POST-EARTHQUAKE STATUS OF LIFELINE INFRASTRUCTURE BASED ON INTERDEPENDENCY EFFECTS IN SCIENCE PARK, TAIWAN

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Abstract

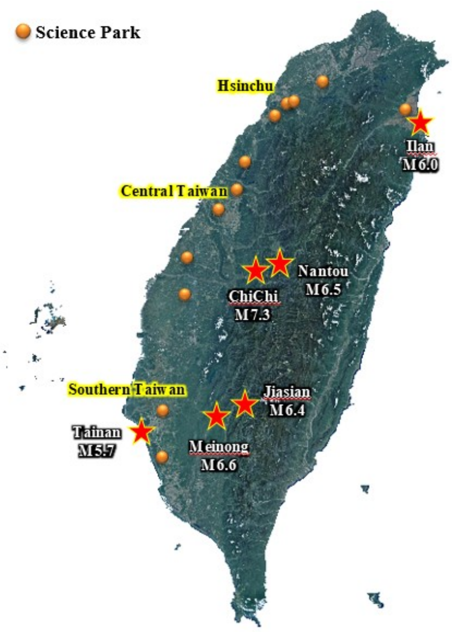
Lifeline infrastructure is an aggregation of numerous facilities constituting the backbone of the urban operation. Moderate-to-large earthquakes adversely affect infrastructure, severely impairing most urban function. For instance, 2018 Osaka, Japan earthquake (M_w 6.6) Osaka, 2016 Kumamoto, Japan earthquake (M_w 7.0), and 2016 Meinong, Taiwan earthquake (M_w 6.4) caused infrastructure damage, including power outage, water shortages et al in the urban areas. Furthermore, the impacts on Science Park might extensively affect the economic and industry chain at both large scales of time and space. Taiwan is located in the Circum-Pacific seismic zone, and earthquakes occur frequently. Therefore, understanding the effect of infrastructure on disaster scenarios in urban areas when moderate-to-large earthquakes occur is an urgent task for Taiwan government. This study aims to consider the characteristics of earthquake disaster management, the direct impact of strong ground motion and the system-related characteristics, and scenario analysis is performed and focuses on the Science Park in a demonstration area. The results of this study may assist the authorities in making effective decisions regarding Science Park facility disasters and resource management.

Keywords: Lifeline Infrastructure, Interdependency effects, Science Park, Post-Earthquake

1. Introduction

Lifelines are essential infrastructure, such as water and electricity supply systems, that are required for normal urban operation. In a seismic event, ground shaking may damage these critical facilities, causing serious disruption to the urban service functionality. Because these events impact social, economic, industrial, and commercial activities, society as a whole might be extensively affected at both large and small scales over varying degrees of time and space.

The 2011 East Japan Earthquake and the 2016 Kumamoto Earthquake caused semiconductor industry supply chain disruptions in the global, the 1999 ChiChi Earthquake、2010 Jiasian earthquake and the 2016 Meinong Earthquake severely damaged to Science Park in Taiwan, and resulting in serious economic losses (Figure 1、2). Therefore, lifelines maintain and disaster response are important issues for maintaining Science Park normal operation and economic prosperity. In recent years, significant earthquakes in Taiwan have demonstrated that lifelines in areas which experience a magnitude six earthquakes or higher are often damaged, and there by indirectly impact various other critical infrastructure (Table 1)[1,2,3,4].



Year	Area	Earthquake Magnitude (M_L)	Main Effect Science park (Seismic Intensity Scale)
2017	Tainan	5.7	Southern Taiwan (4)
2016	Meinong	6.6	Southern Taiwan (5)
2013	Nantou	6.5	Southern Taiwan (3) Central Taiwan (4) Hsinchu (4)
2010	Jiasian	6.5	Southern Taiwan (5)
2005	Ilan	6.0	Hsinchu (3)
1999	ChiChi	7.3	Hsinchu (5) Southern Taiwan (4)

Fig. 1 –Significant Earthquake disaster event of science park in Taiwan (1999~2017)

