Application of a Mesh-based Earthquake Impact Assessment Tool for Water Supply System on Policy Support

Bing-Ru Wu and Siao-Syun Ke

ABSTRACT

A mesh-based earthquake impact assessment tool for water supply system, is developed in the Taiwan Earthquake Impact Information Platform (TERIA) with the collaboration of NCDR and academic institutions. The quantitative impact analysis in various levels of excitations, consisting of extreme and operational scenarios, can be applied to find the weak items and distribution for disaster preparedness. Two examples illustrate the application of impact analysis on disaster preparedness and policy support: (1) Scenario simulation for the National Earthquake Drill; (2) Impact analysis for policy suggestion on disaster management. The quantitative impact analysis in various levels of scenarios is helpful to disaster prevention planning.

Bing-Ru Wu, Associate Researcher, Earthquake and Man-made Disasters Division, National Science and Technology Center for Disaster Reduction, 9F, 200, Sec. 3, Beisin Rd., Xindian District, New Taipei City, 23143, Taiwan
Siao-Syun Ke, Associate Researcher, Earthquake and Man-made Disasters Division, National Science and Technology Center for Disaster Reduction, 9F, 200, Sec. 3, Beisin Rd., Xindian District, New Taipei City, 23143, Taiwan

INTRODUCTION

Approximately 70% of the population is concentrated in 6 metropolitan cities in the western plain of Taiwan (Figure 1). Three catastrophic earthquakes (Meishan, Hsinchu-Taichung, and Chi-Chi) caused thousands of deaths in the past century. In recent decades, the disaster vulnerability has increased because of population concentration and complex infrastructures constructed in urban areas. If a large-scale earthquake like the Chi-Chi earthquake occurred in metropolitan cities, the induced casualty and loss may become several times of those in 1999. After the Chi-Chi earthquake, remarkable progress on disaster prevention has been achieved by central and local governments. However, the capability of disaster resilience against large-scale earthquakes should be examined under vulnerable environmental conditions. Detailed impact analysis for various levels of disaster scenarios is necessary for disaster prevention planning.

No.	Earthquake	Date	Magnitude (M_L)	Depth (km)	Casualty	
					Ceased	Injured
1	Douliou	1904/11/06	6.1	7.0	145	158
2	Meishan	1906/03/17	7.1	6.0	1,258	2,385
3	Nantou Series	1916/08/28	6.8	45.0	71	285
		1916/11/15	6.2	3.0		
		1917/01/05	6.2	0.0		
		1917/01/07	5.5	0.0		
4	Hsinchu-Taichung	1935/04/21	7.1	5.0	3,276	12,053
5	Chungpu	1941/12/17	7.1	12.0	358	766
6	Shinhua	1946/12/05	6.1	5.0	74	182
7	Longitudinal Valley Series	1951/10/22	7.3	4.0	>85	>1,000
		1951/10/22	7.1	1.0		
		1951/10/22	7.1	18.0		
		1951/11/25	6.1	16.0		
		1951/11/25	7.3	36.0		
8	Hengchun	1959/08/15	7.1	20.0	17	85
9	Paiho	1964/01/18	6.3	18.0	106	653
10	Hualien	1986/11/15	6.5	15.0	13	45
11	Chi-Chi	1999/09/21	7.3	8.0	2,405	11,305
12	Taoyuan	2010/03/04	6.4	5.0	0	96
13	Meinong	2016/02/06	6.6	14.6	117	551

