Intensity, attenuation and building damage from the 27th May 2006 Yogyakarta earthquake

P. Widodo[1], H. H. Wijaya[2] & Sunarto[3]
[1]*Department of Civil Engineering, Islamic University of Indonesia, Indonesia*
[2]*Former Student of Earthquake Engineering Management Master Program, Indonesia*
[3]*Department of Geography, Gadjah Mada University, Indonesia*

Abstract

The 27th May 2006 Yogyakarta earthquake caused more than 5500 casualties and hundreds of thousands of non-engineered buildings collapsed. It is necessary to investigate the seismic intensity, ground acceleration and building damage index. Direct site investigations to collect the severity distribution of objects, humans and environments have been done. The result of the investigation shows that in general isoseismic lines are in-line with Opak fault, the proposed attenuation relationship for seismic intensity and horizontal ground accelerations are matching well with previous research results and the distribution of the building damage index has a similar pattern with isoseismic lines.
Keyword: seismic intensity, isoseismic lines, ground acceleration, attenuation, damage index.

1 Introduction

According to several sources (Walter et al. [24]; Tsuji et al. [23]), the focus of the 27th May 2006 Yogyakarta earthquake with $M_w = 6.2$ was at approximately 10 km depth and only 15 km away from Yogyakarta city. Elnashai et al. [7] and Tsuji et al. [23] stated that there are several versions of the location of the epicenter.

www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/DMAN110061

So far the investigations soon after the 27th May 2006 Yogyakarta earthquake have concentrated on the earthquake parameters such as earthquake magnitude, epicenter and focal mechanism by Walter et al. [24], ground motions by Elnashai et al. [7] and Widodo and Trianto [25], non-engineered building damage and its distribution by Boen [3], Gousheng et al. [9] and Miura et al. [14], effects of the soil condition on building damage by Kertapati and Marjiono [13], and post disaster damage assessment by using satellite image by Miura et al. [14]. It is necessary therefore to extend the research especially on the seismic intensity. The main aim of this paper is to present the seismic intensity, ground acceleration and the non-engineered building damage from the 27th May 2006 Yogyakarta earthquake.

2 The seismic intensity and its development

Since a few decades ago the seismic or earthquake intensity has been used by seismologists and engineers to describe the severity of the site under earthquake attack. The severity of the site is mainly described by the damage of the man-made structures and the damage of the environments (Trifunac and Brady [22]). The level of human response due to anxiety, or discomfort, response of any object due to external disturbance, damage in particular types of structure and damage of the environment are the usual parameters used in the survey.

The seismic intensity can be determined by using traditional techniques or human judgment such as the direct interviewing of respondents and site visits. Further development in determining the seismic intensity is achieved by using ground motion records (Devenport [4]; Miura et al. [14]). This is one of the developments of the technique/method in determining the scales. Freeman [8] presented further development of the seismic intensity, i.e by constructing the demand spectra.

3 Seismic intensity and peak ground acceleration relationship

In many countries, the availability of the ground motion records is still a big problem including Indonesia. Several Indonesian strong earthquakes such as the 26th December 2004 Sumatera earthquake ($M_w = 9.2$), the 18 March 2005 Nias ($M_w = 8.5$) earthquake and the 27th May 2006 Yogyakarta earthquake ($M_w = 6.2$) occurred without any significant ground motion records. Accordingly the site response (ground acceleration for example) can not be easily connected to the seismic intensity.

The simplest relationship model between site response Y and seismic intensity I_{mm} can be expressed in the equation (Trifunac and Brady [22]; Panza et al. [17])

$$Log\, Y = b_o + b_1 . I_{mm} \tag{1}$$

where b_o and b_1 are constants.

Several aspects will affect the seismic intensity including soil site condition. Dynamically, the soil site condition can be represented by the predominant period T_G of the soil layers. Accordingly, Kanai [10] proposed the mathematical model for the ground acceleration and seismic intensity relationship.

