Seismic Preparedness and Emergency Response of Water Systems — Visions and Experiences

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ABSTRACT

In this paper, the tasks related to seismic preparedness and emergency response of water systems were reviewed and discussed. The first task is to identify the water facilities and pipelines at risk. The inventory database containing geographical information and seismic attributes of water facilities and pipelines should have been collected and checked. Various kinds of seismic hazard maps, such as the hazard maps of earthquake ground motion, known active faults, soil liquefaction potential due to earthquakes, and so on, should have been studied carefully. The second task is to propose a feasible and efficient disaster reduction plan, which is based on seismic scenario simulation technology. Based on the scenario simulation of disastrous earthquakes, the probable damage-state of critical water facilities, the serviceability of transmission/distribution pipeline systems, the amount of water available for emergency usage such as medical-care and fire-fighting, the number of households without potable water, the expected interruption/restoration time, and so on, should be evaluated quantitatively. In addition, various kinds of resource needs after devastating earthquakes and comparison with the existing capacity, such as man-power, material and equipment, should be reviewed. The third task is to develop an early seismic loss estimation and notification system, which may provide brief but valuable information about probable disaster scale and damage distribution. The system should automatically notify emergency response sectors soon after earthquake occurrences. The immediate notification may assist starting-up and decision-making in emergency responses. With the help of early seismic loss estimation, it is expected to reduce casualties, losses and secondary disasters.

INTRODUCTION

Taiwan is located in high seismicity circum-pacific belt. According to the historical records in Taiwan, a devastating earthquake causing more than 100 deaths had been occurred in every 15~20 years. So far, it is still impossible by using the current technologies to eliminate earthquake occurrence or disaster in Taiwan. However, it might be possible to reduce or to minimize the influence, inconvenience, loss and disaster, as long as each strategy of preparedness and emergency response has been carefully reviewed and put into action.

There are many subsystems of water supplies, such as raw water supply system, treatment system, transmission/storage system and distribution system. The water facilities and pipelines are almost all over the place. It is not practical to entirely avoid passing through

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active faults or soil liquefaction susceptible regions. If an existing water facility or pipeline is identified to locate at soil liquefaction susceptible region or close to known active faults, it does not matter as long as the preparedness and/or emergency response strategy, such as conducting seismic retrofit, installing valves and bypass pipes, etc., has been carefully reviewed and put into action. On the other hand, if we overlook the problem or do not know the fact, then it is dangerous.

Early warning of earthquake occurrence may help to prevent losses or casualties. For example, with a few seconds of warning, high speed train may slow down gradually to avoid derailment; high-tech fabrication plants may stop immediately the manufacturing process to reduce damage and loss. However, the warning time is usually too short to take any effective action on water facilities and pipeline systems. The most effective way to reduce damage and loss of water facility and pipeline system is to develop/improve the seismic design for new constructions and to evaluate/retrofit the existing aged facility/pipeline. Since there are a lot of existing old-constructed water facilities and pipelines, seismic evaluation and retrofit are urgent; development and enhancement on seismic evaluation and retrofit technology are very important topic.

Devastating earthquakes, which may cause damage, loss and casualty, do not occur every year. Sufficient historical damage and loss investigation data could not be obtained; the statistical analysis could not be used to reasonably predict the consequences due to future earthquakes. Moreover, the seismic capacity of infra-structures, the migration pattern of populations, and other environment variables are changing all the time. Historical observations should not be used directly in prediction of future risk. Nonetheless, with the help of the limited information about the amount of damage/loss and its distribution, it is possible to develop seismic damage and loss assessment models, which may provide various kinds of quantitative estimation results to use in disaster reduction plans.

Unlike typhoons and floods, the location and magnitude of earthquakes cannot be predicted in advance without uncertainty; the duration of strong ground shaking is often less than a few minutes; but the devastating disasters may happen during these few minutes and spread in wide range. Immediate after earthquakes, emergency response personnel should be informed. However, without information of disaster assessment or reports, it is difficult to deploy rescue/fire-fighting/medical resources and to plan emergency responses.