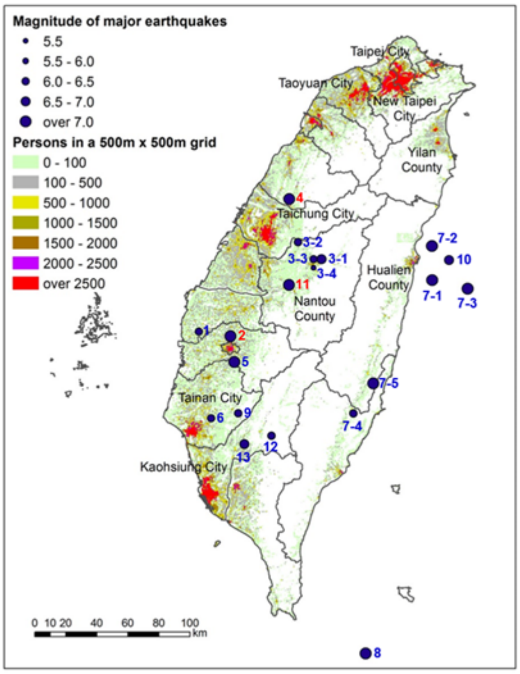


Figure 1. Location of disastrous earthquakes and population distribution in Taiwan

A MESH-BASED EARTHQUAKE IMPACT ASSESSMENT TOOL

Verity of analysis modules by means of the state-of-the-art techniques in conjunction with the inventory database were built in an open platform on the basis of mutual cooperation among the academic institutions, governmental agencies, and NCDR (Figure 2). Considerable efforts were devoted to construct the inventory database, including building, population, infrastructure, and lifeline system. The TERIA platform [1, 2] is capable of analyzing the response of ground motion, potential of liquefaction and landslide, casualty, damages of building, road, bridge, electricity, and portable water facility. With variety of inventory database constructed in this study, the analytical results in a 500 m × 500 m mesh at different layers can be integrated to interpret the disaster scenario in details.

Database of Portable Water System

The basic data of portable water system, including wells, treatment plants, pumping plants, and water pipeline, was obtained from the Taipei Water Department and Taiwan Water Corporation. The original files in various formats, such as SHP, UIF, DWG, were processed to retrieve the attribute to assemble a database covering the entire Taiwan (Figure 3). Table 1 shows the classification of brittle and ductile pipelines based on pipe materials.