4 Seismic intensity attenuation

Variations of the level of the seismic intensity scale over the distance mean that the seismic energy was attenuated. Over the distance, the seismic energy spreads out in 3-dimensional directions. Accordingly the imparted seismic energy per unit volume of soil mass will rapidly be attenuated. The principle of seismic energy attenuation has been used in attenuations of peak ground acceleration, velocity, displacement, attenuation of Arias intensity as well as attenuation of seismic intensity.

Dowrick [6] and Szeliga et al. [19] proposed the seismic intensity attenuation model as described in the equation as follows:

$$I = a + bM + c.r + d\log r \tag{2}$$

where I is the seismic intensity, a, b, c and d respectively are the coefficients, M is the earthquake magnitude, r is the focal distance, and the second and third terms in Eq. (3) indicate the effect of earthquake magnitude and focal distance.

In addition, Dowrick [6] also incorporated the effect of the earthquake mechanism in the attenuation model by setting different coefficients. Sometimes the required data is not completely provided. Another attenuation model as used by Karim and Yamazaki [12] is presented in the equation

$$I = c_o + c.M + c_2.Ln(R + \Delta) \tag{3}$$

where c_o, c_1 and c_2 are coefficients, R is epicenter distance and Δ is a particular value.

In the case when the data are very limited as in this study, the use of simpler attenuation is required, an example of which was presented by Sutardjo et al. [21],

$$I_x = I_o.e^{-b.x} \tag{4}$$

where x is the distance (in km) from the center of the maximum isoseismic line, I_x is the intensity level at x km from the center of the isoseismic line, I_o is the maximum intensity level and b is the attenuation rate of the intensity.

5 The building damage and damage index

Damage in general terms can be defined as something broken physically, shapely and as a function of things and causes partially/mostly loss of its value. Researchers have tried to transfer qualitative meaning to the quantitative value with the so-called damage index, damage factor or damage ratio. Several quantitative concepts of damage index/factor/ratio have been proposed by researchers. An example of building damage index quantification was presented by Qiwen et al. [18].

6 Methods of research

6.1 Parameters, time and building types

The main parameters for determining the seismic intensity scales respectively are the human behavior during earthquake, the response of any objects and the damage of the structure and environment. The direct site surveys were carried out from March to September 2009 by Wijaya [26]. The building objects are mainly non-engineered buildings such as un-reinforced clay brick buildings, partially reinforced clay brick buildings and only a small amount of well reinforced clay brick buildings.

6.2 Instruments, respondents, data and method of analysis

Instruments for collecting site data are mainly maps, questionnaire sheets, interview question lists, electronic camera, GPS and amount of supporting utensils. The head of villages, the head of sub-villages and the particular persons who are able to give relatively accurate information were selected as respondents. The data were collected according to purposive sampling in 17 districts and from 294 respondents. The collected data were analyzed both qualitatively and quantitatively. Transferring the qualitative information to the seismic intensity scales was carried out qualitatively.

7 Results and discussion

7.1 Isoseismic lines, seismic energy and moment, soil liquefaction

The seismic intensity scales of the site were determined based on the results of the interviews and recorded data in which more than 290 data were collected from the site. After smoothing the results, the isoseismic lines of the 27th May Yogyakarta earthquake are presented in Fig. 1.

