**3**
BASIC STRUCTURAL MODIFIER (BSM)												
Mainly masonry wall	-4	-3	-3	-3	-2	-2	-3	-2	-2	-2	-2	-2
Mainly RC frame	-3	-2	-2	-2	-1	-1	-1	0	0	0	0	0
Mainly Wood frame	0	0	0	0	0	0	0	0	0	3	2	2
BASIC VULNERABILITY SCORE (BV)						2						

PERFORMANCE MODIFIERS (PMFs)

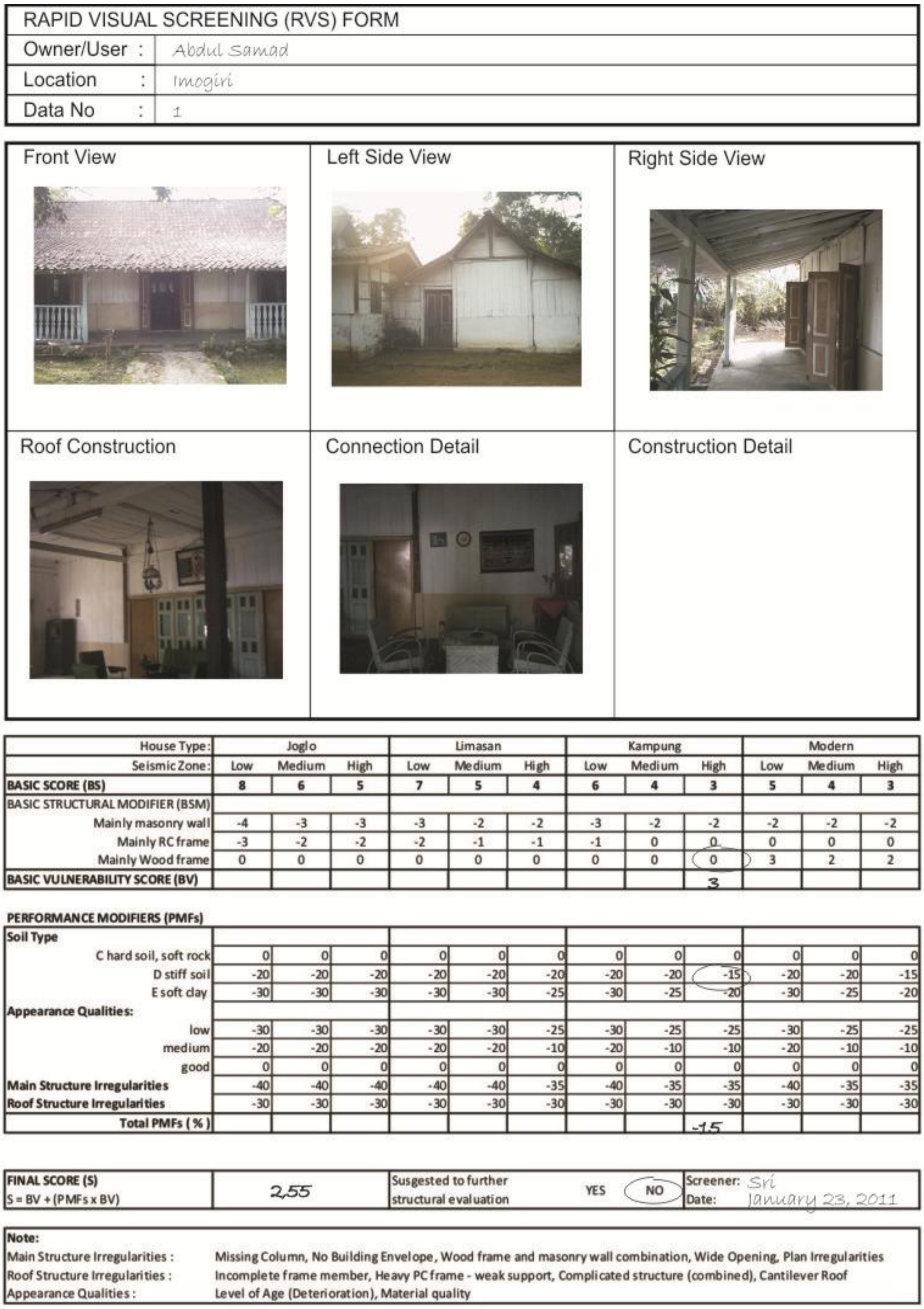
Soil Type												
C hard soil, soft rock	0	0	0	0	0	0	0	0	0	0	0	0
D stiff soil	-20	-20	-20	-20	-20	-20	-20	-20	-15	-20	-20	-15
E soft clay	-30	-30	-30	-30	-30	-25	-30	-25	-20	-30	-25	-20
Appearance Qualities:												
low	-30	-30	-30	-30	-30	-25	-30	-25	-25	-30	-25	-25
medium	-20	-20	-20	-20	-20	-10	-20	-10	-10	-20	-10	-10
good	0	0	0	0	0	0	0	0	0	0	0	0
Main Structure Irregularities	-40	-40	-40	-40	-40	-35	-40	-35	-35	-40	-35	-35
Roof Structure Irregularities	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30
Total PMFs (%)						-20						

FINAL SCORE (S) S = BV + (PMFs x BV)	1,6	Susgested to further structural evaluation	[✓ YES] NO
Screener: Bayu Ajie Santoso Date: January 23, 2011			

Note:

Main Structure Irregularities :	Missing Column, No Building Envelope, Wood frame and masonry wall combination, Wide Opening, Plan Irregularities
Roof Structure Irregularities :	Incomplete frame member, Heavy PC frame - weak support, Complicated structure (combined), Cantilever Roof
Appearance Qualities :	Level of Age (Deterioration), Material quality

C.8. 2.55 scorer *Kampung* before and after the earthquake



RAPID VISUAL SCREENING (RVS) FORM	
Owner/User :	Abdul Samad
Location :	Imogiri
Data No :	1

Front View

Left Side View

Right Side View

Roof Construction

Connection Detail

Construction Detail

House Type:	Joglo			Limasan			Kampung			Modern		
Seismic Zone:	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High
BASIC SCORE (BS)	8	6	5	7	5	4	6	4	3	5	4	3
BASIC STRUCTURAL MODIFIER (BSM)												
Mainly masonry wall	-4	-3	-3	-3	-2	-2	-3	-2	-2	-2	-2	-2
Mainly RC frame	-3	-2	-2	-2	-1	-1	-1	0	0	0	0	0
Mainly Wood frame	0	0	0	0	0	0	0	0	[✓ 0]	3	2	2
BASIC VULNERABILITY SCORE (BV)									3			

