DEVELOPMENT OF EARTHQUAKE DISASTER MANAGEMENT SYSTEM IN BANTUL: PRELIMINARY STUDY ON INFRASTRUCTURES DAMAGES

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ABSTRACT :
The earthquake of 6.3 M_W scale in Yogyakarta and Central Java on May 27, 2006, caused 5,800 death, injuring around 38,000 and robbed hundreds of thousands of residential buildings. Right after the devastation emergency response procedures, reconstruction and recovery programs were undertaken. This paper presents the study of development of disaster management system, which currently becomes an important issue in Indonesia, to provide data and information for the governmental rehabilitation programs after the earthquake, especially for infrastructure damages. The benefit of the system is to assist the government in managing regional society and infrastructure development after the disaster. The system has been developed based on the Taiwan Earthquake Loss Estimation System (TELES), integrating research accomplishments on seismic hazard analysis, structural damage assessments and socio-economic impacts as developed by the Chinese Taiwan Center for Research on Earthquake Engineering (NCREE). The system has been used for decision-making support system and it is proposed to be part of the completed system of disaster management in Bantul, Indonesia.

KEYWORDS:
TELES, YOGYAKARTA EARTHQUAKE, DISASTER MANAGEMENT, INFRASTRUCTURES

1. INTRODUCTION

On May 27, 2006, a magnitude 6.3 earthquake on the M_W scale which lasted for 52 seconds struck Central Java and Yogyakarta. This area is the center for Javanese traditional arts and culture as well as a center of Indonesian higher education. Because the epicentre of the earthquake was relatively shallow i.e. at 33 kilometers underground, shaking on the surface was more intense than deeper earthquakes of the same magnitude, resulting in major devastation, in particular in the districts of Bantul in Yogyakarta Province and Klaten in Central Java Province. The earthquake caused loss of life of over 5,800 people, injuring about 38,000 more and robbed hundreds of thousands of residential buildings. Simultaneously, during the earthquake, the Mt. Merapi's volcanic activity was increasing and producing lava flows, toxic gases, and clouds of ash, prompting the evacuation of tens of thousands of people. At the same time, the government of Indonesia started the emergency response procedures right after the earthquake while preparing reconstruction and recovery programs. The earthquake was the third major disaster to hit Indonesia within the past 18 months of the May 27 earthquake.. In December 2004, a major earthquake followed by a tsunami devastated large parts of Aceh and the island of Nias in North Sumatra. in March 2005, another major earthquake hit the island of Nias again. With Indonesia's more than 18,000 islands closely located along the Pacific "ring of fire" of active volcanoes and tectonic faults, the recent disaster is a reminder of the natural perils facing this country.

A comprehensive analysis by a team of Indonesian Government and international experts estimated the total amount of damage and losses caused by the earthquake at IDR 29.1 trillion, or US$ 3.1 billion. Total damage and losses are significantly higher than those caused by the tsunami in Sri Lanka, India and Thailand and are similar in scale to the earthquakes in Gujarat (2001) and in Pakistan (2005) (BAPPENAS, 2006). The damage was heavily concentrated on housing and private buildings. Private homes were the hardest hit, accounting for more than half of the total damage and losses (IDR 15.3 trillion). Private sector buildings and productive assets also suffered heavy damage (estimated at IDR 9 trillion) and are expected to lose significant future revenues. It was estimated that 154,000 houses were completely destroyed and 260,000 houses suffered some damage. More houses will have to be replaced and repaired than in Aceh and Nias at a total cost of about 15% higher than the damage and loss estimated of the tsunami. The impact of the earthquake on public and private infrastructure was relatively limited, with the value of damage and losses estimated at IDR 397 billion and IDR 153.8 billion, respectively. The sector worst affected is energy with damage to the electricity transmission and distribution facilities estimated at a total IDR 225 billion and losses at a further IDR 150 billion from other physical damage.

