

# **SEISMIC DAMAGE ASSESSEMENT FOR SURABAYA CITY, INDONESIA USING GEOGRAPHICAL INFORMATION SYSTEM (GIS)**

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***ABSTRACT:*** Surabaya, the second biggest city in Indonesia, has high seismic risk because of high population density and the relatively poor quality control enforcement of buildings. This paper performs preliminary assessments for potential damage and loss distribution from a scenario earthquake in Surabaya City using appropriate methods, models, and engineering judgments depending on available data using GIS as a platform. Suitability of two well-known loss estimation methodologies, ATC-13 and HAZUS, are examined using building damage data from a real earthquake in Bengkulu City, Indonesia. HAZUS methodology gave a better result than ATC-13 did for the 2000 Bengkulu earthquake and thus, it was applied to the Surabaya case study. Microzonation using microtremor observations was also carried out to verify the results from the seismic damage assessment study. The results showed that the building collapse and casualty ratios are influenced by the soil condition and building type proportion. The damaged buildings are concentrated in soft soil area. There is a reasonable correlation between the results of building damage distribution and the microzonation map. The results from this study are expected to serve as a basis for seismic disaster mitigation planning of the city.

***KEYWORDS:*** damage assessment; loss distribution; GIS; ATC-13; HAZUS Methodology; microzonation; microtremor

## **1. INTRODUCTION**

Surabaya, the capital city of East Java Province, is located within latitudes S 7° 11' and S 7° 21' and longitudes E 112° 38' and E 112° 51' on a broad deep basin filled with alluvial and deltaic sediments. Situated in lower stream of the Brantas River Basin, the region is also called Surabaya Basin. Surabaya is the second largest city after Jakarta with about 2.4 million inhabitants in the municipality with 326.37 km<sup>2</sup> area that is divided into 28 sub-districts. Surabaya is currently considered as one of the most densely populated cities in Indonesia with the average about 75 people per hectare.



**Figure 1. Location of Surabaya City**

Many researchers have recently studied seismic hazard of Indonesia. The hazard is presented including the effect of soft soil in term of peak ground acceleration (PGA) for the 500 years return period. Seismic hazard maps for the whole country might not be suitable to identify the variation of seismic hazards within a city. Therefore, it is important for a city to conduct seismic microzonation. Microzonation provides a basis for a site-specific risk analysis, which can assist in mitigation of earthquake damages.

Microtremor observation can be used to determine the dynamic properties of a site and, hence, can be used for microzonation. The microtremor method measures ambient vibrations in the order of microns present in the ground. Microtremor observations can be used to determine the predominant period of a site. The area then can be classified according to its predominant period of vibration.

The main purpose of demonstrating detrimental effects of earthquakes is to give warning to the government and public organizations so that they will improve their awareness from earthquake disasters. This is done in order to prevent the severe damage in the city and to prepare a mitigation plan and strategy for future earthquakes.

## **2. CONDITION OF SURABAYA CITY**

### **2.1 Geological Condition of Surabaya City**

The geological map of Surabaya is shown in Figure 2.

