RESEARCH OF SEISMIC DAMAGE FOR NETWORK OF GAS PIPES BASED ON GIS

Jie Yu*, Fuling Bian, Pingxiang Li**
Wuhan Technical University of Surveying and Mapping, P. R. China
Informatics School
*yuj@wtusm.edu.cn
**flbian@wtusm.edu.cn

KEY WORDS: GIS, Earthquakes, Predictive modeling, Networks.

ABSTRACT

The discussion in this paper is prediction of seismic damage for underground gas pipeline based on GIS, and the reliability of network of gas pipes is studied. A set of methods which are based on burst mechanism are employed to predict the seismic damage of underground pipeline, and the resistance analysis about the network of gas pipe again the seismic wave is depend on graph theory and fuzzy mathematics. The weak position on the pipelines is analyzed through calculating, the valves that should be closed are determined, and the affected gas pipes and regions are predicted by spatial analysis function. Finally, a case study for network of underground gas pipes in Guangzhou is given.

1 INTRODUCTION

Geographical Information System (GIS) can be seen as a system of hardware, software and procedures designed to support the acquisition, management, manipulation, analysis, modeling and display of spatially referenced data for solving complex planning and management problems. The range of GIS's application continues to expand as the technology develops. It is one of the most important objectives of GIS's application to reduce the loss of life, property damage, and social and economic disruption caused by natural disaster. The system of pipeline's network in a city is an important basic facility. Research that is about the possible seismic damage for system of pipeline is meaningful for improving the city's mitigation capacity. This paper discusses the application of GIS in prediction of seismic damage for underground network of gas pipes. The data including geometric graph and attributes is organized by Arc/Info. Guangzhou, which is a developed and densely populated city that is on the southeast coast of China, is a case study. The research shows that GIS technique can play the more and more important role in the field of natural disaster reduction, and it can help the decision-making department to make disaster mitigation measures.

2 THE PRINCIPLE AND METHODS OF RESEARCH

The pipeline's axial deformation under shearing wave is the basis of research of seismic damage for network of pipes. The model can be built provided the underground pipeline is the beam that is in the elastic ground, and the equation is:

$$\rho \cdot S \cdot \frac{\partial^2 u}{\partial t^2} - E \cdot S \cdot \frac{\partial^2 u}{\partial x^2} + k \cdot u = k \cdot u_g(x,t) \qquad (1)$$

where:
ρ is density of material
S is area of pipe's cross section
E is pipe's modulus of elasticity
k is spring coefficient of ground in a unit of length of pipe's axis
u is axial displacement of pipe
u_g is axial displacement of ground.
The solution of equation (1) is

$$u(x,t) = \xi u_g(x,t) \qquad (2)$$

and

$$\xi = \frac{1}{1 + \frac{E \cdot S}{k}(\frac{2\pi}{\lambda})^2 - (\frac{\omega}{\omega_0})^2}$$

and

$$\lambda = V \cdot T, T = \frac{2\pi}{\omega}, \omega_0 = \sqrt{\frac{k}{\rho \cdot S}},$$

where, λ represents the wavelength of seismic wave along the pipeline's axis, V represents the speed of seismic wave along the pipeline's axis, T represents the vibration period, ω represents the vibration frequency, ω_0 represents the vibration frequency of rigid pipe which is in elastic ground, generally, $(\omega / \omega_0)^2 << 1$, thus,

$$\xi = \frac{1}{1 + \frac{E \cdot S}{k} (\frac{2\pi}{\lambda})^2} \qquad (3)$$

Above what we discuss is based on the ideal condition, and we suppose that the pipe is in the well-distributed ground. Considering the ground is not well distributed, and the factors of geology and topography can influence the seismic damage of underground pipe, we can revise the formula (2), there is:

$$u(x,t) = \xi (1 + a) u_g (x,t) \qquad (4)$$

where a is an adjustable coefficient, usually $a \geq 0$.
The ground displacement along the shearing wave at any time can be calculated according to the wave theory, and the formula is as follows:

$$Y = A \cdot \sin \frac{2\pi}{L} \cdot z \qquad (5)$$

where, A represents the displacement of ground, $L = V_s \cdot T$ represents the wavelength, V_s represents the speed of shearing wave (Figure 1).

$$A = \frac{k_h \cdot g \cdot T^2}{4\pi^2} \qquad (6)$$

where, g is acceleration of gravity, k_h can be 0.1□0.2 or 0.4, when earthquake intensity is VII □ $VIII$ or IX .