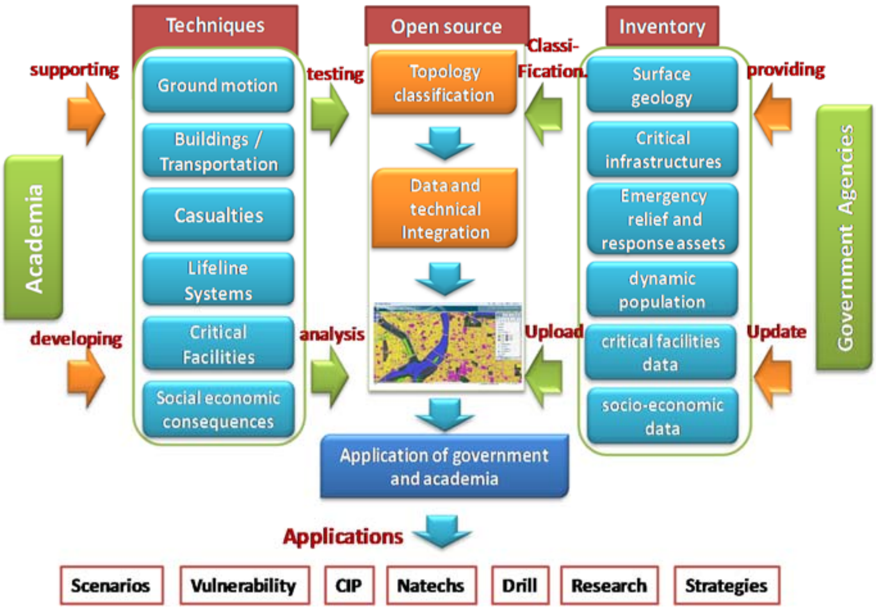


Figure 2. Framework of TERIA platform

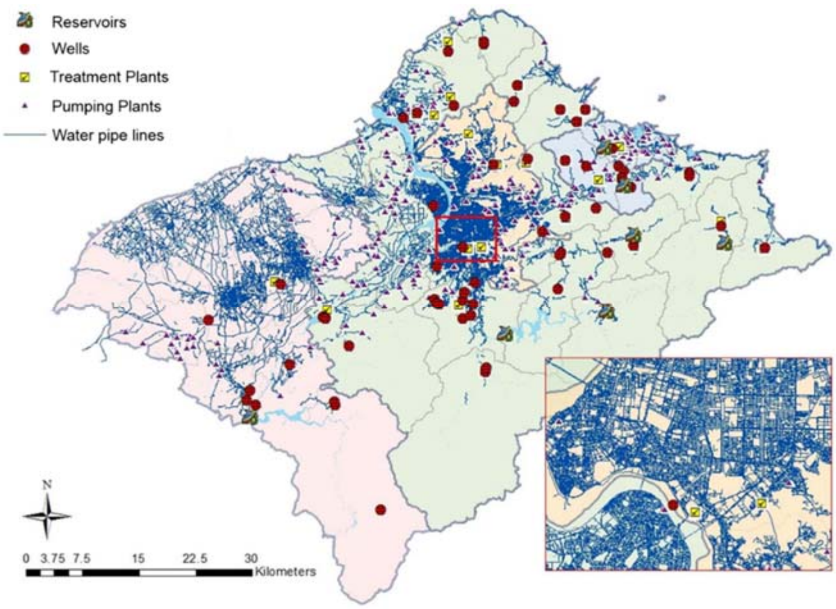


Figure 3. Database of portable water system

TABLE I. CLASSIFICATION OF PIPE MATERIAL [2]

Type	Material
Brittle pipeline	ACP, CIP, PCCP, PCV, PCVP, PCV/PE, PCVP+DIP, PCVPE. RCP
Ductile pipeline	Others

Damage Function for Portable Water Facility

The probability of damage (p) due to ground motion for portable water facility, including wells, treatment plants, pumping plants, and storage tanks, can be interpreted by the log-normal distribution in a cumulative distribution function [3]:

$$p = \frac{1}{2} + \frac{1}{2} erf\left(\frac{\ln PGA - m}{\sqrt{2}\beta}\right) \quad (1)$$

where *m* is the median, β is the standard deviation. Table II lists the median and standard deviation of damage function for portable water facilities.

TABLE II. PARAMETERS OF DAMAGE FUNCTIONS FOR PORTABLE WATER FACILITIES [3]

Facility	Capacity/Type	m	β
Water Treatment Plant	Small	0.38	0.50
	Medium	0.52	0.40
	Large	0.58	0.40
Pumping Plant	Small	0.36	0.65
	Medium/Large	0.36	0.65
Well	Small	0.36	0.65
On-Ground Anchored Storage Tank	Concrete	0.52	0.70
	Steel	0.70	0.60

Damage Functions for Buried Pipelines

The repair rate, *RR*, associated with peak ground velocity (PGV) and permanent ground deformation (PGD) which is induced by soil liquefaction can be calculated by the following equations [3]:

$$RR_{PGV}[\text{Repairs/km}] = 0.0001 \times (PGV)^{2.25} \quad (2)$$

$$RR_{PGD}[\text{Repairs/km}] = Prob[liq] \times (PGD)^{0.56} \quad (3)$$

where *PGV* is expressed in cm/sec, *PGD* is expressed in inches, *Prob*[*liq*] is the probability of liquefaction. The number of repairs in a grid for brittle and ductile pipelines is:

$$R_{brittle} = (RR_{PGV} \times 20\% + RR_{PGD} \times 80\%) \times L \text{ ; for brittle pipeline} \quad (4)$$

$$R_{ductile} = 30\% \times (RR_{PGV} \times 20\% + RR_{PGD} \times 80\%) \times L \text{ ; for ductile pipeline} \quad (5)$$

where *L* is the total length of pipeline in a grid. The damage rate in a grid is:

$$\alpha = (R_{brittle} + R_{ductile})/L \quad (6)$$

The probability of damage for pipelines can be expressed by a log-normal function:

$$p = \frac{1}{2} + \frac{1}{2} erf\left(\frac{\ln \alpha - m}{\sqrt{2}\beta}\right) \quad (7)$$

where *m* is the median, β is the standard deviation. Figure 4 illustrates the analysis steps for the portable water system. The distribution of ground motion, using an input source of either point, line, or user-defined distribution, can be predicted in a mesh of 500 m × 500 m. Accordingly, the seismic impact to the portable water system can be analyzed utilizing the database and damage functions for water facilities and pipelines.

