A Study of Deriving Fragility Curves by Using GPS Data at Control Points before and after Chi-Chi Earthquake

Che-Hao CHANG and Ming-Ko CHUNG, Chinese Taipei

Key words: PGD; fragility curve; ground strain.

SUMMARY

The pipeline network is very important for daily life in Taiwan. It must be kept well maintenance, especially to the city. It offers basic need like water for urban area, but it would be greatly damaged by earthquake. In order to predict the damaged of water pipeline network after earthquake, the fragility curves should be derived. Most of the research of pipeline damages caused by earthquake is to find the correlation of damage ratio and earthquake parameters. This study focuses on Permanent Ground Deformation (PGD) as earthquake parameter to derive the fragility curves. Strain gage Rosettes method and Mohr's circle are applied to PGD by using gps data at control points before and after chi-chi earthquake. The result shows the rough location and higher seismic displacements of Chelungpu Fault. Because of the Chelungpu Fault is a thrust fault, the seismic displacements directions are different at two-side of fault line. Chelungpu Fault pass through Taiwan is one of the major reasons that cause serious damage of central Taiwan. The fragility curves was derived by regression analysis which was performed by repair rate and ground strain that was calculated by PGD applied Strain Gage Rosettes method and Mohr's circle. Therefore, damaged points of water pipeline can be estimated through the fragility curves correspond to different earthquake intensity.

台灣在高度的自來水接管普及率之下，自來水管網系統已經和民眾的生活息息相關，尤其對於人口密集的都市地區，維持自來水管網系統的正常運作是十分重要的工作。自來水管網系統除了提供民眾日常用水及工業用水之外，更在災害發生時扮演提供緊急用水的重要角色，因此在遭受重大的天然災害時，自來水管網系統的效能，對於供水系統及救災系統的運作有決定性的影響。為了預測自來水管線在地震時損壞的情形，必須知道其災損曲線。大部分對於管線受震災影響的研究都著重於災損率與地震參數之間的關係，本研究主要利用地表永久變位(PGD)作為地震參數，以求得災損曲線。因為車籠埔斷層兩側地表位移的方相不同，本研究使用了 Strain Gage Rosettes 方法轉換 PGD 至大地應變量，並和災損率進行迴歸分析，因此不同地震強度所會造成的災損點便可以由災損曲線求得。

A Study of Deriving Fragility Curves by Using GPS Data at Control Points before and after Chi-Chi Earthquake

Che-Hao CHANG and Ming-Ko CHUNG, Chinese Taipei

1. INTRODUCTION

The water pipeline network is essential for daily life. It offers domestic water for 90.4% population in Taiwan, and over 99% in urban area. It also provides industry using and fire-fighting using. However, it is damaged easily by earthquake. In order to predict the damage of water pipeline network, the researches of pipeline damages caused by earthquake are usually showed the correlation of damage ratio and earthquake parameters as fragility curves. Toprak[1] derived fragility curves of San Fernando Earthquake in 1971, Whittier Narrowa Earthquake in 1987, and Loma Prieta Earthquake in 1989. Wang[2] analyzed the damages of water pipelines in Fengyuan, Dungshr, Shrgang, Wufend, and Puli during the 921 Chi-Chi Earthquake. Wang[3] showed the broken pipelines are 84.63% under Ø50mm, 13.8% between Ø50mm and Ø250mm, 1.06% over Ø250mm. According to this report, the damages of water pipelines caused by earthquake were mostly under Ø250mm. But the digitized maps of water pipeline networks are not ready, the researchers have to digitize the maps from construction blueprints by themselves. Therefore, it's not possible that to digitize and analyzed all pipelines. In fact, the maps digitized from over Ø250mm were more complete than the others. We chose the pipelines over Ø250mm for study not only because of the reasons above but also because the purpose of fragility curve in this study is understanding the effects of earthquake for whole water pipeline systems.

The Permanent Ground Deformation (PGD) is the displacement of surface before and after earthquake, including liquefaction, landsliding and subsidence [4]. Because of the PGD data is hard to obtain, the researches of fragility curves are usually using PGA or PGV as earthquake parameter. However, the most important property of PGD is that it can present difference of surface directly before and after earthquake. The Taiwan Land Surveying and Mapping Center resurveyed all triangulation points' coordinates by using GPS after Chi-Chi Earthquake. Therefore, the PGD can be calculated by triangulation points' coordinates before and after Chi-Chi Earthquake.

2. DATA COLLECTION AND PROCESSING OF PIPELINE NETWORK

2.1 Study Area

The central part of Taiwan was damaged seriously by Chi-Chi Earthquake. We chose 7 cities as study area, and collected the GIS data of pipeline networks and damaged points. The chosen cities were Fengyuan, Wufeng, Puli, Mingjian, Huatan ,Lukang and Fusing. The GIS data of water pipeline network was digitized from the construction blueprints(1/500 and 1/1000) (Figure 1). Figure 1 also shows that there were 3 cities passed through by Chelungpu

Fault. The damaged points were digitized from repair work orders which locate point by address.