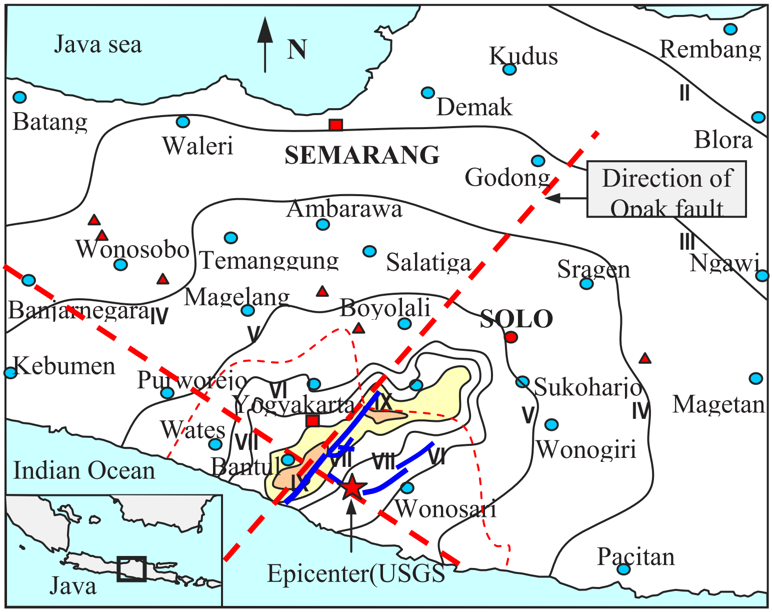

Figure 1: Isoseismic lines of the 27th May 2006 Yogyakarta earthquake.

It can be seen from the figure that the maximum seismic intensity is I_{mm} = IX. Similarly as presented elsewhere, the maximum seismic intensity does not always coincide with the location of the epicenter. It shows that the shape of the isoseismic lines is not nearly circular but tends to be similar to the isoseismic lines due to the Tonghai earthquake.

According to Sulaiman et al. [20] the seismic moment Mo of the 27th May 2006 earthquake is estimated to be equal to $8.1325.10^{25}$ dyne.cm with a rupture area of 200 km^2 (Walter et al. [24]). Plots of these earthquake parameters to the Kanamori [11] graph are presented in Fig. 2 and Fig. 3. They show that these parameters are matching well with the Kanamori [11] plot.

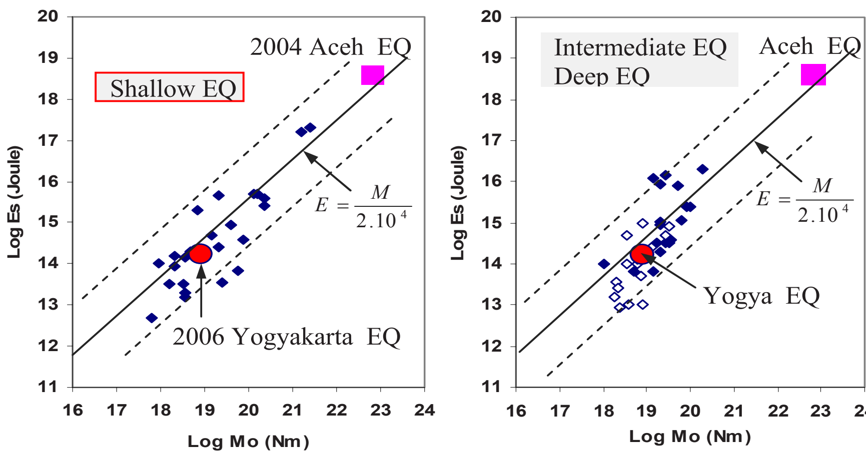

Figure 2: Energy and seismic moment of Yogyakarta EQ plot to Kanamori [11].

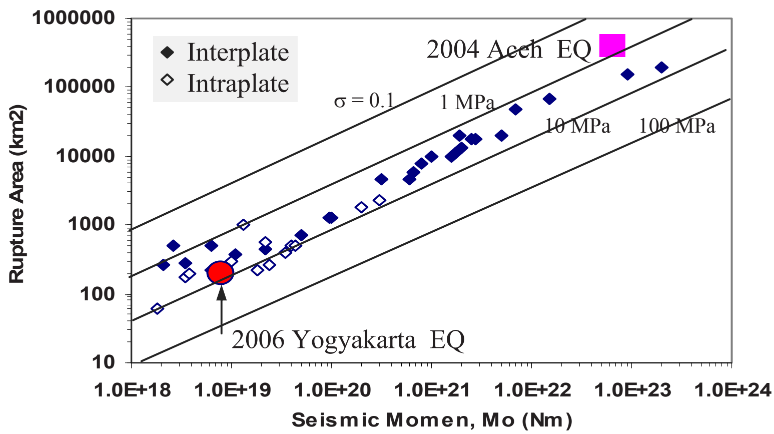

Figure 3: Energy and seismic moment of Yogyakarta EQ plot to Kanamori [11].

