STRONG GROUND MOTIONS AND SOIL DEFORMATIONS IN THE MAY 27, 2006, MID-JAVA EARTHQUAKE*

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ABSTRACT: A devastating earthquake occurred in Mid-Java, Indonesia on May 27, 2006. Japan Society of Civil Engineers (JSCE hereafter) dispatched its first investigation/ technical support team including ERS members to the severely damaged areas, south of Yogyakarta in Indonesia by this earthquake during the period from June 10 to 17, 2006 in a close cooperation with the Indonesian Institution of Engineers (PII) and the Ministry of Public Works, Indonesia. This report describes briefly findings obtained through the authors' reconnaissance, highlighting some geotechnical issues for better rehabilitations.

Key Words: Mid-Java earthquake, geotechnical issues, rehabilitations

INTRODUCTION

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),

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* Greater part of the report was taken from the Provisional JSCE Reports by the authors [1] and [2].

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3 Professor, Department of Architectural Engineering, Nagoya University
4 JSCE/EWBJ Coordinator, Indonesia.

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 of ERS members 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.

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 engineering 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 the MMI intensity scale*.

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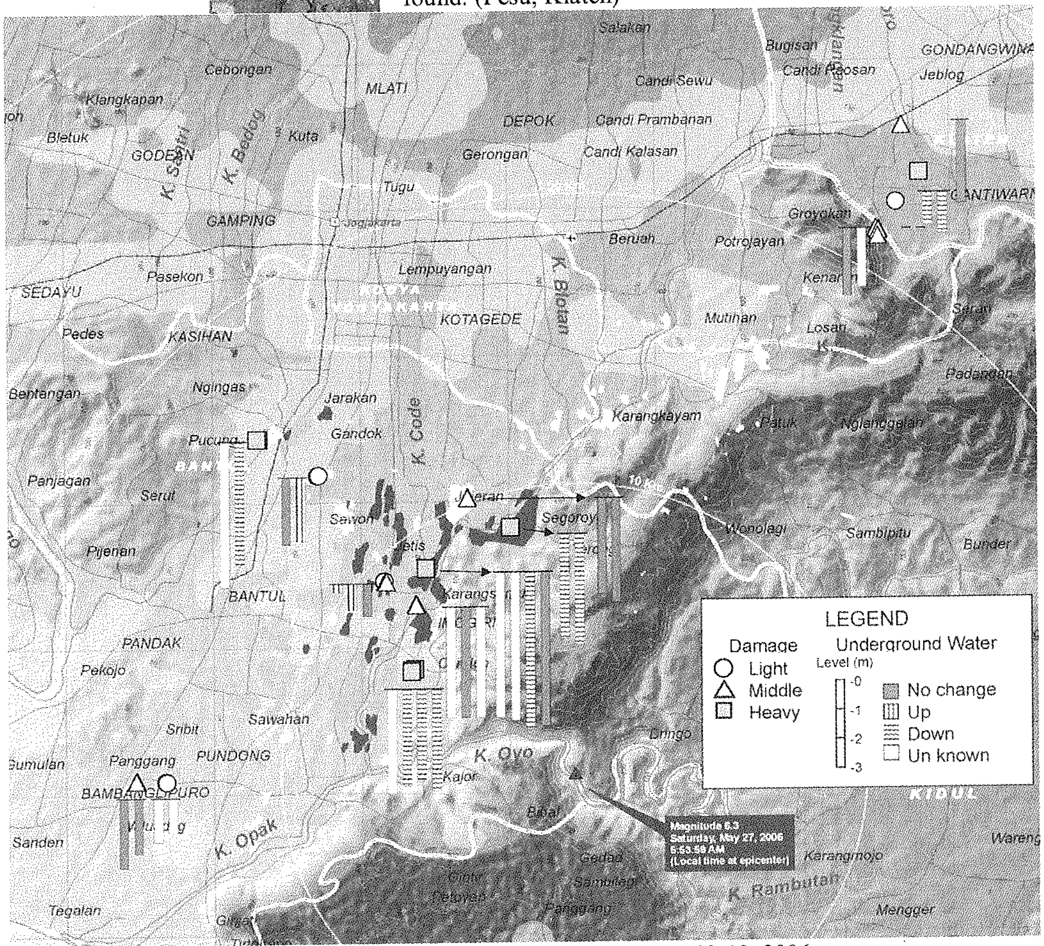
* The Center for Volcanology Hazard Mitigation made a quick estimate of seismic intensity distribution. According to their estimate, there are two zones of MMI intensity 7 along the fault running diagonally up from SW to NE direction.

