FIELD INVESTIGATION ON THE DAMAGE OF PRAMBANAN TEMPLE, HOUSING AND INFRASTRUCTURE CAUSED BY EARTHQUAKE IN CENTRAL JAVA, INDONESIA

Tsuneo OHSUMI[1)] and Koji Baba[2)]

1) Senior Researcher, Dr. Eng., Nippon Koei. Co., Ltd, Research & Development Center
2304, Inarihara, Tsukuba , Ibaraki 300-1259, Japan
2) General Manager, Nippon Koei. Co., Ltd, Jakarta Office
JL. Sulutan Hasanuddin No.45, Kebayoran Baru, Jakaluta Sulatan, Indonesia

An earthquake with a magnitude of 6.3 has occurred on May 27, 2006 and caused 5,700 casualties. Investigation on damage for the Prambanan temple, housing and infrastructure was carried out in and around Yogyakarta, in central JAVA from June 5 to 8, 2006 The Prambanan complex sustained heavy damage, even this complex is located 40 km far north east of the epicenter. It is considered that the seismic wave was amplified due to the directivity effect and attacked Prambanan complex. Extensive damaged areas are distributed in the west side of the Imogiri fault. Serious damaged areas are limited in Bantul and in Klaten Regency. Damaged areas begin in Klaten Regency between Solo and Yogyakarta. In Bantul Regency, there were more than 4,000 casualties. The infrastructure suffered comparatively light damages, however, housing sustained heavy damages and totally collapsed in Bantul Regency. In this report, reasons why the infrastructure sustained light damage while housing suffered heavily and as well as why damage areas are distributed unevenly are discussed.

Key words: *central JAVA earthquake, Prambanan, Yogyakarya, infrastructure, housing*

1. INTRODUCTION

An earthquake with a magnitude of 6.3 occurred at 5:54 a.m. (local time: Indonesian West Standard Time) on June 27, 2006. According to the Indonesian Social Affairs Ministry, the earthquake caused 5,700 casualties. The damage investigation was carried out in and around Yogyakarta from June 5 to8, 2006.

Two interesting phenomena were observed in the results of the investigation on damage caused by the earthquake. The infrastructures sustained light damage but houses were heavily damaged. The extensive damaged areas are located in the east side of Bantul Regency (prefecture) and in Klaten. In this report, two phenomena are discussed. The ideas for the site-specific effect and the seismic wave effect are also described.

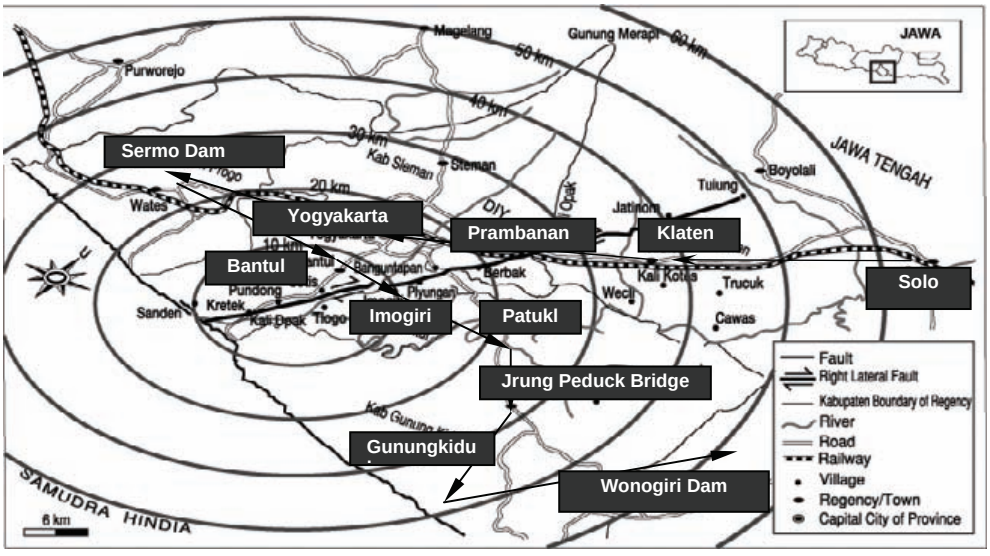


Figure 1
Epicenter and Survey route

2. HYPOCENTER & TECTONIC

The Late Neogene Sunda orogeny affected the segment of the Indonesian arc between West Java and the islands of Nusa Tenggara as far east as Flores. In this segment of the arc convergence between the Indian Ocean and SE Asian plates is normal to the subduction trace in the Java Trench with a rate of c. 7 cm/year. The subduction system comprises an accretionary complex composed of offscraped Indian Ocean floor materials in the Java forearc ridge, a forearcbasin developed on extended continental crust and containing late Paleogene to Recent sediments. The volcanic arc which forms the backbone of Java and forms the islands to the east is constructed on continental crust in West Java, whereas on Mesozoic accretionary complexes in Central and east Java and on oceanic crust in Sumbawa and Flores (**Figure 2**)[1].