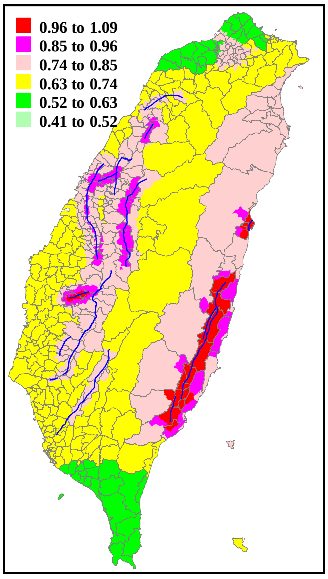
MULTIDISCIPLINARY DATABASES OF INVENTORY AND SEISMIC HAZARDS

There are two water utilities in Taiwan, i.e. Taipei Water Department and Taiwan Water Corporation. The two utilities have been established for many years. Part of existing water facilities and pipeline systems had been constructed long time ago, when the seismic technology and design codes were not so advanced as the current standards. It is desirable to seismic retrofit the old facilities and to upgrade the old pipes to meet the modern seismic standards gradually. However, as shown in Table 1, the total length of pipelines is too large; it may take very long time and cost very much to upgrade all the pipelines. In view of the importance of transmission pipelines, it may have the first priority to conduct seismic evaluation and retrofit for those transmission pipelines that are vulnerable and located at soil liquefaction susceptible region or near known active faults.

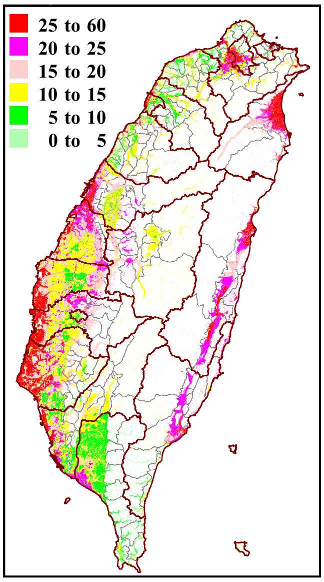
Since the total length of transmission pipelines with diameter greater than or equal to 800 mm is still very large, the two water utilities are encouraged to cooperate with academic or research organizations in order to develop a systematic and effective way to prioritize the seismic evaluation and retrofit sequence of the critical transmission pipelines, which may not have any backup or redundant pipeline. One of the important tasks in this concern is to establish inventory database of facilities and pipelines in GIS (geographic information system) format and record their attributes including location, service capacity, seismic ability, buried depth, pipe size, material-joint type, construction year, and so on. Once the seismic hazard maps, as shown in Figure 1, are available, the map of facilities and pipelines may overlap with seismic hazard maps and to identify the pipelines in hazardous areas.

Table 1 Total length statistics of pipeline systems

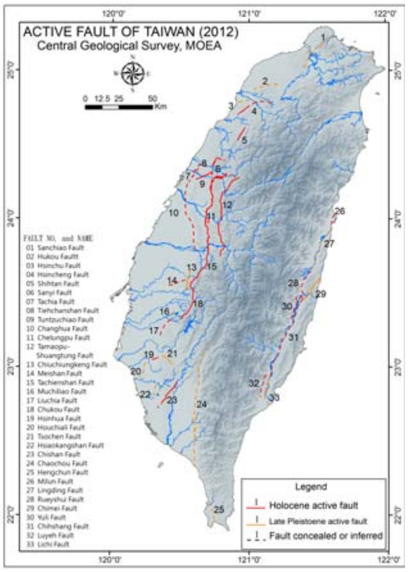
Class		Range of pipe diameter	Total length
Raw water	Transmission pipelines	$d \geq 700$ mm	335 km
Treated water	Transmission pipelines	$d \geq 800$ mm	2,163 km
	Sub-transmission pipelines	500 mm $\leq d <$ 800 mm	2,535 km
	Distribution pipelines	100 mm $\leq d <$ 500 mm	53,493 km