Walter et al. [24] illustrated the cross section of soft sediment soil deposits from Merapi Mountain to Opak river/fault. According to Walter et al. [24] the depth of soft sediment may reach 200 m. Meanwhile Nurwidyanto et al. [16] found that the Opak fault is buried by soil sediment with the depth ranging approximately from 40 to 75 m. Eko et al. [5] studied potential liquefaction of the site. Their study revealed that the elevation ground water level is relatively high ranging from -0.60 to 4.0 m from the local ground surface. A plot of isoseismic lines into the Eko et al. [5] result is depicted in Fig. 4.

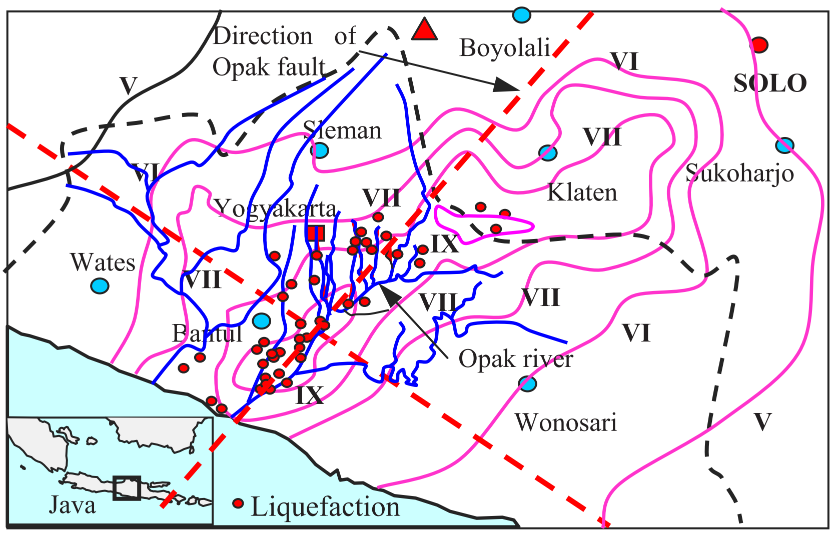

Figure 4: Liquefaction sites (Eko et al. [5]) plot to isoseismic lines.

It is clearly shown in Fig. 4 that the Opak fault is exactly in-line with the Opak river. It is shown in the figure that the liquefied soil mostly occurred at the ground with the seismic intensity I_{mm} = VIII and partly occurred at the region with I_{mm} = VII. This result confirms that of Anonym [1].

7.2 Seismic intensity attenuation

The result of the research presented in this paper is based only on the data collected from the 27th May 2006 Yogyakarta earthquake. Having limited data, the seismic intensity attenuation model based on Eq. (4) was used and the result is presented in Fig. 4. The attenuation is constructed based on data from all respondents. The attenuation is constructed in-line direction with the Opak fault as presented in Fig. 1 and can be expressed mathematically as follows:

$$I_{mm} = 8.889.e^{-0.0088.L} \tag{5}$$

where L is the distance from the center of isoseismic lines.

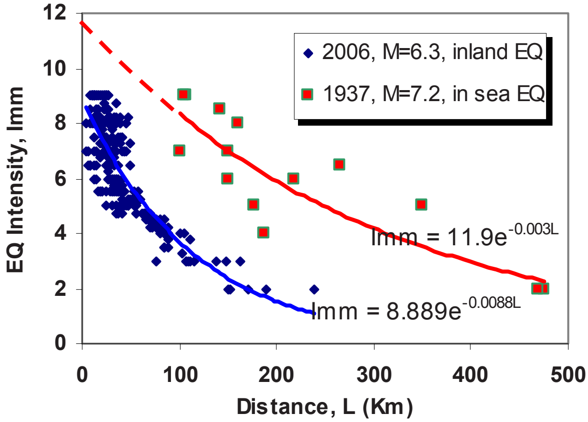

Figure 5: Modified mercalli intensity I_{mm} attenuation.

Fig. 5 is the comparison between two seismic intensity attenuations, i.e attenuation for seismic intensity of the 27th May 2006 and the 27th September 1937 Yogyakarta earthquake (Sutarjo et al. [21]). It is shown in the figure that land earthquakes attenuate faster than sea earthquakes. This result confirms the common theory which says that the shallow crustal earthquakes attenuate faster than the in-sea /subduction earthquakes.