PERFORMANCE MODIFIERS (PMFs)

Soil Type												
C hard soil, soft rock	0	0	0	0	0	0	0	0	0	0	0	0
D stiff soil	-20	-20	-20	-20	-20	-20	-20	-20	[✓ -15]	-20	-20	-15
E soft clay	-30	-30	-30	-30	-30	-25	-30	-25	-20	-30	-25	-20
Appearance Qualities:												
low	-30	-30	-30	-30	-30	-25	-30	-25	-25	-30	-25	-25
medium	-20	-20	-20	-20	-20	-10	-20	-10	-10	-20	-10	-10
good	0	0	0	0	0	0	0	0	0	0	0	0
Main Structure Irregularities	-40	-40	-40	-40	-40	-35	-40	-35	-35	-40	-35	-35
Roof Structure Irregularities	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30
Total PMFs (%)									-15			

FINAL SCORE (S) S = BV + (PMFs x BV)	2,55	Susgested to further structural evaluation	YES [✓ NO]	Screener: Sri Date: January 23, 2011

Note:

Main Structure Irregularities :	Missing Column, No Building Envelope, Wood frame and masonry wall combination, Wide Opening, Plan Irregularities
Roof Structure Irregularities :	Incomplete frame member, Heavy PC frame - weak support, Complicated structure (combined), Cantilever Roof
Appearance Qualities :	Level of Age (Deterioration), Material quality

C.9. 1 scorer *Kampung* before and after the earthquake

RAPID VISUAL SCREENING (RVS) FORM	
Owner/User :	Titik
Location :	Banguntapan
Data No :	2

Front View

Left Side View

Right Side View

Roof Construction

Connection Detail

Construction Detail

House Type:	Joglo			Limasan			Kampung			Modern		
Seismic Zone:	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High
BASIC SCORE (BS)	8	6	5	7	5	4	6	4	3	5	4	3
BASIC STRUCTURAL MODIFIER (BSM)												
Mainly masonry wall	-4	-3	-3	-3	-2	-2	-3	-2	[✓ -2]	-2	-2	-2
Mainly RC frame	-3	-2	-2	-2	-1	-1	-1	0	0	0	0	0
Mainly Wood frame	0	0	0	0	0	0	0	0	0	3	2	2
BASIC VULNERABILITY SCORE (BV)									1			

PERFORMANCE MODIFIERS (PMFs)

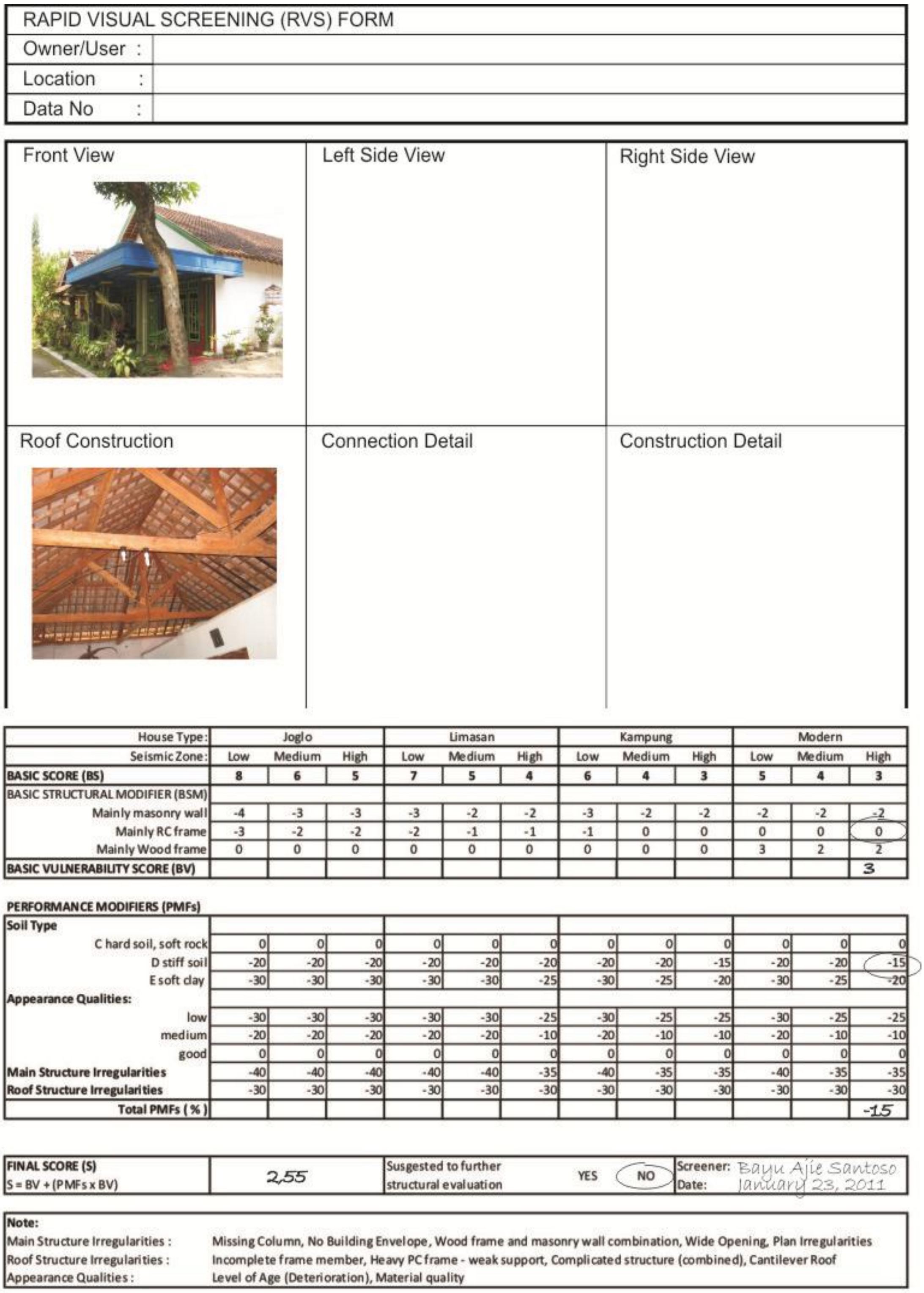
Soil Type												
C hard soil, soft rock	0	0	0	0	0	0	0	0	[✓ 0]	0	0	0
D stiff soil	-20	-20	-20	-20	-20	-20	-20	-20	-15	-20	-20	-15
E soft clay	-30	-30	-30	-30	-30	-25	-30	-25	-20	-30	-25	-20
Appearance Qualities:												
low	-30	-30	-30	-30	-30	-25	-30	-25	-25	-30	-25	-25
medium	-20	-20	-20	-20	-20	-10	-20	-10	-10	-20	-10	-10
good	0	0	0	0	0	0	0	0	[✓ 0]	0	0	0
Main Structure Irregularities	-40	-40	-40	-40	-40	-35	-40	-35	-35	-40	-35	-35
Roof Structure Irregularities	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30
Total PMFs (%)									0			