The Mesozoic accretionary complexes have a NE fault system with right-lateral strike-slip.

3. WAVEFORM DATA

National Research Institute for Earth Seience Disaster Prevention (NIED) estimated the source location and mechanism of this earthquake using waveform data obtained by the Indonesian broadband seismograph network (Realtime-JISNET: **Figure 3**) operated by Indonesia Meteorological and Geophysical Agency (BMG) and NIED. These results indicate that the epicenter was located

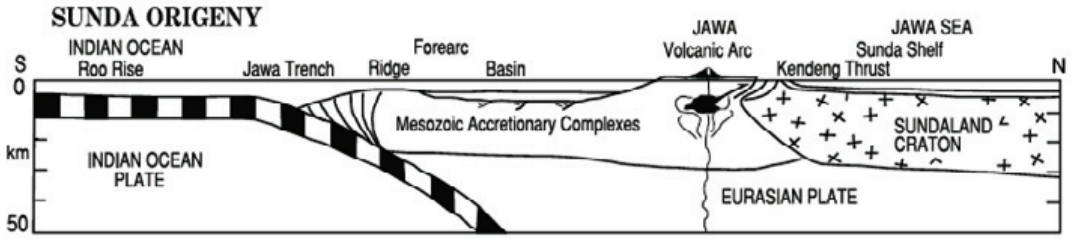


Figure 2 Cross section of Java in Sunda arc adopted from Hall and Blundell (1996) [1] .

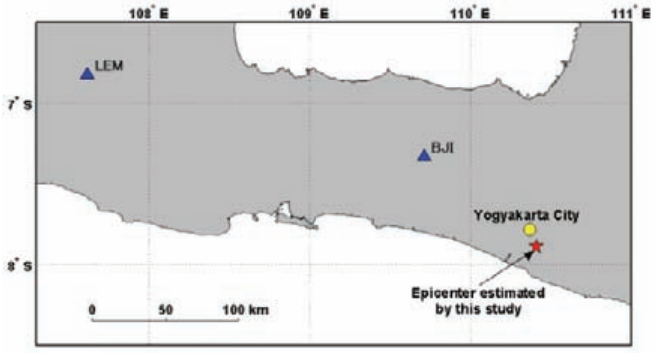


Figure 3 Indonesian broadband seismograph network (Realtime-JISNET)[2]

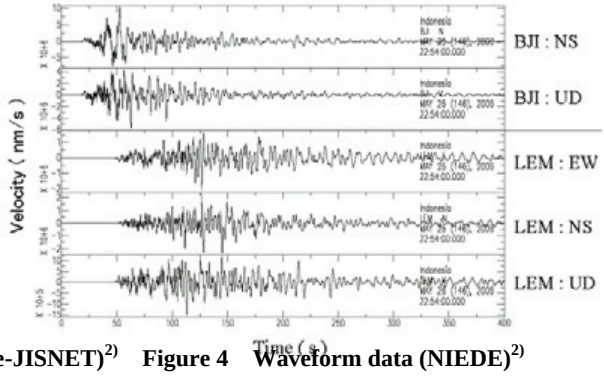


Figure 4 Waveform data (NIEDE)[2]

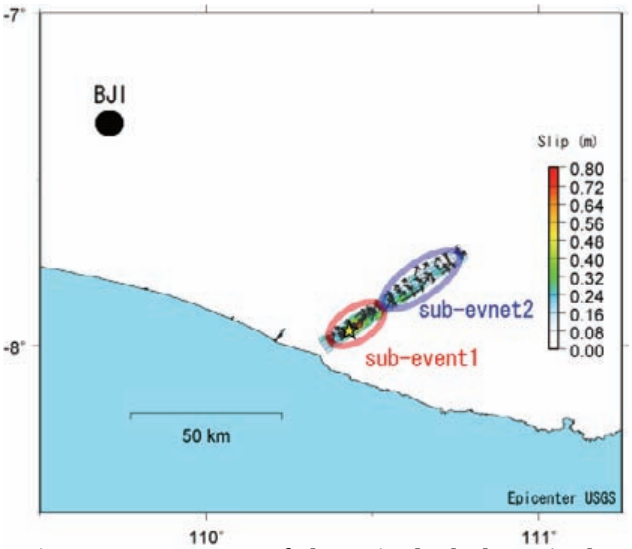


Figure 5 Hypocenter of the main-shock determined by USGS (Yagi, 2006) [3].