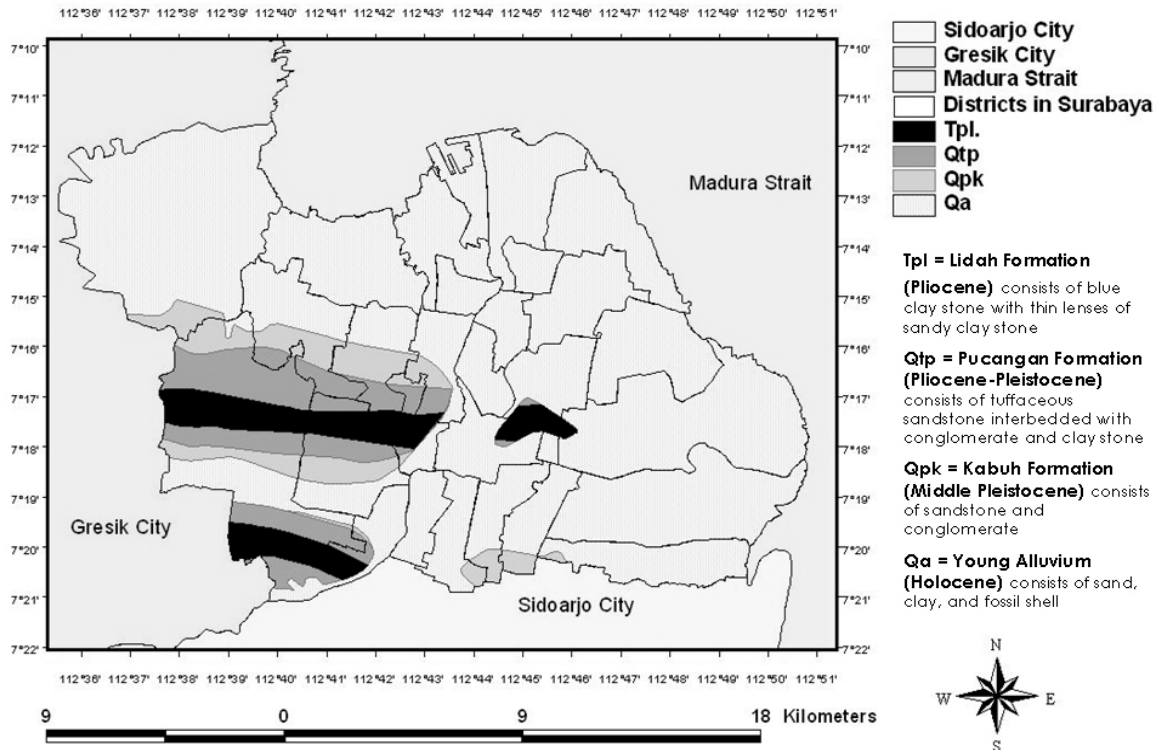


Figure 2. Topographical condition of Surabaya

## 2.2 Topographical and Morphological Condition of Surabaya City

The maps of topographical and morphological condition of Surabaya are shown in Figure 3

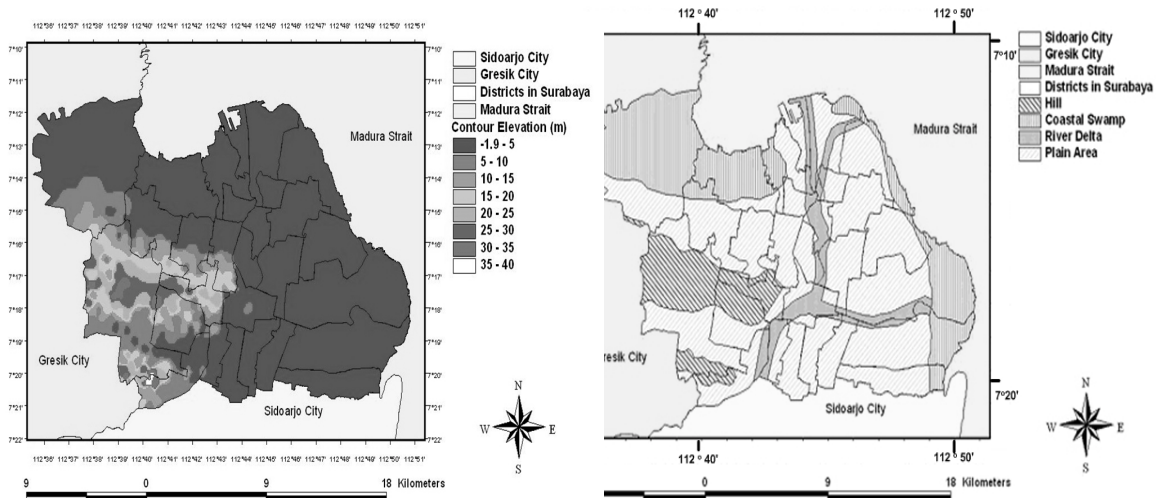


Figure 3. Topographical and morphological condition of Surabaya

## 2.3 Historical Earthquake in Surabaya

Two active sources have possibility to trigger earthquakes in Surabaya. The first one is the subduction zone along the south of Java Island, that is located around 300 km at the south of Surabaya, and the second one is a strike slip fault (Lasem Fault), that is located around 75 km at the northwest of Surabaya. Recently, there have been minor earthquakes that were felt in Surabaya. Table 1 presents the destructive earthquakes in Surabaya from 1800 to 1985.

**Table 1. Destructive earthquakes in Surabaya in the period 1800 - 1985**

Date	Epicenter	Epicenter Distance (km)	Magnitude or Intensity (MMI)
22- March-1836	Mojokerto	60 (South West)	VII - VIII MMI Scale
31-Aug-1902	Sedayu Gresik	40 (North West)	VI MMI
11-Aug-1939	Java Sea	60 (North West)	VII MMI
19-Jun-1950	Java Sea	110 (North West)	VII MMI

## 3. METHODOLOGY

### 3.1 Seismic Damage Assessment Methodology

The goal of a seismic damage assessment is to quantify the potential damages and losses in a region due to future earthquakes. This analysis requires the synthesis of several types of information. The basic steps in a regional seismic damage assessment procedure typically include:

1. Identification of earthquake sources.
2. Modeling of earthquake scenario.
3. Determination of regional bedrock motion.
4. Evaluating the local site effects.
5. Estimating the damages to the regional inventories.
6. Estimating the expected losses in the region.

In this case, HAZUS (1999) methodology is applied to carry out procedures 3-6.