FINAL SCORE (S) S = BV + (PMFs x BV)	1	Susgested to further structural evaluation	[✓ YES] NO	Screener: Sri Date: January 23, 2011

Note:

Main Structure Irregularities :	Missing Column, No Building Envelope, Wood frame and masonry wall combination, Wide Opening, Plan Irregularities
Roof Structure Irregularities :	Incomplete frame member, Heavy PC frame - weak support, Complicated structure (combined), Cantilever Roof
Appearance Qualities :	Level of Age (Deterioration), Material quality

C.10. 2.55 scorer the Modern type before and after the earthquake



RAPID VISUAL SCREENING (RVS) FORM

Owner/User :

Location :

Data No :

Front View

Left Side View

Right Side View

Roof Construction

Connection Detail

Construction Detail

House Type:	Joglo			Limasan			Kampung			Modern		
Seismic Zone:	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High
BASIC SCORE (BS)	**8**	**6**	**5**	**7**	**5**	**4**	**6**	**4**	**3**	**5**	**4**	**3**
BASIC STRUCTURAL MODIFIER (BSM)												
Mainly masonry wall	-4	-3	-3	-3	-2	-2	-3	-2	-2	-2	-2	-2
Mainly RC frame	-3	-2	-2	-2	-1	-1	-1	0	0	0	0	[✓ 0]
Mainly Wood frame	0	0	0	0	0	0	0	0	0	3	2	2
BASIC VULNERABILITY SCORE (BV)												3

PERFORMANCE MODIFIERS (PMFs)

Soil Type												
C hard soil, soft rock	0	0	0	0	0	0	0	0	0	0	0	0
D stiff soil	-20	-20	-20	-20	-20	-20	-20	-20	-15	-20	-20	[✓ -15]
E soft clay	-30	-30	-30	-30	-30	-25	-30	-25	-20	-30	-25	-20
Appearance Qualities:												
low	-30	-30	-30	-30	-30	-25	-30	-25	-25	-30	-25	-25
medium	-20	-20	-20	-20	-20	-10	-20	-10	-10	-20	-10	-10
good	0	0	0	0	0	0	0	0	0	0	0	0
Main Structure Irregularities	-40	-40	-40	-40	-40	-35	-40	-35	-35	-40	-35	-35
Roof Structure Irregularities	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30
Total PMFs (%)												-15

FINAL SCORE (S) S = BV + (PMFs x BV)	2,55	Susgested to further structural evaluation YES [✓ NO]	Screener: Bayu Ajie Santoso Date: January 23, 2011

Note:

Main Structure Irregularities :	Missing Column, No Building Envelope, Wood frame and masonry wall combination, Wide Opening, Plan Irregularities
Roof Structure Irregularities :	Incomplete frame member, Heavy PC frame - weak support, Complicated structure (combined), Cantilever Roof
Appearance Qualities :	Level of Age (Deterioration), Material quality

C.11. 2.25 scorer the Modern type before and after the earthquake

RAPID VISUAL SCREENING (RVS) FORM	
Owner/User :	
Location :	
Data No :	

Front View

Left Side View

Right Side View

Roof Construction

Connection Detail

Construction Detail

House Type:	Joglo			Limasan			Kampung			Modern		
Seismic Zone:	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High
BASIC SCORE (BS)	**8**	**6**	**5**	**7**	**5**	**4**	**6**	**4**	**3**	**5**	**4**	**3**
BASIC STRUCTURAL MODIFIER (BSM)												
Mainly masonry wall	-4	-3	-3	-3	-2	-2	-3	-2	-2	-2	-2	-2
Mainly RC frame	-3	-2	-2	-2	-1	-1	-1	0	0	0	0	0
Mainly Wood frame	0	0	0	0	0	0	0	0	0	3	2	2
BASIC VULNERABILITY SCORE (BV)												3

PERFORMANCE MODIFIERS (PMFs)