7.3 Comparison with other seismic intensity attenuations

It is necessary to make a comparison of the seismic intensity attenuation as written in Eq. (6) with attenuation of other earthquakes.

The comparison between the 27th May 2006 seismic intensity attenuation and the Californian earthquake (Barosh [2]) is presented in Fig. 6. It can be identified that the proposed seismic intensity attenuation is well performed.

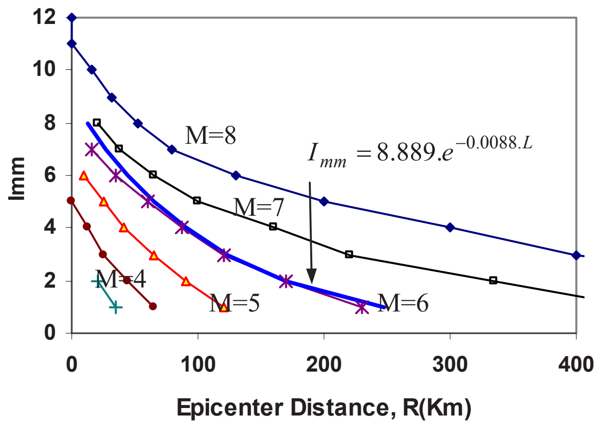

Figure 6: Comparison with other seismic intensity attenuations.

7.4 Ground acceleration attenuation

Elnashai et al. [7] conducted earthquake reconnaissance at the site and found only two records from two closer stations, i.e YOGI (Yogya) and BJI (Banjarnegara) at distances of 10 km and 90 km respectively from the epicenter.

According to Elnashai et al. [7], the most probable ground acceleration histories for the N-S components are 0.27 g (10 km from the epicenter) at YOGI station and 0.028 g (90 km from the epicenter) at BJI station. In addition, Elnashai et al. [7] also presented several possible ground acceleration attenuations that might be applied at the region. The interpolation of the applied attenuation gives the I_{mm}- ground acceleration relationship presented in Fig. 7 and is expressed mathematically in the following equation,

$$Log\ a_h = 0.2208.I_{mm} + 0.5446 \tag{6}$$

where a_h is the peak horizontal ground acceleration.

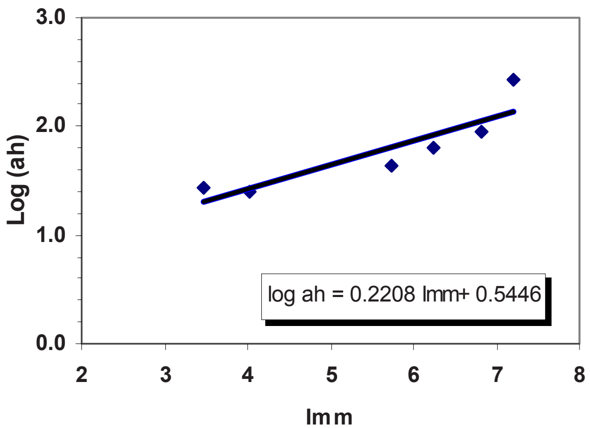

Figure 7: I_{mm}-Log a_h relationship.

The proposed peak horizontal ground acceleration attenuation can be developed by substituting Eq. (5) into Eq. (6) to yield (for $M_w = 6.2$)

$$Log\ a_h = 1.96.e^{-0.0088.L} + 0.544\ . \tag{7}$$

The comparison of the peak ground acceleration attenuation from Eq. (7) and several shallow crustal peak ground acceleration attenuations is presented in Fig. 8. It is shown in the figure that ground acceleration attenuations are widely variable, everything depends on the aspects that have been mentioned before. The proposed ground acceleration attenuation is very close to that of Campbell (1989) for a distance L > 20 km and very close to that of McGuire (1977) for a distance L < 20 km.