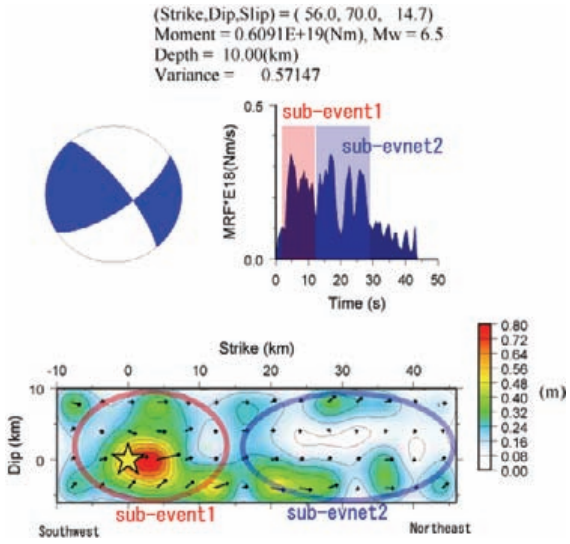


Figure 6 Focal mechanism (upper left); Total moment-rate function(upper right); Distribution of coseismic slip. Star indicates the location of the initial break (lower). (Yagi, 2006) [3].

approximately 10 km SSE of Yogyakarta City at a depth of 10 km beneath the surface. The moment magnitude (*Mw*) was estimated as 6.3. **Figure 4** shows three-component waveform data acquired by CMG-3T EBB (0.02-360 s) at BJI (Banjar Negara) and LEM (Lembang) stations of Realtime-JISNET. Waveform data were not available for the EW component at BJI due to trouble with the seismometer in this component.

According to Dr. Yagi's inversion (**Figure 5,6**)[3], the rupture of this earthquake happened in two stages. In first stage as sub-event 1, the direction of the rupture was expanded from the southwest to northeast and then the second the rupture as sub-event 2 happened. The strike-slip of the Imogiri fault in which the direction is a southwest to northeast happened at a depth of less than 15 km. The moment release history was complicated and duration time of the earthquake was about 40 seconds. Even if duration time is assumed at 30 seconds, it is longer by 2 times than one of an ordinary earthquake of *Mw*6.5 class. Moreover, the rupture velocity is rather slow at about 1.4 km/sec. First, sub-event1 occurred 3 seconds after the earthquake started and the rupture mainly expanded to the north and the northeast of the epicenter. Then, sub-event 2 occurred 12 seconds after the earthquake started. At this time, the rupture mainly spread toward the northeast. Due to the directivity effect, the seismic wave was amplified and the areas in the expanding direction were damaged heavily.

4. DAMAGED STRUCTURES

4.1 Prambanan Temple

The Prambanan temple is the ancient masterpiece of Hindu architecture. Prambanantemple (candi) was built in the 10th century by Mataram Kingdom and located in Klaten, Central Java. The Prambanan complex was listed a UNESCO World Heritage siteNo.642 in 1991. The Siwa and Garuda temple in the Prambanan complex suffered heavy damage (**Figure 7**). The temples were leaned slightly and cracked. This complex is located 40 km north east of the epicenter,however, this area is located at the end of the Imogiri (Opak) fault. Therefore, it is considered that the seismic wave was amplified by the directivity effect and Prambanan complex was damaged heavily. For the time being, the Prambanan complex is closed to the public. According to the UNESCO damage survey team[4], about 1000 stones has fallen down by the earthquake, further roughly 300 number of cracks were observed. Foundations of three main temples have moved at least 10 centimeters.

(1) Location of the individual temple

As feature of Hindu temple, Prambanan temple has three main temples (**Figure 8**) which dedicated to the Hindu Trinity, Siwa, Wisnu, and Brahma. All of three temples face a small temple of gods mount（vehicle）, Wahana. The Siwa temple having 47 meters high faces the temple of Nandi enshrining the bull used by Siwa as the destroying god. The Wisnu temple with 27meters high faces the temple of Garuda enshrining the eagle used by Wisnu as the guardian god. And the Brahma temple having 37 meters high faces the temple of Angsa enshrining goose/swan used by Brahma as the creating god. The stones used for temples are local Andesites and Basalts. Both stones are described in the book written by Gonggong & Untoro Drajat (2004).