### 3.2 Microtremor Observation Methodology

Microtremor observations were performed using a portable equipment. The velocity sensor that was used can measure three components, two horizontal and one vertical. The Fourier spectra were calculated using the Fast Fourier Transformation (FFT) algorithm and the Fourier spectra were smoothed using a Parzen window of bandwidth 0.4 Hz. The Fourier amplitude ratio of the two horizontal Fourier spectra and one vertical Fourier spectrum were obtained using Equation 1.

$$r(f) = \frac{\sqrt{F_{NS}(f) \times F_{EW}(f)}}{F_{UD}(f)} \quad (1)$$

where  $r(f)$  is the horizontal to vertical (H/V) spectrum ratio,  $F_{NS}$ ,  $F_{EW}$ , and  $F_{UD}$  are the Fourier amplitude spectra in the NS, EW, and UD directions, respectively. The peak period of the H/V spectrum plot shows the predominant period of the site.

#### 4. VERIFICATION OF LOSS ESTIMATION METHODOLOGIES

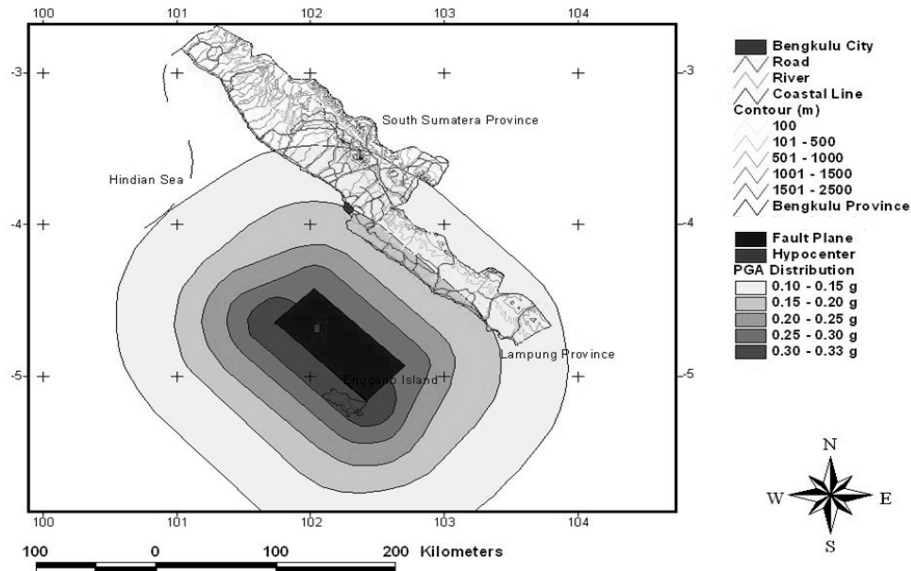
Two well-known loss estimation methodologies, ATC-13 and HAZUS, are compared for the case of a real earthquake in order to choose the most suitable methodology for Indonesia. In this case, the result of building damages from the 2000 Bengkulu earthquake in Bengkulu City was chosen for the analysis because the building damage data from this earthquake is available. The most suitable methodology for the Bengkulu earthquake is applied to the Surabaya City case study.

##### 4.1 General Description of the 2000 Bengkulu Earthquake

Geographically, Bengkulu City is located at the seashore of the Indian Ocean (west beach of Sumatra Island) between  $102^{\circ} 16'$  east longitude and  $2^{\circ} 48'$  south latitude. The width of Bengkulu City is  $144.52 \text{ km}^2$  (14,452 ha). The population in Bengkulu City is around 313,190. On June 4, 2000, at 22:27 local time, a powerful earthquake stroke Bengkulu City. The magnitude of the earthquake is 7.9  $M_s$ , and its epicenter is located in the center of Enggano Island, about 100 km southwest of Bengkulu City with  $102^{\circ}$  east longitude and  $4.7^{\circ}$  south latitude.

##### 4.2 Modeling of Bengkulu Earthquake Source

The Bengkulu earthquake was caused by tectonic movements in a subduction zone. From the hypocentral depth, this earthquake can be considered as a shallow earthquake. The attenuation relation proposed by Youngs et al. (1997) was used to calculate the bedrock motion in the region. From a seismotectonic map of Indonesia, it can be seen that the soil condition in Bengkulu City is mostly similar for the whole city. The geological age of Bengkulu soil is mostly Tertiary Pleistocene. The result of Peak Ground Acceleration (PGA) distribution for medium soil around Bengkulu Province is shown in Figure 4.