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

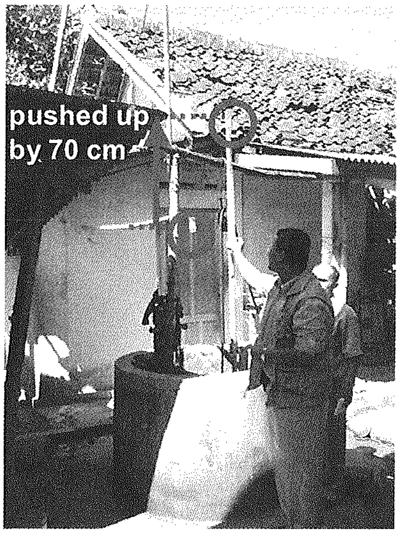


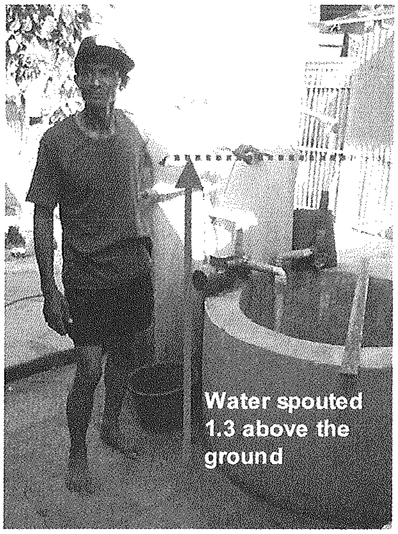
* Lengths of bars show depths of water levels as of June 12-13, 2006.

* 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.

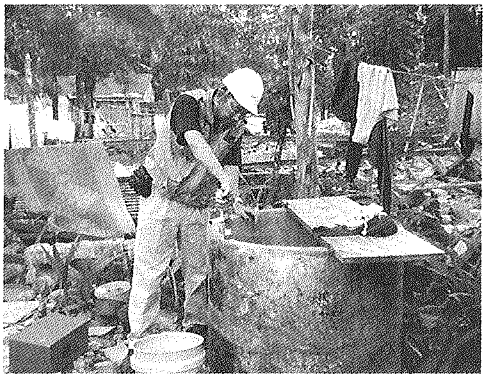
Fig. 2. Locations of investigated wells





(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. 3. Measuring water levels of wells

Soil Liquefaction

Even in the SW-NE trending narrow belt of the most serious devastation, the damage were distributed in clusters probably due to local ground conditions and soil deformations. However the team observed just few evidences showing that soils have been deformed visibly. The team members checked if underground water levels had changed due to the strong ground motions at a total of 40 wells randomly distributed in the damaged area (Fig. 2). Some eyewitnesses said that they saw muddy dark-colored water spouted out of their wells, and plastic pipes for pumping water out of these wells were found bent, broken and pushed up. They clearly indicate that soils beneath the wells have liquefied, however no clear sand volcanoes were found in their vicinities. Damage to houses surrounding the wells were seemingly less serious than in other areas with no clear evidence of liquefaction. Examples of this contrast are shown in Fig. 3. 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.

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. 4. 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. 5).

Fig. 4. Mataram canal bridge: Soil mass of right embankment behind masonry abutment has gone.

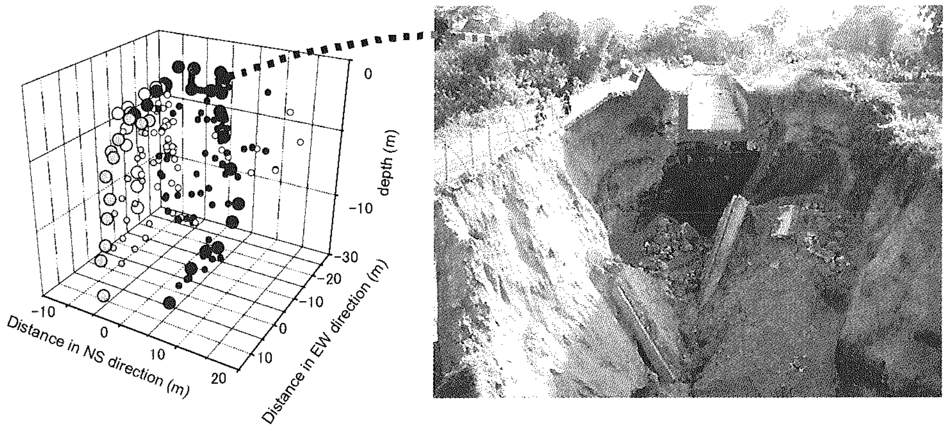


Fig. 5 Measured cave: The cave of the embankment was laser-scanned for its 3D image. Total soil volume about 2,000 m^3 has gone. Scar did appear immediately beneath the construction joint.

