INTRODUCTION

On Saturday early morning, May 27, 2006 at 5:54 AM, Yogyakarta city and its surrounding areas, including several places in Mid-Java, were shaken by a moderate earthquake while most people were still sleeping. Until now, the epicenter of this earthquake is still not decided because USGS (United State Geological Survey) and BMG (Badan Meteorologi dan Geofisika) issued different figures. According to USGS, the magnitude was 6.3 SR and the epicenter at 7.96°S, 110.46°E with 10 km depth. The epicenter is 20 km from Yogyakarta, and 115 km from Semarang. BMG published information is: the magnitude was 6.3 SR and the epicenter at 8.03°S, 110.32°E with 11.8 km depth, 37 km from Yogyakarta. Other institution, NIED said that the May 27, 2006 earthquake is a shallow crustal earthquake. The magnitude was 6.3 SR and the epicenter at 7.89°S, 110.41°E with 10 km depth.

The epicenter of Yogyakarta earthquake, 27 May 2006

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Buildings that were damaged or collapsed during the May 27, 2006 Yogya earthquake were mostly non-engineered buildings, consisting of one or 2 stories houses, house shops, religious and school buildings. Some engineered buildings were also severely damaged or collapsed but the number is small compared to the non-engineered ones. The damaged buildings are scattered and some areas have more damage, such as Jetis, Imogiri, Sewon, Bantul in Bantul; Prambanan in Sleman; and Gantiwarno, Wedi in Klaten, Mid Java. The scattered areas of damage might be caused by either geologic conditions or quality of buildings.
Masonry buildings failure modes due to seismic shaking may be characterized as (1) out-of-plane toppling of wall, for unreinforced masonry walls; and (2) out-of-plane bending failure of walls, and / or in-plane shear failure, for reinforced masonry walls. Both failure modes could result in wholesale structural collapse or could result in “typical” damages such as walls tend to tear apart; walls tend to collapse; failure at corners of walls; failure at corners of openings; walls tend to shear off diagonally and additional shear due to twisting or warping for unsymmetrical building. Factors contributing to such failures are weak connection between wall and wall, wall and roof, wall and foundation; seismic forces are not properly transferred into the supporting walls and frames.

**INFRASTRUCTURE**

Although the large number of masonry houses damaged by the May 27, 2006 earthquake, the infrastructure Yogyakarta and Mid Java provinces are practically intact. There was a slight disturbance in electrical power supply in parts of Yogya due to the damage of a transformer; however, it was restored in a relatively very short time. The electric powers to the damaged areas are still switched off for safety reasons to prevent people from getting hurt when clearing the debris of the collapsed houses.

**NON-ENGINEERED BUILDINGS**

Generally non-engineered buildings in the provinces of Yogyakarta and Mid Java can be divided in two main categories.

1. One (one and half) brick thick masonry building without reinforcement.
2. Half brick thick masonry building with and without reinforcement.
1. **Category 1, one (one and half) brick thick masonry buildings built in accordance with the Dutch introduced tradition.**

Masonry buildings were introduced by the Dutch when Indonesia was a colony of the Dutch hundreds of years ago. This type of masonry buildings is copied from Europe and consists of one brick thick walls, using brick pilasters without any RC columns and beams as confinement. At that time the Dutch used mortar mix consisting of burnt brick powder, lime powder and sand, mixed with water. Some used pozolan and lime mix as mortar. The strength of this type of mortar mix can be maintained provided that certain moisture content is maintained. During the Dutch occupation all such buildings were annually white washed with lime mixed with water. Such layer of paint is porous and during rainy season, rain water / moisture can penetrate and will be absorbed by the mortar, therefore the moisture content was maintained. Since the moisture content is maintained, the strength of the mortar is retained. However, with the introduction of new building materials, particularly in the past 30 years, including the introduction of acrylic, weather shield paints, most of the houses are painted with acrylic based paints. Acrylic seals the masonry wall surface and rain water can hardly penetrate. Therefore the moisture content in the mortar is not maintained and this makes the mortar very brittle. Thus the masonry wall becomes brittle and easily disintegrated when shaken by an earthquake. However, from the damage survey, in actuality, many of the masonry buildings following the Dutch tradition but built in the post colonial era in Yogya and Mid Java used sand and lime only as mortar. This is apparently a common practice in Yogya as well as Mid Java. The strength of lime and sand mortar is less than if mixed with burnt brick powder and this is also one of the causes of brittle failure. The foundation of most of this category buildings are river stone foundation without r.c. foundation beams. Roof trusses are usually embedded in walls without proper anchoring.