(2) Siwa temple

The statue of Siwa niched inside the Siwa temple was not damaged by earthquake. It is clear by comparison of before (left side of **Figure 9**) and after (right side of **Figure 9**) the earthquake. The Ramayana epic engraved on the inner wall of the Siwa temple is very well known (**Figure 10**). Regrettably, this sculpture was damaged by the earthquake (**Figure 11**). The falling stones damaged some parts of the gallery of the Siwa temple (**Figure 11,13**). Some cracks are observed in all corners of this temple. The structure of this temple is a cantilever structure supported by the base stage, then, shaking by earthquake caused a large moment at the support, consequently cracks happened. The width-wise of the cracks is deemed not so serious, and depth of crack is not clear. It is difficult to judge whether temple suffered serious damage or not. Thus, detailed diagnosis of these temples is recommended to be done.

(3) Brahma temple

Many parts of the top of Brahma , which has a height of 37m, fell down and closed the entrance. Stone works called as Ratna (crown form decoration) fell down from the top of Brahma and are scattered around the site (**Figure 12**).

(4) Wisnu temple

The Wisnu temple is damaged relatively light by the earthquake. Many parts of Ratna which fell from the top caused damage to the corridor (**Figure 14,15**).

Figure 7 Full view of the Prambanan Complex.

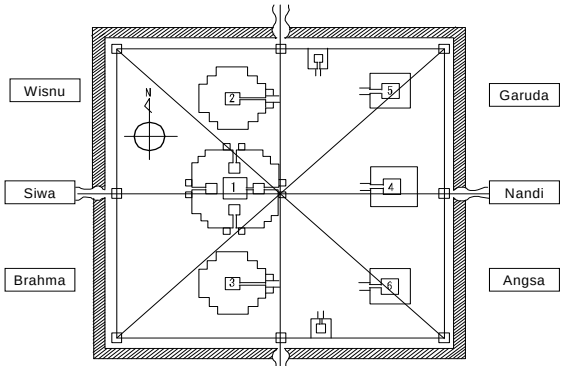


Figure 8 Location of the individual temples in the central part of the Prambanan Complex[5].

Before the earthquake
Photo was taken by Prof. Ishi.

Figure 9 Statue of Siwa There was no damage to the statue of Siwa.

Figure 10 Ramayana epic
Regrettably, this sculpture was damaged in the earthquake.

Figure11 The gallery of the Siwa temple were damaged.
Some cracks appeared in the corner section of this temple. All corner sections of the Siwa temple had cracks.

Figure 12 Falling parts from the top of the Brahma temple.

Figure 13 All corner sections of the Siwa temple had cracks.

Figure14 The Wisnu temple sustained relatively little damage.

(5) Garuda temple

The Garuda temple was being repaired and many parts suffered serious damage. This temple is leaned slightly due to the earthquake (**Figure 16**).

(6) Nandi temple

Many parts, which fell from the top of Nandi damaged the front stairs. However, the damage was not so serious (**Figure 17**).

(7) Angsa temple

Many parts, which fell from the top of Angsa damaged the side wall. However, the damage was not so serious (**Figure 17**).

(8) How did Wahana reconstruct ?

According to UNESCO report [6], the reconstruction started 1918 and lasted until 1953, when Siwa was formally inaugurated. The reconstruction of the other temples followed, Brahma temple (1987), Wisnu temple (1991) and the three Wahana temples (Garuda, Nandi and Angsa) and further smaller temples (1993). For these reconstructions again reinforced concrete was used but this time the concrete was coated by a layer of ARALDITE TAR (mixture of Araldite TAR with sand of grain size < 1mm) to isolate the concrete from the rest of the construction (**Figure 18**). Originally all individual temples of the site were built by the sun burned masonry with the stones interlocking. This originally void space was filled with cement during reconstruction of Siwa temple and the cement was given a surface coating to camouflage it. For the reconstructions of the other temples this procedure was changed and the surface joints were filled with a mortar made from epoxy resin and sand. These reconstruction methods are giving hint for rehabilitation of damage by the earthquake.