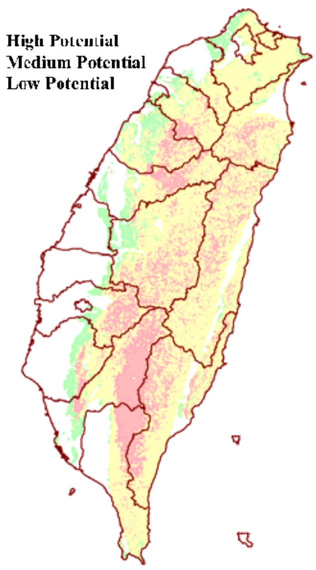
(a) Peak ground velocity hazard



(b) Soil liquefaction potential



(c) Active faults



(d) Landslide potential

Figure 1 Seismic Hazard Maps in Taiwan

COMPREHENSIVE SCENARIO-BASED DISASTER REDUCTION PLAN

An earthquake loss estimation methodology, HAZUS, was introduced to Taiwan in 1998 through a project called HAZ-Taiwan. The analysis framework of HAZUS and HAZ-Taiwan were very similar, as shown in Figure 1. Given any scenario earthquake, which has been properly described by earthquake magnitude, epicenter location, focal depth, rupture fault geometry, etc, the potential earth science hazards, the direct physical damages, the indirect physical damages and the socio-economic losses can be estimated by various state-of-the-art analysis models. Since all of the analysis models require localized database and site-dependent parameters in order to obtain reliable results, various kinds of nation-wide database such as seismic source characteristics, geologic site conditions and inventory databases were collected and calibrated. The analysis models and associated parameters, such as ground-motion prediction, soil liquefaction assessment, building damage assessment, casualty assessment, and so on, were also studied and calibrated accordingly to meet observations in the 1999 Chi-Chi Taiwan earthquake. Furthermore, to enhance the functionality and to improve the graphical user interface, the original software HAZ-Taiwan was totally revised and renamed as Taiwan Earthquake Loss Estimation System (TELES) [1].

The analysis models for different types of infrastructures, such as buildings, bridges, water facilities and pipelines, are all distinct; the characteristics for different lifeline systems and the main issues concerned by different users and authorities are not the same. Therefore, TELES was decomposed into several sub-systems, which may be run independently, to meet various kinds of user needs and to facilitate the maintenance of software. For example, sub-systems Tgbs, Twater and Thighway were customized to estimate the damage and loss of general building stocks, potable water systems and highway systems, respectively, as shown in Figure 1.