**Damage of Category 1, One (One and Half) Brick Thick Masonry Buildings Built in Accordance to Dutch Tradition**

SD Kaligondang, Bambanglipuro, Bantul  
SDN Grogo I, Bambanglipuro, Bantul
SDN 1 Panggang, Bambanglipuro, Bantul

TK Bustanul Athfal, Banguntapan, Bantul

TK Pertiwi 28 Potorono, Banguntapan, Bantul

SDN Bendosari, Jetis, Bantul

Trimulyo Village, Jetis, Bantul

Srandakan, Bantul
Imogiri, Bantul

Trimulyo Village, Imogiri

BP4 (Balai Pengobatan Penyakit Paru-Paru), Bantul

PKK Canan Village, Gantiwarno, Klaten

Tobacco processing factory, Wedi, Klaten
Most of the one or one and half brick thick masonry buildings built in accordance to Dutch tradition are very old and many are dilapidated due to lack of maintenance. As can be observed in many other earthquake disasters, there is a relationship between the age of the buildings and their quality particularly in non engineered buildings. The deterioration of the materials, in particular the mortar, contributed to many of the damages and / or collapses of this category 1 buildings. It was also observed that the lack of integrity between the various components, the foundation, the walls and the roof. Inadequate connections are causing the building to tear apart. Proper connections and detailing must be developed to improve the structural integrity of the non engineered masonry buildings of this category. Non-Engineered buildings in this category consist of houses, small shops as well as religious and one story school buildings.

2. Category 2, the “new culture”, half brick thick masonry buildings, mostly with reinforcement.

After Indonesia becomes an independent nation, the demand for masonry buildings / houses is substantial and due to the increase in cost, people started building half-brick masonry houses. In the very beginning, those half-brick masonry buildings / houses were built without any reinforcement. However, from documenting earthquake damages in various areas in Indonesia over the past 30 years, it can be stated that in almost all rural as well as urban areas all over Indonesia, a good earthquake resistant design feature can be identified, namely almost all half-brick thick masonry buildings are built with reinforced concrete framing, consisting of the so called “practical columns and beams”.

“Practical columns”, size 120x120mm with four 10 or 12 mm diameter bars as longitudinal reinforcement and 8 mm stirrups spaced at 150-200 mm, are commonly cast after the construction of the masonry walls is complete, and sometimes the “practical columns” were cast first. “Practical beams”, size 120x200 mm with four 10 or 12 mm diameter bars as longitudinal reinforcement and 8 mm stirrups spaced at 150-200mm, are cast directly on top of the brick wall and served as ring beams. “Practical beams”, size 150x200 mm with four 10 or 12 mm diameter bars as longitudinal reinforcement and 8mm stirrups spaced at 150-200 mm, are cast directly on top of the foundation and served as tie beams. Almost all houses in Java have timber or bamboo roof trusses and clay roof tiles for roofing. Outside Java galvanized iron sheets are more common for roofing. Typical concrete compression strengths range from 12.5 MPa to 15.0 MPa with rebar having a yield capacity of 240 MPa. The
masonry infill wall is made of 50 x 100 x 200 mm brick using running bond with mortar thickness ranging from 8-15mm. The mortar mix usually consists of ranging from 1 sand: 3 cement to 1 sand: 4 cement. The walls are plastered on both sides with sand and cement mortar of approximately 10 mm thickness. Such type of masonry construction has become a new culture all over Indonesia and from past earthquakes it is evident that provided they were built with good quality materials and good workmanship, they survived the most probable strongest earthquake in accordance with the Indonesian seismic hazard map. In 1978, the author encouraged the use of such r.c. framing for masonry walls as can be seen in Ref. 25.

However, in Yogya, the common mortar mix consists of 1 lime and 2 sand and like in other areas in Indonesia, the reinforcement of the practical columns and beams are mostly not in accordance with the requirement as mentioned earlier. The reinforcing bars detailing are also not appropriately done for earthquake resistance. During the damage survey it was found that in Yogya as well as Mid Java, many of the half brick masonry houses are unreinforced which are not advisable for earthquake areas.

In general, the damage and collapse of the new culture “non-engineered” reinforced masonry buildings during the Yogya earthquake of May 27, 2006 are mostly caused by the poor quality of materials and poor workmanship, resulting in, among others poor detailing, poor mortar quality, poor concrete quality, and poor brick laying. It is a common practice that roof trusses are not strongly anchored to the ring beams. The structural reinforcement needs for new or existing unreinforced category 1 buildings must be disseminated to the house owners and artisans. Non-engineered buildings in this category include houses, one story shops, two story shops, religious and school buildings.