The comparison of the I_{mm}-ground acceleration relationship presented in Eq. (7) with several similar relationships is presented in Fig. 9. The figure shows that the relationship proposed by Coulter, Waldron and Devine (1973) and Medvedev and Sponheuer (1968) respectively fall in the upper bound and the

www.witpress.com, ISSN 1743-3509 (on-line)

lower values; the same as reported by Murphy and O'Brien [15]. The I_{mm}-ground acceleration relationship proposed by Hershberger (1956) is completely crossing with the proposed relationship result of this research/study. However, those proposed relationships still fall in the range of the upper and the lower bound values.

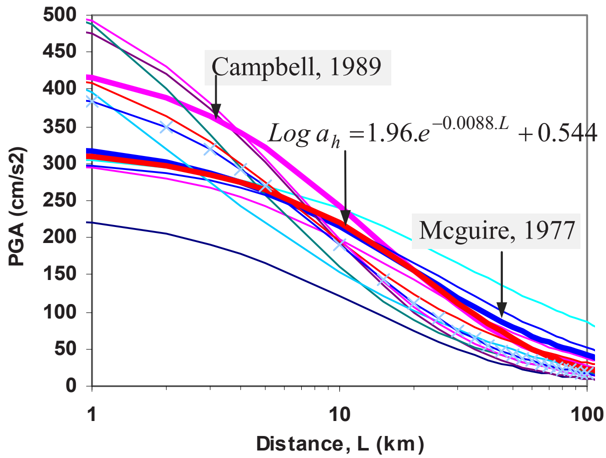

Figure 8: The comparison of ground acceleration attenuation.

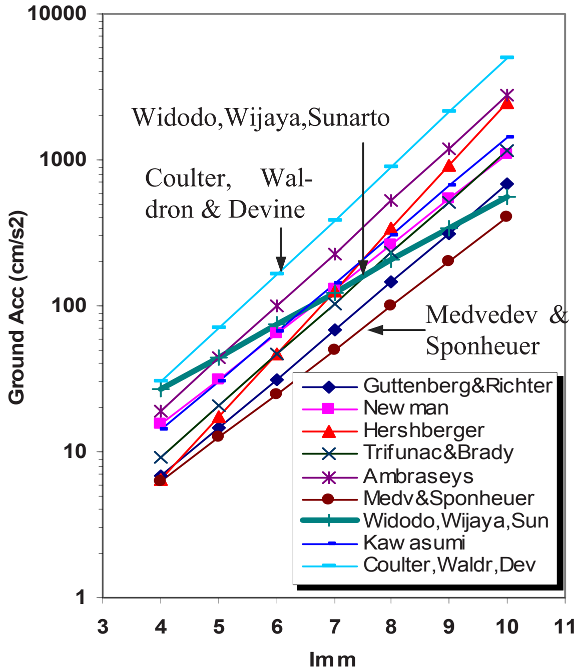

Figure 9: I_{mm}-ground acceleration comparison.

7.5 Damage index map

From a Civil Engineering point of view, the damage index is commonly used to describe the damage level of structural element, storey and whole structure quantitatively. The quantification of the damage can be determined from simple assessment of an object to a very complicated formulation. As shown in Table 1, Qiwen et al. [18] presented an estimation of damage index values at every damage category for dwellings. The damage descriptions are connected to damage state category.

Data concerning the descriptions of building damage have been collected during a direct site survey. These data have then been connected to the descriptions which are presented by Qiwen et al. [18]. Accordingly, the level of the damage index of the building at every site can be determined approximately. The result then is plotted in the map as presented in Fig. 10.

It can be seen from Fig. 10 that the shape of the damage index contours very closely resemble the isoseismic lines which are shown in Fig. 1. At the sites where the seismic intensity I_{mm} = IX most of the buildings were totally collapsed. This condition is associated with a damage index equal to 1. Most researchers agree that the buildings can still be repaired when the level of structural damage index less than 0.35-0.4.