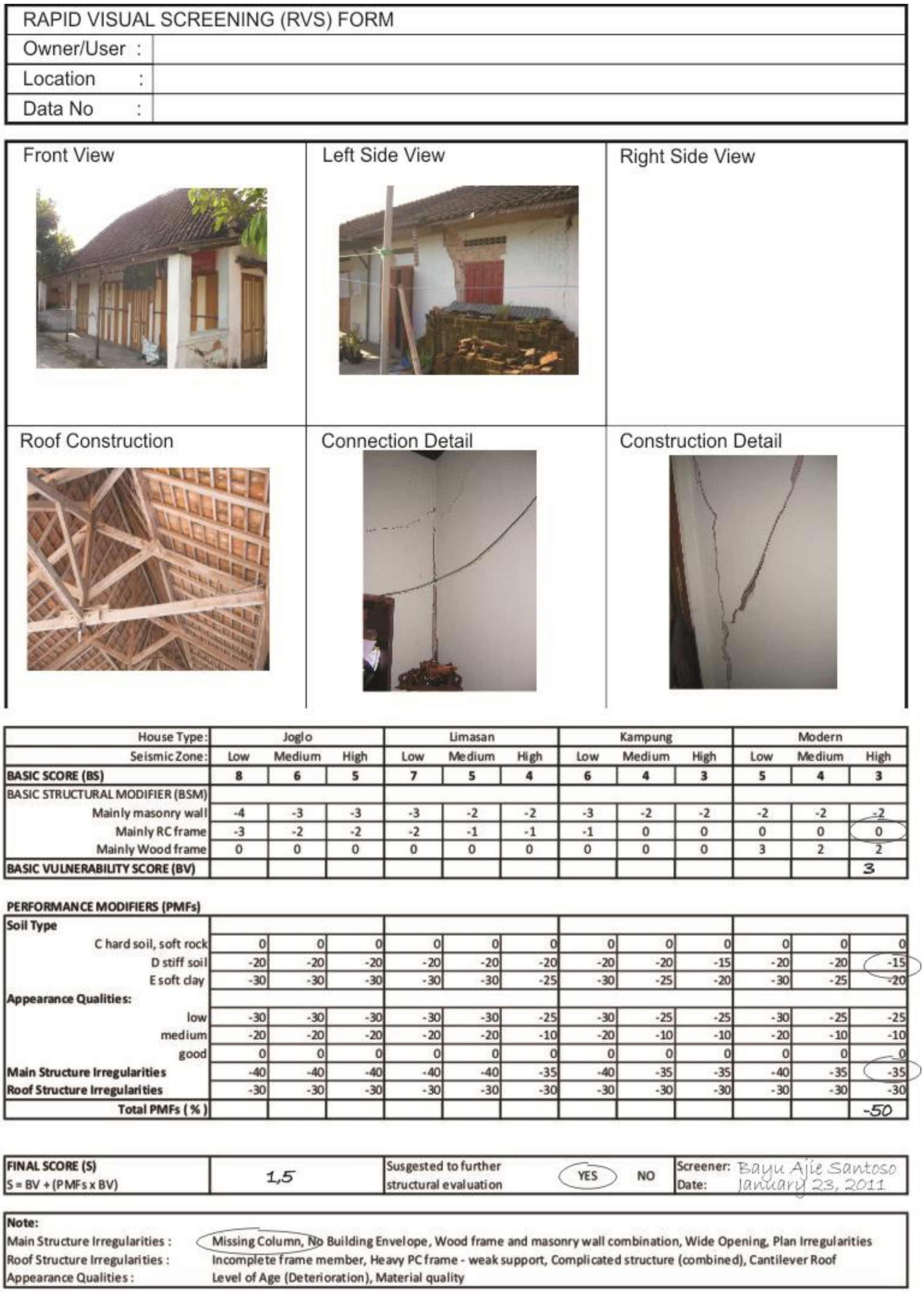
Soil Type												
C hard soil, soft rock	0	0	0	0	0	0	0	0	0	0	0	0
D stiff soil	-20	-20	-20	-20	-20	-20	-20	-20	-15	-20	-20	-15
E soft clay	-30	-30	-30	-30	-30	-25	-30	-25	-20	-30	-25	-20
Appearance Qualities:												
low	-30	-30	-30	-30	-30	-25	-30	-25	-25	-30	-25	-25
medium	-20	-20	-20	-20	-20	-10	-20	-10	-10	-20	-10	-10
good	0	0	0	0	0	0	0	0	0	0	0	0
Main Structure Irregularities	-40	-40	-40	-40	-40	-35	-40	-35	-35	-40	-35	-35
Roof Structure Irregularities	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30
Total PMFs (%)												-25

FINAL SCORE (S) S = BV + (PMFs x BV)	2,25	Susgested to further structural evaluation YES [✓ NO]	Screener: Bayu Ajie Santoso Date: January 23, 2011

Note:

Main Structure Irregularities :	Missing Column, No Building Envelope, Wood frame and masonry wall combination, Wide Opening, Plan Irregularities
Roof Structure Irregularities :	Incomplete frame member, Heavy PC frame - weak support, Complicated structure (combined), Cantilever Roof
Appearance Qualities :	Level of Age (Deterioration), Material quality

C.12. 1.5 scorer the Modern type before and after the earthquake



RAPID VISUAL SCREENING (RVS) FORM

Owner/User :

Location :

Data No :

Front View

Left Side View

Right Side View

Roof Construction

Connection Detail

Construction Detail

House Type:	Joglo			Limasan			Kampung			Modern		
Seismic Zone:	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High
BASIC SCORE (BS)	8	6	5	7	5	4	6	4	3	5	4	3
BASIC STRUCTURAL MODIFIER (BSM)												
Mainly masonry wall	-4	-3	-3	-3	-2	-2	-3	-2	-2	-2	-2	-2
Mainly RC frame	-3	-2	-2	-2	-1	-1	-1	0	0	0	0	[✓ 0]
Mainly Wood frame	0	0	0	0	0	0	0	0	0	3	2	2
BASIC VULNERABILITY SCORE (BV)												3

PERFORMANCE MODIFIERS (PMFs)

Soil Type												
C hard soil, soft rock	0	0	0	0	0	0	0	0	0	0	0	0
D stiff soil	-20	-20	-20	-20	-20	-20	-20	-20	-15	-20	-20	[✓ -15]
E soft clay	-30	-30	-30	-30	-30	-25	-30	-25	-20	-30	-25	-20
Appearance Qualities:												
low	-30	-30	-30	-30	-30	-25	-30	-25	-25	-30	-25	-25
medium	-20	-20	-20	-20	-20	-10	-20	-10	-10	-20	-10	-10
good	0	0	0	0	0	0	0	0	0	0	0	0
Main Structure Irregularities	-40	-40	-40	-40	-40	-35	-40	-35	-35	-40	-35	[✓ -35]
Roof Structure Irregularities	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30
Total PMFs (%)												-50

FINAL SCORE (S) S = BV + (PMFs x BV)	1,5	Susgested to further structural evaluation	[✓ YES] NO	Screener: Bayu Ajie Santoso Date: January 23, 2011

Note:

Main Structure Irregularities : [✓ Missing Column], No Building Envelope, Wood frame and masonry wall combination, Wide Opening, Plan Irregularities

Roof Structure Irregularities : Incomplete frame member, Heavy PC frame - weak support, Complicated structure (combined), Cantilever Roof