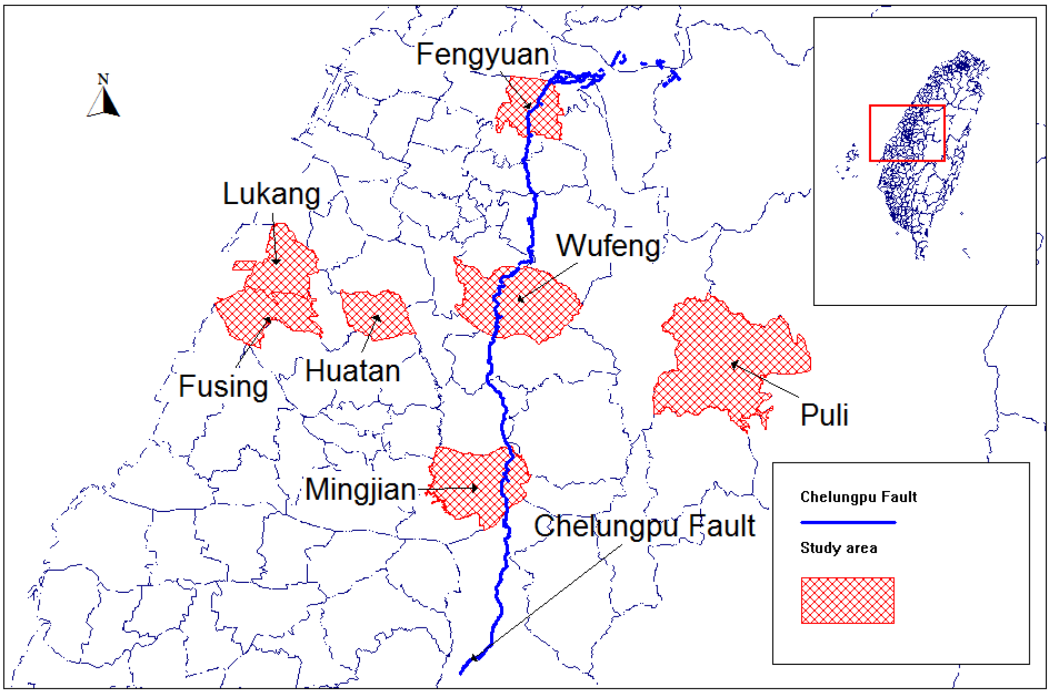


Figure 1. The study area

2.2 Data Processing of Pipeline Networks

Although the digitized maps of study area have been collected, they were digitized from different scales of construction blueprints. It means that the maps digitized from 1/500 blueprints have more details than 1/1000. For example, the digitized map in Fengyuan has smaller diameter pipelines than Puli (Figure 2).

There is an one more reason, the larger diameter pipelines have more resistance for the same material [5]. Therefore, we have to determine the range of diameters for regression analysis.

1. The digitized maps of pipelines over Ø250mm were more complete.
2. There was no damaged point at pipeline larger than Ø 500mm.For example, there were 412 damaged points in Mingjian, and no one was located at pipelines larger than 500mm.

For the reasons mentioned above, the regression analysis will be performed by using the pipelines between 250mm and 500mm.