**Figure 4. PGA distribution of the Bengkulu earthquake (4 June 2000) in Bengkulu Province**

#### 4.3 Earthquake Loss Estimation from ATC-13 Methodology

The structural types in Bengkulu can be classified into four classes according to Earthquake Engineering (EE) Facility Classification of ATC-13:

- Low-Rise Steel Frame (EE 12)
- Low-Rise Non-Ductile Concrete Moment Resisting Frame (EE87)
- Low-Rise Un-reinforced Masonry (EE78)
- Wood Frame (EE1)

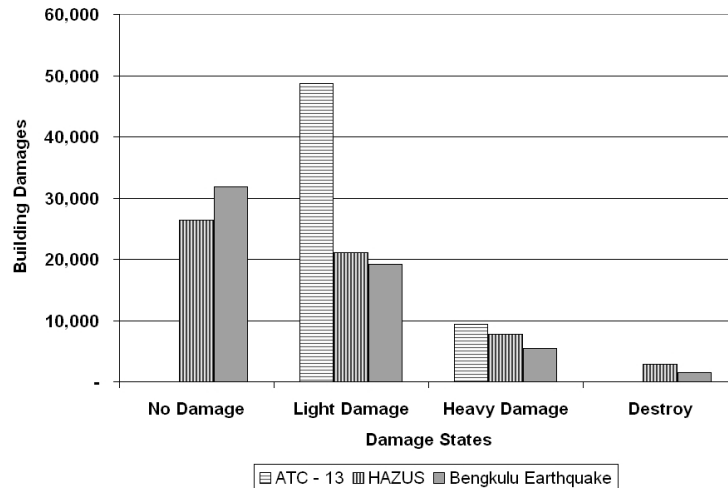
#### 4.4 Earthquake Loss Estimation from HAZUS Methodology

The most available structural types in Bengkulu City can be classified into four classes according to model building types of HAZUS:

- Low-Rise Steel Frame with Un-reinforced Masonry Infill Walls (S5L) for Low-Code Seismic Design Level,
- Low-Rise Concrete Frame with Un-reinforced Masonry Infill Walls (C3L) for Low-Code Seismic Design Level,
- Low-Rise Un-reinforced Masonry Bearing Walls (URML) for Pre-Code Seismic Design Level
- Wood, Light Frame ( $\leq 5,000$  sq. ft.) (W1) for Pre-Code Seismic Design Level

#### 4.5 Comparison Results of ATC-13 and HAZUS Methodology

Figure 5 shows the comparison among the assessment results from ATC-13, HAZUS, and the real earthquake loss from the 2000 Bengkulu earthquake.



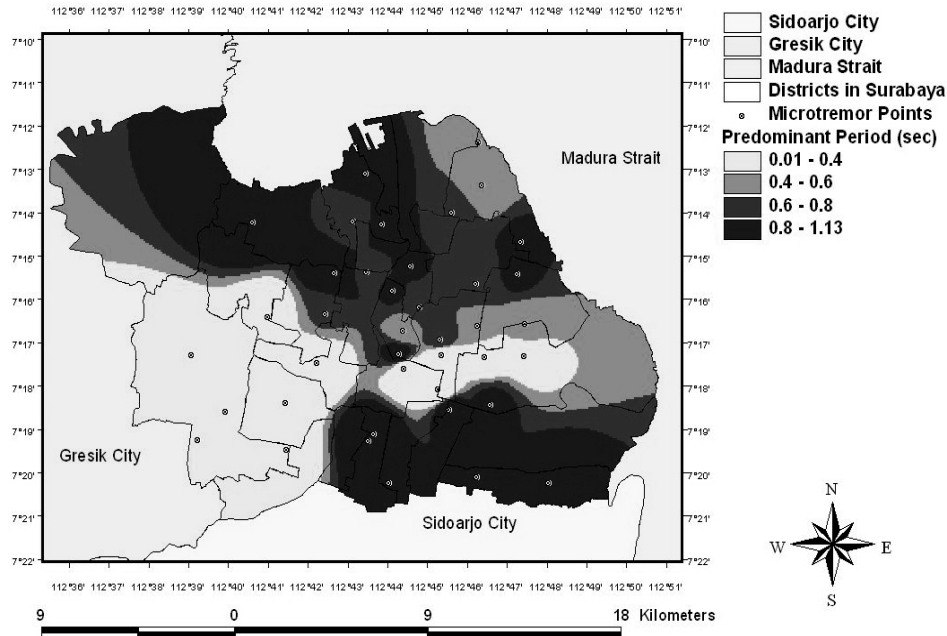
**Figure 5. Result of building damages from ATC-13, HAZUS, and the Bengkulu earthquake**

From Figure 5, it can be seen that the results from HAZUS give better correlation with the real earthquake loss. It also can be seen that the mean difference of buildings damage proportion for each damage state from HAZUS is lower than that from ATC-13. It can also be seen that the results from ATC-13 are mostly concentrated in Light and Heavy Damage. On the other hand, the results from HAZUS show better loss distribution of buildings damage for each damage level and the distribution is close to the distribution from the real earthquake event. Because HAZUS methodology gave the better result in the Bengkulu earthquake case, HAZUS methodology is used for the seismic damage assessment for Surabaya City.