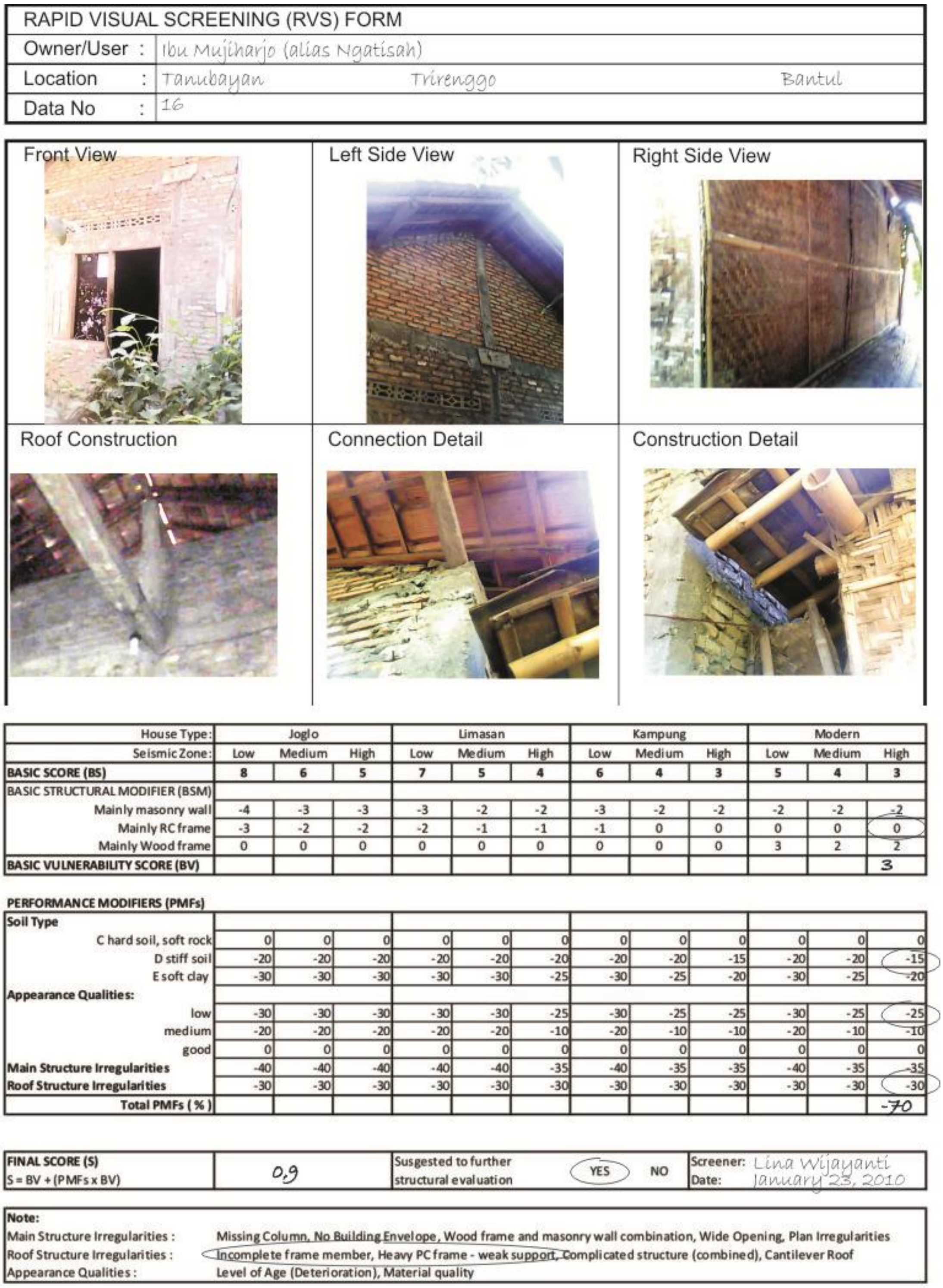
Appearance Qualities : Level of Age (Deterioration), Material quality

Appendix D: Javanese House Vulnerability RVS Result

No	BB Lipuro	Bantul	Imogiri	Jetis	Kretek	Pandak	Piyungan	Pleret	Pundong	Sewon
1	1.65	2.55	2.55	2.55	1.35	1.8	2.55	2.55	1.8	1.35
2	2.55	1.8	4.25	2.55	2.55	1.8	2.55	0.9	2.55	2.25
3	2.55	2.25	1.65	2.55	1.65	2.55	2.55	2.55	1.8	0.9
4	2.25	1.35	2.55	1.65	0.3	1.65	1.65	2.55	1.5	2.25
5	2.55	2.55	2.55	2.55	1.35	2.55	2.55	2.55	1.65	1.65
6	1.8	2.55	2.55	2.55	2.55	2.55	2.55	2.55	1.8	1.65
7	1.65	2.55	2.55	2.55	1.65	2.55	1.65	1.65	4.25	2.55
8	1.65	2.55	2.55	1.5	1.35	2.55	2.55	1.65	2.55	2.25
9	1.35	3.75	2.55	2.55	3.75	1.65	1.65	1.65	1.35	1.65
10	2.55	2.55	2.25	1.65	2.55	2.55	2.55	1.65	1.65	2.25
11	1.35	1.65	2.25	1.35	1.35	2.55	1.65	1.5	2.55	1.65
12	1.65	0.9	2.25	2.55	1.65	2.55	2.55	2.55	2.55	2.25
13	1.65	2.55	2.25	1.35	2.55	1.65	1.8	1.65	2.55	1.65
14	1.65	2.55	2.55	2.25	2.55	2.25	1.65	1.65	2.55	2.25
15	1.65	2.55	2.55	2.55	2.55	2.55	1.65	2.55	2.55	2.25
16	1.65	0.9	1.65	1.65	1.65	2.25	2.55	1.65	1.65	1.65
17	2.55	2.55	2.55	2.55	1.8	1.65	1.65	1.65	1.35	0.9
18	2.55	2.55	2.55	1.65	1.65	2.55	2.55	2.55	1.65	1.65
19	1.65	2.55	1.65	2.25	2.55	2.55	2.55	1.65	1.95	0.9
20	1.65	1.65	3.4	0.9	1.65	2.55	2.55	2.55	2.25	2.25
21	2.55	2.55	1.65	2.25	1.65	1.8	1.65	1.65	1.5	1.65
22	2.55	1.8	2.55	0.75	1.35	1.65	2.55	2.25	1.5	1.65
23	1.65	1.35	2.25	1.8	2.55	2.55	1.65	2.55	1.5	1.65
24	2.55	0.9	2.55	2.55	1.65	2.55	2.2	2.55	1.35	2.55
25	2.55	2.55	2.55	2.55	1.35	2.25	1.8	2.55	2.55	1.65
26	1.65	2.55	2.55		1.35	1.65	2.7	2.55	2.55	1.65
27	1.35	1.35	2.55		1.65	2.25	1.8	2.55	1.65	1.65
28	2.25		1.65			0.9	1.95	2.55	1.65	1.65
29	2.55		2.55			1.65	2.7	2.55	1.65	1.65
30	1.65		1.65			1.65	2.7	2.55	1.65	1.65
31								2.25		
32								2.25		
33								1.8		

Appendix E: Javanese House Vulnerability RVS Form Examples

E.1. Lowest score sample (0.9)



RAPID VISUAL SCREENING (RVS) FORM

Owner/User : Ibu Mujiharjo (alias Ngatisah)

