

# **Provisional Report of the May 27, 2006, Mid Java Earthquake, Indonesia**

June 15, 2006

**Advanced Body of the  
“JSCE/AIJ mission for reconstruction  
recommendations for areas devastated by the  
May. 27, 2006, Java earthquake, Indonesia”**



Japan Society of Civil Engineers

Architectural Institute of Japan

## PREFACE

A strong earthquake occurred in mid Java Island, Indonesia, at 5:53 local time, May 27, 2006. Though the moderate moment magnitude of 6.3 (United States Geological Survey (USGS) and Earthquake Research Institute (ERI), University of Tokyo) calculated for this earthquake was not surprisingly large compared to major earthquakes that have occurred before in this country, Bantul-Yogyakarta area, with Mt. Merapi, spewing hot ash immediately north behind, was seriously ravaged. The death toll keeps rising, and at least 5,700 people were reportedly killed, more than 38,000 injured making this earthquake the worst natural disaster in Indonesia since the tsunami of Dec. 26, 2004.

Japan Society of Civil Engineers (JSCE), with the approval of the Architectural Institute of Japan (AIJ), is establishing a non-profit organization (NPO), “Engineers without Borders, Japan (EWBJ)” to contribute to retrofitting and reconstructing areas affected by natural disasters. Though it is still in progress, both JSCE and AIJ decided that they would dispatch a quick advance team to Indonesia (June 10- 17, 2006). The preliminary strategy of JSCE/AIJ advance team is to make a first reconnaissance laying stress on the damage to dwellings, civil infrastructures etc, and then to discuss with experts from both Japan and Indonesian organizations about tactics for better rehabilitation. The team has been sharing necessary information among the following Japanese and Indonesian organizations:

**Japanese side:**

Asian and Oceanian Affairs Bureau, Ministry of Foreign Affairs (MOFA),  
Ministry of Land Infrastructure and Transport (MLIT),  
Global Environment Department, Japan International Cooperation Agency (JICA), and  
Japan Bank for International Cooperation (JBIC)

**Indonesian side:**

Institution of Engineers,  
Ministry of Social Affairs,  
Ministry of Public Works,  
Government of Central Java, etc.

This report outlines the findings obtained through the quick three-days survey and recommendations for rehabilitating affected areas and mitigating earthquake-inflicted losses. Some descriptions in this report are not fully evidenced yet, and therefore, some comments are not yet the conclusions reached after thorough discussions among the members. However, providing both Japan and Indonesian specialists and persons in charge with a rough-an-ready overview will be important for taking measures for the disaster relief and precautions against possible secondary disasters.

It is our sincere wish that JSCE, AIJ and the abovementioned organizations, will be in tight collaborations lucrative for both Indonesian and Japanese sides. Lastly, on behalf of the Japan Society of Civil Engineers and the Architectural Institute of Japan, we would like to extend hereby our deepest condolences to the families of those who have been killed or injured in the earthquake.

## TEAM MEMBERS

<b>Dr. Kazuo KONAGAI (Leader)</b>		
Position	Professor, Institute of Industrial Science, The University of Tokyo	
Specialty	Geotechnical Earthquake Engineering	
Phone	+81-3-5452-6142	
Fax	+81-3-5452-6144	
e-mail	konagai@iis.u-tokyo.ac.jp	
URL	<a href="http://shake.iis.u-tokyo.ac.jp/home/">http://shake.iis.u-tokyo.ac.jp/home/</a>	
<b>Dr. Masaomi TESHIGAWARA</b>		
Position	Professor, Dept. of Architecture, Nagoya University	
Specialty	Building Material Engineering and Reinforced Concrete Design	
Phone	+81-52-789-3580	
Fax	+81-52-789-3580	
e-mail	teshi@corot.nuac.nagoya-u.ac.jp	
URL	<a href="http://www.degas.nuac.nagoya-u.ac.jp/">http://www.degas.nuac.nagoya-u.ac.jp/</a>	
<b>Dr. Yoshiaki NAKANO</b>		
Position	Professor, Institute of Industrial Science, The University of Tokyo	
Specialty	Earthquake Engineering of Building Structures	
Phone	+81-3-5452-6145	
Fax	+81-3-5452-6146	
e-mail	iisnak@iis.u-tokyo.ac.jp	
URL	<a href="http://sismo.iis.u-tokyo.ac.jp/index-e.html">http://sismo.iis.u-tokyo.ac.jp/index-e.html</a>	
<b>Mr. Tomoji SUZUKI</b>		
Position	JSCE Coordinator in Indonesia	
Specialty	International Relation	
Phone	+62-811-913921 (Mobile Phone)	
Fax	+62-21-31931916	
e-mail	jisuzuki@cbn.net.id	
URL	-----	
<b>Mr. Takaaki IKEDA</b>		
Position	Senior Research Engineer, Tobishima Corporation	
Specialty	Earthquake Engineering	
Phone	+81-4-7198-7553	
Fax	+81-4-7198-7586	
e-mail	Takaaki_ikeda@tobishima.co.jp	
URL	<a href="http://www.tobi-tech.com">http://www.tobi-tech.com</a>	
<b>Mr. Tetsuya OGUSHI</b>		
Position	Manager, Indonesia Office, Tobishima Corporation	
Specialty	Civil Engineering	
Phone	+62-813-10309966	
Fax	+62-21-31931916	
e-mail	tetsuya_ogushi@hotmail.co.jp	
URL	<a href="http://www.tobishima.co.jp">http://www.tobishima.co.jp</a>	

## ITENERARY

[As of June. 16]