Damage and / or Collapse of Category 2, the “New Culture”, Half Brick Thick Masonry Buildings without Reinforcement

Imogiri, Bantul

SD 3 Jejeran, Pleret, Bantul

Mlese Village, Gantiwarno, Klaten
Category 2, the “New Culture”, Half Brick Thick Reinforced Masonry Buildings

Srandakan, Bantul

Damage and / or Collapse of Category 2, the “New Culture”, Half Brick Thick Reinforced Masonry Buildings

Reinforced masonry
Dusun Bembem, Trimulyo Village, Jetis, Bantul

Reinforced masonry house in Jetis, Bantul
Poor reinforcement detailing

SMP 2 Jetis, Bantul

SMP Muh.2 Bambanglipuro, Bantul
Reinforced masonry, Imogiri, Bantul

SDN Putren I, Pleret, Bantul

SD Muh. Wonokromo II, Pleret, Bantul

M.I. Negeri Jejeran, Pleret, Bantul

SDN Timbulharjo, Sewon, Bantul

SD Patalan I, Jetis, Bantul

Dusun Kembang Songo, Trimulyo Village, Jetis

Jabung Village, Gantiwarno, Klaten
ENGINEERED BUILDINGS

Engineered buildings in Yogya province consist mostly of reinforced concrete structures. Several engineered buildings in Yogya city as well as its surroundings were damaged and some even collapsed.

The most obvious type of damage is a first soft story type. Buildings damaged by such types of collapse are among others the BPKP (Badan Pengawasan Keuangan dan Pembangunan) – Annex building, Institut Seni Indonesia building, one of the STIE buildings, Ibis hotel in the city of Yogya. From the damaged columns of all those buildings, it can be concluded that the reinforcement detailing, particularly the size and spacing of stirrups are not catered for earthquake resistance. Most probably those buildings were designed as 2D frames or as 3D open frames without modeling the rigid walls and windows. The lack of proper seismic detailing was evident in the debris of most collapsed buildings. In most columns examined, the spacing of the transverse reinforcement (column ties) was inadequate. The hooks at the ends of the column ties were not 135°. Inadequate lap splices and embedment lengths for longitudinal bars observed in the damaged columns. Poor quality concrete was evident in many damaged columns and in several buildings plain bars were used for the longitudinal reinforcement in columns. The STIE and Institut Seni buildings are worth observing. There are 4 identical buildings at the STIE site. One suffered a first soft story type of damage, in the 2nd building the roof collapsed and the top floor suffered structural damage and other floors non structural damage. The 3rd and 4th buildings survived the shaking with minor damage. There are 2 identical buildings at the Institut Seni complex, one suffered a partial first soft story type of damage and the 2nd one survived without any visible damage.

Another type of damage is the collapse of the roof trusses and this can be seen at Departemen Agama building, Sport Stadium Krida Mandala, STIE Kerja Sama building, Jayakarta hotel.
Damage and / or Collapse of Engineered Buildings

First soft story type of collapse
BPKP (Badan Pengawasan Keuangan dan Pembangunan) – Annex Building, Parangtritis Road

BPKP (Badan Pengawasan Keuangan dan Pembangunan) – Annex Building, Parangtritis Road

2 identical buildings at the Institut Seni complex
Institut Seni Indonesia

One building suffered a first soft story type of collapse
First soft story type of collapse – Institut Seni Indonesia

Two buildings with minor damage

First soft story type of collapse

STIE Kerja Sama Buildings

2nd building, the roof collapse, plus non-structural damage – STIE Kerja Sama Buildings
One of the STIE Kerja Sama Buildings

Plain bars for main reinforcement – STIE Kerja Sama Buildings

First soft story type of collapse – STIE Kerja Sama Buildings
Indication of pounding – Ibis Hotel, Malioboro

First soft story type of damage – Ibis Hotel, Malioboro

First soft story type of damage – Departemen Agama
Engineered Buildings, Collapse of the Roof Trusses

Departemen Agama

GOR Mandala Krida

Jayakarta Hotel, Adisucipto Road

STIE Kerja Sama

ISTI Campus, Parangtritis Road

SMAN 1 Kalasan, Sleman
Non-Engineered Buildings, Collapse of the Roof Trusses

Some other engineered buildings suffered “non structural” damage such as the collapse of partition walls in the Saphir Square in Yoyga city and partition walls cracks in Ambarukmo shopping mall. In general, engineered buildings, that suffered heavy as well as moderate structural damage, suffered non-structural damage as well; mostly diagonal cracking of walls, cracking originating at corners of openings, cracks around stairs, falling of partition walls, falling of ornamentation, etc.

“Non-Structural” Damage at Engineered Buildings
It was observed that in the Yogya earthquake many roof tiles were dislodged and it occurred to engineered as well as non engineered buildings.

Roof Tiles Dislodged
REFERENCES