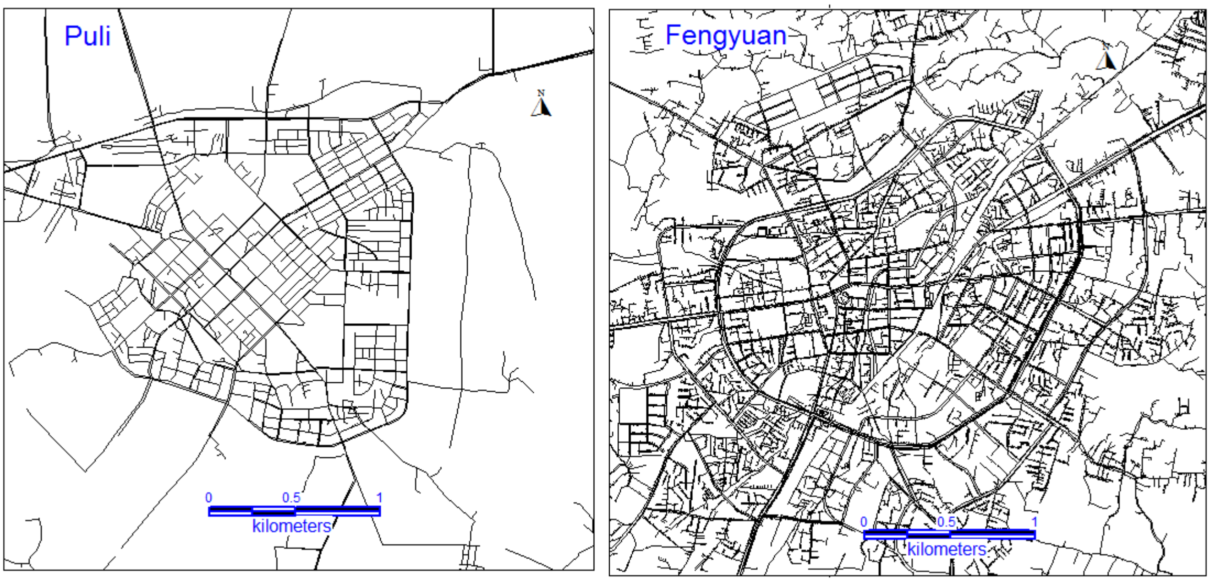


Figure 2. The water pipelines in Puli and Fengyuan at the same scale.

2.3 Data Processing of Damaged Points

The damaged points was digitized by address from repair work orders. We can't locate them at accurate location because there was no maps with address. Furthermore, the damaged point may be not located at pipeline (Figure 3), because the digitized map was not detail enough. Therefore, an processing to select the damaged points near the pipelines has be made.

Considering the inaccuracy of digitizing, we selected the damaged points near the pipelines within a radius of 20m by using GIS (Figure 4). This processing can filter the damaged points that was far from pipelines. However, Figure 5 shows the damaged points belong to pipelines smaller than Ø250mm had been selected at intersection of pipelines. The red lines mean the pipelines over Ø250mm, and the asterisks mean the damaged points selected by the processing. We can find out the asterisks are not belong to lager pipelines. Therefore, we also filtered this kind of damaged point manually.

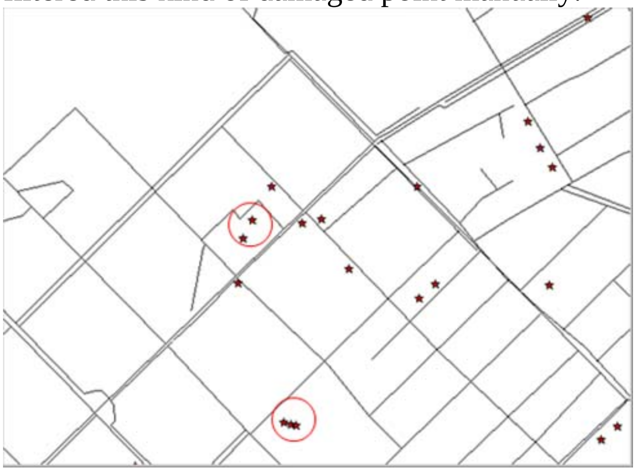


Figure 3. The location of damaged points and pipleines.

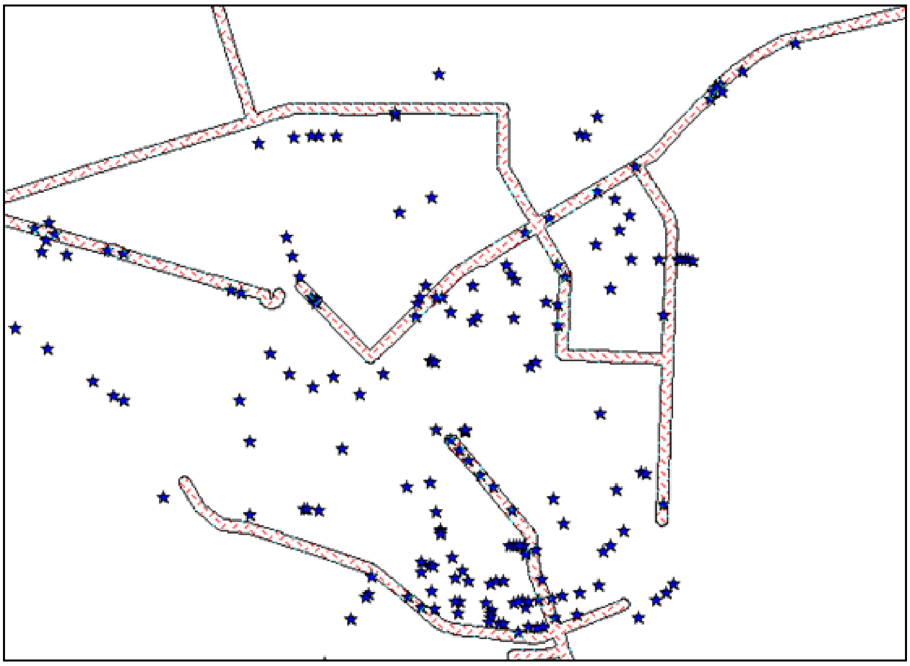


Figure 4. Buffer select by using GIS.