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 reconstruction 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[*]) 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[**]. But they yet can drain well where the surface configuration allows. Fill materials with the features mentioned above, requires appropriate drainage works. (See **APPENDIX** for the action taken)

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.

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

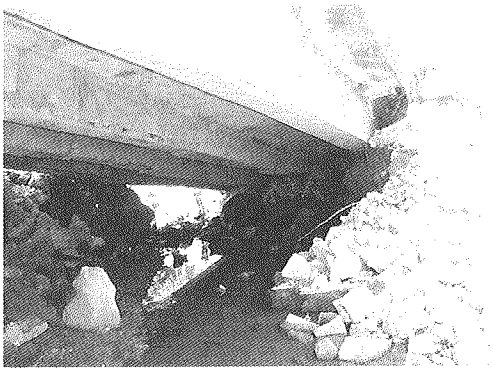
** Example of rapid soil flow from Japan

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.

(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

A crack?



(c) Four simple beams support the deck.

Fig. 6. 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 these fill materials are unavoidable appropriate drainage works are required, and open channels should not allow water to leak in to the sub soil.

*** Liquefaction and underground lifelines (Water supplies and Sewage)**
The team members checked if underground water levels had changed due to the strong ground motions at a total of 40 wells randomly distributed in the most seriously affected areas along and west of the Opak fault. Some eyewitnesses said that they saw muddy water spouted out of their wells, and plastic pipes for pumping water out 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 of wells. For 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.

APPENDIX: THE ACTION TAKEN FOR MATARAM CANAL BRIDGE

The approach of the canal bridge, an open concrete channel, is now supported by three piers, and therefore this part seems to be rationally reconstructed avoiding possible repetition of embankment erosion due to water leakage (See Fig. A1 left).

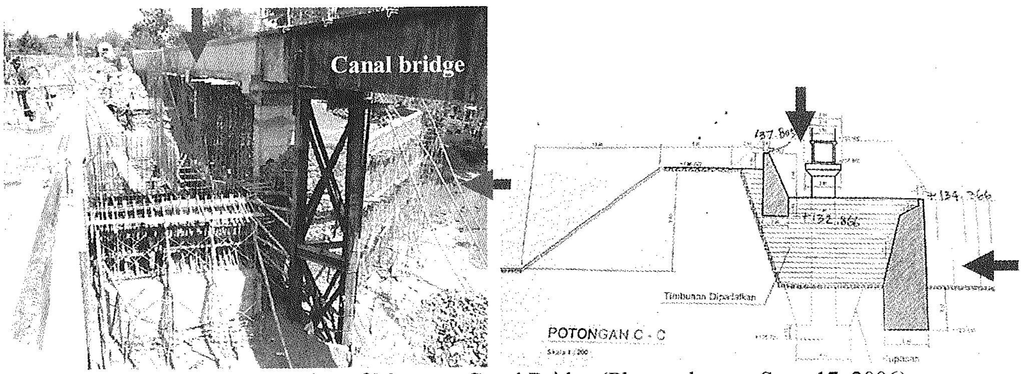


Fig. A1. Reconstruction of Mataram Canal Bridge (Photo taken on Sept. 17, 2006)

However difficult problem seems to be lying in that a road runs along the canal on the embankment. To fully utilize the remaining embankment, a loading berm is being put at the toe and on the canal bridge side of the embankment to stabilize the slope. This loading berm is retained by about 9.5m high masonry wall standing upright. Eventually piers of the bridge are half embedded in the loading berm. Moreover to make some clearance between the road embankment and the canal bridge, a massive retaining wall is being constructed in between the canal and the road (See Fig. A1 below). If the 9.5m high masonry retaining wall with no reinforcement breaks and/or displaced, the piers for the canal bridge can move with the loading berm, causing some damage to the concrete open channel of the canal.

ACKNOELEDGMENT

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 ERS members, we would like to extend hereby our deepest condolences to the families of those who have been killed or injured in the earthquake.

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