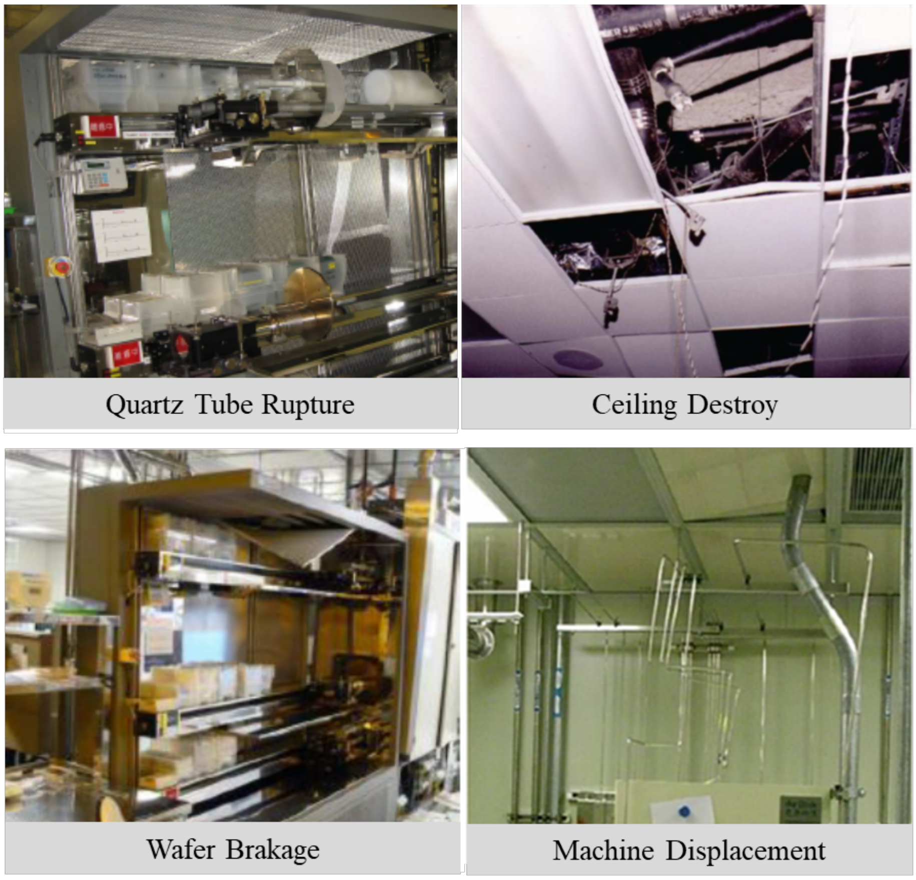


Fig. 2 –Equipment damaged of Science Park in Taiwan (2016 Meinong earthquake event)

Table 1 – Seismic impact of Science Park in earthquake event (1999~2017) [1, 2, 3, 4]

Time	Area	Earthquake Magnitude (M_L)	Disaster Impact Description	Finance Loss (NT)
2017	Tainan	5.7	Response: The Southern Science Park implement emergency response plan and evacuate the employees. Direct impact: The vendor equipment shutdown in Southern Science Park.	No significant affect
2016	Meinong	6.6	Response: The Southern Taiwan Science Park implement emergency response plant and evacuate the employees. Direct Impact: The equipment and product damaged, and vendor short-term shutdown. Indirect Impact: the electronic power interrupt, and vendor short-term shutdown. Secondary Effect: The factory fire event.	One hundred million
2013	Nantou	6.5	Response: The Central Taiwan Science Park implement emergency response plant and evacuate the employees. Direct Impact: The equipment and product damaged, and vendor short-term shutdown. Indirect Impact: the electronic power interrupt, and vendor short-term shutdown.	No significant affect
2010	Jiasian	6.5	Response: The Southern Science Park implemented emergency response plant and evacuate the employees. Direct Impact: The equipment and product damaged, and vendor short-term shutdown. Indirection Impact: The electronic power interrupt, and vendor short-term shutdown.	Ten million
2005	Ilan	6.0	Direct impact: The Hsinchu Science Park implement emergency response plant and evacuated the employees.	One million
1999	ChiChi	7.3	Direct impact: The Hsinchu Science Park equipment damaged, ceiling damage, and wall cracked. Indirect impact: The electronic power interrupt, vendor long-term shutdown.	One hundred million