## 5. MICROZONATION OF SURABAYA CITY

The seismic microzonation map is very useful to verify the results from a seismic damage assessment study. In this part, the results and discussions of microzonation using microtremor observation are described. Microtremor observations were carried out at 39 locations around Surabaya City. After a digital signal processing and the horizontal to vertical (H/V) spectrum ratio analysis of microtremor, the H/V spectrum ratios were plotted for each of the sites. The predominant periods of the ground vibration were estimated from the peak of H/V spectral ratio plots. The variation, in the form of contour map, of the predominant period in Surabaya is shown in Figure 6. According to the variation of the predominant period of the ground, Surabaya then can be classified into four zones:

- a) Zone I - predominant period shorter than 0.4 sec
- b) Zone II - predominant period ranging from 0.4 sec to 0.6 sec
- c) Zone III - predominant period ranging from 0.6 sec to 0.8 sec
- d) Zone IV - predominant period longer than 0.8 sec

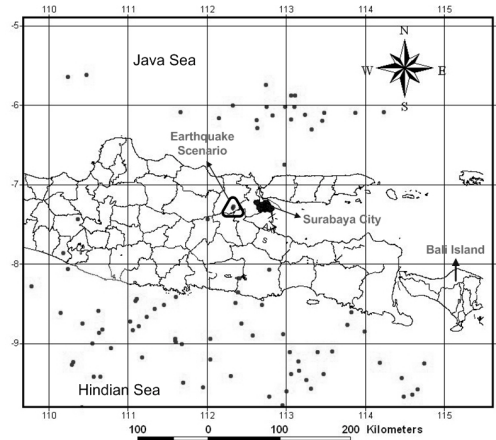


**Figure 6. Variation of the predominant period in Surabaya City by microtremor observations**

## 6. SEISMIC DAMAGE ASSESSMENT STUDY FOR SURABAYA CITY

### 6.1 Modeling of Scenario Earthquake for Surabaya City

There are two active sources, which have possibility to trigger earthquakes in Surabaya. The first one is the subduction zone along the south of Java Island, that is located around 300 km at the south of Surabaya and the last one is a strike slip fault, that is located around 75 km at the northwest of Surabaya. The distribution of earthquake focuses for the historical earthquakes with magnitude greater than 5 near Surabaya City is shown in Figure 7. From the historical earthquake data, the earthquake events were mostly caused in the subduction zone with high magnitude values.





**Figure 7. The distribution of earthquake focus of the historical earthquakes near Surabaya City with  $M_w > 5$**

The maximum possible earthquake that is considered as a scenario earthquake:  
 Latitude : 7.19 °S, Longitude : 112.15 °E, Hypocentral depth = 178.6 km, Input maximum Earthquake = 7.28  $M_w$ .

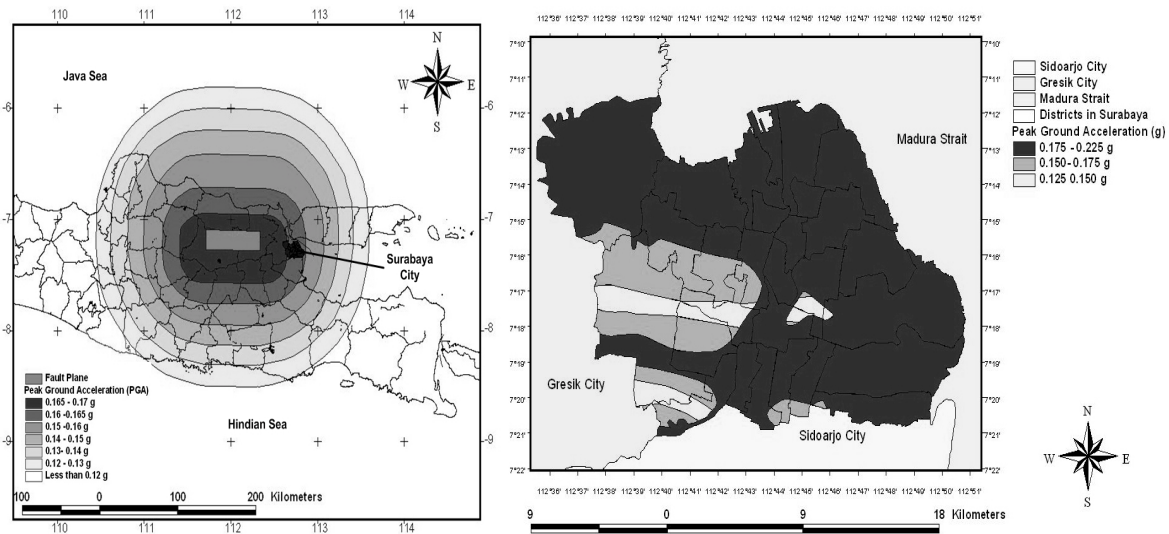
This earthquake is caused by tectonic movement in the subduction zone. From the hypocentral depth, this earthquake can be considered as a deep earthquake (in Benioff zone).