Location : Tanubayan Trirenggo Bantul

Data No : 16

Front View

Left Side View

Right Side View

Roof Construction

Connection Detail

Construction Detail

House Type:	Joglo			Limasan			Kampung			Modern		
Seismic Zone:	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High
BASIC SCORE (BS)	8	6	5	7	5	4	6	4	3	5	4	3
BASIC STRUCTURAL MODIFIER (BSM)												
Mainly masonry wall	-4	-3	-3	-3	-2	-2	-3	-2	-2	-2	-2	-2
Mainly RC frame	-3	-2	-2	-2	-1	-1	-1	0	0	0	0	0
Mainly Wood frame	0	0	0	0	0	0	0	0	0	3	2	2
BASIC VULNERABILITY SCORE (BV)												3

PERFORMANCE MODIFIERS (PMFs)

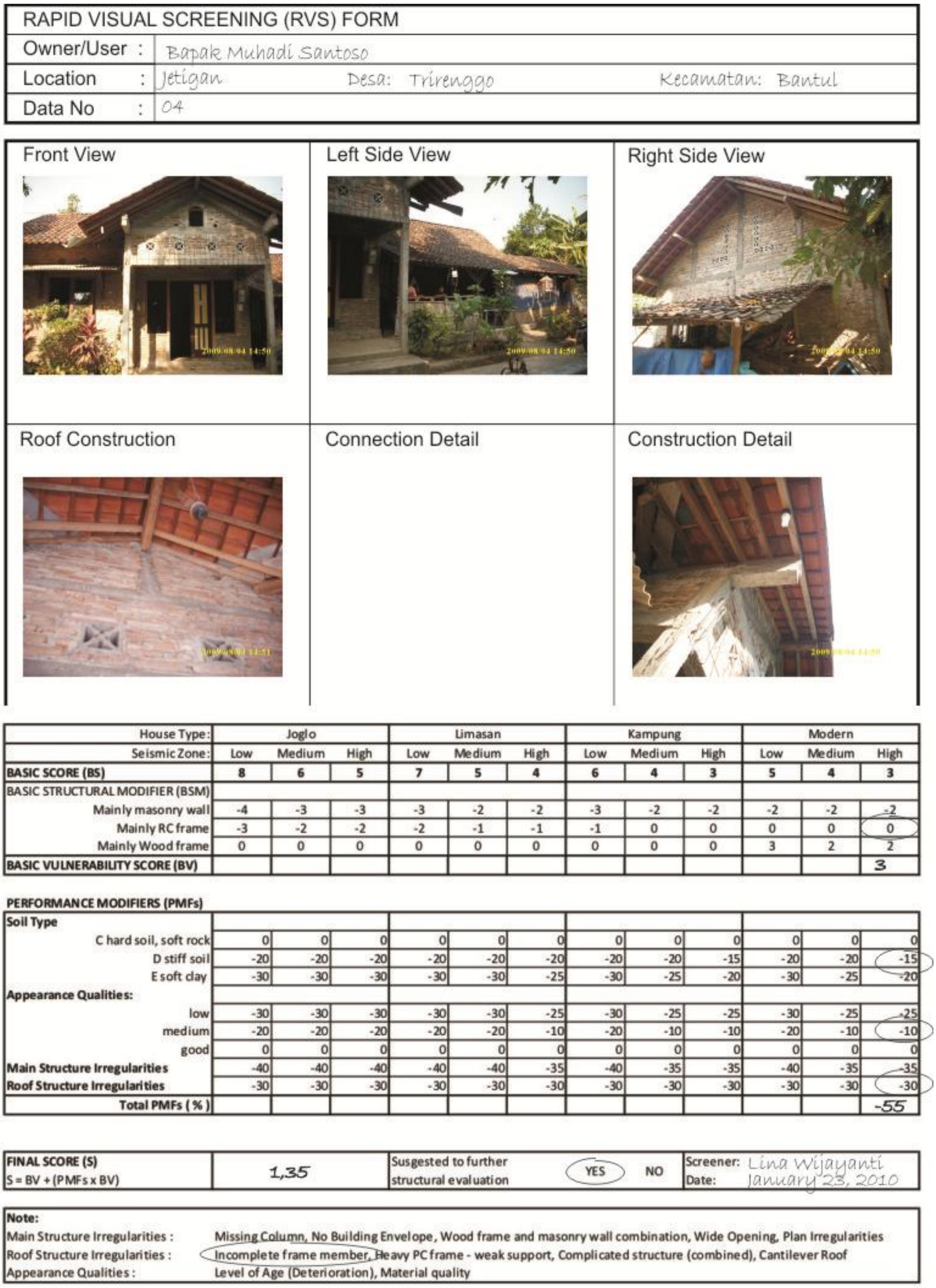
Soil Type												
C hard soil, soft rock	0	0	0	0	0	0	0	0	0	0	0	0
D stiff soil	-20	-20	-20	-20	-20	-20	-20	-20	-15	-20	-20	-15
E soft clay	-30	-30	-30	-30	-30	-25	-30	-25	-20	-30	-25	-20
Appearance Qualities:												
low	-30	-30	-30	-30	-30	-25	-30	-25	-25	-30	-25	-25
medium	-20	-20	-20	-20	-20	-10	-20	-10	-10	-20	-10	-10
good	0	0	0	0	0	0	0	0	0	0	0	0
Main Structure Irregularities	-40	-40	-40	-40	-40	-35	-40	-35	-35	-40	-35	-35
Roof Structure Irregularities	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30
Total PMFs (%)												-70

FINAL SCORE (S) S = BV + (PMFs x BV)	0,9	Susgested to further structural evaluation	[✓ YES] NO	Screener: Lina Wijayanti Date: January 23, 2010

Note:

Main Structure Irregularities :	Missing Column, No Building Envelope, Wood frame and masonry wall combination, Wide Opening, Plan Irregularities
Roof Structure Irregularities :	Incomplete frame member, Heavy PC frame - weak support, Complicated structure (combined), Cantilever Roof
Appearance Qualities :	Level of Age (Deterioration), Material quality

E.2. Lower score sample (1.35)