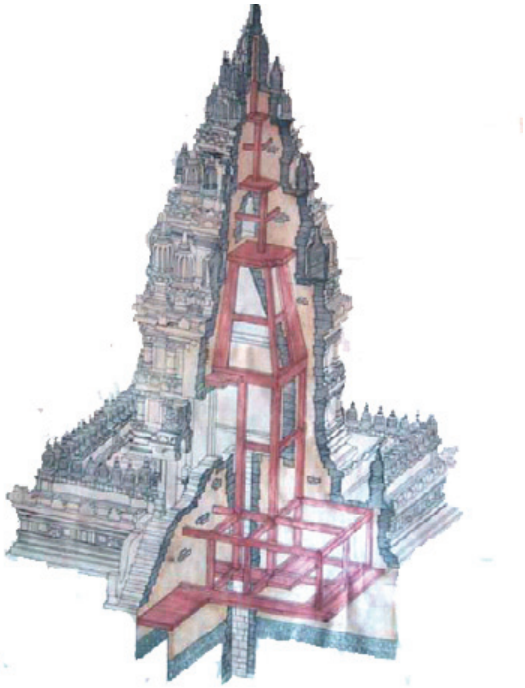


Figure 18 3D view of how the reconstruction of Wahana[6].
The concrete frame is shown in shaded area.

Figure 16 The Garuda temple is leaning due to the earthquake.

Figure 15
Many Ratna parts which fell from the top of the Wisnu temple caused damaged to the corridor.

Figure 17 the damage sustained was not so serious at the Nandi temple (right) and the Angsa temple (center).

4.2 Infrastructure

(1) Roads and Bridges

The road shoulder was collapsed by the earthquake. This site is located at the steep slope formulated by the Imogiri fault at Patuk (**Figure 19**). Jrung Peluk Bridge was collapsed in the left side of abutment, which is located near Patuk. Expansion joint of Jrung Peluk Bridge was broken at the left side of bridge (**Figure 20**).

(2) Dam Structure

The Sermo dam (**Figure.21**) is located in 30 km west from the epicenter. Final movement is observed at 12 mm. There is no crake in this crest. A seismograph was installed on the embankment, but this instrument was out of order. The Wonogiri dam is far from the epicenter with 60 km, and there is no damage (**Figure.22**). As for neighboring people, the false rumor that a crack went into the dam and became with panic immediately after the earthquake.

4.3 Housing

In Bantul Regency, especially at around Imogori County, housing is totally collapsed (**Figure 23**). Refugees live in the tentative tent fear the aftershock (**Figure 24**). Structure of almost all collapsed houses is made of burned brick masonry and wall infilling with cement mortar or reinforced concrete frame rarely. A roof structure is a tile-roofed on wooden mesh, which is top-heavy structure, (**Figure 25**). These structures are typical and traditional houses in Java. This is main reason of collapsing of numerous numbers of houses. At Imogiri county, this earthquake killed 260 people (**Figure.26**). Among those, at Turi village, 22 people were killed in the total population of 700 persons. Emergency diagnosis of housings for public facilities, hospitals, and schools are necessary whether such damaged structures are still in use or not. Civil Engineering of Gajah Mada University (UGM) published two papers about earthquake resistant structures. These papars covered the application of vertical strengthening and use of bamboo for the construction of earthquake resistant buildings. In order to strengthen the masonry houses, three kinds of bands (Roof band, Lintel band, Plinth band) and a vertical reinforcement are introduced.. The explaination ofthe benefits of retrofitting, mechnisms of earthquake response of hipped roof masonry building and protection cracks at openings are shown in **Figure 27**.

5. POSKO & MEDIA CENTER

There were many kinds of local urgent correspondence places (POSKO:**Figure 28**), which were working in cooperation with other local and foreign organizations to share information and give businesslike support. Satellite digital photographs, etc. were able to be copied in the media center (**Figure 29**), where the information sharing takes place.

Figure 19 The road-shoulder was collapsed at Patuk

Figure20 JrungPeluk Bridge: Expansion joint was broken

Figure 21 The Sermo dam: no crake in this crest.