Date	Itinerary	Stay
June. 10 (Sat.)	1) Leave for Indonesia (Dr. Konagai, Dr. Teshigawara, Dr. Nakano, Mr. Ikeda) <i>JL725: Departure from Narita at 11:25 / Arrival at Jakarta at 16:50</i>	Jakarta
11 (Sun.)	1) Leave for Yogyakarta (Dr. Konagai, Dr. Teshigawara, Dr. Nakano, Mr. Ikeda, Mr. Suzuki, Mr. Ogushi). <i>GA430: Departure from Jakarta at 10:00 / Arrival at Yogyakarta at 11:00</i>  <b>Meeting &amp; Presentation:</b> 2) 12:00 Provincial Secretary Office & Posko BMG - Dr. Surono, Geophysicist, Center for Volcanology and Geological Hazard Mitigation - Mr. Jaya Murjaya, Head of BMG Yogyakarta <i>(Information and data collection).</i>  3) 14:00 Meeting and presentation of the earthquake damage by Bantul regency's team with Indonesian Consultant, Mr. Anton Lonard from Duta Hari Murthi Consultans  4) 15:30 Survey in Yogyakarta City accompanied by Consultant.  5) 19:00 Mr. OHNO, JICA Coordinator, Mr. T. NARAFU, Senior Coordinantor for International Cooperation, Building Research Institute.	Yogyakarta
12 (Mon)	<b>Meeting &amp; Presentation:</b> 1) 07:00 Prof. S. NAKATA (Kochi University of Technology)  2) 09:00 – 10:30 Dr. Sarwidi (Vice Rector of UII/ Chief of Earthquake Research Center) and Mr. Edy Suandi Hamid ( Rector of UII). Accompanied by Mr. T. NARAFU  3) 11:30 Site Survey accompanied by Consultant of Bantul Regency  4) 12:00 Head of Bantul Regional Planning Board  5) 17:30 Head of Water Resources, Mr. Ir. Djoko Sasongko and Mr. Ir. Erwin Tri Nugroho Sigit, CES	Yogyakarta

<b>Date</b>	<b>Itinerary</b>	<b>Stay</b>
13 (Tue)	<p><b>Meeting &amp; Presentation:</b></p> <p>1) 08:00 Mr. Drs. Anwar Cholil, Head of Regional Development Planning Board of the Provincial Government of Central Java. Dr. Anung Sugihantono (Vice head of BAPPEDA and assistant of the Governor). Mr. Ir. Subagito Loekito, Governor Staff Expert</p> <p>2) 10:00 Survey site (Klaten Regency and other five Regency)</p>	Yogyakarta
14 (Wed)	<p><b>Meeting &amp; Presentation</b></p> <p>1) 08:00 Meeting with Mr. Noro, JICA Expert. Sabo Center</p> <p>2) 09:00 – 13:00 Site Survey</p> <p>3) Return to Jakarta: GA 433: Departure from Yogyakarta at 15:30 / Arrival at Jakarta at 16:30</p> <p>4) 18:00 Meeting with Consultant regarding Mount Merapi Situation</p> <p>5) 19:00 – 01:00 Internal Team meeting</p>	Jakarta
15(Thu)	<p>1) am: Internal Team meeting</p> <p><b>Meeting &amp; Presentation</b></p> <p>2) 15:00 JICA Indonesia Office (Mr. Hanazato, Deputy Resident Representative)</p> <p>3) 17:00 – 20:30 Dr. Ir. M. Basuki Hadimuljono Msc, Director General, Agency for Research and Development, Ministry of Public Works and Staff.</p>	Jakarta
16 (Fri)	<p><b>Meeting &amp; Presentation</b></p> <p>1) 10:00 – 12:00 Mr. DR. Ir. A. Hermanto Dardak, MSc, IPM (Secretary General of Ministry of Public Works and President of The Civil Engineering Chapter, PII (The Institution of Engineers, Indonesia) and Mr. Bachtiar (General Secretary of PII)</p> <p>2) 13:00 – 14:00 Courtesy call, Mr. Muronaga and Mr. Watanabe (Minister) from Embassy of Japan.</p> <p>3) Pm, Internal Team Meeting</p>	
17 (Sat)	<p>1) Return to Japan (Dr. Konagai, Dr. Teshigawara, Dr. Nakano, Mr. Ikeda) <i>JL726: Departure from Jakarta at 00:25 / Arrival at Narita at 09:45</i></p>	

# Geotechnical Aspects

## STRONG GROUND MOTIONS AND SOIL DEFORMATIONS

### Utility poles and lampposts

Damage caused by this devastating earthquake is to be discussed in terms of strong ground motion features that dwellings have experienced. One of the most important lessons that devastating earthquakes teach engineers and decision makers will be fragility curves for existing real structures. Fragility curves are functions, which represent the probability that a given structure's response to various seismic excitations exceeds performance limit states. The fragility curves thus can be used in various ways as part of a seismic vulnerability analysis methodology for structures, and will provide both engineers and decision makers with possible damage estimates in an assumed earthquake.

It was just lucky among many misfortunes that some seismic records were obtained by both Badan Meteorology and Geophysics Observatory (BMG) and the Center for Volcanology Hazard Mitigation (Pusat Vulkanologi dan Mitigasi Bencana Geologi). However, as is often the case, damage differed from village to village. In countries ranked as the most seismic hazard prone zones in the world, strong ground motion networks are often very dense to describe seismological features of earthquakes, but yet very sparse to describe damage distribution frustrating many attempts for learning lessons from tragedies. Among possible breakthroughs, measuring traces of intense shake remaining in structures, which are seen everywhere and have common features, can be very effective. Some of the team members used utility poles and/or lampposts as this structure in their surveys after massive earthquakes such as the Jan. 18, 2001 El Salvador earthquake, El Salvador, June 23, 2001, Atico Earthquake, Peru, July 15, 2001, Changureh earthquake, Iran, May 21, 2002, Boumerdes Earthquake, Algeria, Dec. 26, 2003 Bam earthquake, Iran, etc. This time however, neither clear clack nor clear gap between soil and pole was found in affected areas (Fig. 1) suggesting that the shake was less intense than those of areas devastated by earthquakes listed above. In other words, the abovementioned earthquakes may suggest that the upper bound of shake that jolted Bantul-Yogyakarta area was at most about 6 to 7 on MMI scale\*.

### Soil Liquefaction

Even in SW-NE trending narrow belt of the most serious devastation, damage differed cluster-wise. Local ground conditions and soil deformations can be the cause of the damage distribution. However the team observed just few evidences showing that soils have been deformed visibly. The team members took total 40 wells randomly to check if underground water levels have changed due to the strong ground motions (Fig. A-3). Some eyewitnesses said that they saw muddy dark-colored water spouted out of their wells, and plastic pipes for pumping of these wells were found bent, broken and pushed up. They clearly say that soils beneath the wells have liquefied, while no clear sand volcanoes were found in their vicinities, and damage to houses surrounding the wells were seemingly less serious than the other areas with no clear evidence of liquefaction. Examples of this contrast are shown in Fig. 2. Liquefaction can be the cause of serious destructions to be sure, but it is often observed that liquefied soil isolate the upper soil mass from intense seismic motions. As long as a surface soil mass above the liquefied sand remains coherent, damage to dwellings on the soil mass can be slight. Further studies will be needed.