2. Method of seismic impact evaluation

The procedure used to evaluate seismic impact on infrastructure is shown in Figure 3. First, seismic parameters, such as the earthquake epicenter, focus depth, and magnitude were set, and then a database of facilities was established. Next, we assessed the direct impact caused by ground shaking, then constructed the cascading effects model, and finally carried out a detailed analysis to better understand regional operational disruption within a specific area caused by seismic scenario simulation.

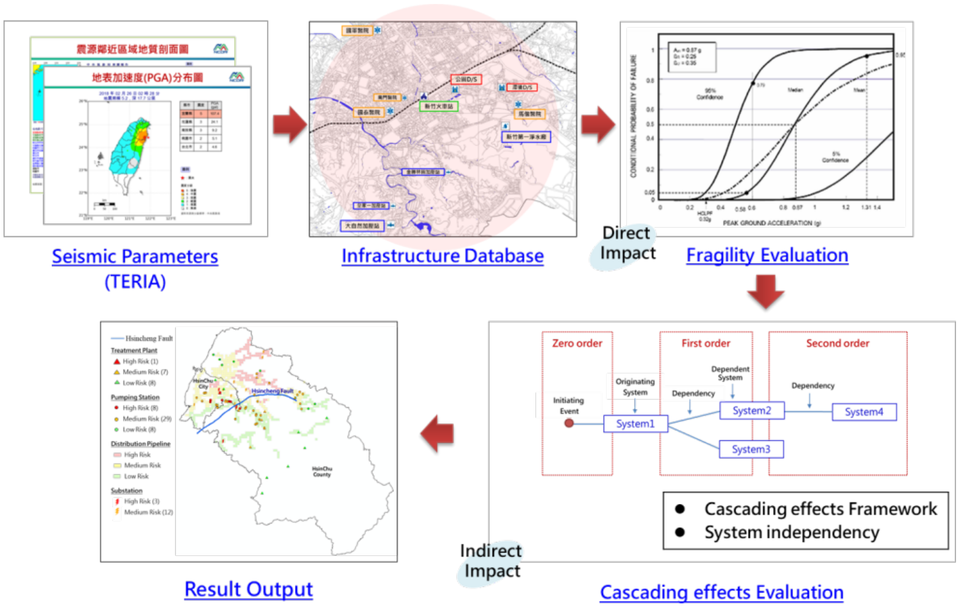


Fig. 3 – Procedure for assessing seismic impact

The National Science and Technology Center for Disaster Reduction (NCDR) established the Taiwan Earthquake Impact Research and Information Application (TERIA) platform, an integrated framework for earthquake impact scenario assessment and application(Figure 4).The ground shaking characteristic in the urban area were illustrated by incorporating geographic information system (GIS) analysis in 500m×500m grids. The seismic scenario analysis included building damage, causalities, bridges, the roadway system, lifelines, and the emergency relief and response systems, etc. [5]. In addition, the established database was adopted as a reference for future compound-disaster studies. This study investigates interdependence characteristics, to better understand system relationships that include external supply and influence facilities. The basic characteristic data of lifelines as shown in table 1, and the interdependence characteristics data are investigated as shown in Table 2.