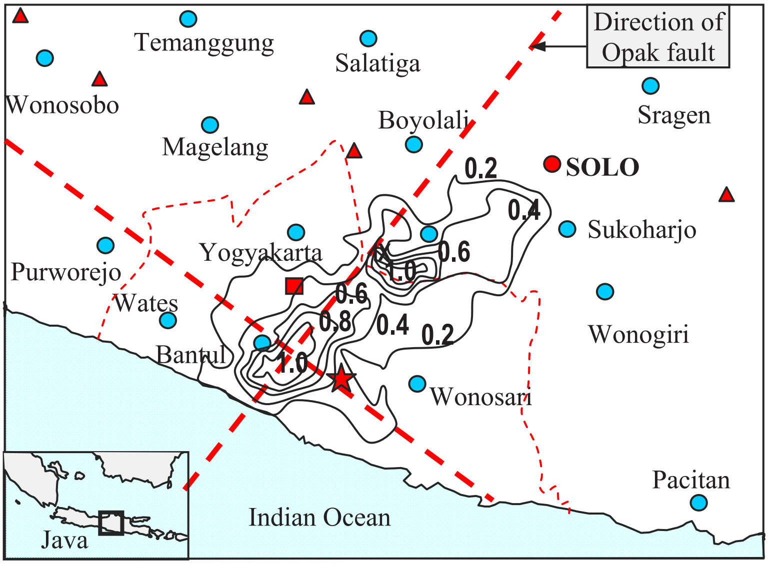

Figure 10: Damage index map.

8 Concluding remarks

The research/site investigation of the seismic intensity, the ground acceleration and the distribution of structural damage from the 27th May 2006 Yogyakarta earthquake has been carried out. Findings from the site and the analysis can be formulated as follows:

a. Isoseismic lines under the 27^{th} May Yogyakarta earthquake in general are in-line with the direction of Opak fault and meet well with the soil liquefaction as reported by Eko et al. [5].
b. The proposed seismic intensity attenuation in general confirms well the similar attenuation which is proposed by researchers.
c. In addition, the simple proposed ground acceleration attenuation also conforms to the Campbell (1989) and McGuire (1977) attenuation.
d. Even though the I_{mm}-ground acceleration relationship is completely crossing with a similar relationship proposed by Hershberger (1956), in general it still falls in the range value.
e. The shape of the building damage indexes in general has a similar pattern to the seismic isoseismic lines.

Acknowledgements

Acknowledgements are addressed to the Biro Perencanaan Kerjasama Luar Negeri (BPKLN), Kementerian Pedidikan Nasional Republic of Indonesia for full financial support of this research.

References

[1] Anonym, *ABAG Engineering Program*: Appendix B: The Process of Developing Liquefaction Hazard Map, 2001.
[2] Barosh P.J, *Used of Seismic Int. Data to Predict the Effects of Earthq. and Underg. Nuclear Explosion in Varieties Geol. Setting*, US Geol. Survey, 1969.
[3] Boen T, *Yogya Earthquake 2006 Structural Damage Report, 2006.*
[4] Devenport P.N, *Seismic Intensities Derived from Strong Motion Instruments in New Zealand*, NZEEI Conference, 2001.
[5] Eko S, Tohari A, Sarah D, *Study Potensi Lukuifaksi di Daerah Zona Patahan Opak Patalan Bantul, Yogyakarta*, Seminar Geoteknologi, Bandung, 2007.
[6] Dowrick D.J, *Attenuation of Modified Mercalli Intensity in New Zealand Earthquakes*, Earthq. Eng. and Str.Dynamics, Vol.21, pp.181-196, 1992.
[7] Enashai A, Kim C.J, Yun, G.J, Sidarta J, *The Yogyakarta Earthq. of 27th May 2006*, Mid American Earthq. Center, Un. of Illinois at Urbana-Champaign, 2006
[8] Freeman S A, *Response Spectra As a Useful Design and Analysis Tool for Practicing Structural Engineers*, Iset Journal Vol.44, No.1,2007.
[9] Gousheng Q, Fengxin Z, Jianfa H, Yigang L, Yanfeng L, Xiaoxia D, Baukun, *Earthquake Disaster assessment on 27th May 2006 Yogyakarta Earthquake of Indonesia*, Nat. Earthq. Resp. Support Service and Administration, 2006.
[10] Kanai K, A *Short Note on Seismic Intensity and Seismic Intensity Scale*s, Bulletin of the Earthquake Research Institute, Vol.45, pp.339-345,1967.