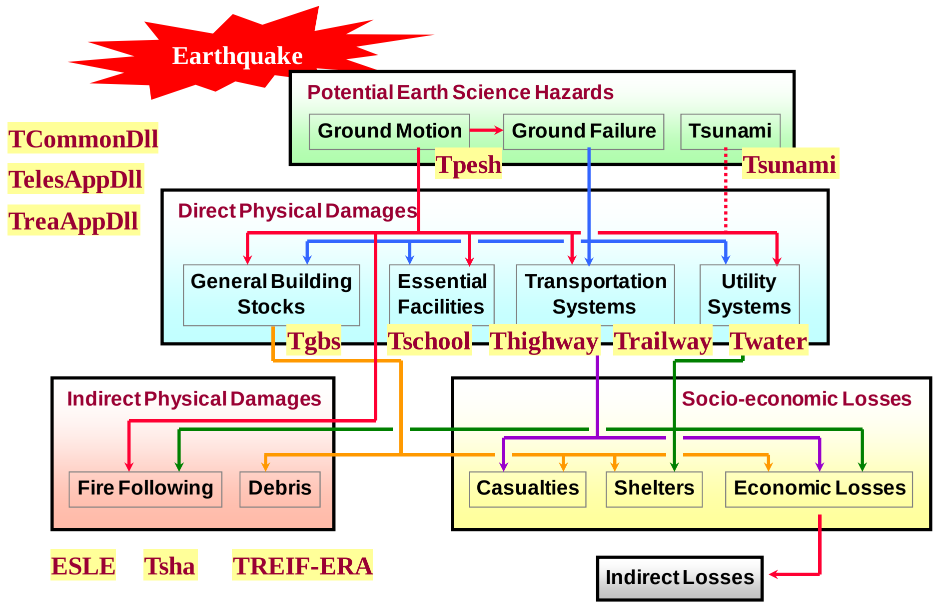


Figure 2 Analysis framework of HAZUS, HAZ-Taiwan and the family of TELES-related subsystems

Different transportation and utility systems may have interactions with each other, especially after devastating earthquakes. For example, efficient fire-fighting to extinguish a lot of post-quake fires at the same time needs uninterrupted highway system to transport fire-fighters and equipments; it also needs sufficient water supply. However, the highway system may be blocked due to damage bridges or collapse buildings; the water treatment plants and pumping stations may need electric power to function normally, not to mention transmission and distribution pipelines for emergency water supply may be damaged after earthquakes. In order to propose a feasible and efficient seismic disaster reduction plan, it is required to run comprehensively many kinds of scenario simulations on different essential facilities, transportation and utility systems, taking into consideration that some of the dependent systems may have lost of their functions.

EARLY SEISMIC LOSS ESTIMATION, NOTIFICATION AND JUDGEMENT

In case a strong earthquake occurs, the emergency response sectors of government or enterprise should be notified and have reliable information to decide whether or not to initiate Emergency Operation Center (EOC) in order to shorten response time and to reduce casualties and losses. Once the EOC initiated, it is also necessary to predict probable disaster distribution in order to dispatch efficiently the rescue, medical and livelihood resources. In addition, probable isolated hotspots may exist due to disruption of electricity, communication and/or transportation after strong earthquakes. These isolated hotspots should be identified as soon as possible to prevent delay of rescue operations.

Traditionally, there are two approaches to estimate disasters soon after strong earthquakes. The first approach uses the monitored peak ground acceleration (PGA) at each real-time station of the Central Weather Bureau (CWB) and conducts interpolation of the PGA to obtain site-dependent ground-motion intensity. Based on the PGA estimates, structural damage, human casualty and other disaster assessments are then conducted to obtain rough results. The second approach applies the seismic scenario simulation technology, but inputs point-source parameters which are provided by the CWB immediately after earthquakes. However, the rupture fault geometries such as fault trace, dip angle, length and width are important input in obtaining accurate estimates. Without this information, it is not possible to obtain reliable disaster estimates.

To avoid inadequate interpolation of PGA and to overcome difficulties in obtaining accurate seismic source parameters soon after strong earthquakes, NCREE has developed early seismic loss estimation (ESLE) technology. The methodology of ESLE is briefly explained as follows. A scenario simulation database was built first before earthquake occurrences. The scenario database contains simulation results of thousands of earthquakes, which may represent all possible earthquakes in the future. When a strong earthquake occurs, the ESLE system will be automatically triggered when it receives earthquake alert email from the CWB. Several scenarios are selected by matching the following criteria: they have similar earthquake magnitude, epicenter location and focal depth with the real earthquake; furthermore, the simulated PGA and the observed PGA at the CWB real-time stations are close to each other. Since the source characteristic and the ground-motion intensity pattern are similar to the observed earthquake, it can be reasonably speculated that the predicted damage and loss in the selected scenarios will be close to the actual ones. In some sense, the ESLE technology adopts every piece of information contained in the earthquake alert email from CWB.