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\* The Center for Volcanology Hazard Mitigation made a quick estimate of seismic intensity distribution. According to their estimate, there are two zones of MMI intensity 7 along the fault running diagonally up from SW to NE direction.



Fig. 1. No clear cracking of lamppost pedestal was found. (Pesu, Klaten)



(a) S7deg. 57.416 min,  
E110deg. 18.291 min  
plastic pipe was pushed 0.7m up.



(b) S7deg. 53.706 min,  
E110deg. 22.995 min  
dark colored water spouted about  
1.3 m up above the ground level.



(c) S7deg. 53.458 min,  
E110deg. 23.186 min  
no change in water level of -5.0 m.



(d) S7deg. 51.044 min,  
E110deg. 20.031 min  
water level decreased by about 0.25 m.

Fig. 2. Measuring water levels of wells

## DAMAGE TO CIVIL INFRASTRUCTURES

Overall Damage to civil infrastructures did not seem to be serious. If any, they are mostly due to soil settlement, lateral soil flows etc. Some examples follow.

### **Mataram canal bridge**

A bridge of Mataram canal, supplying drinking water and irrigating 19,000 ha of land extending the lower basin of Progo and Opak river, was damaged as shown in Fig. 3. Two masonry abutments and four RC piers support a steel box aqueduct of 80m long. RC open channels on both riversides resting on embankments narrow to this aqueduct. The sandy soil mass of the right embankment behind the masonry abutment of about 10m high slid down towards the river. The scar was formed 26 m west behind the abutment immediately beneath a construction joint of the open channel, suggesting that water might have been seeping through the joint into the embankment soil.



Fig. 3. Mataram canal bridge: Soil mass of right embankment behind masonry abutment has gone.

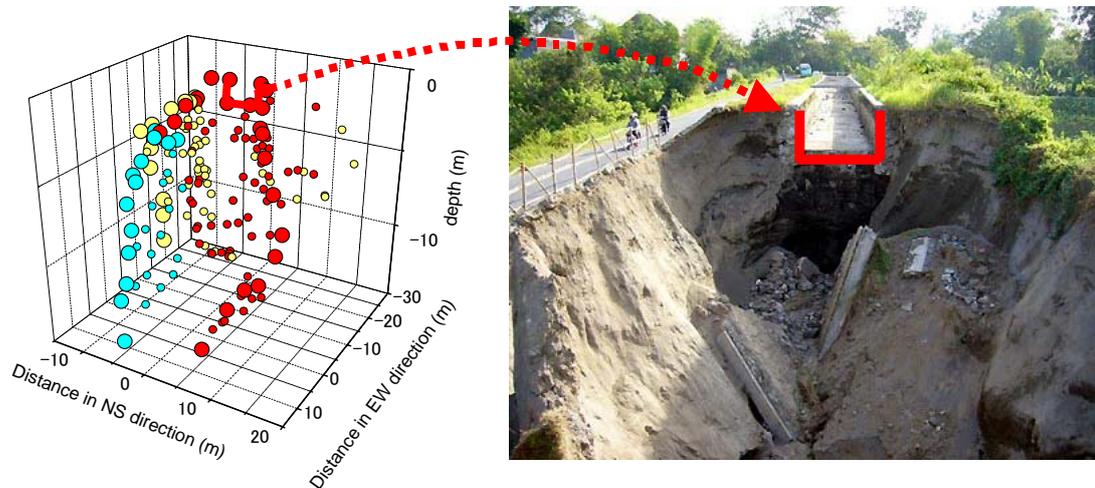


Fig. 4 Measured cave: The cave of the embankment was laser-scanned for its 3D image. Total soil volume about 2,000 m<sup>3</sup> has gone. Scar did appear immediately beneath the construction joint.

Quick restoration of the bridge is a must because of the canal's important functions. Moreover, a road running along the canal resting on the remaining soil mass of the same embankment is under a threat of subsidence. However, a complete reproduction of the embankment will be just a stop-gap measure, and won't mitigate its geotechnical hazard potential. Even an inch settlement of the embankment will cause cracking of concrete joints, and water will leak again through the joints. A possible and efficient measure may be to replace the embankment with some piers.

It is seemingly often that gritty sandy loam of volcanic products (tephra<sup>\*</sup>) is used as fill materials. These soils often have inclusion of porous fragments of pumice. When they are dry, they loose cohesion. But when moist, they are plastic, and retain water easily. When porous wet pumice fragments are crushed, porewater pressure increases causing the entire soil to fluidize<sup>\*\*</sup>. But they yet can drain well where the surface configuration allows. With these features mentioned above, filling up these materials requires appropriate drainage works.

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\* Tephra is air-fall material produced by a volcanic eruption regardless of composition or fragment size.

**\*\* Example of rapid soil flow from Japan**

An intense earthquake, with a moment magnitude of 7.0 took place at 18:24JST on June 24, 2003. The epicenter was located at latitude 38.8° N and longitude 141.8° E. Its intense shake was responsible for a landslide at Tsukidate, Miyagi. The horizontal distances from the top end of the scar to the toe of the slope and to the farthest reach of the soil mass are 100m and 180m respectively. The landslide descended 27 m over a horizontal distance of 180 m. The average inclination from the top of the source area to the toe of the deposit is about 6-7 degrees. A pair of aerial photographs taken in 1962, was perceived as a single image in terms of depth, and a valley was seen cutting in a hillside. This valley was filled with tephra for cultivation, and the landslide took place exactly along this valley.

**Bridge (S7deg 47.102 min, E 110 deg 34.680 min)**

A skewed simply supported RC bridge (4 beams) of 3.5 m wide fell down due to embankment soil subsidence. The sunken soil mass seems to have pushed bottom of a stream flowing near by the embankment.



(a) Location of skewed bridge: Edge lines of road are seemingly dislocated right-lateral. However no clear dislocation was found in rice paddies.



(b) Bottom of stream along the road has been pushed up



(c) Four simple beams support the deck.

Fig. 5. Bridge (S7deg 47.102 min, E 110 deg 34.680 min)

## OVERALL RECOMMENDATIONS AND COMMENTS

### \* Seismic intensity distribution

As is often the case, damage differs from village to village, and seismometer arrays are always too sparse to describe damage distribution frustrating many attempts for learning lessons from tragedies. Quick and ready estimation of seismic intensity distribution is a must for both engineers and decision makers for future seismic vulnerability analysis, and measuring traces of intense shake remaining in structures, which are seen everywhere and have common features, can be very effective. Performances of lampposts and/or utility poles are one of those that can be checked for empirical estimation of seismic intensity, and it was guessed that the upper bound of shake in the most seriously devastated area was at most 6 to 7 on MMI scale. Data archiving will be necessary for better understandings of seismic effects on dwellings and civil infrastructures.