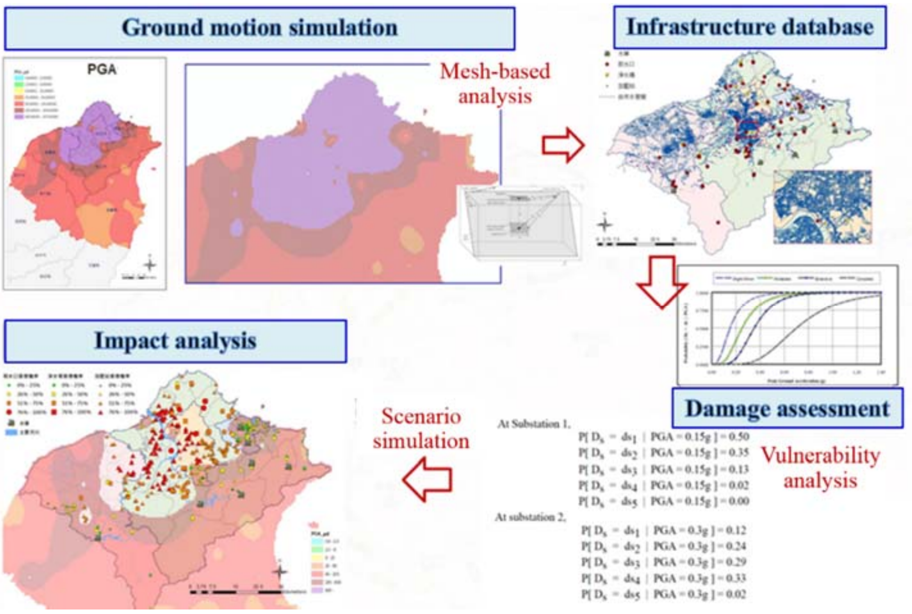
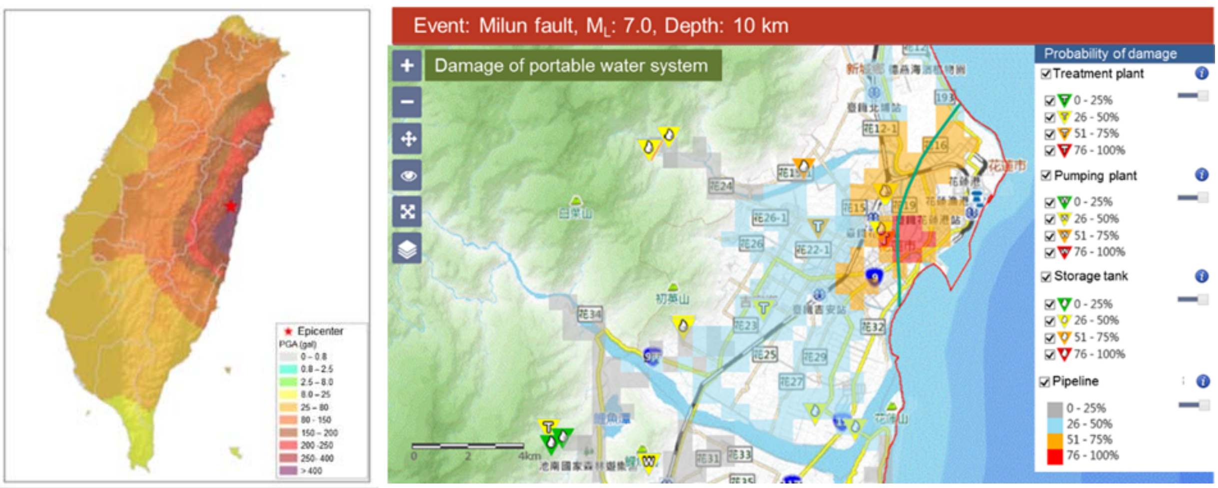


