Damages to the 9th century Prambanan temple caused by the 2006 Yogyakarta earthquake (Java, Indonesia)

Kázmér, Miklós (1), Hariyadi, Agus (2)

(1) Department of Palaeontology, Eötvös University, Pázmány sétány 1/c, H-1117 Budapest, Hungary. E-mail: mkazmer@gmail.com
(2) Department of Architecture and Planning, Faculty of Engineering, Gadjah Mada University, Yogyakarta, Indonesia.

Abstract: An M 6.5 earthquake hit Yogyakarta on May 26, 2006. The region, considered aseismic, suffered high damages: 155,000 houses were destroyed. The Prambanan temple complex was among the severely damaged masonry buildings. Location and direction of damages have been investigated: displacement and falling directions of masonry blocks were surveyed. We reconstructed the direction of strong motion responsible for the damages. It is parallel to the strike of the causative fault (30°-210°).

Key words: archaeoseismology, Java, Indonesia, Middle Ages.

INTRODUCTION

There was an M 6.5 earthquake on 26 May 2006 at dawn in Yogyakarta sultanate on Java island, Indonesia (Fig. 1). The city of 4 million did not suffer considerable damage, but 150,000 houses collapsed in the surrounding rural area and further 200,000 were severely damaged. Six thousand people died.

The earthquake occurred in a sector of Java which have been considered aseismic (Luehr et al., 2008). There was no surface rupture and the causative fault could not be identified with any of the known faults (Setijadji et al., 2008). Twelve temporary seismic stations were operated for three months to record aftershocks (Walter et al., 2007). Engineering geological mapping provided explanation for the great damage caused: thick, loose succession of repeated mudflows, lahars, derived from nearby Merapi volcano amplified the shaking (Walter et al., 2008).

We carried out an archaeoseismological survey three year after the earthquake, supposing that Medieval Hindu masonry temples in the region preserved earthquake-induced damages. The displacements – if caused by an earthquake of known focal mechanism – will be suitable for calibration of archaeoseismological studies, where the mechanism is unknown. The largest temple complex, Prambanan, suffered heavy damages in 2006. Restoration was in progress, and we were allowed to study the shrines before repairs covered the damages.

Fig. 1: Location and focal mechanism of the May 26, 2006 Yogyakarta earthquake

Fig. 2: Aerial view of the Prambanan temple complex.

PRAMBANAN

The Loro Jonggran temple complex (mentioned by the better-known name of the village Prambanan where it is located) was probably built during the first half of the 9th century (Fig. 2). The pervasive Hindu cultural influence and rule erected a multitude of temples at that time, including the UNESCO World Heritage site Borobudur 35 km to the NW. Prambanan has been a site for cultural and religious tourism (Jordan, 1996) since its discovery by Sir Thomas Raffles, the then British governor of Java during the Napoleonic wars (Raffles,
Excavation and surveying started at that time has been going on for two centuries (Tiffin, 2009): old temples are restored and long-forgotten ones are excavated from below thick volcano-sedimentary succession.

A modern restoration of Prambanan satisfying the needs of the tourist industry followed the grandiose aims set for Borobudur nearby. That, financed by UNESCO in the 1960s, was completely dismantled and re-built again, supported by a reinforced concrete structure (Soekmono, 1976). Therefore nothing can be seen on Borobudur which could offer any information on its twelve-century history in earthquake-stricken Indonesia. Fortunately, Prambanan’s reconstruction was made in a financially less successful environment: only the external, carved stones were removed, a reinforced concrete layer constructed, and the carved stones replaced on select portions.

**METHODS**

Visibly recent damages on several buildings of the temple complex, considered to be made by the 2006 earthquake by Mr. Darmojo, the master builder, have been surveyed by compass and measuring tape, and documented on photographs. Restoration documentation prepared at various times was studied, commented by Mr. Darmojo. A manuscript map recording the surface deformations right after the 2006 earthquake was seen as well. Although the fallen masonry have mostly been removed by the time we visited the site, a few major pieces were located and their falling direction recorded. Observed damage features are also named as Earthquake Archaeological Effects (EAE - Rodríguez-Pascua et al., 2011), and are correlated to the intensity scale of Rodríguez-Pascua et al. (2013). We determined the shifting directions of masonry blocks as well. Recorded features were interpreted as parts of a strong-motion field, and principal directions were determined graphically (Angelier, 1984).

**EARTHQUAKE ARCHAEOLOGICAL EFFECTS**

The Shiva shrine of the Prambanan complex has excellent foundations: 8 m deep white tuff blocks, underlain by compacted sand down to 14 m. Groundwater level is at 11 m depth (Suryolelono, 2008).

Various damages were surveyed to determine the direction of the strong motion responsible for the displacement. The tip of the 14 m high Apit Utara shrine fell towards 120° for 7.7 m (Fig. 3) (EAE: impact block mark, I = VI-). The largest shrine, the 60 m high Shiva temple has a reinforced concrete mantle at the middle and upper parts, while the lower level has not been restored extensively. This unreinforced lower part suffered horizontal extension in 20-200° direction (Figs 4-5) (EAE: displaced masonry blocks in walls, I = IX-).

Tip of the Brahma temple fell towards 215° for 15 metres. (EAE: impact block mark, I = VI-).

Ground fissure
A 20 m long, several centimetre wide fissure extended in 15°-195° direction near Brahma temple. Further ground fissures were mapped regionally by Pramumijoyo and Sudarno (2008). Was there a a higher water table, this ground fissure would have yielded liquefaction and sand volcano (EAE: liquefaction, I = VIII-).
damages, where the displacement direction is the least constrained by the geometry of the building. Additionally, evidence of damages affecting major buildings are considered stronger than those affecting minor constructions (Fig. 8).

The least constraints are those which affected the falling directions of the tips of the Apit Utara and Brahma temples, both temples close to being centrally symmetrical. The top part can fall in any direction as dictated by shaking. Their falling direction is perpendicular to each other; i.e. both regular components of strong motion directions could affect them (Fig. 7).

The causative fault of the 2006 Yogyakarta earthquake is a left-lateral strike-slip fault. Epicentre was at the SW termination, from where fracture spread towards NE, probably as far as indicated by the hypocentres of the aftershocks (Fig. 9). Prambanan complex is approximately at the hypothetical northeastern extension of the fault; this explains its major damage as compared to other temples nearby. Possibly the P-waves caused the extension of the unreinforced lower level of the Shiva temple. S-waves caused the jumping of the tip decorations off their tenons and subsequent fall.

Left-lateral strike-slip faulting of Brahma temple is also caused by P waves: these created the diagonal fracture across the building according to the Mohs planes. The left lateral displacement has no particular meaning: the shaking stopped at this particular moment. If stopped another second the displacement would have been right-lateral.

These suggestions serve a better understanding of the multitude of damage data recorded by archaeological monuments.

Acknowledgements: Supported by Hungarian Science Foundation OTKA grant K67583. Special thanks for the support of prof. Subagyo Pramumijoyo and Husein Salahuddin (Gadjah Mada University, Yogyakarta), director Haryana (Prambanan Complex, Klaten), master builder Darmojo, and Ditto Haryana. Comments of an anonymous reviewer improved the text. This study is part of IGCP Project 567 Earthquake Archaeology: Archaeoseismology along the Alpine-Himalayan Seismic Zone.
References