### \* Soil fill

It is seemingly often that gritty sandy loam of volcanic products (tephra) is used as fill materials. These soils often have inclusion of porous fragments of pumice. When they are dry, they loose cohesion. But when moist, they are plastic, and retain water easily. When porous wet pumice fragments are crushed, porewater pressure can increase causing the entire soil to fluidize. But they yet drain well where the surface configuration allows. With these features mentioned above, It is desirable to avoid construction of a water channel on a fill. If necessary, filling up these materials requires appropriate drainage works, and openchannels should not allow water to leak.

### \* Liquefaction and underground lifelines (Water supplies and Sewage)

The team members took total 40 wells randomly in the most seriously affected areas along and west of Opak fault to check if underground water levels have changed due to the strong ground motions. Some eyewitnesses said that they saw muddy water spouted out of their wells, and plastic pipes for pumping of these wells were found bent, broken and pushed up. They clearly say that soils beneath the wells have liquefied, while no clear sand volcanoes were found in their vicinities. This is firstly because the ground was covered thick with cohesive clay loam, and secondly the shake was not intense for the built-up pore-water pressure to force its way up through the surface clay-loamy soils. However the liquefaction was certainly responsible for destroying and/or clogging wells. For spreading water supply systems and sewage systems, these features of soils are to be studied.

### \* Hazard mapping

Local soil conditions and surface soil profiles can change seismic motions remarkably. Borehole data are to be archived for hazard mappings for important areas.

### Others

#### \* Volcanic hazards

For now, there is no convincing direct links between volcanic activity and the earthquake of May 27. However for possible disaster mitigation, information of some mechanical features of pyroclastic flows and lahars such as their velocities, locations and total volumes of sources (lava domes etc), is to be shared by both volcanologists and engineering experts.

# Building Aspects

Damage Observations

Jayakarta Hotel (RC 6F)

URM walls (brick walls) in RC frames had damage and a connecting bridge between two adjacent buildings (reception building and lodging building) was damaged at the expansion joint as well as its roof and handrail wall due to pounding. Roofing tiles on a steel truss system fell down through the ceiling board of guest rooms on the top floor, and falling debris were likely to have been life-threatening to guests staying at the time of the earthquake.



<== Lodging bldg.    Reception bldg. ==>



<== Lodging bldg.    Connecting bridge ==>



Damage to roof system above top story (some column rebar were not anchored to beams)

Amongrogo Sport Center (RC 3F)

Extensive damage was found in cantilever RC columns on the top floor as well as in the roof system. The column damage may be attributed to the inertia force due to shaking, the inward force acting on the columns due to collapse of the roof, and the small amount of reinforcement provided in the columns.



Amongrogo Sport Center / Collapsed roof system associated with column failure underneath



Heavy damage to RC columns and exposed rebars

University of Economic Science (STIE: Sekolah Tinggi Ilmu Ekonomi Kerja Sama / RC3F - 6F)

The university campus had several multi-story buildings. Serious structural and nonstructural damage was found in most buildings. One 4 story RC building, which was located just across the open square at the entrance gate, lost its first story due to beam-column joint failure. It had 2 URM wall frames while the neighboring 5 story building had 4 URM wall frames and did not collapse.



4 story building with 2 URM walls frames



5 story building with 4 URM wall frames

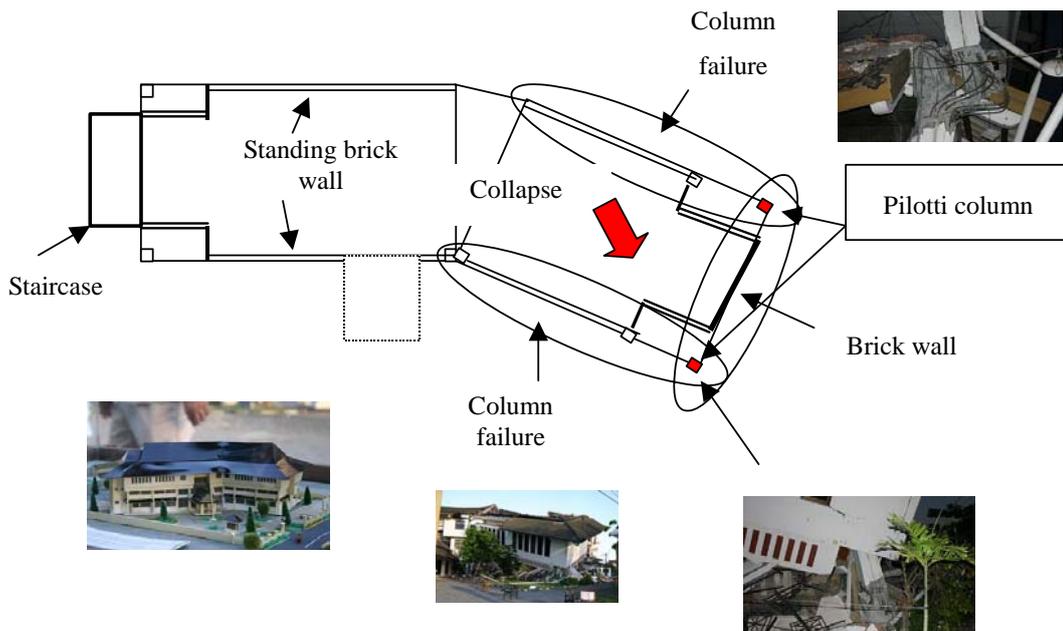
The damage was also attributed to the inadequate detailing of rebar ends placed at the bottom of beams and the insufficient section volume of beam-column joint as compared to the amount of reinforcing bars, which resulted in the pull-out failure of beam rebars at the joints.



University of Economic Science (STIE) / Beam bottom rebars inadequately anchored to joints

Finance and Development Audit Agency (BPKP: Badan Pengawasan Keuangan dan Pembangunan / RC 3F)

The 3 story RC office building lost its first story in the west wing due to beam-column joint failure in the 2nd floor while the east wing survived the shaking with damage to URM walls. Some rebars in columns were lap-spliced at joints, resulting in joint failure. The lateral reinforcement was placed at a space of 25cm to 30cm with 135-degree hooks. The serious damage to the west wing may be attributed to large deformations of soft columns supporting confined URM walls above on the west-end exterior frame and torsional response effects.