Figure 4. Analysis flow chart

SCENARIO SIMULATION FOR THE NATIONAL EARTHQUAKE DRILL

A major earthquake (M_L=7.0, depth=10 km) on the Milun Fault in Hualien county was assumed as the source of scenario simulation for the National Earthquake Drill on September 21, 2014. The Central Emergency Operation Center was operated by government officials from central ministries to provide assessments and suggestions to the commander. Figure 5 (a) shows the distribution of peak ground acceleration (PGA). The maximum PGA in areas close to the epicenter exceeds 400 gal. The damages of water facility and pipeline were evaluated by TERIA platform (Figure 5b). The probability of damage for pipeline is greater than 75% in downtown Hualien city which implies the portable water possibly cannot be transmitted to end users. The probability of damage for some pumping plants and storage tanks exceeds 50% where some damages may be found and need manual repairs.



(a) Distribution of PGA (b) Damage assessment of portable water system

Figure 5. Scenario simulation for the National Earthquake Drill in 2014

The evaluation results in a 500 m × 500 m mesh for casualty, buildings, roads, bridges, electricity, and portable water system can be integrated to interpret the disaster scenario in details (Figure 6). The building damage and casualty are serious in downtown Hualien city which need emergency rescue and medical care. However, many bridges have high possibility of damage (greater that 75%) which may influence the transportation of resources from the other counties. The probability of damage for portable water system is larger than 50% which implies some areas may be short of water supply. Some water tankers should be prepared for disabled welfare and nursing institutions in those areas.

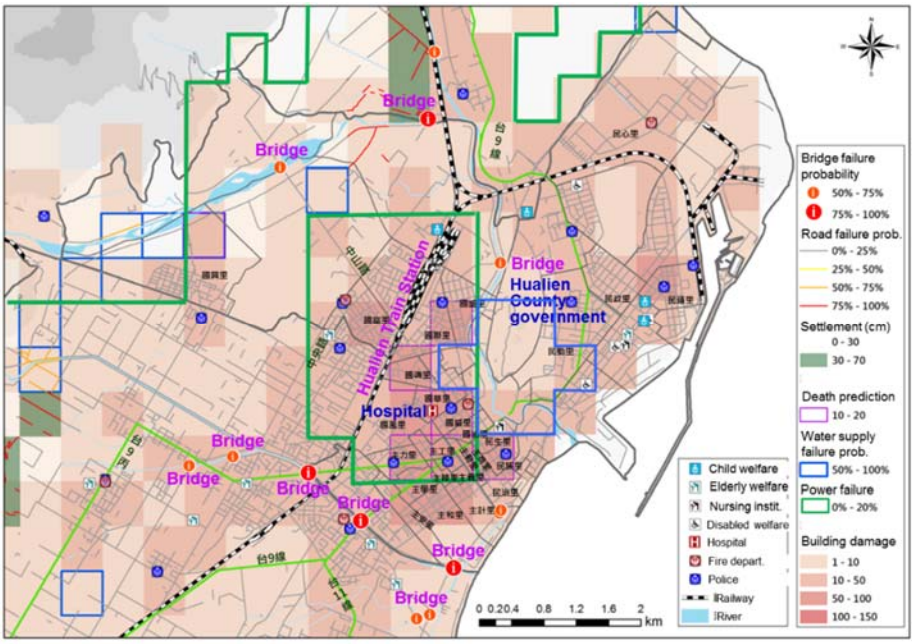


Figure 6. Summary of scenario simulation in Hualien city for the National Earthquake Drill in 2014