Indonesia is located in a seismically active region. Seismic disaster of earthquake is one of the devastating natural hazards that people in Indonesia must face to. Probabilistic seismic hazard analysis is often applied in estimating seismic risk in different regions. The hazard curves obtained from the analysis are often in terms of ground motion intensity parameters such as peak ground acceleration (PGA), response spectra, etc. Other quantities, such as soil liquefaction potential, damage-state probabilities of civil infrastructures, number of casualties and amount of losses, are then derived indirectly from the hazard curves of ground motion intensity. Since the relationships among these factors are very complicate, they can not be expressed as simple linear functions of ground motion intensity parameters. In order to mitigate seismic disasters and to manage catastrophic risks, it is necessary to have appropriate damage assessment tools and risk management strategies in all times including emergency response period as well. The proposed tool must be based on the reliable information from scenario simulation, which is based on the existing inventory database and state-of-the-art analysis models. Therefore, development of such seismic scenario simulation technology is very important in countries that suffer from earthquake threats. This paper intends to introduce the study on earthquake disaster management system which is needed to develop in order to assist the Indonesian government to minimize the mismanagement of infrastructure analysis and reconstruction after earthquake occurrence. The proposed system has been developed from the Taiwan Earthquake Loss Estimation System (TELES) considering its useful application in Taiwan earthquake experience.

2. DISASTER MANAGEMENT SYSTEM OF TELES

The Center for Research on Earthquake Engineering (NCREE) of Taiwan has developed "Taiwan Earthquake Loss Estimation System (TELES)" to estimate ground motion intensity, ground failure extent, damage-state probabilities/quantities of civil infrastructures and pipeline systems, induced socio-economic losses, etc. The TELES software intends to provide scenario-based data for preparing seismic disaster mitigation plans in normal times for central and local governments. It can also provide useful information for emergency response actions soon after occurrence of strong earthquakes (Yeh et al., 2003).

In order to build a loss estimation system similar to TELES, three major tasks are needed: 1. the collection of seismic sources, geologic and inventory database. 2. the development and modification of analysis modules in estimating hazard, risk and losses. 3. updating of integrated application software. The input database consists of three types of data: inventory data with GIS information, earthquake hazard and geologic data maps, and analysis parameters. The analysis modules take the required inventory and analysis parameters as input, conduct risk assessment and loss estimation for scenario earthquakes based on site-specific outputs from hazard analysis, and output estimates in the result database. The third part, integrated with commercial GIS software, is the PC-based application software to execute user's requests, to display input/output databases in both tabular and graphical forms, to generate summary reports, and so on.

The analysis part of TELES contains four groups of modules, namely, potential earth science hazard (PESH) analysis, direct physical damage assessment, induced damage assessment, and social/economic loss estimation (Figure 1). These modules and sub-modules are interdependent. The output from one module acts as input to another. The modular approach allows estimates based on simplified models and limited inventory data. Addition or replacement of existing modules/data may be done without changing the entire methodology. The modular approach also facilitates the rapid transfer of information and technology between the academic/research communities as well as the end users. Specific regional analysis models and data can be incorporated in the framework. Another advantage of modular approach is that it enables users to limit studies to selected losses, which may be desirable because of limited budget and inventory constraints. In general, each module requires a comprehensive loss estimation study. However, the degree of required sophistication and associated cost varies greatly by user and application. It is necessary and appropriate that the modules accept multiple levels of detail and precision of input data.

The collection of complete and useful database is the key factor in success of the TELES project. However, database collections are often the most time consuming and expensive aspects while performing a comprehensive study. In general, the inventory data are often classified by their usage and functionality. For example, engineered structures are classified into four categories: general building stocks, essential facilities, transportation systems and utility systems, as shown in Figure 1. Each category is further divided into several classes according to their structural types, seismic resistant capacity, etc. to assess damage-state probability of individual object based on ground motion intensity and ground failure extent. The data classification schemes and the associated analysis models depend on the content of inventory database.

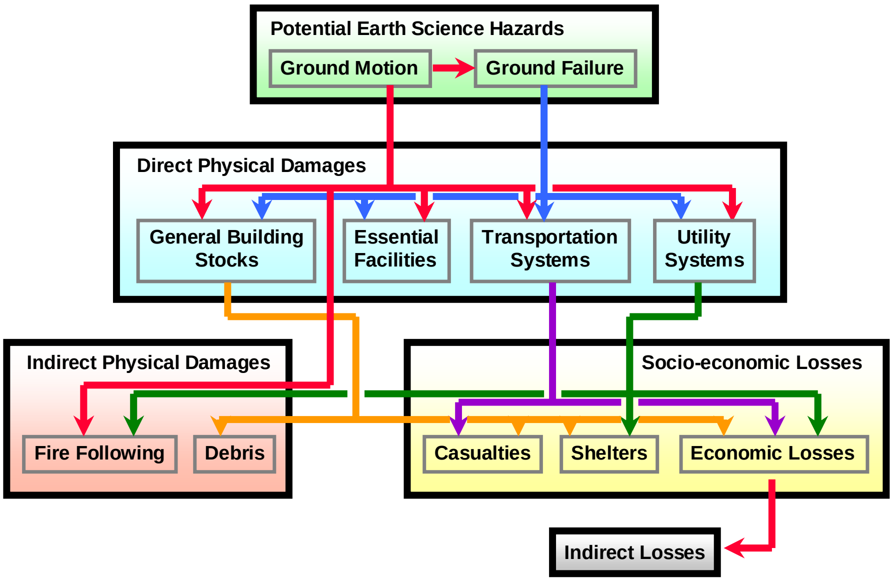

Figure 1 Framework of TELES (Lin et al., 2006)