Building sketch and typical damage (BPKP)



General view of Finance and Development Audit Agency (BPKP) and collapsed west wing



Beam-column joint failure



135-degree hooks in a column

### Tempel Elementary School (SD Tempel at Bambanglipuro, Kecamatan Baglipuro / URM / 1F)

No lintel beams were found and the timber roof truss was directly placed on URM walls. Major damage was found in URM walls and the roof truss, and some ceiling boards fell down in the classrooms.



SD Tempel at Bambanglipuro / Heavy damage to URM wall and fallen ceiling boards

Bambanglipuro 2nd Middle School (SMP 2 at Bambanglipuro, Kecamatan Baglipuro / URM+RC column / 1F)

Each class had 3 bays in the longitudinal direction. No major damage was found in the structure.



SMP 2 at Bambanglipuro, Kecamatan Baglipuro / No major damage found in the building

Houses in Imogiri

Houses in Imogiri were extensively devastated. They were URM structures with timber truss system and roofing tiles on it. URM walls were typically 20cm to 25cm thick with 2 or 1.5 brick units, having a geometry of 26cm x 12cm x 6cm. Since demolitions to reconstruct damaged houses had started in Imogiri, it was not easy to identify which debris were due to shaking and which were not. Those with RC frames to confine URM walls often survived the shaking although they had some damage.



Devastated URM house



Survived house with URM and RC frame

**Parangtritis 2nd Elementary School (SD 2 Parangtritis at Parangtritis, Kecamatan Kretek / URM+RC column / 1F)**

The school had 2 single story buildings. Each class had 2 bays in the longitudinal direction. Each bay was 3.5m long and the column in the center of each two-bayed frame was 175mm thick and 350mm wide. The eaves of one building were supported by  $\Gamma$ -shaped RC columns with cantilever beam while those of the other were supported by columns provided at the tip of eaves. No major damage was found in the structures. Note that less damage was found in the coastal areas around Parangtritis (to Opak river) than inland areas.



SD 2 Parangtritis / No major damage found in the building

**School at Trimulyo (SLB-PGRI Trimulyo, Kecamatan Jetis / URM(+RC column?) / 1F)**

Each class had 2 bays in the longitudinal direction. Each bay was 3.5m long. Columns had flexural cracks at both ends. The presence of reinforcing bars was not confirmed at the site since the building had minor cracks and rebars were not exposed.



SLB-PGRI Trimulyo / Cracks found in column ends

**Kembangsono 2nd Elementary School (SD 2 at Kembangsono / URM+RC column / 1F)**

The school was located just north of the school at Trimulyo. The eaves were supported by

Γ-shaped RC columns with cantilever beam, which was similar to SD 2 Parangtritis. The exterior URM wall was damaged and repaired, but no other major structural damage was found in the structure.



SD 2 at Kembangsono / No major structural damage found in the building

#### Traditional houses in Gantiwarno Sub-Regency (Kecamatan Gantiwarno)

Traditional stone masonry houses in Gantiwarno Sub-Regency had some damage in masonry walls. They had some RC beams on the wall but no RC columns were provided in the houses. Although they were heavy, the stone masonry walls were thick and long enough to resist and survive the shaking. Another traditional house older than the stone masonry construction had minor damage since they had light bamboo-net walls. The bamboo-net house investigated by the reconnaissance team was older than 70 years.



Stone masonry house with cracks in walls



Bamboo-net wall house

#### Sawit Elementary School (SD Sawit at Gantiwarno, Kecamatan Gantiwarno / URM / 1F)

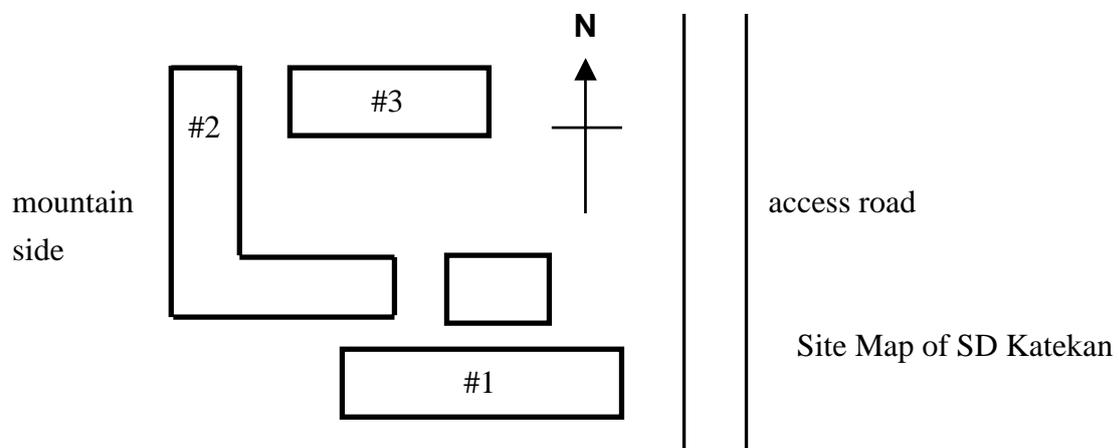
The school building most probably had RC columns only at the 4 exterior corners but no columns in the middle of the structure. Each class had 2 bays and each bay was 3.5m long. Extensive damage was found in 20cm thick URM walls and the roof system.



SD Sawit at Gantiwarno / Collapsed building

Katekan Elementary School (SD Katekan at Katekan, Kecamatan Gantiwarno / URM & URM+RC column / 1F)

The school had 3 buildings, one of them (building #2) was stone masonry structure constructed in the 1970s while the other two buildings (#1 and #3) were URM structure with RC columns. Each classroom of the building #1 had 3 bays, each of which was 3m long. Damage to the roof system and ceiling boards was found in buildings #1 and #3 while cracks in URM stone walls were found in building #2.