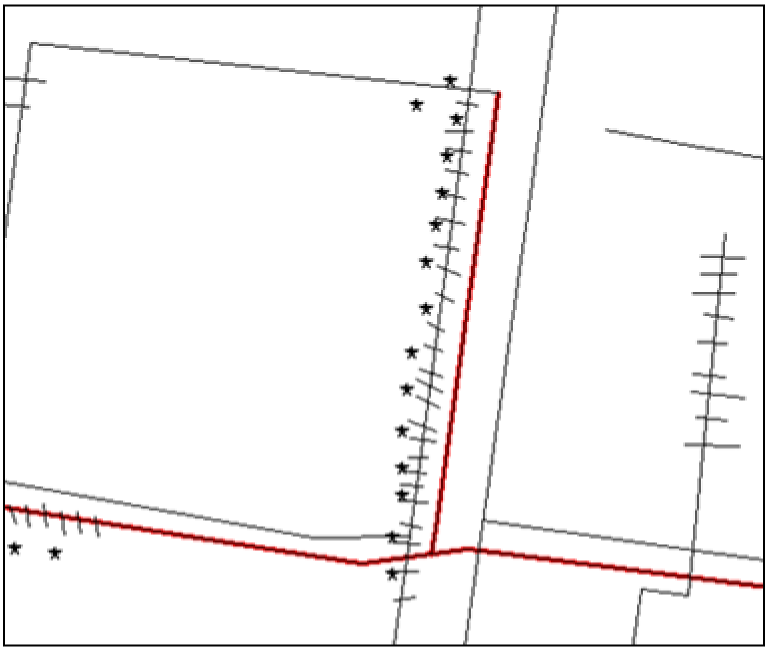


Figure 5. To judge which pipeline does damaged point belong to.

3. FRAGILITY ANALYSIS OF PIPELINE NETWORK

3.1 Calculation of Ground Strain

The Permanent Ground Deformation (PGD) can be calculated by the difference of coordinates before and after earthquake. There are 891 control points with coordinates before and after Chi-Chi Earthquake. The triangles can be made of every three points as triangle network (Figure 6). Therefore, we applied Strain Gage Rosettes method for calculating plane-strain of every triangle. The Strain Gage Rosettes method can be written as

$$\begin{bmatrix} \varepsilon_A \\ \varepsilon_B \\ \varepsilon_C \end{bmatrix} = \begin{bmatrix} Cos^2\alpha_A & Sin^2\alpha_A & \frac{1}{2}Sin2\alpha_A \\ Cos^2\alpha_B & Sin^2\alpha_B & \frac{1}{2}Sin2\alpha_B \\ Cos^2\alpha_C & Sin^2\alpha_C & \frac{1}{2}Sin2\alpha_C \end{bmatrix} \begin{bmatrix} \varepsilon_x \\ \varepsilon_y \\ \gamma_{xy} \end{bmatrix} \tag{1}$$

Where, $\varepsilon_A, \varepsilon_B, \varepsilon_C$ are strains of each side(Figure 7), $\alpha_A, \alpha_B, \alpha_C$ are the angles from the x-axis, and $\varepsilon_x, \varepsilon_y, \gamma_{xy}$ are the plane-strains to calculate.

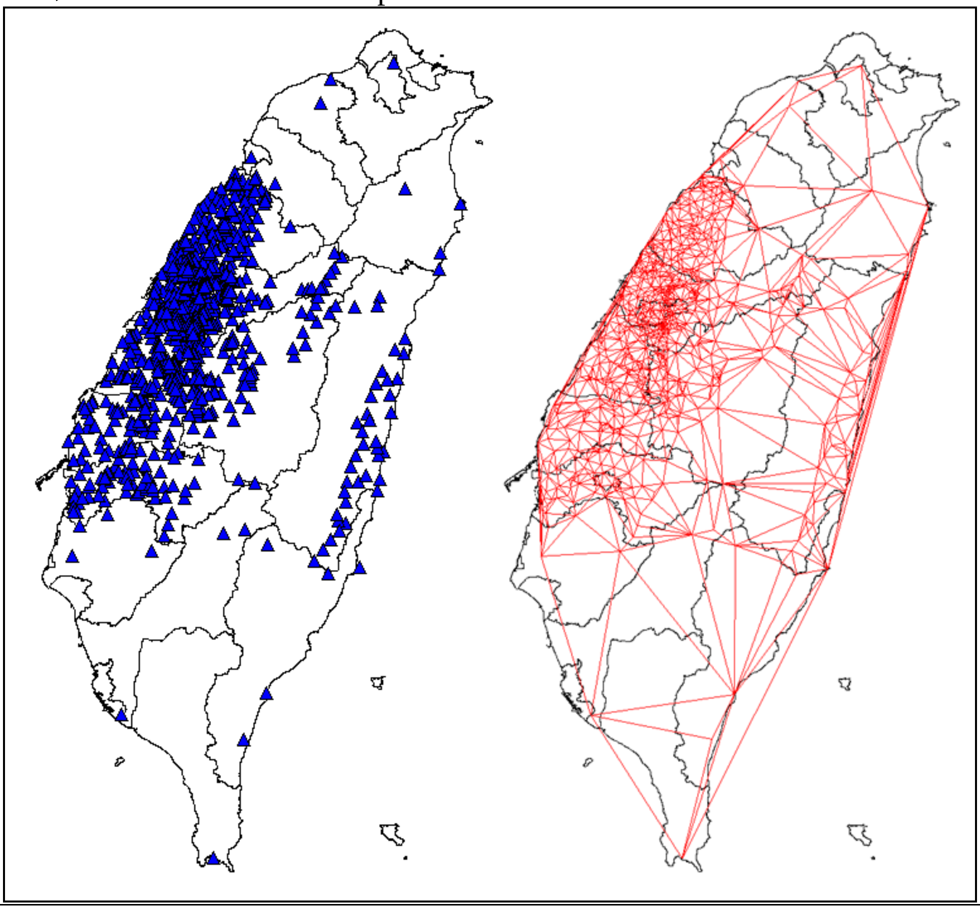
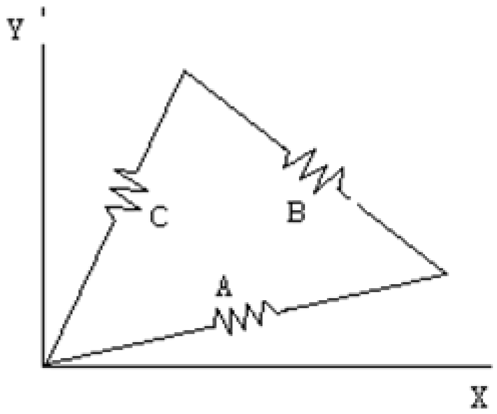