3. DEVELOPMENT OF PROPOSED IELES

Based on TELES study, an earthquake disaster management system on infrastructures assessment and reconstruction has been proposed. This system is still understudy and only the concept of system is presented herein. The system which is called as IELES (Indonesian Earthquake Loss Estimation System), has been developed in order to verify the damage causes, to classify the destruction level and to give the alternative reconstruction scenarios of infrastructures. IELES is divided into three main modules: 1. Database Module, 2. Destruction Identification and 3. Reconstruction Scenario. IELES is developed to compare different thematic maps and obtain in-depth understanding of the relationships between input and output database. It is also used to provide the information of potential areas which are much affected by earthquake occurrence and simulation the reconstruction scenarios where the system users will not miss any important information from seismological analyses. The frame of IELES is illustrated in Figure 2.

3.1 Database Module

The database module is divided into three groups: 1. Data suppliers, 2. Data distribution system (DDS) and 3. Data management system (DMS). Figure 2 shows the organization of this database system. Data suppliers are local (province and district or kabupaten) and central government and non-government organizations that will support daily and/or required data in the event of requirement. BAKORNAS, BAKORDA, Department of Public Works, Fire Rescue Department, Department of Defense, Indonesian Military, Indonesian Police, Department of Energy and Minerals Sources, Meteorology and Geophysics Board, are examples of the data suppliers for IELES. Data are classified into three main groups as described below:

Group 1 : Populations and areas which shows the people density in each hectare.
Group 2 : Infrastructures database and housing types.
Group 3 : Damage areas after earthquake occurrence.
Group 4 : Visual observation in each important damage areas after earthquake disaster.