Building #1 : URM with RC columns



South side of building #1



Building #1



Building #1 : RC column and beam



Building #2: Stone masonry structure



Damage to corner wall

Pesu Elementary School (SD Pesu at Pesu, Kecamatan Wedi / URM+RC column / 1F)

The school had two buildings, one was seriously damaged in the roof system and the other survived the shaking. Columns having a geometry of 150mm x 150mm with 4- $\phi$ 13 main rebars and  $\phi$ 6 hoops were provided between classrooms. Mid-span walls were 150mm thick and 500mm wide. The eaves were supported by the timber truss fastened to RC columns

provided between classrooms.



One building extensively damaged in the roof system



SD Pesu / Exposed rebars in a column supporting roof system above

## Findings and Recommendations

### (1) Damage to URM walls

Devastating damage was found in URM houses in Bantul Regency, Yogyakarta City, and Klaten Regency, killing residents due to heavy debris of brick walls. URM houses with RC beams and columns confining URM walls, however, were relatively less damaged, even when they were not intact. Providing RC frames to confine masonry walls, therefore, is strongly recommended to reduce structural damage to URM houses.

Educational programs would provide opportunities to train practitioners and to disseminate the important role of confining frames.

### (2) Damage to Roof system

Even when a building had minor structural damage, some schools were significantly damaged in their roof system. Since the earthquake occurred early in the morning (5:53 local time), the loss of human lives was minimized. Falling debris such as bricks, ceiling boards, roofing tiles etc. are significantly life-threatening especially to school children. The structure underneath the roof should be rigid and strong enough to properly support the roof system during an earthquake. As pointed out in (1) above, providing RC frames is strongly recommended to provide sufficient in-plane and out-of-plane stiffness and strength to buildings.

### (3) Beam-column joints of RC buildings

Concrete spalling at beam-column joints was observed in some RC buildings, exposing buckled longitudinal reinforcement. Some beam bottom reinforcing bars were improperly detailed and pulled out of the beam-column joints. They had 180-degree hooks in the ends but were straightly terminated in the joints without bent anchorage into the joint core concrete. Rigid beam-column joints properly confined with lateral reinforcement and beam reinforcement bent into the joint core to develop its full anchorage are most essential for RC structures to perform successfully during earthquakes.

Congestion of rebars was found in some buildings. Beams and columns therefore should be large enough to provide enough concrete volume at the beam-column joints for sufficient embedment length and anchorage of reinforcing bars.

### (4) Pounding

Closely neighboring structures with narrow gaps at expansion joints in between sustained pounding damage. Expansion joints should be therefore designed and constructed properly considering deformations expected during shaking.

(5) Comparison of seismic capacity of buildings and their observed damage

School buildings in the affected areas could be categorized in several structural types. Since they were single story and had simple structural plans, their seismic capacity could be calculated based on a simplified structural model. Comparing the capacity of an identical structural plan with their observed damage in different locations may serve as a tool to estimate the earthquake intensity although strong motion records were not fully available in the affected areas. Furthermore, the obtained results would be of great help to discuss the required capacity of buildings against future earthquakes.

(6) Relationship between city development and damage distribution

Damage observed in the Yogyakarta city seemed localized, although not fully and statistically investigated during this survey, and this may be strongly affected by the development process of the affected areas (old city area, expanded new city area, volcano ash deposit area, former river stream etc.). The background history of the areas may help understand the damage distribution and propose a future city planning as well as reconstruction strategies.