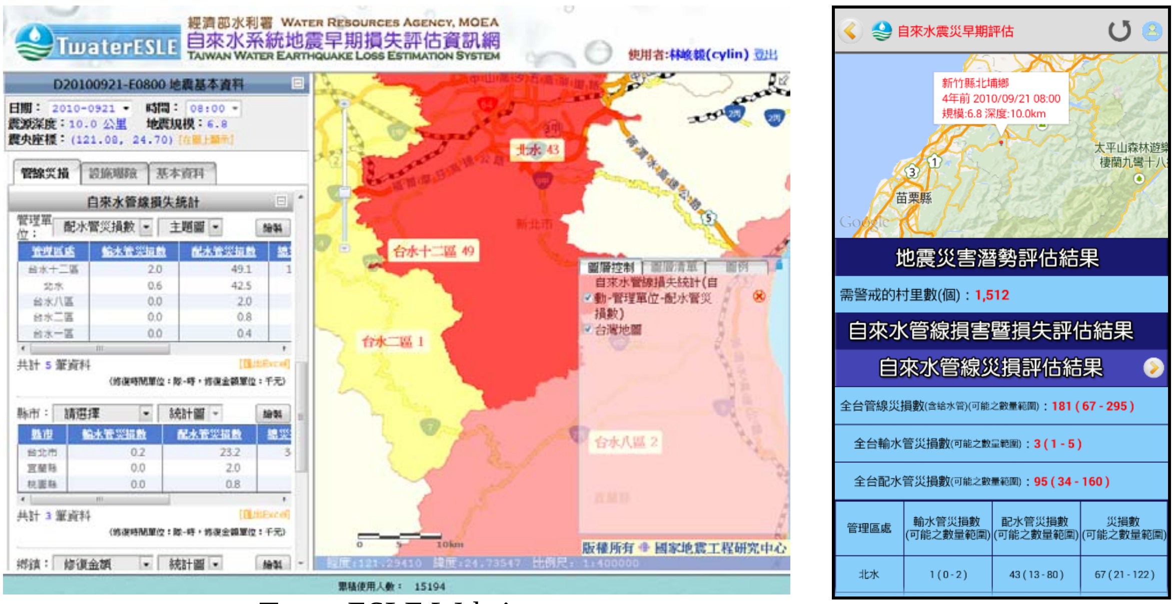
Application of ESLE immediately after earthquake may divide into two stages:

(1) First stage: within two minutes after receiving earthquake alert email from the CWB. The system automatically starts and completes assessment of probable disasters within two minutes. Emergency response personnel will be notified by simple text message, email, push notification, or other media, as shown in Figure 3. The content of simple text message had been customized to fit individual needs and contains information of the predicted disaster severity, which may be used to decide whether it is necessary to start EOC as soon as possible to gain valuable rescue time.

Other detail information, such as the distribution of water facilities and pipeline systems, the thematic maps and the statistical data of probable disasters, may be queried through the TwaterESLE Website or APP, as shown in Figure 4.

(2) Second stage: within six hours after earthquake occurrence. Combining information of the acceleration time histories at the real-time stations, the fault plane solutions provided by USGS and/or CWB, and the distribution of aftershocks, several probable sets of seismic source parameters may be proposed and justified by running additional scenario simulations. Based on the simulation results, the most probable scenario can be identified and used to avoid overlook of isolated hotspots.

Figure 3 Customized simple text messages from ESLE in Meinong, Kaohsiung Earthquake, 2016. The first text message contains estimates on number of pipe repairs in different branches of Taiwan Water Corporation; the second text message contains estimates on casualties and insurance losses



TwaterESLE Website TwaterESLE APP

Figure 4 Screen snapshot of TwaterESLE Website and APP

A strong earthquake with magnitude 6.6 occurred in Meinong, Taiwan on February 6, 2016 was taken as an example. It is noted that the earthquake magnitude was originally announced as 6.4 and modified to 6.6 several hours later.

One minute after receiving the CWB earthquake alert, the ESLE completed the disaster estimation and sent the simple text messages to notify emergency response personnel. The content of simple text message (see Figure 3) indicated that the probable number of casualties was between 5 and 30 with the best estimate 12; the residential earthquake insurance losses were between 179 and 546 million NT dollars with the best estimate 529 million NT dollars; the number of water pipe repairs was about 1432 and concentrated in Tainan area; there were more than one thousand villages (1045) with PGA greater than 0.16g. Due to the predicted severity of the disasters, it was recommended to partially initiate emergency responses. Other detailed information could be found at the related website. Six scenarios (see Figure 5) which may represent Meinong earthquake were selected automatically by ESLE in the first stage.