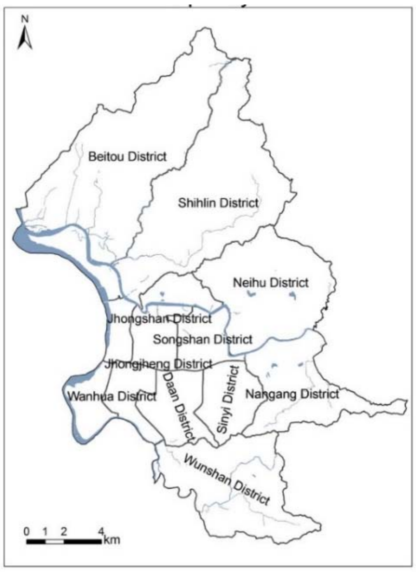
IMPACT ANALYSIS FOR POLICY SUGGESTION ON DISASTER MANAGEMENT

Scenario simulations in various levels of seismic excitations were applied to evaluate the disaster-resistant capability for disaster management. Three levels of input sources, including Intensity V (240 gal), Intensity VI (320 gal), and Intensity VIII (450 gal), were assumed as uniform acceleration distributed in Taipei city to check the weak points and their distributions (Figure 7).

Intensity level	Acceleration range	Scenario setting
V	80~250gal	240gal*
VI	250~400gal	320gal*
VII	>400gal	450gal**

* Based on the building code in return periods of 475 and 2500 years
**According to the average PGA measured in the central Taiwan for the Chi-Chi earthquake

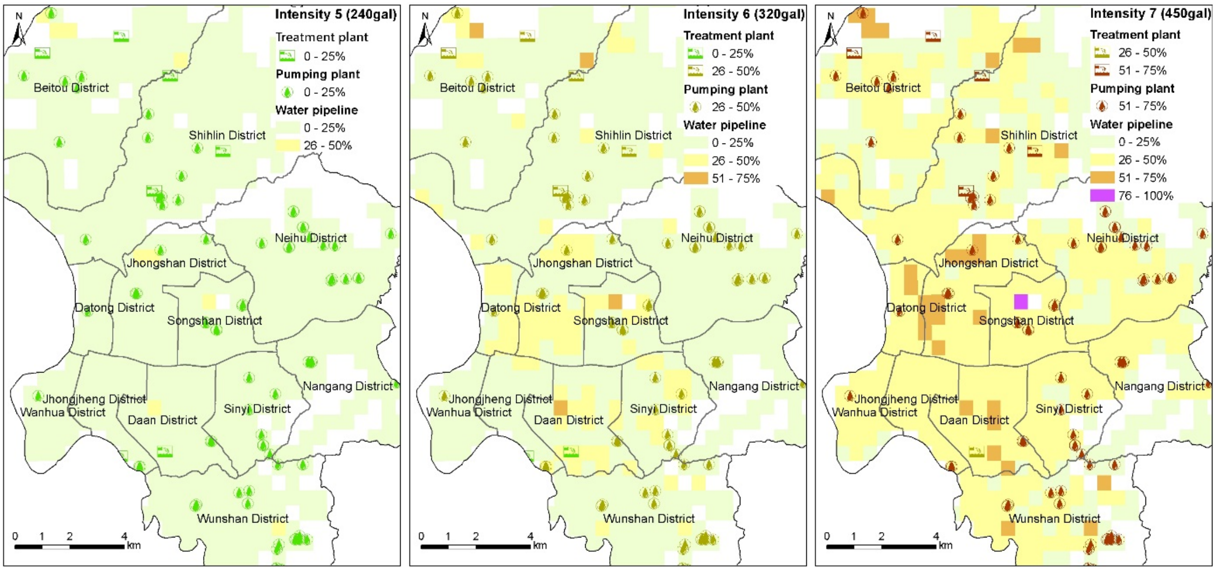
(a) Scenario setting



(b) Taipei city

Figure 7. Input sources of scenario simulations for Taipei city

From the simulation results in three levels for portable water system (Figure 8), the probabilities of damages and the extents of influence areas for treatment plants, pumping plants and water pipelines all increase as the PGAs increase. For the scenario of Intensity VII, the probability of damage is high as more than 75% and most of the treatment plants and pumping plants have probability of damage greater than 50%. Shortage of portable water supply could be expected in some districts such as Songshan and Jhongshan.