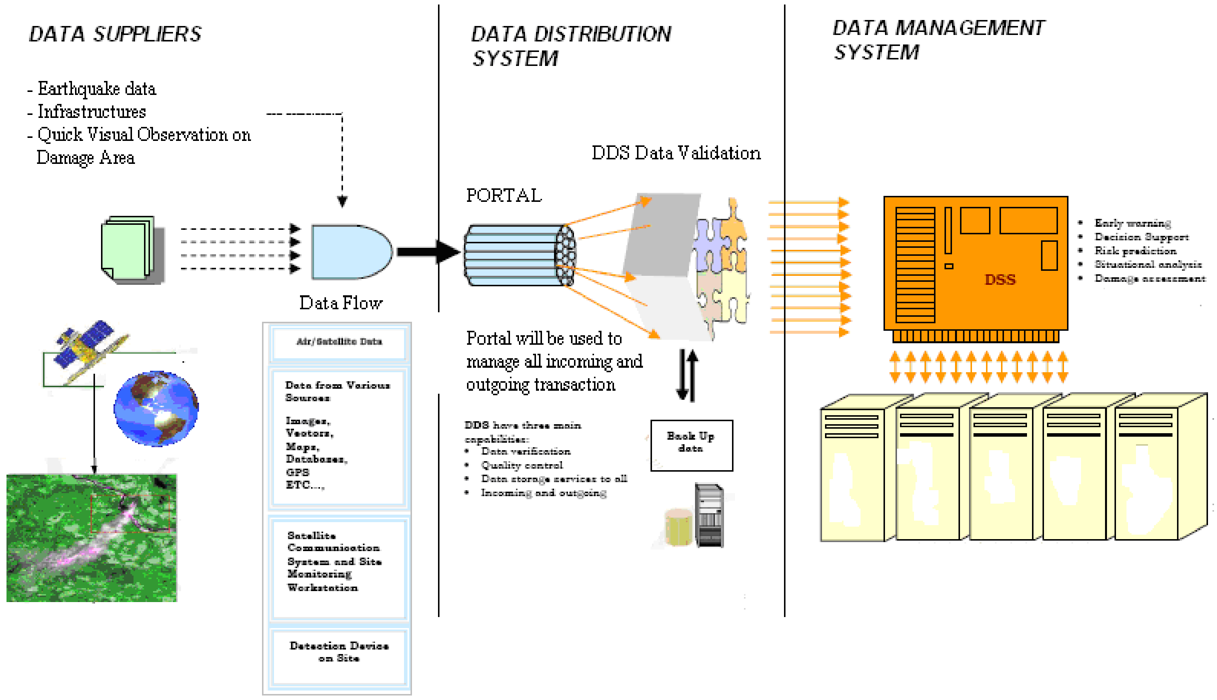

Figure 2. IELES data system configuration

The format of data are quite variable i.e air/satellite data, data from various sources, images, vectors, maps, databases, GPS, ETC, satellite communication system and site monitoring, workstation, detection devices on site, hot links and so on.

At the interface level, the DDS has the functionality of administrating user and portal. It manages data information distribution by controlling who gets what, at in different time, at different places. Its functionality can be summarized as follow:

1. Perform rapid and accurate mapping of disaster evolution
2. Easy, efficient and enable real-time communication
3. Able to support the distribution of data
4. Support at central level, the configuration users' profiles and security issues
5. Serves the needs of emergency managers that include the on-scene commander and management of the personnel in the field
6. Serve the needs of operational crews that include all squads in charge of various field activities

DDS has three main capabilities; data verification, quality control and data storage services to all incoming and outgoing data. There have to be a sub system as portal to manage all incoming and outgoing transaction. In the DDS, data/information have to be managed and stored properly. The quality of the data including its format will be strictly controlled so that it can be used throughout the system.

DMS is a collection of state-of-the-art hardware and software that can be used for the management of earthquake disaster at every stage of the crisis before, during and after. It has to be designed in a modular and expandable architecture concept and have to be able to evolve later in an incremental way through the integration of new sensors, the implementation of new centers and actors (fixed or mobile) and the integration of new application software when available.

3.2 Destruction Identification

3.2.1 Ground Response Analysis

To set source parameters of a seismic event is the first step while conducting simulation. In general, three ways are provided to define source parameters in a deterministic approach: historical events, active faults and arbitrary events. The source parameters include event date, time, magnitude, epicenter location and focal depth. In addition, the fault mechanism (reverse, normal, or strike), the orientation of trace, the inclination angle, length and width of rupture plane are required to define the source parameters if the earthquake accompanies with fault rupture. Estimation of ground motion intensity due to a scenario earthquake may divide into three steps. As shown in Figure 3, the first step is to predict the intensity at bedrock level using the attenuation laws. The second step is to obtain the intensity at ground surface through the local site modification factors. Finally, the local intensity can be updated accordingly when the monitored data at strong-motion stations are available.

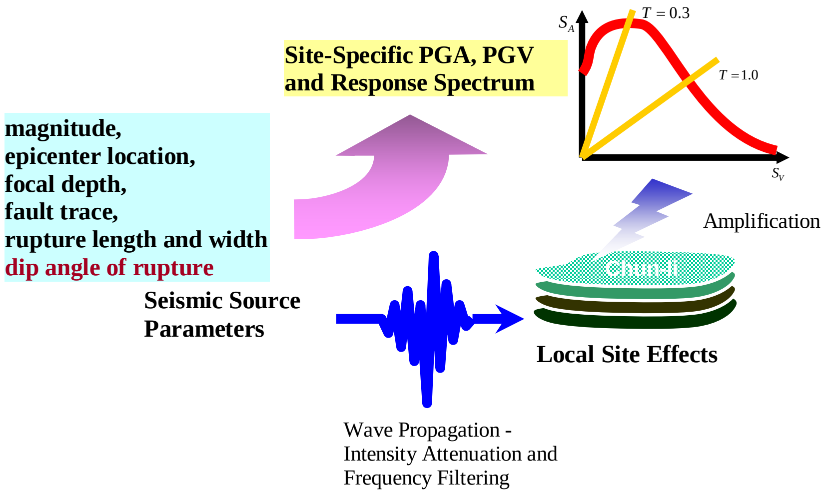

Figure 3. Estimation of ground motion intensities (Lin et al., 2006)

In the case of Yogyakarta earthquake on May 2006, the strong ground motion measuring stations were not available. Thus, ground response map of Yogyakarta is taken from the measurement of ground response analysis by Center for Volcanology & Geological Hazard Mitigation, Indonesia.