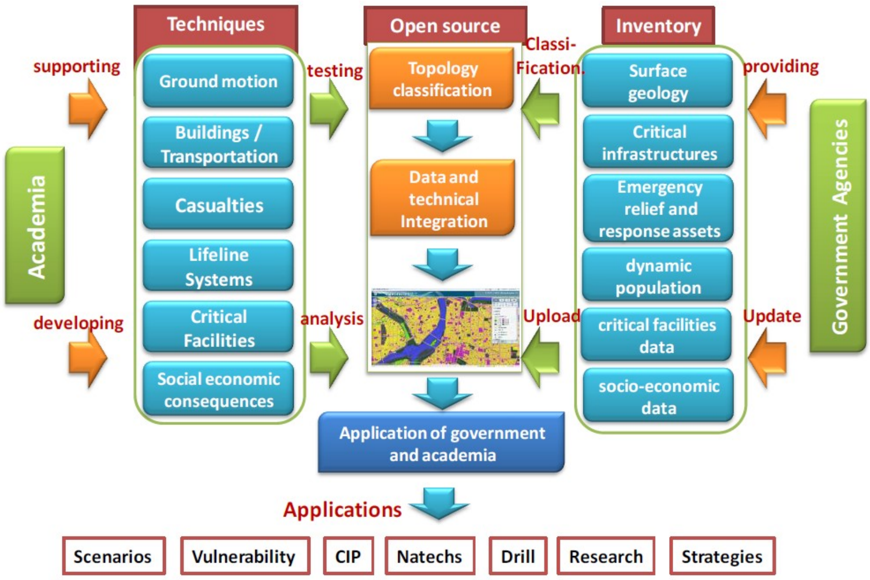


Fig. 4 – Taiwan earthquake impact research and information application platform (TERAI)

Table 2 – Basic characteristic data of water supply system

Code	System	Facility Type	Facility Name	County	Town	Supply Area
W10	Water	Treatment plant	Hsinchu I	Hsinchu City	East District	• Hsinchu County • Hsinchu City • Hsinchu Science Park

Table 3 – Interdependent characteristic data of water supply system

Code	External Supply Facility	External Influence Facility	External Source
W10	Touqian River Water Intake	Hsinchu Pumping Station	Gongyuan Primary Substion

3. Seismic impact chain mode

Life During a seismic event, ground shaking may cause damage to critical urban facilities that supply electrical power, water, transportation, and other important services. These lifelines are increasingly reliant on each other for varying required functionalities, and are therefore interdependent. These operational interactions significantly increase the likelihood that even minor disruptions in a single facility will lead to a cascade impact. The characteristics are as follows:

- ✓ The system dependencies lead to impacts that propagate to other systems
- ✓ The combined impacts of the propagated event are of greater consequence than the root impacts
- ✓ Multiple stakeholders and/or responders are involved

[6] Proposed a conceptual model of indirect disaster impact (Figure 5). The figure shows that during the initiating event, the original system(s) is/are directly impacted (first-order). Once the systems internal equipment/components are damaged, the external chain system is impacted (second-order), or derives other systems (third-order).

There are many important assets in the lifelines infrastructure that are used to produce and transfer resources. Under normal operating conditions, the facilities depend on external sources to operate. [6] proposed that the system relationships can be classified into the following categories: (1) “dependency” where the facility depends on external resources for daily operations, e.g., the substation step-down depends on the power generated at and transferred from the plant power; and (2) “interdependency” where the facilities interdependent on each other’s resources to maintain operations, i.e., the power plant needs cool water, but pumping water requires external power. Figure 6 depicts the infrastructure interdependencies of the emergency service system.

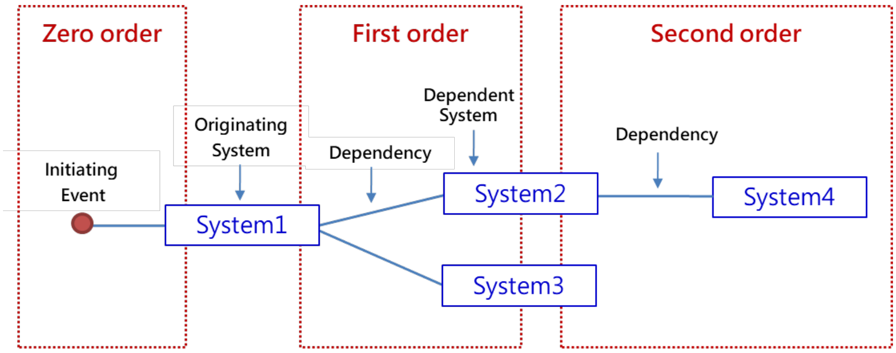


Fig. 5 –Sample of dependencies between systems [2]

4. Earthquake impact evaluation caused by scenarios earthquake

In this study, we considered direction damage and the cascade effect, and then carried out a detailed analysis using data from a simulated earthquake. The simulated earthquake was centered on the Hsincheng fault and exhibited a magnitude of M_L6.8 and focus depth of 10 km. The seismic ground motion distribution generated by the earthquake simulation is shown in Figure 6. The cascading effect model caused by this earthquake event is shown in Figure 7. Note that the water, electrical power are impacted by the earthquake.