[11] Kanamori H, *Magnitude Scale and Quantification of Earthquakes*, Tectonophysics, 93, 185-199, 1983.
[12] Karim K.R, Yamazaki F, *Correlation of JMA instrumental Seismic Intensity with Strong Motion Parameters*, Earthquake Engineering and Structural Dynamics, Vol.31, pp.1191-1212, 2002.
[13] Kertapati E. K, Marjiono, *Correlation of Soil Condition-Building Damaged and Ground Rupture at 27th May 2006 Yogyakarta Earthquake-Center Java and Microzonation of the Area Damage*, HAKI Seminar, 2007.
[14] Miura H, Yamasaki F, Matsuoka M, *Identification of Damaged Area due to the 2006 Central Java Indonesia Earthquake Using Satellite Optical Image*, 2007 Urban Remote Sensing Joint Event, 2007.
[15] Murphy J.R, O'Brien L.J, *The Correlation of Peak Ground Acceleration Amplitude with Seismic Intensity and Other Physical parameters*, Bulletin of the Seismological Society of America, Vol.67, No.3, pp 877-915, 1977.
[16] Nurwidyanto M.I, Indriana R.D, Darwis Z.T, *Pemod. Sesar Zona Opak di Pleret Bantul Yk dng Metode Gravitasi*, Berkala Fisika, Vol. 10, No.1,, 2007.
[17] Panza G.F, Cazzaro R, Vaccari F, *Correlation Between Macrosismic Intensities and Seismic Ground Motion Par.*, Annali Di Geofisika, Vol.11, No.5. 1997.
[18] Qiwen T, Pinshan S, Xilin Z, Hongqing T, *Eartq. Dmg Survey of Anomalous Area of Lower Intensity in Yutian*, Chaper 3: Earthq. Int., Tangshan, 2007.
[19] Szeliga W, Hough H, Martin S, Bilham R, *Intensity, Magnitude, Location and Attenuation in India for Felt Earthquake since 1762*, Bulletin of the Seismological Society of America, Vol.100, No.2, pp 570-584, 2010.
[20] Sulaiman C, Dewi L.C, Triyoso W, *Karakteristik Sumber Gempa Yogyakarta 2006 Berdasarkan Data GPS*, Jurnal Geologi Ind., Vol.3, No.1, 2008
[21] Sutarjo, Untung M, Arnold E P, Soetadi R, Ismail S, Kertapati E K, *Series on Seismology Volume V*, Indonesia, 1985.
[22] Trifunac M.D, Brady A.G, *On the Correlation of Seismic Intensity Scales with the Peak of Recorded Strong Ground Motion*, Bulletin of the Seismological Society of America, Vol.65, No.1, pp 139-162, 1975.
[23] Tsuji T, Yamamoto K, Matsuoka T, Yamada Y, Onishi, Bahar K, Meilano I, Abidin H.Z, *Earthquake fault of the 27th May 2006 Yogyakarta Earthquake observed by SAR Interferometry*, Earth Planet Space, 61, 2009.
[24] Walter T.R, Wang R, Luehr B.G, Wassermann J, Behr J, Parolai S, Anggraini A, Gunther E, Sobiesiak S, Grosser H, Wetzel H.U, Milkereit C, Brotopuspito K.S, Haryadi P, S\Zschau C, *The 26 May 2006 magnitude 6,4 Yogyakarta Earthquake South of Mt Merapi Volcano: Did Lahar Deposit Amplify ground Shaking and thus Lead to Disaster*?, 2007.
[25] Widodo, Trianto Y, *Estimasi Perc. Tanah Akibat Gempa 27 Mei 2006 dengan Pendekatan Line Source Method*, Seminar Tahunan ITS Surabaya, 2008.
[26] Wijaya H.H, *Isoseismal, Kerentanan dan Rasio Kerusakan Bangunan Rumah Tinggal; Studi Kasus Gempa Bumi Yogyakarta 27 Mei 2006*, Thesis Magister Teknik Sipil (MTS), Universitas Islam Indonesia (in bahasa), 2009.