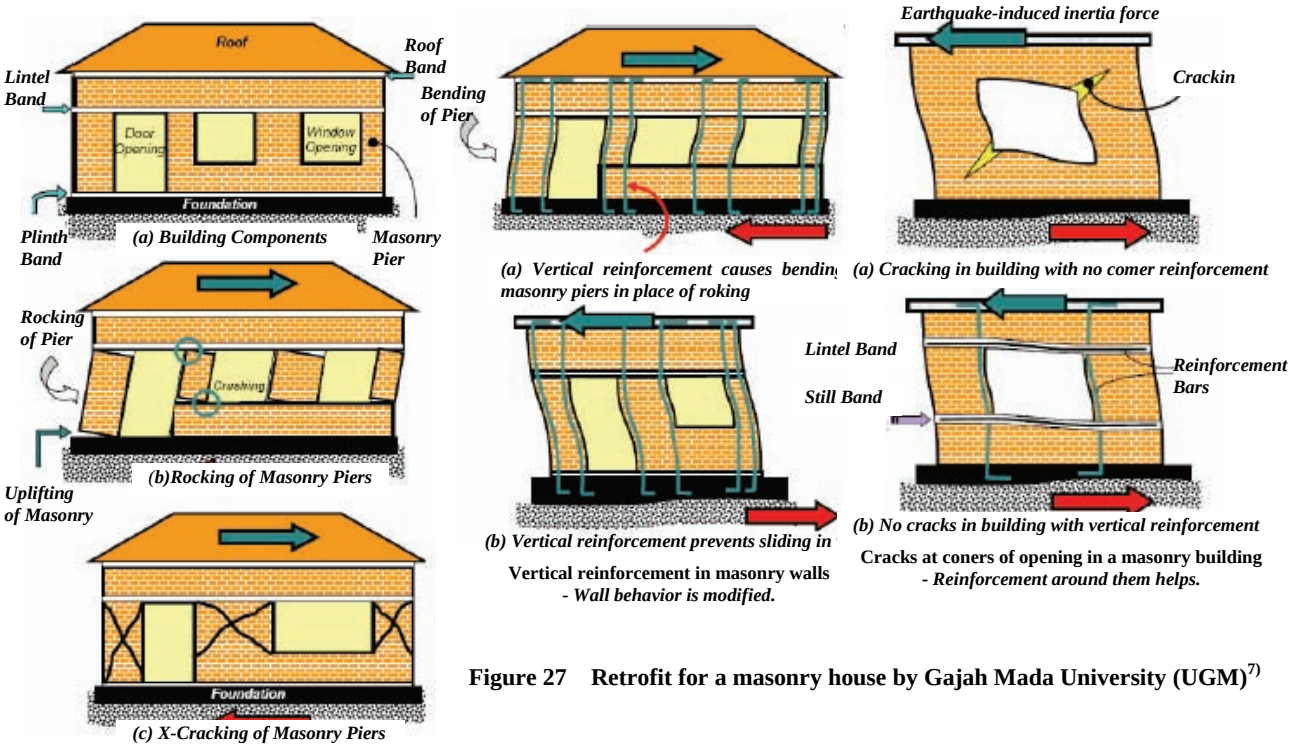
Figure 22 Wonogiri dam: no damage

Figure 23 Totally collapsed housing in Bantul Regency.

Figure 24 Residents live on the tent for fear of aftershock.

Figure 25 A roof structure is a tile-roofed on wooden mesh.

Figure 26 Imogiri county: 260 casualties



Earthquake response of a hipped roof Masonry building
- No vertical reinforcement is provided in walls.

Vertical reinforcement in masonry walls
- Wall behavior is modified.

Cracks at coners of opening in a masonry building
- Reinforcement around them helps.

Figure 27 Retrofit for a masonry house by Gajah Mada University (UGM)[7)]

Figure.28 POSKO
POS mean office. O mean command.

Figure.29 Media Center

6. DAMAGED AREAS AND VICTIM DATA

The **Table 1** shows damage data of Yogyakarta[8),9)]. In Bantul Regency, there were more than are more than 4,000 casualties. In Klaten Regency, more than 1,000 people were killed. The UNOSAT map[10)] illustrates a preliminary damage assessment of the affected areas by this earthquake. The darker spots show extensively damaged areas and the lighter spots show moderate to light devastation areas. According to this map, the extensively damaged areas are located in the west side of the Imogiri (Opak) fault and on the east part of Bantul Regenc (shown by circle in **Figure 29**).

7. DISCUSSION

7.1 *Why did the infrastructure sustain little damage while the housing had much more?*

The high frequency waves were included in waveform as the specific character of the earthquake at this time and it created large acceleration. As a result, the low flat house, which is built with brick and top heavy roof tiles, is a typical and traditional house in Java and weak against high frequency vibration. Thus, many such houses were destroyed. On the other hand, civil infrastructures were constructed rather stiff and strong against high frequency vibration.