If this infrastructure is not restored in a timely manner, then rescue operations, medical treatment, and the ability to contain and extinguish fires will be hindered. Using the procedure described in Figure 3, we attempted to obtain of topic chart that includes lifelines function (water and power), and Science Park (Figure 8).

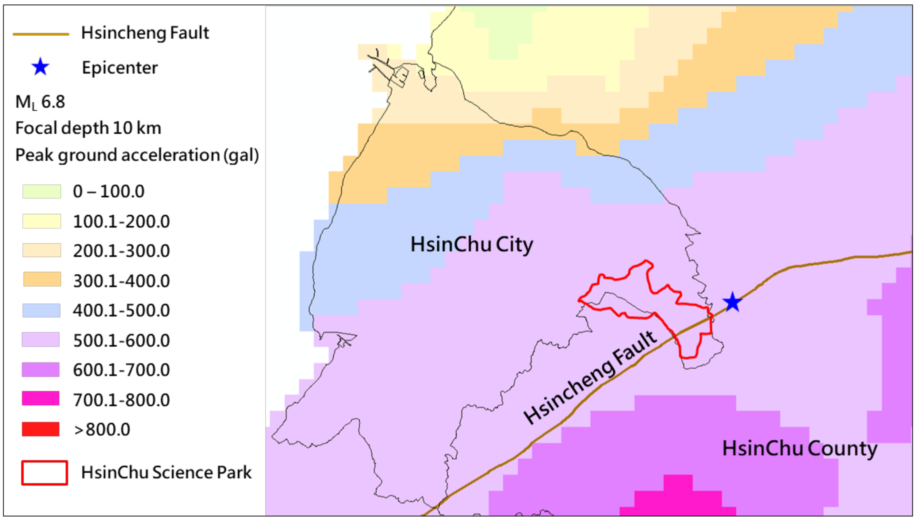


Fig. 6 – The seismic ground motion distribution caused by the earthquake simulation

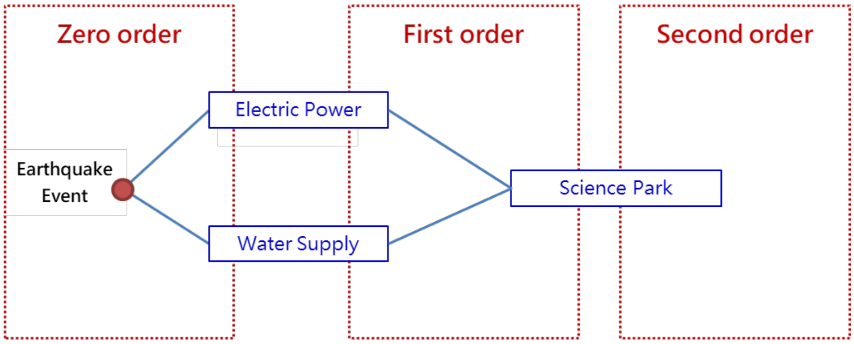


Fig. 7 – The cascading effect model caused by scenario earthquake

- Level 1: simulating earthquake damage to power and water system

The simulated earthquake in Hsinchu showed that lifelines may sustain some damage caused by ground shaking. Three substations, 12 substations, all the high voltage towers, and the end pipeline may suffer extensive damage, moderate damage, slight damage, and moderate to slight damage, respectively. Furthermore, eight treatment plants and 37 pump stations may suffer moderate damage, while the distribution piping line may suffer may suffer extensive to moderate damage. The distribution of damaged electrical power facilities and the distribution of damaged water facilities is shown in Figure 8. It is also worth mentioning that if the electric power is interrupted, the treatment plant and the two pumping stations will experience a power outage. Thus, the standby power supply requires urgent activation. Table 4 depicts a summary of the lifelines damage resulting from the simulated earthquake.