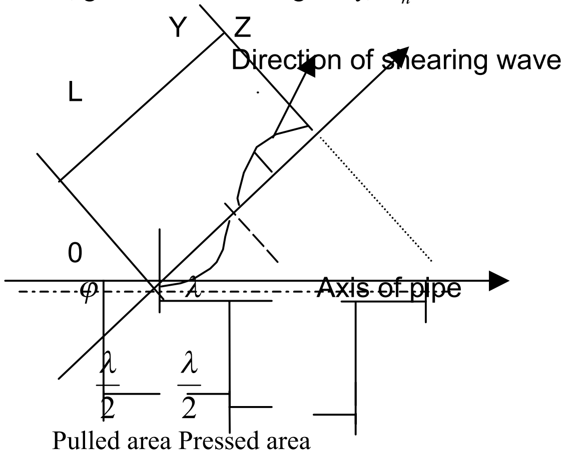

Fig. 1 Axial Deformation of the Pipe under Shear Wave

The ground's displacement along pipeline can be calculated through the following formula (7) when the shearing wave spreads at the angle φ , which is between direction of shearing wave and pipeline.

$$u_g = y \cdot \sin \varphi = A \cdot \sin \varphi \cdot \sin \frac{2\pi}{\lambda} \cdot x \qquad (7)$$

where $\lambda = L / Cos\varphi$.
The axial displacement of pipe can be got by formula (8), there is:

$$u = \xi \cdot (1 + a) \cdot A \cdot \sin \varphi \cdot \sin \frac{2\pi}{\lambda} \cdot x \qquad (8)$$

The axial strain is:

$$\varepsilon = \frac{\pi \cdot \xi \cdot (1 + a) \cdot A}{L} \cdot \sin 2\varphi \cdot Cos \frac{2\pi}{\lambda} \cdot x$$

The axial strain is maximum when $\varphi = 45^0$:

$$\varepsilon = \varepsilon_{max} \cdot Cos\frac{2\pi}{\lambda} \cdot x, \varepsilon_{max} = \frac{\pi \cdot \xi \cdot (1+a) \cdot A}{L} \qquad (9)$$

There is a different phase when the shearing wave spread. The pipes will have axial deformation because it is pressed in a half wavelength, and is pulled in another wavelength at same time. So the deformation of pipes that it is pulled or pressed in the half wavelength can be estimated by the following formula (10) when $\varphi = 45^0$.

$$[\Delta x] = \varepsilon_{max} \int_{-\frac{\lambda}{4}}^{\frac{\lambda}{4}} Cos\frac{2\pi}{\lambda} \cdot xdx = \sqrt{2} \cdot \xi \cdot (1+a) \cdot A \qquad (10)$$

The deformation will be shared by all the interfaces of pipe in the half wavelength, so the possible biggest deformation of pipe in the half wavelength is:

$$[\Delta X] = 2[\Delta x] = 2\sqrt{2} \cdot \xi \cdot (1+a) \cdot A \qquad (11)$$

Suppose the biggest deformation that the pipeline can bear in the half wavelength is $[U]$, and then $[U]$ is summation of [u_i], which is deformation that each interface can bear. The function can be built to research the seismic damage for the pipes.

$$Z = [U] - [\Delta X] \qquad (12)$$

Then, the pipe is in good condition when Z>0; the pipe is in damaged condition when Z<0, and pipe is in critical condition when Z=0. We estimate if the pipe will be damaged through fuzzy mathematics at critical.

3 PREDICTION OF SEISMIC DAMAGE FOR NETWORK OF PIPES AND ANALYSIS OF RELIABILITY

3.1 Analyzing Basis for the Reliability of Network of Pipes

The system of underground pipes is a network that includes source, pipes, and users. Usually, a network can be seen as a graph. In this graph, source and users can be as nodes, and pipes can be as edges. The basis of reliability's analysis about the network of pipes is graph theory.

Assume $V = \{v_1, v_2, \Lambda\ , v_n\}$ is a set of nodes, $E = \{e_1, e_2, \Lambda\ , e_m\}$ is a set of edges, and $R = \{r_1, r_2, \Lambda\ , r_m\}$ is a set of weight of edges. The weight of edges represents the reliability of pipes.

The system of pipeline's network is a complex system which consist of several series connection and parallel connection subsystem. If the route is the series connection by N edges, then the reliability of pipelines is:

$$R_s = \min_{1 \le i \le j}\{r_i\}$$

where r_i is the reliability of edge i.

If the route is the parallel connection by N edges, then the reliability of pipelines is:

$$R_p = \max_{1 \le i \le j}\{r_i\}$$

where r_i is the reliability of edge i.

Suppose there are m routes from node S to node D, the reliability of route i is R_i, the reliability of node D is:

$$R_D = \max\{R_i\}$$

3.2 Data Organization and Analysis

The data in this research is organized by Arc/Info. Geometric data includes administrative area, geological rock, and network of underground gas pipes in Guangzhou city (Figure 2). The attributes, which are used in this research of seismic damage for network of gas pipes, include pipe type, pipe's diameter, pipe's thickness, modules of elasticity, limiting intensity, permitted deformation, length of pipe, start node and end node, valve's number and coordinate, etc. The detail about some parameter list in table 1.

3.3 Reliability Analysis for Network of Underground Gas Pipes

Usually, the seismic intensity VII is the defensive intensity in Guangzhou city, and k_h is 0.1. Let a=0, and k = 1200 N/cm^2 according to the geological condition in Guangzhou. Here what we research is gas pipes of middle pressure.