7.2 *Why are damaged areas distributed unevenly?*

The extensively damaged areas are located in the east part of Bantul Regency or on the west side of the Imogiri (Opak) fault. Comparing the west and east sides of the fault, the west side is downthrown and the east side is up thrown. Volcanic sediments and lava exist on the west side of the fault, in which volcanic sediments and lava are not consolidated. Amplitude and deformation of the foundation by vibration of the earthquake in these areas are deemed to be large because of the site-specific character due to the geology mentioned above. As a result, these areas were damaged seriously. Contrary, the geology on the east side of the Imogiri fault is composed of limestone and sand stone; thus the amplitude and deformation of the foundation is considered to be small comparatively and less damage happened. Moreover, the reason for the serious damage in

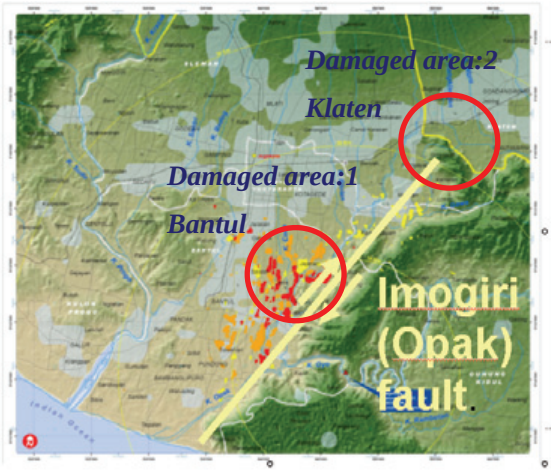


Figure 30 Locations of extensive damaged area.

Klaten is considered as follows; The rupture mainly extended toward the northeast and due to the directivity effect, the seismic wave was amplified in the extending direction. Therefore, the Klaten area was damaged heavily.

8. KEY ISSUES

8.1 Plambanan complex

1) Some temples sustained damaged the top fell down during earthquake. However, the damage was not so serious.
2) As the width of the cracks is not so large and the depth of the cracks is not clear in the Siwa temple, it is difficult to judge whether the temple was seriously damaged or not. In this sense, a detailed diagnosis of these temples is recommended.
3) Reconstruction of the damaged parts of the temple is recommended to be carried out by gluing and experience of previous reconstruction is useful.

8.2 Infrastructure and Housing

1) The clean up program for the removal of wreckage is vital importance and urgent need for the rehabilitation and reconstruction of infrastructures.

2) Emergency diagnosis of housings for public facilities, hospitals, and schools is necessary to access whether such damaged structures can still be used or not.

3) An effective earthquake resistance method for masonry structure houses should be developed.

Table1 Quake Victim Data of Yogyakarta Special Region of 12 June 2006 at 12:00[7),8)] Population, Houses

Location	Victims				Damage (Residential Houses)			
	Death	Heavily Injured	Lightly Injured	Number of Population (2004)	Came Down to the Ground	Heavily Damaged	Lightly Damaged	Household (2004)
Bantul	4,141	8,673	3,353	816,300	71,683	70,796	66,512	229,500
Sleman	232	690	3,099	943,900	5,243	16,003	33,233	303,000
Yogya	204	245	73	398,000	7,161	14,536	21,192	134,400
Kulon Progo	22	276	2,490	375,900	4,527	5,178	8,501	12,500
Gunung Kidul	81		1,086	686,700	7,746	10,670	27,130	190,100
Total	4,680		19,985	3,220,800	96,360	117,183	156,568	869,500

Data Korban Gempa di Kabupaten Bantul sampai dengan
Population and Household Source : BPS 2004

CENTRAL JAVA	Victims				Damage (Residential Houses)			
	Death	Heavily Injured	Lightly Injured	Number of Population (2000)	Came Down to the Ground	Heavily Damaged	Lightly Damaged	Household (2000)
Kabupaten Klaten	1,045		18,127	1,109,500	29,988	62,979	98,552	306,000
Kabupaten Magelang	10		24	1,102,400	199	507	658	31,000
Kabupaten Boyolali	4		300	897,200	307	696	708	239,000
Kabupaten Sukoharjo	3		67	780,900	51	1,808	2,476	207,000
Kabupaten Wonogiri	0		4	967,200	17	12	74	249,000
Kabupaten Purworejo	1		4	704,100	10	214	780	191,000
Total	1,063	18,526		5,561,300	30,572	66,216	103,248	1,223,000

Data Korban Gempa di Kabupaten Bantul sampai dengan
Population and Household Source : Cencus 2000

YOGYAKARTA & CENTRAL JAVA	5,743	38,511		126,932	183,399	259,816	2,092,500

Public Facilities

Location	Public Facilities								
	Praying Location			School			Government Building		
	Came Down	Heavily Damaged	Lightly Damaged	Came Down	Heavily Damaged	Lightly Damaged	Came Down	Heavily Damaged	Lightly Damaged
Bantul				6	85	45			
Sleman				67	125	90	11	34	41
Yogya				7	67	85			
Kulon Progo	1	20	110	5	108	145		39	57
Gunung Kidul	307			15	75	38	120		
Total	438			100	460	403	302		