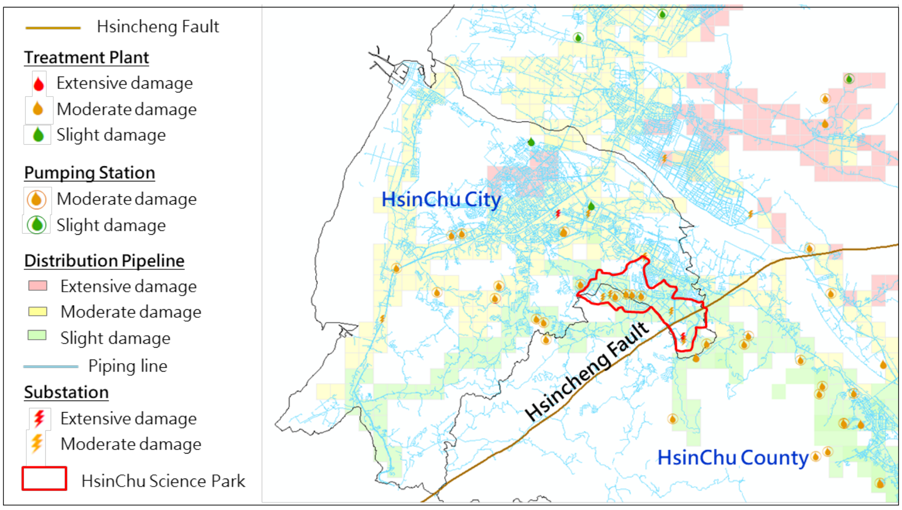


Fig. 8 –Seismic damage to power and water systems in Hsinchu area

Table 4 – Summary of lifelines facilities damaged by scenario earthquake

Category	Type	Slight Damage	Moderate Damage	Extensive Damage
Power	Substation	0	12	3
Power	Voltage Tower 345kV	419	0	0
Power	Voltage Tower 161kV	667	0	0
Water	Treatment Plant	8	8	0
Water	Pump Station	8	37	0

- Level 2: simulating earthquake damaged to Hsinchu Science Park

A Science Park operational needs consist of a building, water, power, and human resources. The relationship between those necessities is as follows: the equipment needs power to operate and will not function during a power failure; the inability to access clean water will prevent high-tech factory operations and procedures from taking place and will therefore hinder product process.

This study comprehensively considers the influencing factors and performs an impact chain evaluation. The results are as follows, the substations in the high seismic zone are extensively damaged, the end pipelines are moderately damaged, and the power supply to science park facilities in the disaster area may be affected (Figure 9). The treatment plant and the pump station are moderately damaged, the water distribution pipeline is extensively to moderately damaged, and the water supply and quality is reduced, again, affecting science park treatment (Figure 10). As a result of this study, we were able to summary the operational risk potential to Hsinchu Science Park (Table 5). Such data may assist government authorities in making effective decisions regarding lifelines facility disasters and resource management.