The acceleration time histories at the real-time stations were downloaded and analyzed soon after the earthquake, in order to understand the ground motion characteristics in different districts. It was found that the vibration in east-west direction was greater than that in south-north direction. Some of the waveforms showed significant velocity pulse. About one hour after the earthquake, the fault plane solutions were released by the US Geological Survey (USGS) and the Central Weather Bureau. Integrating the previous data and the distribution of aftershocks within three hours (see Figure 6), the seismic source parameters were judged to be as follows: the fault strike should be approximately east-west orientation, the fault plane should be slightly north-dipping, the fault rupture had a left-slip component and the directivity effect was significant. In summary, the input source parameters in the ESLE second stage were set to magnitude 6.4, focal depth 15 km, strike west 20 degree to the north, rupture length 20 km. It is noted that the rupture fault-line assumed in the ESLE second stage (see Figure 6) starts from the epicenter of Meinong earthquake to reflect the observed directivity effect.

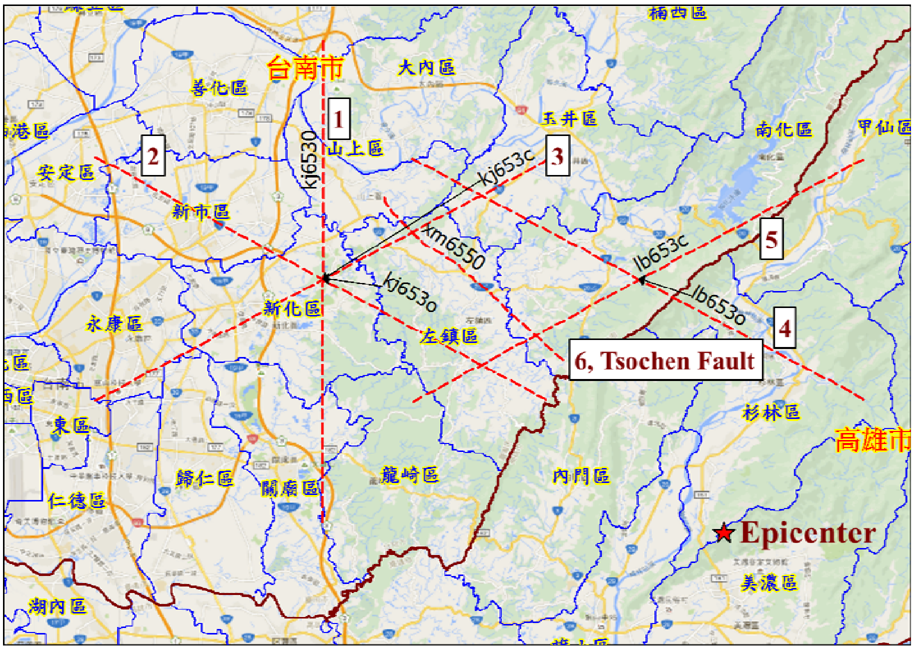


Figure 5 Six scenarios selected automatically by ESLE in Meinong earthquake, 2016

SUMMARY

There are many tasks need to be done before and after earthquakes. This paper focuses on three important tasks. The first task is to establish and continuously update multidisciplinary databases including inventory data of facilities and pipeline systems, and to collect various kinds of state-of-the-art knowledge on seismic technologies and probable hazards. Based on financial considerations, it is desirable to prioritize seismic retrofit sequence depending on the importance, vulnerability, and probable hazards of specific aged targets. The second task is to propose a feasible and efficient disaster reduction plan based on quantitative results from comprehensive scenario simulations, including those from general building stocks, essential facilities, and transportation and utility systems; because these systems may have interactions with each other after devastating earthquakes. The third task is to develop early seismic loss estimation and notification system in order to enhance emergency initialization and response efficiency. Corporation between water utilities and academic/research organizations on disaster reduction and emergency response should be put more emphasis on.