(a)Intensity 5 (PGA=240 gal) (b)Intensity 6 (PGA=320 gal) (c)Intensity 7 (PGA=450 gal)

Figure 8. Damage assessment for 3 intensity levels

In summary of simulation results for Intensity VII (Figure 9), there are more than 5,000 building seriously damaged and approximately 6,000 injury and death. The demand of medical care is larger than 4,000 which needs 2,000 to balance. The sheltering demand is more than 190,000 which is overloaded and need 30,000 to balance. Most of the cross-river bridges may be failed to transportation of resources. Power failure in the whole city could interrupt the communication and emergency operation of government. Based on the simulation results, some policy suggestions were proposed by the Disaster Prevention and Protection Expert Consultation Committee to the Executive Yuan to improve the framework of disaster management: (1) Launch a task force for configuration and promotion; (2) Inter-ministry coordination and administrative mechanism; (3) Enhance the resilience and continuity operation of infrastructure; (4) Promote the application of scenario simulation on disaster management.

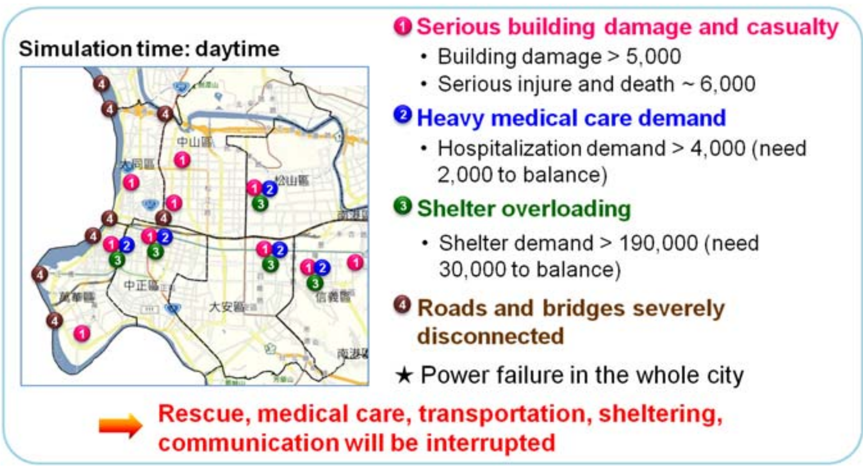


Figure 9. Summary of disaster scenarios for Intensity VII

CONCLUSIONS

The TERIA platform is capable of analyzing the response of ground motion, potential of liquefaction and landslide, casualty, damages of building, road, bridge, electricity, and portable water system. The scenario simulations for various levels of excitations interpreted in a mesh of 500 m × 500 m are helpful to disclose the possible disaster scenarios in details. Those accomplishments have been applied to the operation of the National Earthquake Drill and the policy suggestions for disaster management. The practical applications may enable a thorough planning for enhancing the disaster resilience against future major earthquakes.

REFERENCES

[1] Wu,T. H., Huang, M. W., Wu, B. R., Chen, C. Y., Su, C. L., Lee, C. S., Ke, S. S. 2014. *Analysis of Disaster Potential, Buildings, and Casualty for the Large-Scale Earthquake Scenario in Taipei Metropolitan Area*. Technical Report, National Science and Technology Center for Disaster Reduction, New Taipei City, Taiwan (in Chinese).

[2] Liu, S. Y., Wu, C. R., Lee, C. Y., Deng, M. C., Lee, Y. N., Lee, C. S., Ke, S. S., Chien, S. W. 2014. *Scenario Simulation for Taipei Metropolitan Area II: Road, Bridge, Portable Water, Electricity, and Important Infrastructure*. Technical Report, National Science and Technology Center for Disaster Reduction, New Taipei City, Taiwan (in Chinese).

[3] Federal Emergency Management Agency. 2015. *Hazus®-MH 2.1.* Multi-hazard Loss Estimation Methodology, Earthquake Model, Technical Manuals, Department of Homeland Security, Washington, D.C, USA.