# Appendix

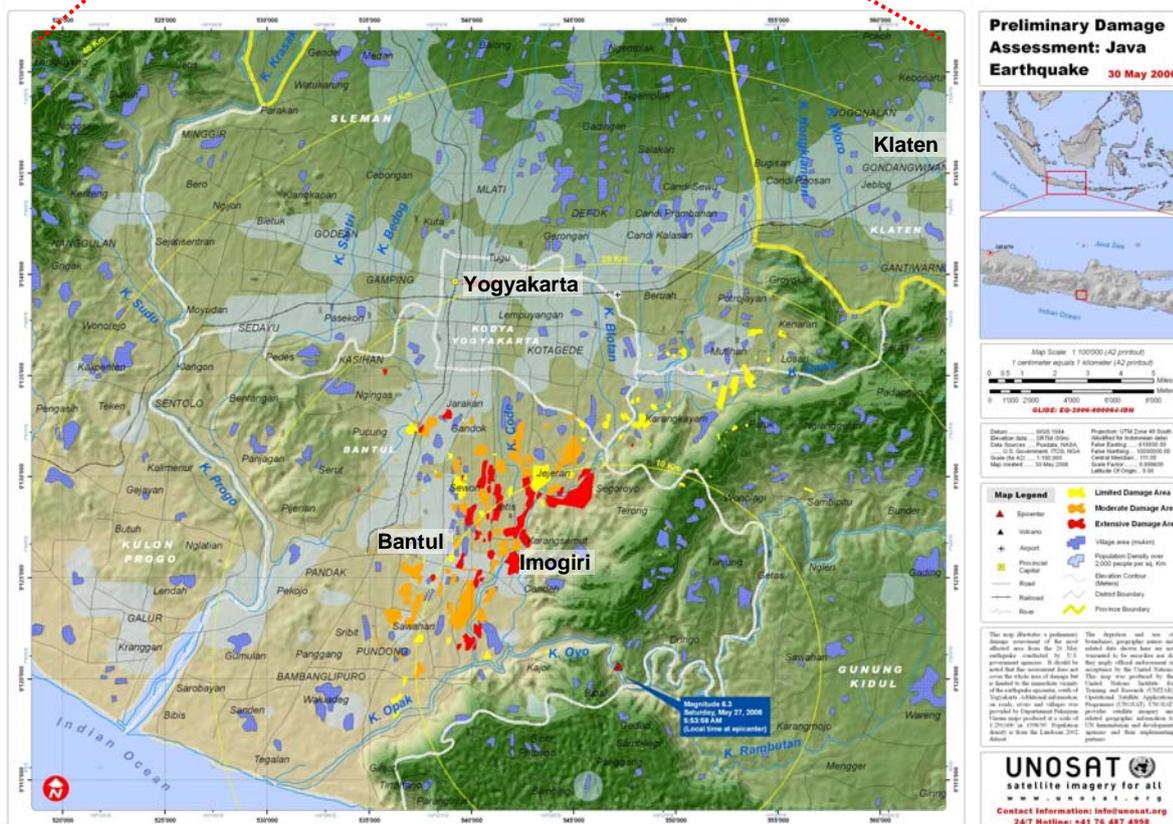
## Investigated Buildings

	Abbreviation*	Building
1	-	Jayakarta Hotel
2	-	Amongrogo Sport Center
3	STIE	University of Economic Science (STIE Kerja Sama)
4	BPKP	Finance and Development Audit Agency (BPKP)
5	S-1	Tempel Elementary School (SD Tempel at Bambanglipuro, Kecamatan Baglipuro)
6	S-2	Bambanglipuro 2nd Middle School (SMP 2 at Bambanglipuro, Kecamatan Baglipuro)
7	-	Houses in Imogiri
8	S-3	Parangtritis 2nd Elementary School (SD 2 Parangtritis at Parangtritis, Kecamatan Kretek)
9	S-4	School at Trimulyo (SLB-PGRI Trimulyo, Kecamatan Jetis)
10	S-5	Kembangsono 2nd Elementary School (SD 2 at Kembangsono)
11	Bamboo House	Traditional houses in Gantiwarno Sub-Regency (Kecamatan Gantiwarno)
12	S-6	Sawit Elementary School (SD Sawit at Gantiwarno, Kecamatan Gantiwarno)
13	S-7	Katekan Elementary School (SD Katekan at Katekan, Kecamatan Gantiwarno)
14	S-8	Pesu Elementary School (SD Pesu at Pesu, Kecamatan Wedi)

\* Buildings 1-10 and 11-14 are found in Figures A-1 and A-2, respectively. Some building names are shown abbreviated in the figures.



[http://www.lib.utexas.edu/maps/cia05/indonesia\\_sm05.gif](http://www.lib.utexas.edu/maps/cia05/indonesia_sm05.gif)



[http://unosat.web.cern.ch/unosat/freeproducts/indonesia/UNOSAT\\_Java\\_EQ\\_damage30may06\\_lowres.jpg](http://unosat.web.cern.ch/unosat/freeproducts/indonesia/UNOSAT_Java_EQ_damage30may06_lowres.jpg)

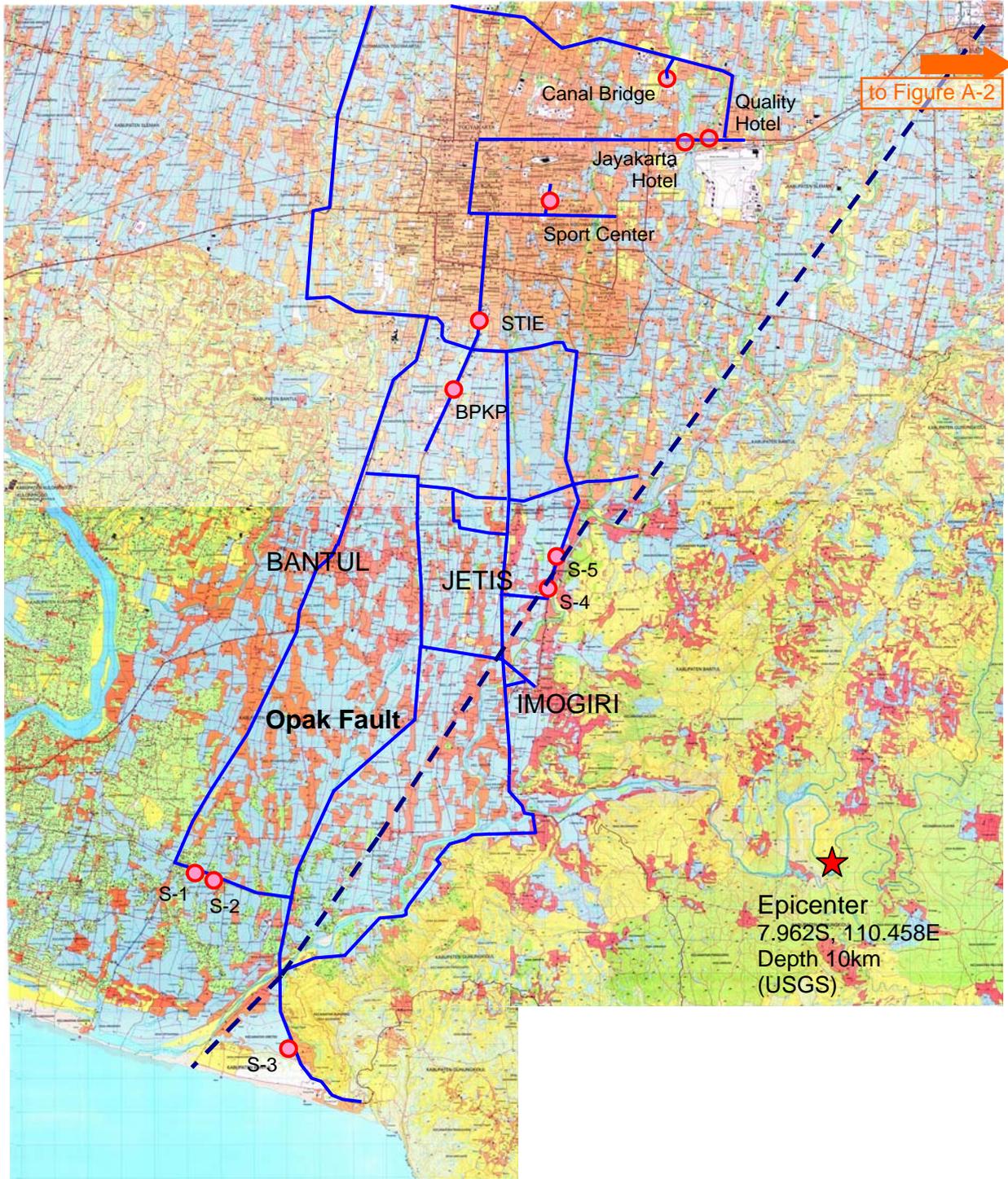


Figure A-1 Route Map (Yogyakarta Province)