3.2 Soil liquefaction potential and settlement

The soil liquefaction potential in the proposed IELES is classified into six categories: “very high”, “high”, “moderate”, “low”, “very low”, and “none”. Further investigations and research by governments and universities are needed to analyze and to propose a classification scheme to identify the liquefaction susceptibility category in each important area in Bantul or other district in Indonesia. Furthermore, the semi-empirical formula to estimate the liquefaction probability and the amount of settlement are obtained from nonlinear regression analysis and statistics (Yeh et al., 2002). The earthquake magnitude, peak ground acceleration and ground water depth were included in the influence factors of the semi-empirical formula.

Rosyidi et al. (2008) reported some geotechnical damages occurred by the Yogyakarta earthquake. However, the complete database from geotechnical damage events particularly on soil liquefaction and settlements from all involved districts in Yogyakarta have been not completely provided. In addition, some districts also do not have the complete soil profiles. Although, the geological map of Yogyakarta is available, it cannot cover detail information for ground assessment needed in IELES system. These databases are still being updated.

3.2.3 Building and Public Infrastructures damage assessment

The scale of the natural disaster was compounded by man-made failures to build earthquake resistant structures. Large-scale damage to buildings is associated with a lack of adherence to safe building standards and basic earthquake resistant construction methods. Most of the private homes used low-quality building materials and lacked essential structural frames and reinforcing pillars and collapsed easily as a result of lateral shaking movements. The poor are the least able to afford building safe houses and many of their homes were damaged. Many public buildings also collapsed due to poor building standards, in particular schools, many of which were built in the 1970s and 1980 with special government grant funds. Clearly, there was minimal enforcement of building codes.

There has been widespread but generally minor damage to roads and bridges in the earthquake affected areas. Total damage costs are estimated at Rp 45 billion based on road damage data provided by the provincial public works agencies. All important road links are now usable and there has been no significant impact on traffic speeds. Damage to roads includes transverse and longitudinal cracking. Sections of roadway have suffered minor subsidence and pavement deformation mainly due to failure of retaining walls. Damage to bridges includes longitudinal cracking of deck slabs and unfastening of expansion joints. Bridge damage accounts for 60% of total costs, national roads for 16% of total costs, while provincial and district roads account for 84%. Two thirds of the damage to sub-national networks is in Bantul and Sleman.

The first group of structure category for direct physical damages is the general building stocks (GBS). There are many buildings of different structural types, seismic behavior and usages within the GBS. In order to facilitate damage assessment, casualty and loss estimation, these buildings are grouped into several model building types (MBT), seismic design levels, and occupancy classes. Since the only database that provides consistent format and up-to-date information of buildings in Indonesia is the building tax data from ministry of finance and local governments, these information has been used to calculate various statistics of general building stocks. The MBT in this proposed system which is adopted from TELES classification, are mainly defined by their construction material and building height. In TELES, there are 15 MBT, namely, wood (L), steel (L, M, H), light steel (L), reinforced concrete (L, M, H), pre-cast concrete (L), reinforced masonry (L, M), un-reinforced masonry (L), and steel reinforced concrete (L, M, H) buildings. The letter L, M and H in parenthesis indicate low-rise, mid-rise, and high-rise buildings, respectively. Each MBT is further divided into four seismic design levels: high-, moderate-, low-, and pre-seismic design levels. The total floor areas for each MBT and seismic design level are calculated according to their construction years, seismic zoning factors, and local site conditions.

EDIMs evaluate the damage state probabilities for each MBT with different seismic design level due to ground motion and liquefaction-induced settlement. Furthermore, the damages in structural systems and nonstructural components are evaluated separately. While calculating the seismic demand, the effects of hysteretic damping and system degradation are both considered. The seismic capacity and fragility curves for each MBT with different seismic design level are determined by reference to seismic design codes in various periods, nonlinear push-over analysis, and historical data collected after earthquake.

For road and bridge construction, the condition assessment by the visual observation must meet the pavement management system codes. The assessment is grouped into damage type, such as cracking, pot-holes, bleeding, etc., and their damage level as low, moderate and high level. In the case of earthquake disaster, the most damages on road constructions have been found and classified as transversal and longitudinal pavement cracking. Figure 4 and 5 shows example of damage type in housing and road construction after earthquake May, 27, 2006 in Yogyakarta.

Figure 4. Collapsed residential housing

Figure 5. Landslide on edge state road

4. RECONSTRUCTION SCENARIO

The mapping schemes of MBT are used to calculate the number of damaged houses and infrastructure in each type and zoning. The output of module contains estimates in three damage severity levels: "hard damage," "moderate damage," and "low damage." The damage states are calibrated considering the effects of structural and nonstructural damages while hard damage state of buildings is further divided into "collapse" and "without collapse".