### 6.2 Determination of Local Site Effects

For Surabaya City, the borehole data were collected from 79 Standard Penetration Test (SPT) borehole data within the city. The soil type then can be classified as soft soil, stiff soil, and very dense soil and soft rock.

### 6.3 Determination of Regional Ground Motion

The attenuation relation proposed by Youngs et al. (1997) is used to calculate the bedrock motion in region. The ground motion distribution is derived from multiplication of the bedrock motion distribution and soil amplification. The result of Peak Ground Acceleration (PGA) distributions for medium soil around East Java Province and PGA distributions within Surabaya City are shown in Figure 8.



**Figure 8. PGA distributions for medium soil around East Java Province (left) and PGA distributions within Surabaya City**

### 6.4 Inventory Compilation Data

The main source of inventory data was collected from Building and Land Tax Bureau of Surabaya. The collected inventory data consist of four structural material types such as steel, concrete, masonry, and wood structures. The height of the building is classified as low-rise (1-3 stories), medium-rise (4-7 stories), and high-rise (more than or equal than 8 stories). After all consideration, the most commonly available structural types in Surabaya City can be classified into nine classes, according to model building types of HAZUS:

- Steel Light Frame (S3) for Low-Code Seismic Design Level,
- Low-Rise Steel Frame with Un-reinforced Masonry Infill Walls (S5L) for Low-Code Seismic Design Level,
- Medium-Rise Steel Frame with Un-reinforced Masonry Infill Walls (S5M) for Low-Code Seismic Design Level,
- High-Rise Steel Frame with Cast-in-Place Concrete Shear Walls (S5L) for Moderate-Code Seismic Design Level
- Low-Rise Concrete Frame with Un-reinforced Masonry Infill Walls (S4H) for Low-Code Seismic Design Level,
- Medium-Rise Concrete Frame with Un-reinforced Masonry Infill Walls (C3M) for Low-Code Seismic Design Level,
- High-Rise Concrete Shear Walls (C2H) for Medium-Code Seismic Design Level,
- Low-Rise Un-reinforced Masonry Bearing Walls (URML) for Pre-Code Seismic Design Level,
- Wood, Light Frame ( $\leq 5,000$  sq. ft.) (W1) for Pre-Code Seismic Design Level

## **6.5 Number of Occupants**

The occupant data for each structural type are calculated from the floor areas of buildings. The occupancy rates per 1,000 square feet for each social function class for day and nighttime are calculated. HAZUS methodology was adopted and modified accordingly to Surabaya population.

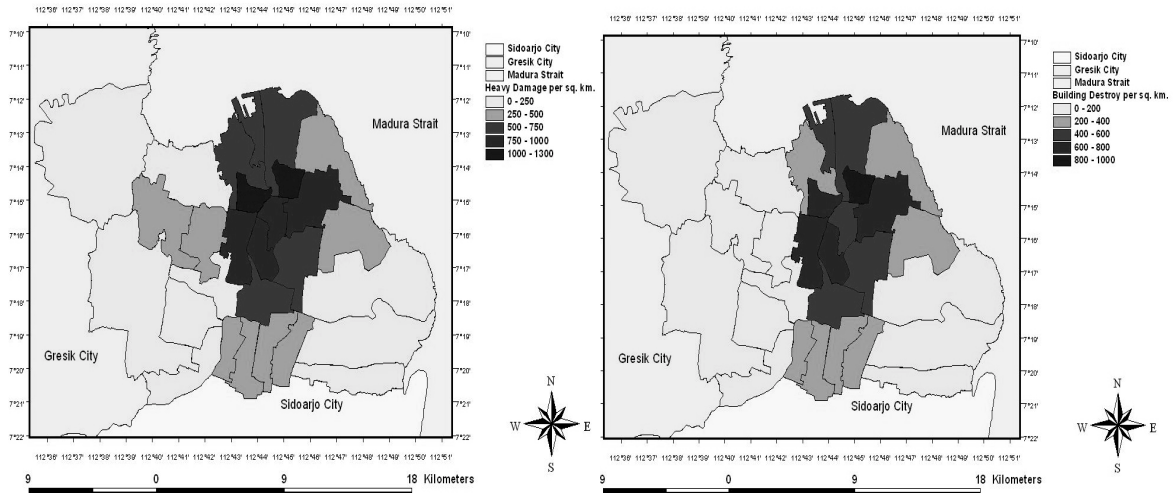
## **6.6 Building Damage Estimation**

Structural fragility curves are evaluated for spectral displacement and spectral acceleration defined by the intersection of the capacity and demand curves. The damage states from HAZUS are then converted into damage states that are used for the Bengkulu earthquake case. The results of damage distribution from the scenario earthquake in Surabaya City are shown in Figure 9. From Figure 9, it can be seen that mostly the building damages per square kilometers are concentrated in the central parts of Surabaya, then, the southern and northern areas along the Surabaya River. These results are caused by higher building density in these areas.