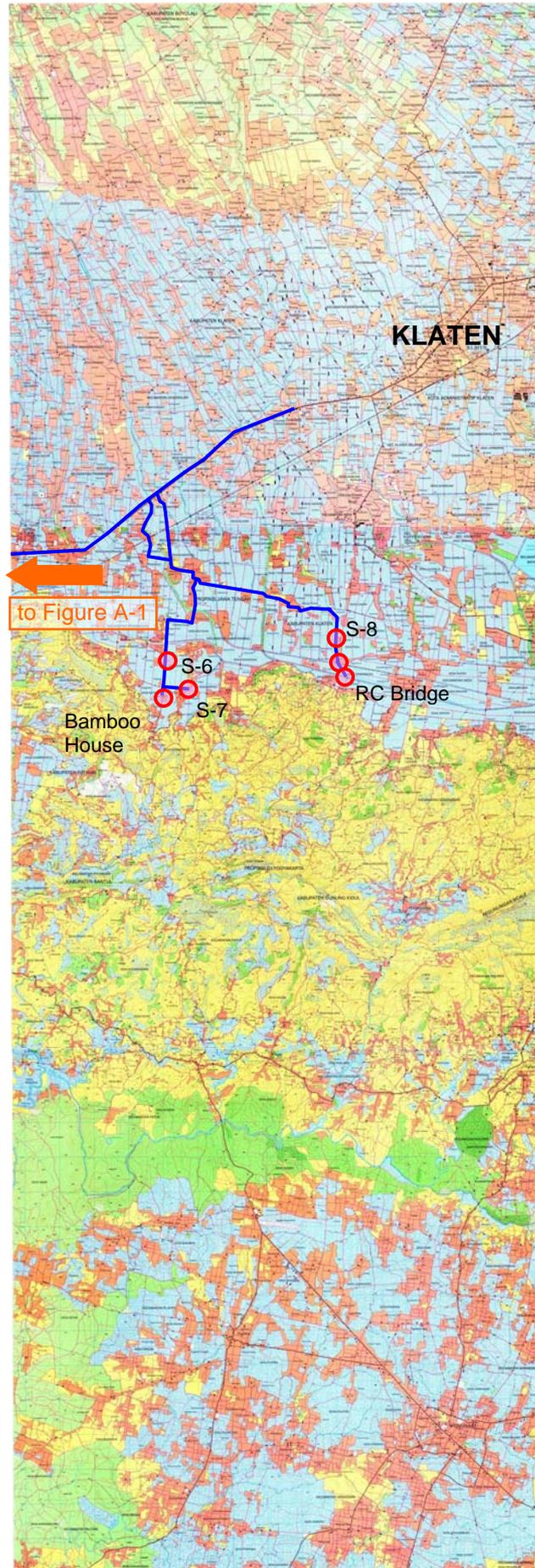
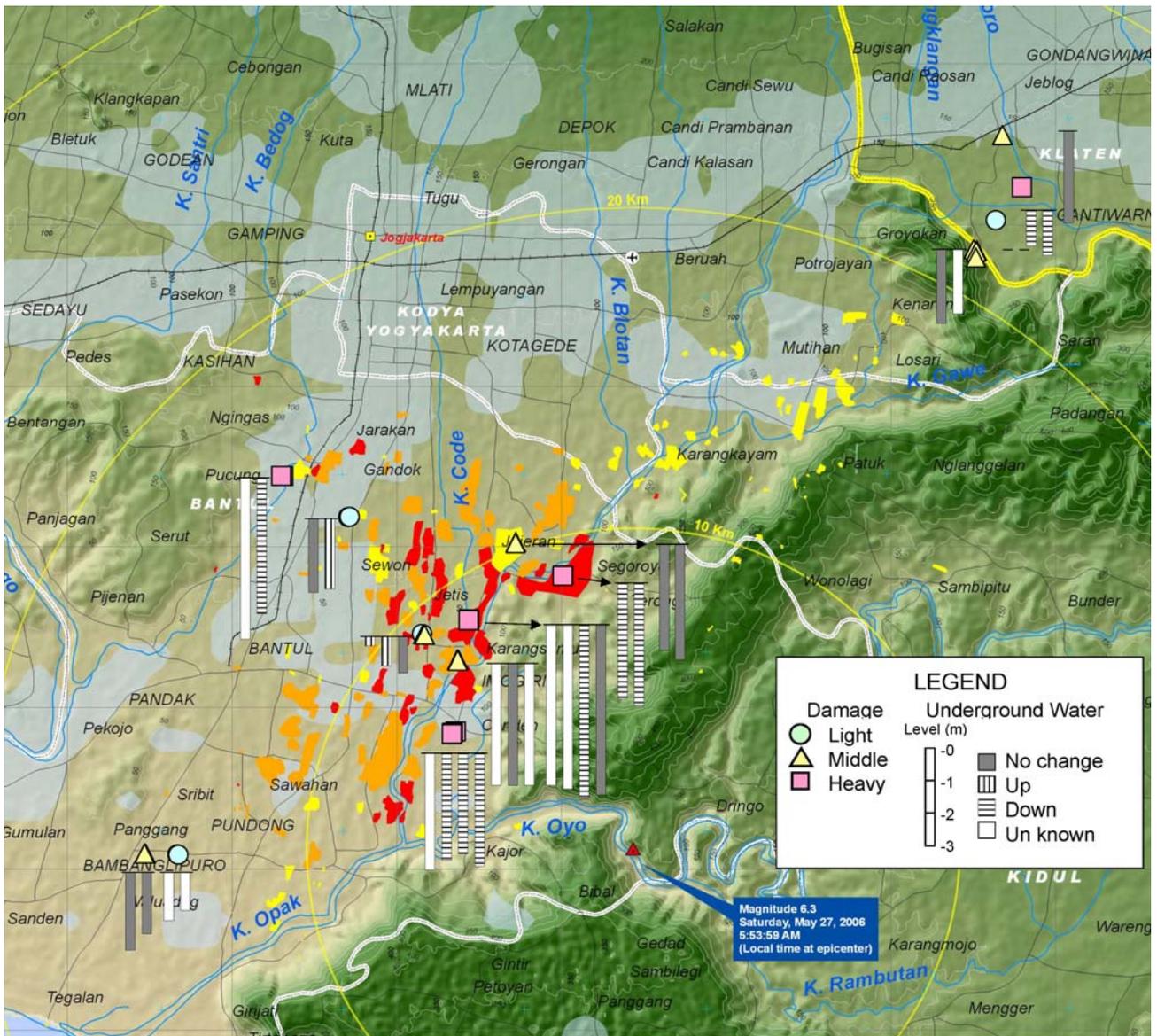


Figure A-2 Route Map (Central Java Province)



- \* Lengths of bars show depths of water levels as of June 12-13, 2006.
- \* Changes of water levels are all from owners and/or eyewitnesses.
- \* The background map illustrates a preliminary damage assessment of the affected areas (UNOSAT website: <http://unosat.web.cern.ch>). Red, orange and yellow colored spots show respectively extensive, middle and limited devastation areas.

Figure A-3 Locations of investigated wells