From the scenario database of IELES, there will be simple applications on calculation of the annual seismic risks of infrastructures in specific regions. The expected annual seismic risks may have different values depending on the assignment of annual occurrence rates of scenario earthquakes. In the plan of IELES, the first scenarios, S_1, denotes the expected loss when the earthquake occurrence rate of grid is uniform in each seismic source zone. S_2 denotes the expected loss when the earthquake occurrence rate of grid is proportional to the number of historical earthquake events. S_3 is the average of the previous two cases. It is suggested that the mean value S_3 can be used to compare the relative magnitudes of annual seismic losses.

The seismic risk maps are useful for local governments in proposing seismic mitigation plans. If the seismic sources zoning scheme are changed or the parameters in the Gutenberg-Richter magnitude recurrence relation are obtained by different methods, the maps of expected annual seismic losses in towns are changed accordingly. For emergency response purpose, local government may prepare alternate plans for reconstruction of building and public infrastructures. They will be studied in more detail in the near future.

5. CONCLUSIONS

Formulation of strategic implementation plan needs to be taken for an effective earthquake disaster management system. To achieve success in these aspects, creation of earthquake disaster data and management system should be given prime importance among policy initiators, decision makers, and administrators at national and local levels, professional bodies, financial institutions, NGOs and voluntary organizations. The scope of disaster management activities need to expand implying participation of wider range of stakeholders in much wider range of activities. Local government institutions need to build up their capacities in order to meet the growing demands in the area of earthquake disaster management. Detailed databases need to be created on hazard occurrences containing damages caused to buildings and infrastructures and the economic losses suffered. Its accessibility should be ensured for effective pre and post disaster analysis. Earthquake disaster management system of IELES (Indonesian Eartquake Loss Estimation System) is proposed to develop the integrate research accomplishments on seismic hazard analysis and infrastructural damage assessments in Indonesia. After establishing the seismic scenario database, several potential applications have been created. When earthquakes actually happen, the response time will be shortened significantly since the damages due to any future earthquake were calculated beforehand. This information is important for decision-making support systems or emergency response centers to properly dispatch rescue forces and medical resources to the right places. It may be used in a systematic approach to estimate various kinds of seismic hazard and risk in different regions. Scenario simulation technologies (including seismic scenario database), which have been developed and used for the decision-making support system, is proposed to be part of the completed system of disaster management application for infrastructures rehabilitation in Bantul, Indonesia and with the expectation of being a handy tool for Indonesia to build a safer society.

ACKNOWLEDGEMENT

We gratefully acknowledge Center for Research on Earthquake Engineering (NCREE), Chinese Taiwan and research assistants in Lembaga Konsultasi dan Pelayanan Teknik, Muhammadiyah University of Yogyakarta and Gadjah Mada University, for their kindness, enormous help and friendship when the authors were conducting the earthquake reconnaissance investigation.

REFERENCES

BAPPENAS. (2006). Preliminary damage and loss assessment, Yogyakarta and Centrak Java Natural Disaster. The 15th meeting of the consultative group on Indoensia, Jakarta June 14, 2006. A joint report of BAPPENAS, the Provincial and Local Governments of D.I. Yogyakarta, the Provincial and Local Governments of Central Java, and international partners.

Lin C-C. J., Yeh C-H, Kao C-Y and Ke S-S. (2006). Application of Taiwan Earthquake Loss Estimation System (TELES) on Hazards Mitigation. International Symposium on Earthquake Engineering and Infrastructure and Building Retrofitting, August 28, 2006.

Rosyidi, S.A., Taha, M.R., Lesmana, S.B., Wintolo, J. and Adi, A.D. (2008). Some lessons from Yogyakarta earthquake of May 27, 2006, Proceeding of 6th International Conference on Case Histories in Geotechnical Engineering, Arlington Virginia, 11 – 16 August 2008.

Yeh, C. H., C. H. Loh, and K. C. Tsai. (2003). Development of Earthquake Assessment Methodology in NCREE, Proceedings of Joint NCREE/JRC Workshop, November 17-18, Taipei, Chinese Taiwan, NCREE-03-029.

Yeh, C. H., M. Y. Hsieh, and C. H. Loh, (2002). Estimations of Soil Liquefaction Potential and Settlement in Scenario Earthquakes, Proceedings of the Canada-Taiwan Natural Hazards Mitigation Workshop, July 17-19, Ottawa, Canada.