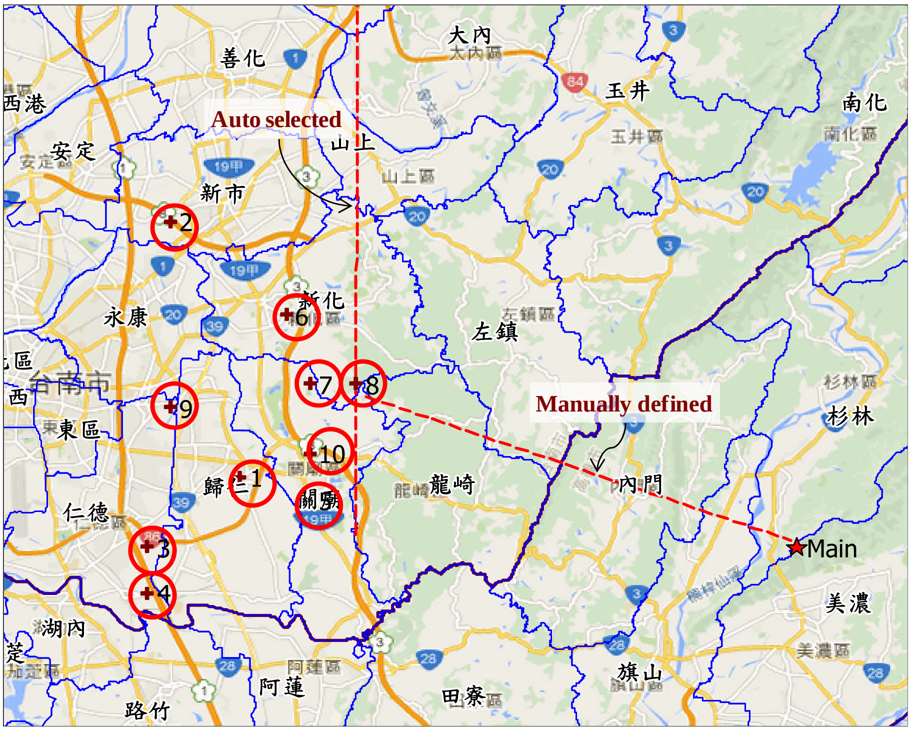


Figure 6 Main and aftershocks within 3 hours of Meinong earthquake, 2016 and the selected scenarios by ESLE

REFERENCES

[1] Yeh, C. H., C. H. Loh and K. C. Tsai (2006). "Overview of Taiwan Earthquake Loss Estimation System", Natural Hazards, 37, pp. 23-37.

[2] Water Resources Agency, MOEA. 2012, “A Study on Upgrading Earthquake Loss Estimation Technology for Water Utilities and Seismic Testing Platform and Procedure for Water Pipes,” in Chinese, Project No. MOEA-WRA-1010381, Taipei.

[3] Water Resources Agency, MOEA. 2013, “A Study on Early Seismic Loss Estimation of Public Water Supply Systems (1/2),” in Chinese, Project No. MOEA-WRA-1020117, Taipei.

[4] Water Resources Agency, MOEA. 2014, “A Study on Early Seismic Loss Estimation of Public Water Supply Systems (2/2),” in Chinese, Project No. MOEA-WRA-1030158, Taipei.

[5] Water Resources Agency, MOEA. 2015, “A Study on the Technology of Seismic Risk Assessment of Public Water Supply Systems,” in Chinese, Project No. MOEA-WRA-1040264, Taipei.

[6] Water Resources Agency, MOEA. 2016, “A Study on the Seismic Scenario Simulation Technology for Public Water Supply Systems,” in Chinese, Project No. MOEA-WRA-1050316, Taipei.