Figure 6. The control points and triangle network.



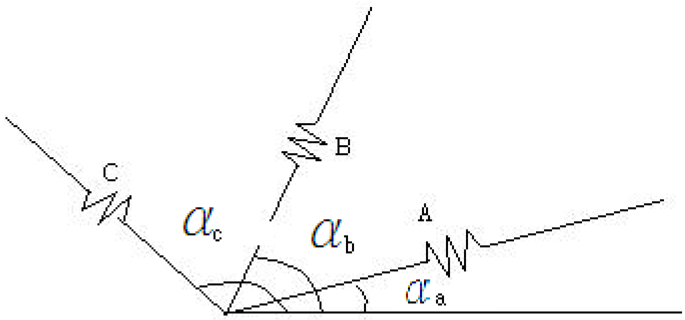


Figure 7. Strain Gage Rosettes method

There are three major steps to calculate plane-strains:

1. The angles: we can calculate the slope of every side by coordinates, and calculate the angles by arctangent.
2. The strains of each side: the triangle OPR and O'P'R' were before and after earthquake (Figure 8). The angles caused by displacement can be ignored because they are too small for whole surface. Therefore, the strains of each side were calculated by dividing difference of distance before and after earthquake by the distance before earthquake.

$$\varepsilon_A = \frac{O'P' - OP}{OP}$$
$$\varepsilon_B = \frac{O'R' - OR}{OR} \qquad (2)$$
$$\varepsilon_C = \frac{P'R' - PR}{PR}$$

3. The plane-strains can be calculated by Eq(1).

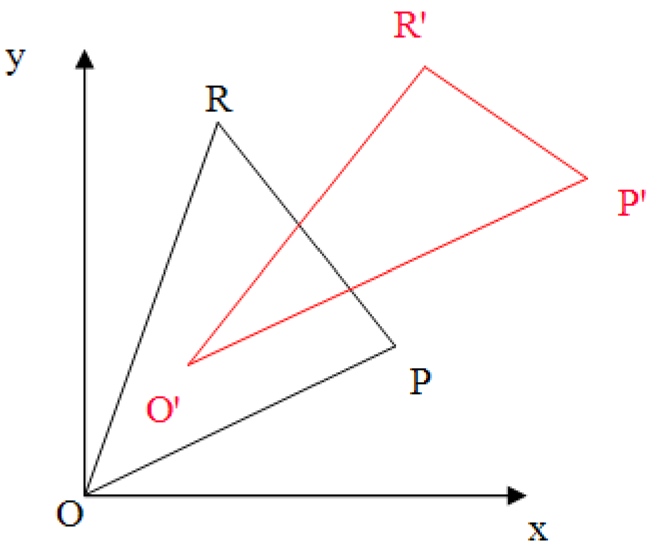


Figure 8. The control points' position before and after earthquake.

.