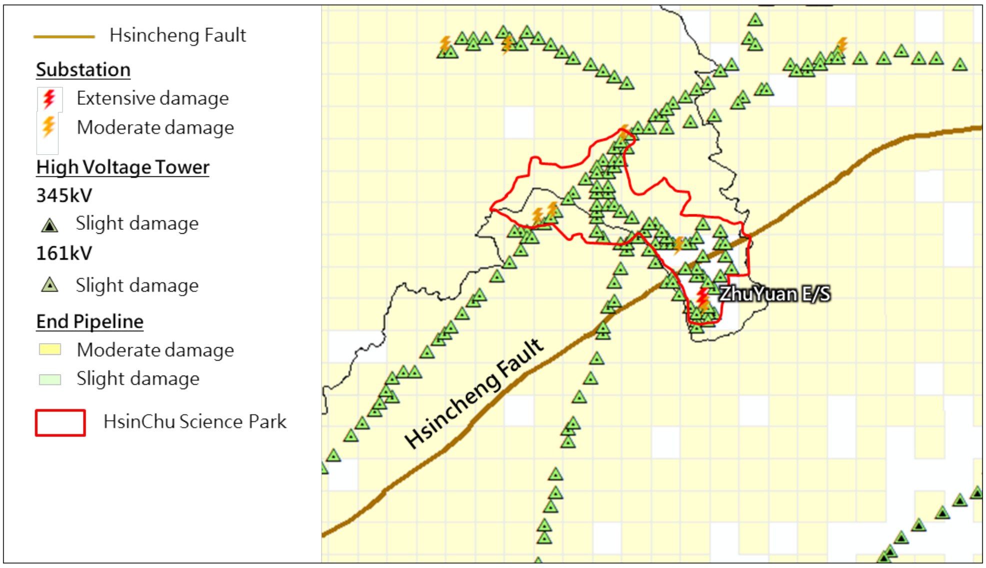


Fig. 9 – Seismic damage to power systems in Hsinchu Science Park

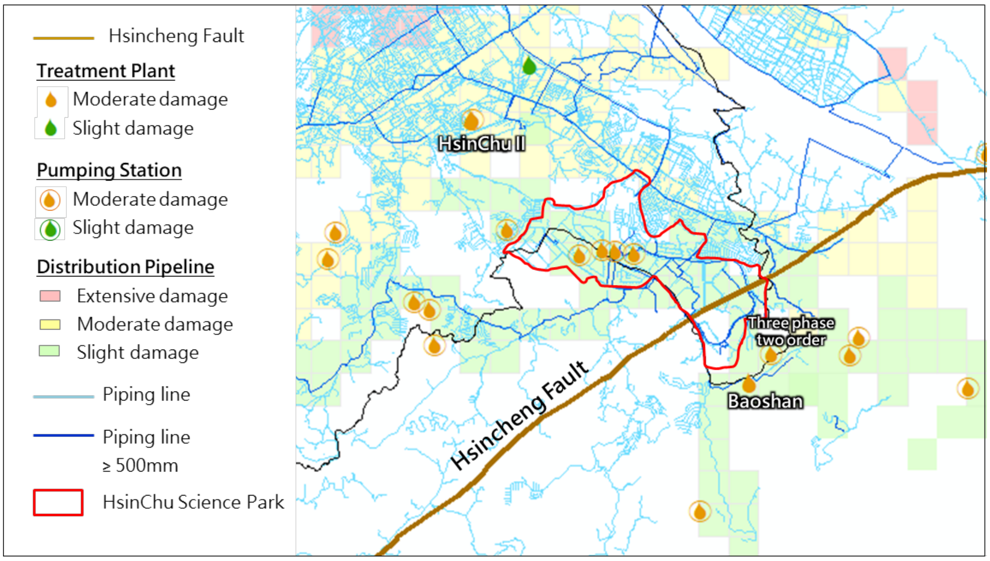


Fig. 10 – Seismic damage to water systems in Hsinchu Science Park

Table 5 – The high-risk of electronic power and water supply systems for Hsinchu Science Park

System	High Risk of Facility	Damage State
Power	ZhuYuan Extra-High Voltage Substation	Extensive Damage
Water	HsinChu II Treatment Plant	Moderate Damage
	Baoshan Treatment Plant	Moderate Damage
	Three phase-Two oder Pumping station	Moderate Damage

5. Conclusions

1. In this study, we considered the direct seismic damage and the cascading effects to develop a method for assessing potential damage and therefore plan earthquake disaster response. Therefore, the result of this study will assist the authorities in making intelligent decisions regarding lifeline infrastructure and resource management.
2. The lifelines are an aggregation of facilities that constitute the backbone of urban operations. For this reason, damage to individual systems can trigger chain effects and cause failures to related and connected systems, which lead to cascading disasters. The operation state and interdependency among lifeline facilities during an earthquake is, therefore, a major concern for disaster reduction of urban areas.

6. References

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