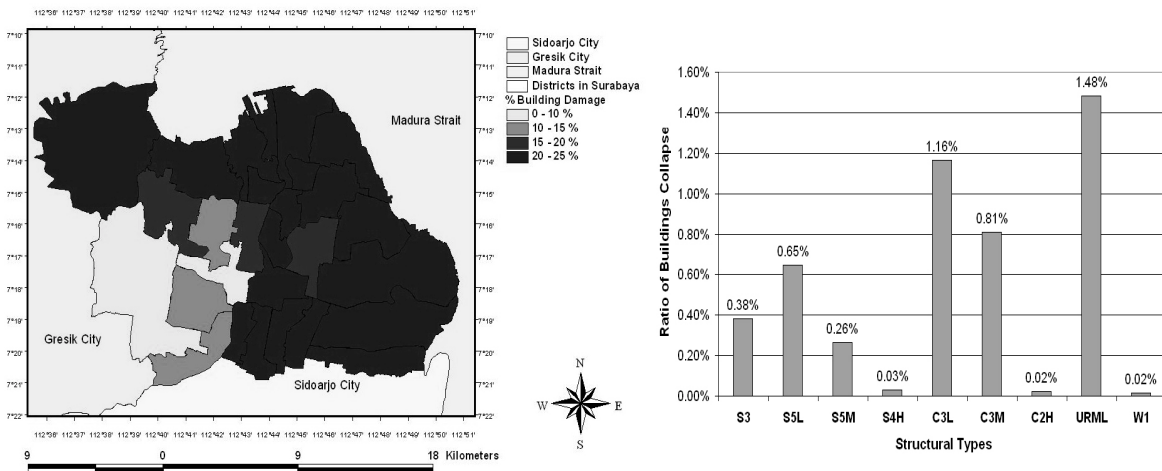
Figure 10 shows the damage ratio of all buildings in Surabaya City and the ratio of building collapse at each structural type. In this case, the density of buildings in an area

does not influence the ratio of building collapse itself but more depend on the soil condition and building type.

In Figure 3 and Figure 10, it can be seen that mostly the buildings lied on soft soil sediment give a higher damage ratio than buildings on stiffer ground condition. The soft ground gives a higher site amplification ratio of ground motion according to NEHRP Provision and Indonesian Seismic Code. It seems that damage ratio map has good correlation with microzonation map in Figure 6.



**Figure 9. Distribution of heavy damaged and destroyed buildings for all structural types.**



**Figure 10. Damage ratio for all building types in Surabaya City and ratio of building collapse for each structural type**

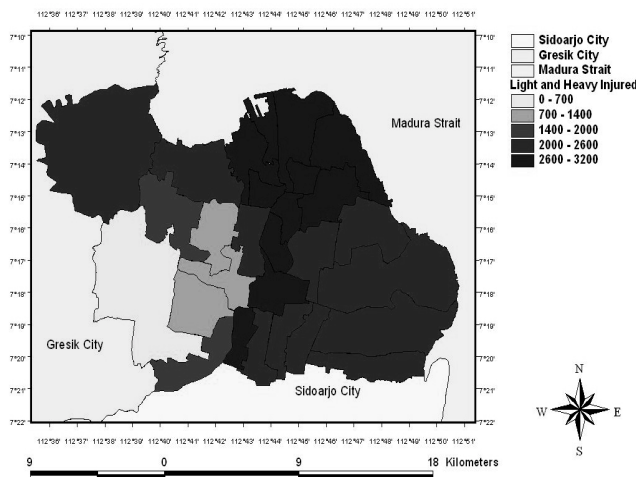
From Figure 10, it can be inferred that the masonry buildings (URML) give the highest collapse ratio than other types of building do. The retrofitting of buildings should be done for the building types that give high damage ratios. It can be seen that low-rise structural types gives higher damage ratios than high-rise structures do. This is happened because

the scenario earthquake in this study has a high earthquake magnitude and the location of hypocenter is near to Surabaya City so that the frequency contents of earthquake motion are quite high. The high frequency contents of earthquake ground motion affect the buildings that have low natural periods most significantly. In this case, low-rise buildings have natural periods lower than those of high-rise buildings. This is the reason why the damage ratio from low-rise buildings is higher than that from high-rise buildings. Therefore, high-rise buildings are commonly safer than low-rise buildings for the case of near source earthquakes. Moreover, mostly high-rise buildings are built under a higher quality control and designed so that high-rise buildings have better structural behavior under earthquake excitations.