We also calculated the maximum strain(ε_{max}) and shearing force(γ_{max}) by Mohr's circle as Eq (3). We use bigger absolute value of ε_{max} and γ_{max} as maximum strain because the plus and minus also mean the direction of ground strain.

$$\begin{aligned} \varepsilon_{ave} &= \frac{\varepsilon_x + \varepsilon_y}{2} \\ R &= \sqrt{\left(\frac{\varepsilon_X - \varepsilon_Y}{2}\right)^2 + \left(\frac{\gamma_{XY}}{2}\right)^2} \\ \varepsilon_{\max} &= \varepsilon_{ave} + R \\ \varepsilon_{\min} &= \varepsilon_{ave} - R \\ \gamma_{\max} &= 2R \end{aligned} \tag{3}$$

Figure 9 and 10 contain the Chelungpu Fault and triangle network with ε_{max} and γ_{max}. They show there are larger ground strains near the Chelungpu Fault.

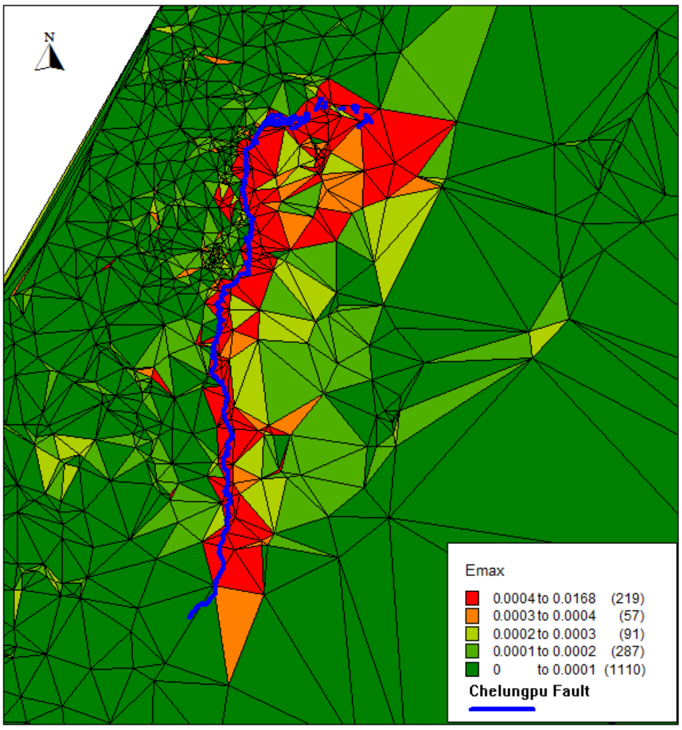


Figure 9. The triangle network of ε_{max} and Chelungpu Fault

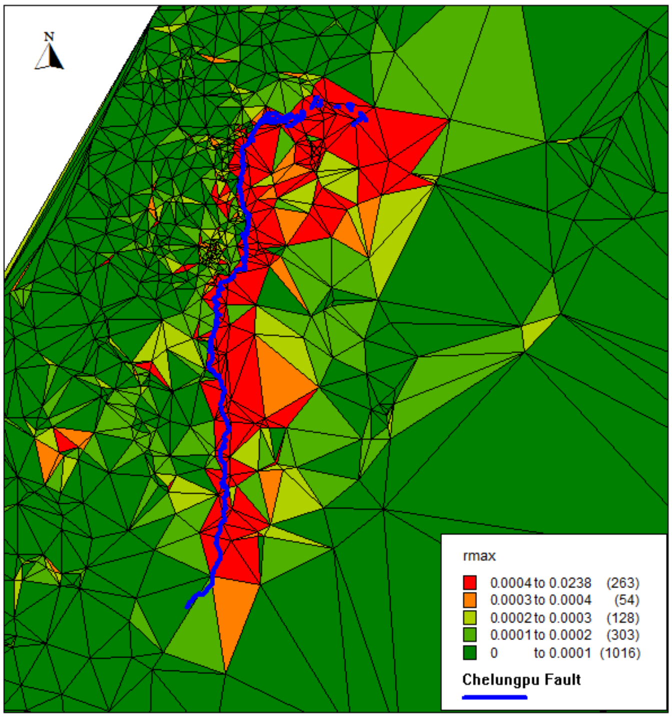


Figure 10. The triangle network of γ_{max} and Chelungpu Fault

3.2 Regression Analysis

The regression analysis was performed by repair rate and PGD applied Strain gage Rosettes method. The repair rate(number of damaged points / km) was calculated by considering one town as a unit. We summed the total damaged point numbers and total pipeline length of the triangles within the town by GIS to calculate the repair rate of each town (Figure 11). The average ε_{max} and γ_{max} of each town can be also calculated by GIS. Therefore, the regression analysis can be conduct. Figure 12 and 13 show the result of regression analysis, the cities passed through by Chelungpu Fault have larger ground strains and repair rate, such as Wufeng, Fengyuan and Mingjian.