RAPID VISUAL SCREENING (RVS) FORM

Owner/User : Bapak Muhadi Santoso

Location : Jetigan Desa: Trirenggo Kecamatan: Bantul

Data No : 04

Front View

Left Side View

Right Side View

Roof Construction

Connection Detail

Construction Detail

House Type:	Joglo			Limasan			Kampung			Modern		
Seismic Zone:	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High
BASIC SCORE (BS)	**8**	**6**	**5**	**7**	**5**	**4**	**6**	**4**	**3**	**5**	**4**	**3**
BASIC STRUCTURAL MODIFIER (BSM)												
Mainly masonry wall	-4	-3	-3	-3	-2	-2	-3	-2	-2	-2	-2	-2
Mainly RC frame	-3	-2	-2	-2	-1	-1	-1	0	0	0	0	[✓ 0]
Mainly Wood frame	0	0	0	0	0	0	0	0	0	3	2	2
BASIC VULNERABILITY SCORE (BV)												3

PERFORMANCE MODIFIERS (PMFs)

Soil Type												
C hard soil, soft rock	0	0	0	0	0	0	0	0	0	0	0	0
D stiff soil	-20	-20	-20	-20	-20	-20	-20	-20	-15	-20	-20	[✓ -15]
E soft clay	-30	-30	-30	-30	-30	-25	-30	-25	-20	-30	-25	-20
Appearance Qualities:												
low	-30	-30	-30	-30	-30	-25	-30	-25	-25	-30	-25	-25
medium	-20	-20	-20	-20	-20	-10	-20	-10	-10	-20	-10	[✓ -10]
good	0	0	0	0	0	0	0	0	0	0	0	0
Main Structure Irregularities	-40	-40	-40	-40	-40	-35	-40	-35	-35	-40	-35	-35
Roof Structure Irregularities	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30	[✓ -30]
Total PMFs (%)												-55

FINAL SCORE (S) S = BV + (PMFs x BV)	1,35	Susgested to further structural evaluation	[✓ YES] NO	Screener: Lina Wijayanti Date: January 23, 2010

Note:

Main Structure Irregularities :	Missing Column, No Building Envelope, Wood frame and masonry wall combination, Wide Opening, Plan Irregularities
Roof Structure Irregularities :	[✓ Incomplete frame member], Heavy PC frame - weak support, Complicated structure (combined), Cantilever Roof
Appearance Qualities :	Level of Age (Deterioration), Material quality

E.3. Medium score sample (1.8)

RAPID VISUAL SCREENING (RVS) FORM

Owner/User : Ny Tumijem

Location : Jetigan Desa: Trirenggo Kecamatan: Bantul

Data No : 2

Front View

Left Side View

Right Side View

Roof Construction

Connection Detail

Construction Detail

House Type:	Joglo			Limasan			Kampung			Modern		
Seismic Zone:	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High
BASIC SCORE (BS)	**8**	**6**	**5**	**7**	**5**	**4**	**6**	**4**	**3**	**5**	**4**	**3**
BASIC STRUCTURAL MODIFIER (BSM)												
Mainly masonry wall	-4	-3	-3	-3	-2	-2	-3	-2	-2	-2	-2	-2
Mainly RC frame	-3	-2	-2	-2	-1	-1	-1	0	0	0	0	[✓ 0]
Mainly Wood frame	0	0	0	0	0	0	0	0	0	3	2	2
BASIC VULNERABILITY SCORE (BV)												3

PERFORMANCE MODIFIERS (PMFs)

Soil Type												
C hard soil, soft rock	0	0	0	0	0	0	0	0	0	0	0	0
D stiff soil	-20	-20	-20	-20	-20	-20	-20	-20	-15	-20	-20	[✓ -15]
E soft clay	-30	-30	-30	-30	-30	-25	-30	-25	-20	-30	-25	-20
Appearance Qualities:												
low	-30	-30	-30	-30	-30	-25	-30	-25	-25	-30	-25	[✓ -25]
medium	-20	-20	-20	-20	-20	-10	-20	-10	-10	-20	-10	-10
good	0	0	0	0	0	0	0	0	0	0	0	0
Main Structure Irregularities	-40	-40	-40	-40	-40	-35	-40	-35	-35	-40	-35	-35
Roof Structure Irregularities	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30
Total PMFs (%)												-40

FINAL SCORE (S) S = BV + (PMFs x BV)	1,8	Susgested to further structural evaluation [✓ YES] NO	Screener: Lina Wijayanti Date: January 23, 2010

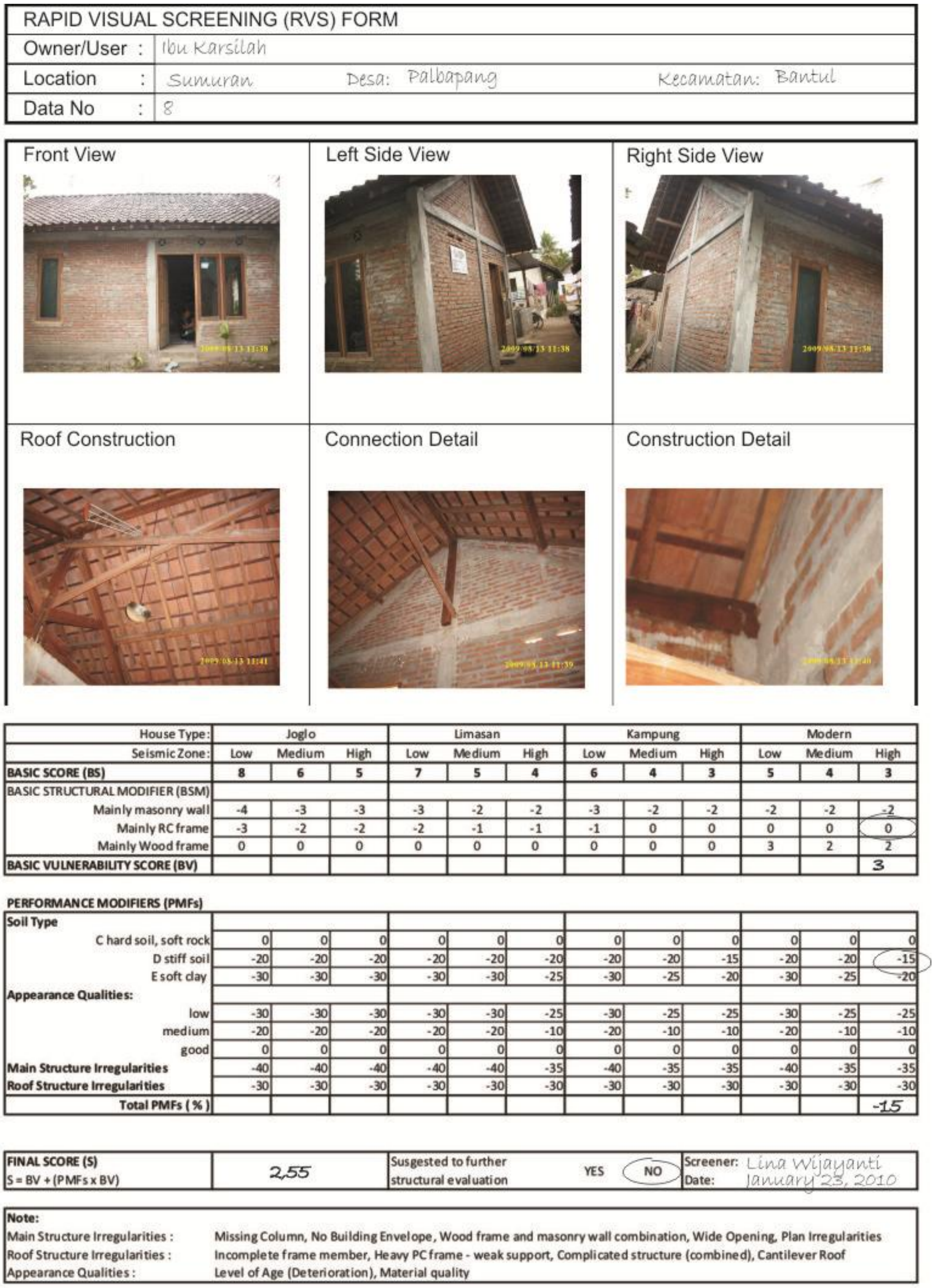
Note:

Main Structure Irregularities : Missing Column, No Building Envelope, Wood frame and masonry wall combination, Wide Opening, Plan Irregularities

Roof Structure Irregularities : Incomplete frame member, Heavy PC frame - weak support, Complicated structure (combined), Cantilever Roof

Appearance Qualities : Level of Age (Deterioration), Material quality

E.4. Higher score sample (2.55)



RAPID VISUAL SCREENING (RVS) FORM

Owner/User : Ibu Karsilah

Location : Sumuran Desa: Palbapang Kecamatan: Bantul

Data No : 8

Front View

Left Side View

Right Side View

Roof Construction

Connection Detail

Construction Detail

House Type:	Joglo			Limasan			Kampung			Modern		
Seismic Zone:	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High
BASIC SCORE (BS)	**8**	**6**	**5**	**7**	**5**	**4**	**6**	**4**	**3**	**5**	**4**	**3**
BASIC STRUCTURAL MODIFIER (BSM)												
Mainly masonry wall	-4	-3	-3	-3	-2	-2	-3	-2	-2	-2	-2	-2
Mainly RC frame	-3	-2	-2	-2	-1	-1	-1	0	0	0	0	[✓ 0]
Mainly Wood frame	0	0	0	0	0	0	0	0	0	3	2	2
BASIC VULNERABILITY SCORE (BV)												3

PERFORMANCE MODIFIERS (PMFs)

Soil Type												
C hard soil, soft rock	0	0	0	0	0	0	0	0	0	0	0	0
D stiff soil	-20	-20	-20	-20	-20	-20	-20	-20	-15	-20	-20	[✓ -15]
E soft clay	-30	-30	-30	-30	-30	-25	-30	-25	-20	-30	-25	-20
Appearance Qualities:												
low	-30	-30	-30	-30	-30	-25	-30	-25	-25	-30	-25	-25
medium	-20	-20	-20	-20	-20	-10	-20	-10	-10	-20	-10	-10
good	0	0	0	0	0	0	0	0	0	0	0	0
Main Structure Irregularities	-40	-40	-40	-40	-40	-35	-40	-35	-35	-40	-35	-35
Roof Structure Irregularities	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30
Total PMFs (%)												-15

FINAL SCORE (S) S = BV + (PMFs x BV)	2,55	Susgested to further structural evaluation	YES [✓ NO]	Screener: Lina Wijayanti Date: January 23, 2010

Note:

Main Structure Irregularities :	Missing Column, No Building Envelope, Wood frame and masonry wall combination, Wide Opening, Plan Irregularities
Roof Structure Irregularities :	Incomplete frame member, Heavy PC frame - weak support, Complicated structure (combined), Cantilever Roof
Appearance Qualities :	Level of Age (Deterioration), Material quality

E.5. Highest score sample (3.75)

RAPID VISUAL SCREENING (RVS) FORM

Owner/User : Bapak Nrimorejo

Location : Sumuran Desa: Palbapang Kecamatan: Bantul

Data No : 9

Front View

Left Side View

Right Side View

Roof Construction

Connection Detail

Construction Detail

House Type:	Joglo			Limasan			Kampung			Modern		
Seismic Zone:	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High
BASIC SCORE (BS)	8	6	5	7	5	4	6	4	3	5	4	3
BASIC STRUCTURAL MODIFIER (BSM)												
Mainly masonry wall	-4	-3	-3	-3	-2	-2	-3	-2	-2	-2	-2	-2
Mainly RC frame	-3	-2	-2	-2	-1	-1	-1	0	0	0	0	0
Mainly Wood frame	0	0	0	0	0	0	0	0	0	3	2	[✓ 2]
BASIC VULNERABILITY SCORE (BV)												5

PERFORMANCE MODIFIERS (PMFs)

Soil Type												
C hard soil, soft rock	0	0	0	0	0	0	0	0	0	0	0	0
D stiff soil	-20	-20	-20	-20	-20	-20	-20	-20	-15	-20	-20	[✓ -15]
E soft clay	-30	-30	-30	-30	-30	-25	-30	-25	-20	-30	-25	-20
Appearance Qualities:												
low	-30	-30	-30	-30	-30	-25	-30	-25	-25	-30	-25	-25
medium	-20	-20	-20	-20	-20	-10	-20	-10	-10	-20	-10	[✓ -10]
good	0	0	0	0	0	0	0	0	0	0	0	0
Main Structure Irregularities	-40	-40	-40	-40	-40	-35	-40	-35	-35	-40	-35	-35
Roof Structure Irregularities	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30
Total PMFs (%)												-25

FINAL SCORE (S) S = BV + (PMFs x BV)	3,75	Susgested to further structural evaluation	YES [✓ NO]	Screener: Lina Wijayanti Date: January 23, 2010

Note:

Main Structure Irregularities :	Missing Column, No Building Envelope, Wood frame and masonry wall combination, Wide Opening, Plan Irregularities
Roof Structure Irregularities :	Incomplete frame member, Heavy PC frame - weak support, Complicated structure (combined), Cantilever Roof
Appearance Qualities :	Level of Age (Deterioration), Material quality

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