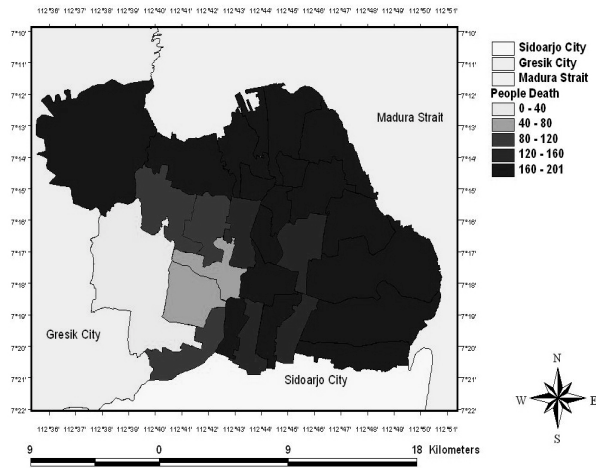
Because the fragility curves in this research are adopted from HAZUS, the damage ratio of the building types from this research is not so accurate for the Surabaya case. It can be seen that wood building gives a very low damage ratio, as low as high-rise buildings with shear wall. Although the building type was chosen from the weakest type of wood structures, the wood structures still give a very low damage ratio. This phenomenon is caused by the building capacity curves that is used in HAZUS methodology are derived from wood structures in the United States of America. This result is different from the real earthquake result in Indonesia, such as the Bengkulu earthquake. Most wood buildings in Indonesia are very weak because of low quality of construction and material, and most wood structures are old. Moreover, the heavy roof tiles make wood structures more vulnerable. The wood building code in Indonesia was adopted from the very old Netherlands Code. The difference in building codes, quality of material and age of buildings are the reasons of rather unexpected results in this case.

### 6.7 Non-Monetary Loss Estimation

For this study, the non-monetary loss focused on the casualties: deaths and injuries. To quantify these values, it is necessary to know the number of occupants of each building type as well as the earthquake casualty models. Due to the lack of casualty statistics from past earthquakes, the casualties models in this study are based on the model from ATC-13 that were developed from expert opinions. In this study, the calculation is done only for permanent dwellings. The result of casualty estimation per 100,000 people is shown in Figure 11.



ng 2004 – Manila, Philippines  
f the Philippines (ASEP)



**Figure 11. Number of light and heavy injured per 100,000 people for permanent dwelling and number of death per 100,000 people for permanent dwellings**

Because the casualty estimation is derived from the structural damage, it can be seen that the areas with the highest casualty ratio are consistent with the areas that have high damage ratios. The value of casualty estimation per 100,000 people is influenced by the building damage ratio. The northern part of Surabaya gives higher casualties because in these areas, buildings are located on soft soil and the proportion of masonry buildings is very high in these areas.

## 7. CONCLUSION

Seismic damage assessments were conducted for Bengkulu City, Indonesia in the 2000 Bengkulu earthquake and for Surabaya City in a scenario earthquake using HAZUS and ATC-13 methodologies. From the study, the following conclusions can be drawn:

1. HAZUS methodology showed a better result than ATC-13 methodology did in a real earthquake in Bengkulu City, Indonesia. The results from HAZUS methodology give a better distribution pattern of damaged buildings and give a lower value of mean difference at each damage state.
2. The results show that the building collapse and casualty ratio are influenced by soil condition and building type proportion. It was seen that the building damage in Surabaya City is concentrated in soft soil areas, which have higher site amplification of ground motion (PGA and PGV amplification ratio) than stiffer soil sites have.
3. Low-rise structural types gave a higher damage ratio because the location of the scenario earthquake is near Surabaya City so that the frequency contents of earthquake ground motion are quite high. High frequency contents affect more to the response of buildings that have low natural periods.

4. The application of the microtremor measurements can be very useful to study the regions with low seismicity. The predominant periods are in good correlation with the surface geology, morphology, and topography data. The correlation of the microzonation map with the damage distribution from the seismic damage assessment study was also reasonable. These results support the use of the present technique in microzonation studies, which could be important in urban and land use planning.

#### REFERENCES

Applied Technology Council, 1985. *Earthquake Damage Evaluation Data for California, ATC-13*. Redwood City, California

City Planning Department of Surabaya, 1995, *Fact and Analysis of City Planning of Surabaya 2005*, City Planning Department of Surabaya, Surabaya, Indonesia

Federal Emergency Management Agency (FEMA), 1999. *HAZUS<sup>®</sup> 99 Service Release 2 (SR 2) Technical Manual – Arc View*, Maryland, U.S.A.

Youngs R.R., Chiou, S.J., Silva W.L., and Humphrey J.R., 1997. Strong Ground Motion Attenuation Relationships for Subduction Zone Earthquakes, *Seismological Research Letters*, January/February

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