CENTRAL JAVA	Public Facilities								
	Praying Location			School			Government Building		
	Came Down	Heavily Damaged	Lightly Damaged	Came Down	Heavily Damaged	Lightly Damaged	Came Down	Heavily Damaged	Lightly Damaged
Kabupaten Klaten							76	430	439
Kabupaten Magelang							0	2	1
Kabupaten Boyolali						108	0	2	1
Kabupaten Sukoharjo							6	14	7
Kabupaten Wonogiri							25	0	0
Kabupaten Purworejo							0	0	0
Total				0	0	108	107	448	448

YOGYAKARTA & CENTRAL JAVA	438			100	460	511	1,305

Data Korban Gempa di Kabupaten Bantul sampai dengan

8.3 Miscellaneous

1) False rumors that a tsunami happened and a crack formed in dam caused with immediate panic after the earthquake. In order to avoid such confusion, a system, which transfers correct information, should be established.
2) The construction system needs to be reconfirmed and a control management system needs to be developed.
3) A water service institution should be installed and a temporary well should be drilled to provide ground water for local people in case of emergency.
4) To realize the aforementioned, the share of responsibility and duty between refugees and governments should be clarified as soon as possible.
5) In addition, government should confirm land registration and re-survey, in the area where housing totally collapsed.

ACKNOWLEDGMENT

The authors would like to thank Prof. Ogawa, Y., A., Prof. Yagi, T. and Prof. Ishii, K. for their encouragement and suggestions for this report.

REFERENCES

1) Simandjuntak, T.O. and Barber, A.J.（1996）: Contrasting tectonic styles in the Neogene orogenic belts of Indonesia. In Hall, R. and Blundell, D. eds. : Tectonic Evolution of Southeast Asia. Geological Society Special Publication. Geological Society, London, 185-199.
2) NIED: Source mechanism analysis of the Java earthquake (May 26, 2006) using waveform data obtained by the Indonesian broadband seismograph network (Realtime-JISNET), 2006, http://www.isn.bosai.go.jp/events/YogyaEq_20060526/index2e.html
3) Yagi, Y., Focal mechanism; Total moment-rate function; Distribution of coseismic slip. Star indicates the location of the initial break analysis of the Java earthquake (May 26, 2006), (in Japanese), http://www.geo.tsukuba.ac.jp/press_HP/yagi/EQ/
4) Rebuilding Gods' Homes, MAINICHI, 19.June,2006, http://www.mainichi-msn.co.jp/shakai/edu/weekly/news/p20060616org00m040028000c.html
5) Ishii, K., PRAMBANAN, 13p.,2006, (in Japanese)
6) UNESCO experts mission to Prambanan and Borobudur World Heritage Sites http://www.unesco.or.id/images/pub/publications/55_2004_058
7) BPS - Statistics of Daerah Istimewa Yogyakarta Web Site, STATISTICS BY REGIONS, http://yogyakarta.bps.go.id/
8) Data Korban Gempa di Kabupaten Bantul sampai dengan, REKAPITULASI TINGKAT KABUPATEN, http://www.bantul.go.id/publikasi/data%20korban%20di%20kabupaten%20bantul.xls
9) UNOSAT website: http://unosat.web.cern.ch

(Received 6 April 2007)

FIELD INVESTIGATION ON THE DAMAGE OF PRAMBANAN TEMPLE, HOUSING AND INFRASTRUCTURE CAUSED BY EARTHQUAKE IN CENTRAL JAVA, INDONESIA

Tsuneo OHSUMI and Koji Baba, Nippon Koei. Co. Ltd.

An earthquake with a magnitude of 6.3 has occurred on May 27, 2006 and caused 5,700 casualties. Investigation on damage for the Prambanan temple, housing and infrastructure was carried out in and around Yogyakarta, in central JAVA from June 5 to 8, 2006 The Prambanan complex sustained heavy damage. It is considered that the seismic wave was amplified due to the directivity effect and attacked Prambanan complex. Serious damaged areas are limited in Bantul and in Klaten Regency. In Bantul Regency, there were more than 4,000 casualties. The infrastructure suffered comparatively light damages, however, housing sustained heavy damages and totally collapsed in Bantul Regency. In this report, reasons why the infrastructure sustained light damage while housing suffered heavily and as well as why damage areas are distributed unevenly are discussed.