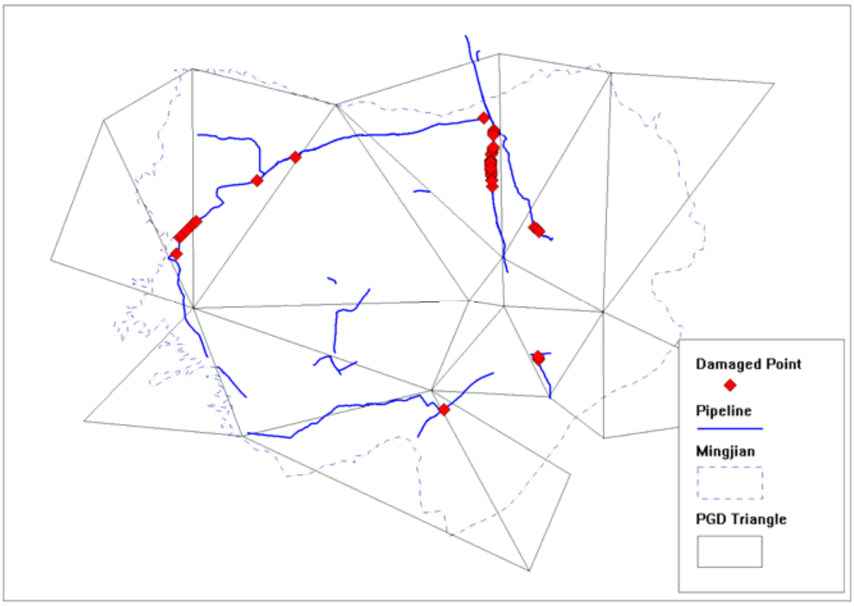


Figure 11. The damaged points , pipeline and triangle network in Mingjian

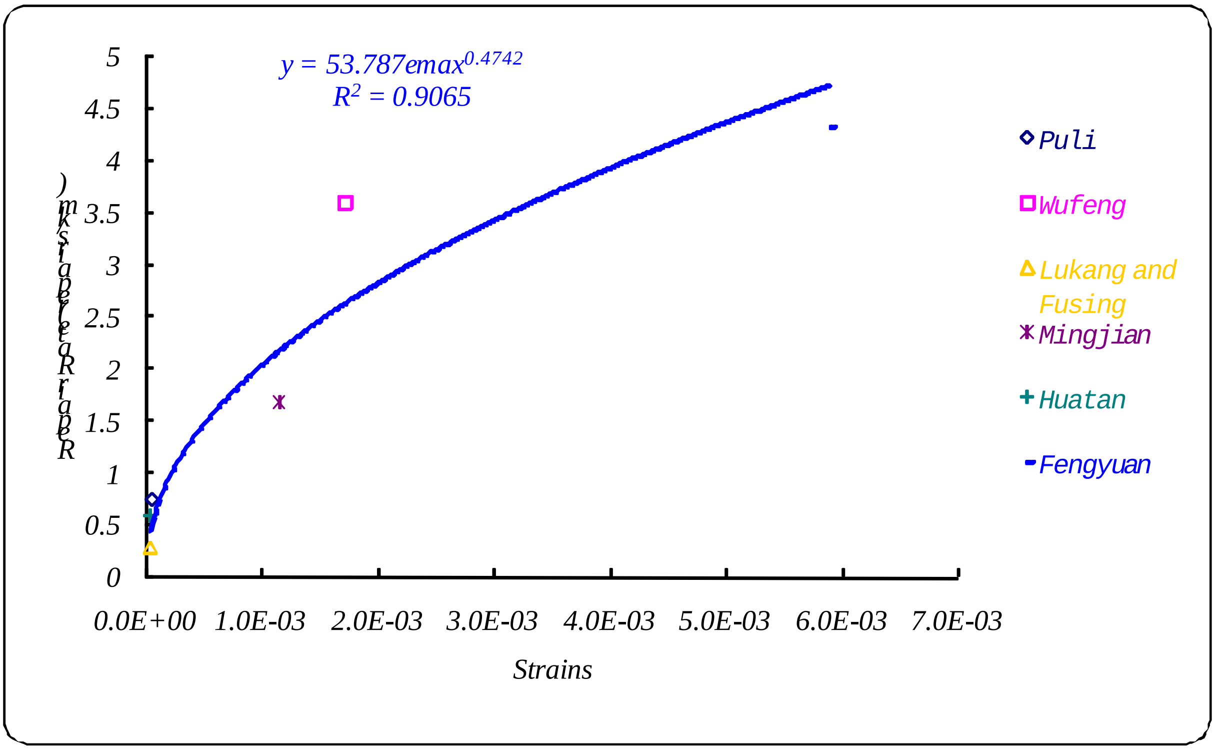


Figure 12. The regression analysis of ε_{max} and RR

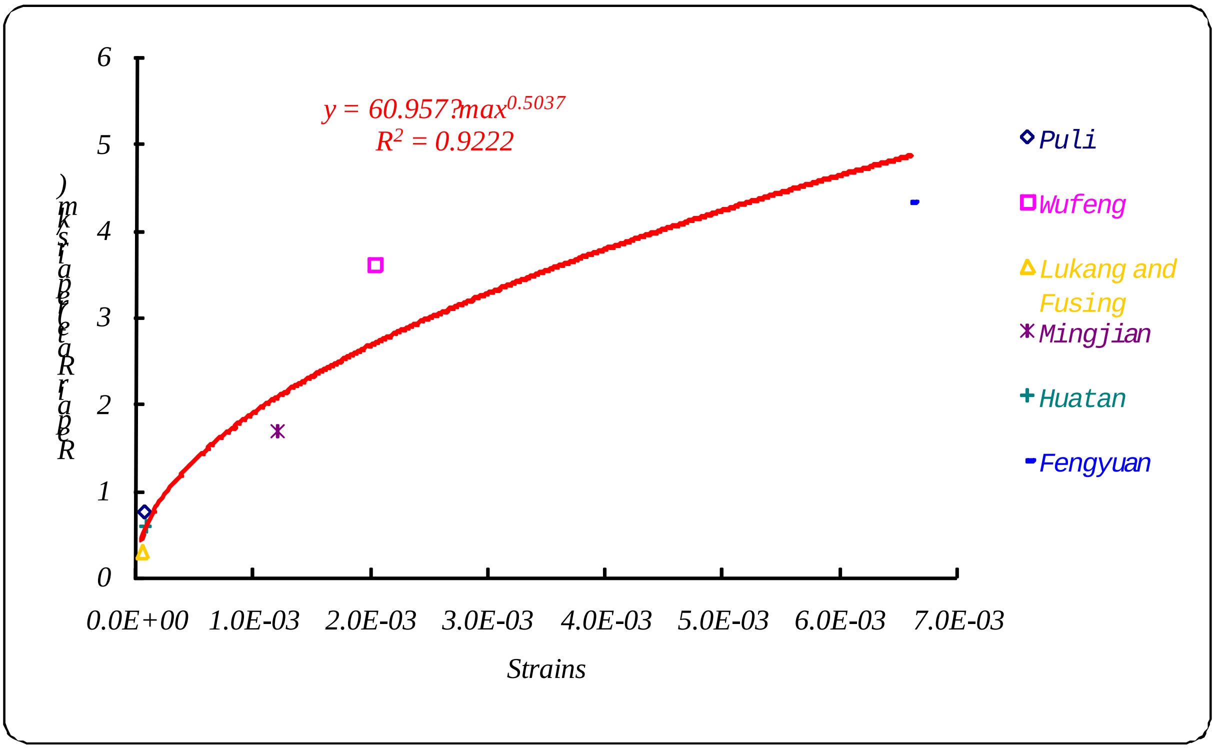


Figure 13. The regression analysis of γ_{max} and RR

4. CONCLUSIONS

In this study, the fragility curves were derived by ground strain and repair rate. The ground strain was calculated by PGD applied Strain Gage Rosettes method and Mohr's circle. The repair rate was calculated from pipelines and damaged points. Therefore, we have some conclusions as below:

1. After we applied Strain Gage Rosettes method to PGD, the result shown that the triangles passed through by Chelungpu Fault have larger ground strain. That means the process transfer PGD to ground strain is reasonable.
2. All the data of pipelines and damaged points should be clarified and consistence. For example in out result, we use damaged points with pipelines over Ø250mm. All the pipeline should be classify to use.
3. The study chose the pipelines between Ø250mm and Ø500mm for regression analysis , because there was only one damaged point at pipeline over Ø500mm after data processing of pipeline networks and damaged points.
4. The regression analysis use one town as a unit. The average repair rate and ground strain can be calculated for each town. The result showed that repair rate and ground strain have high correlation.

REFERENCES

[1] Toprak, S, T. Earthquake Effect on Buried Lifeline Systems,Ph. D. dissertation, Cornell University, 1998

[2] Wang W. S. Damage Analysis of the Water Pipelines in Fengyuan ,Dungshr ,Shrgang ,Wufeng ,and Puli during the 921 Ji-Ji Earthquake, Master thesis, National Taipei University of Technology, 2002 (in Chinese)

[3] Wang, B. S. The damage report of public water system after the Chi-Chi Earthquake, Journal of Water Supply, 2000;19(1): p. 64-81 (in Chinese).

[4] O'Rourke, T. D., and Jeon, S. S. Seismic Zonation for Lifelines and Utilities, Proceedings, Sixth International Conference on Seismic Zonation, 2000, p. 215-218

[5] Chen C. H. The Seismic Risk Analysis of Water Pipelines Considering the Effect of Ground Strain, Master thesis, National Taipei University of Technology ,2003 (in Chinese)

CONTACTS

Che-Hao Chang
Institution: National Taipei University of Technology
Address: 1, Sec. 3, Chung-hsiao E. Rd., Taipei, 10608,Taiwan, ROC
City: Taipei
TAIWAN
Tel. +886 227712171-2665
Email:chchang@ntut.edu.tw