Table 1. The parameters of pipes

Pipe's diameter (mm)	Pipe's thickness (mm)	Modules of elasticity (N/cm^2)	Limiting intensity (N/cm^2)	Permitted deformation (mm)
300	6	$2.0*10^7$	42000	10.40
325	6	$2.0*10^7$	42000	10.80
400	7	$2.0*10^7$	42000	11.86
426	7	$2.0*10^7$	42000	11.86
500	7	$2.0*10^7$	42000	11.90
529	7	$2.0*10^7$	42000	11.90
600	8	$2.0*10^7$	42000	12.26
630	8	$2.0*10^7$	42000	12.26

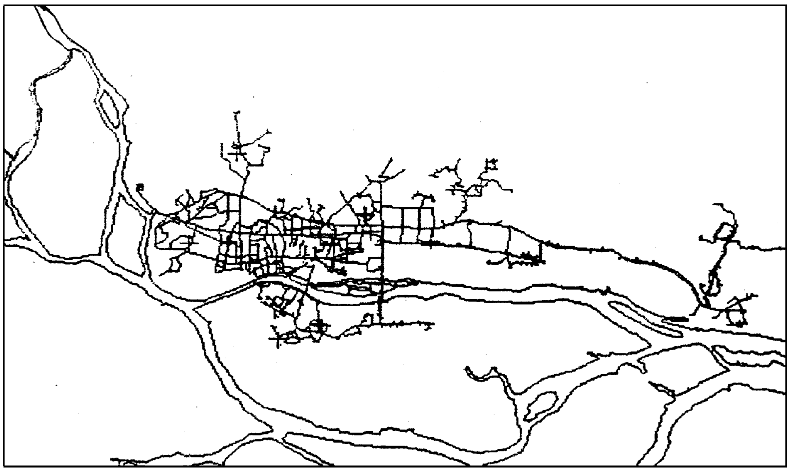

Fig. 2 The network of underground gas pipes in Guangzhou

We divided the studied area into 40 units, then we calculate the deformation of pipes with different diameter in each unit by formula (6) and (11). The interface of pipe will be in good condition if the calculated deformation is smaller than the permitted deformation; the interface of pipe will be damaged if the calculated deformation is bigger than the permitted deformation; we estimate if the interface of pipe will be damaged through following subordinate function that is built according to fuzzy mathematics at critical.

$$r = \begin{cases} 1.0, x \le \Delta u \\ 1 - 2(\dfrac{x - \Delta u}{2\Delta u})^2, \Delta u < x \le 2\Delta u \\ 2(\dfrac{x - 2\Delta u}{2\Delta u})^2, 2\Delta u < x \le 3\Delta u \\ 0, x > 3\Delta u \end{cases} \qquad (13)$$

where:

Δu is a permitted deformation;

r is reliability of pipes.

Suppose r_j^i is the reliability of pipe with i in unit j, then the reliability of pipes in unit j is:

$$R_i = \min_{1 \le i \le j} \{r_i\} \qquad (14)$$

3.4 Results

The result of seismic damage for network of underground gas pipes in Guangzhou city we can get through formula (13) and (14). First, we can get the weak position on the network of underground gas pipes (Figure 3), then, the valves that should be closed are determined based on GIS's network analysis (Figure 4). Meanwhile, we can predict which district will be influenced and how many people will be affected (Figure 5, Table 2).

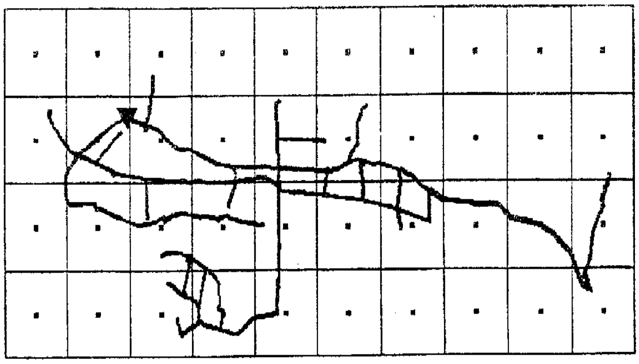

Fig. 3 Process of reliability calculation

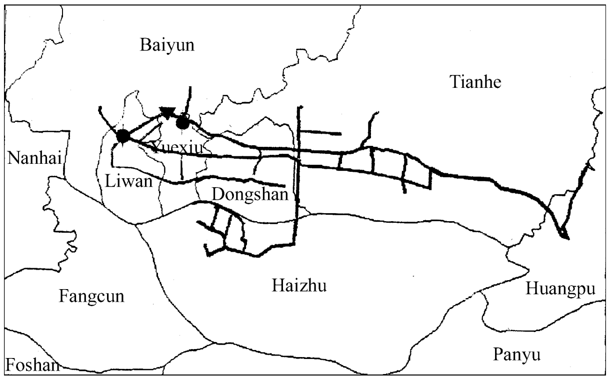

Fig. 4 Analyzing for valve-closed

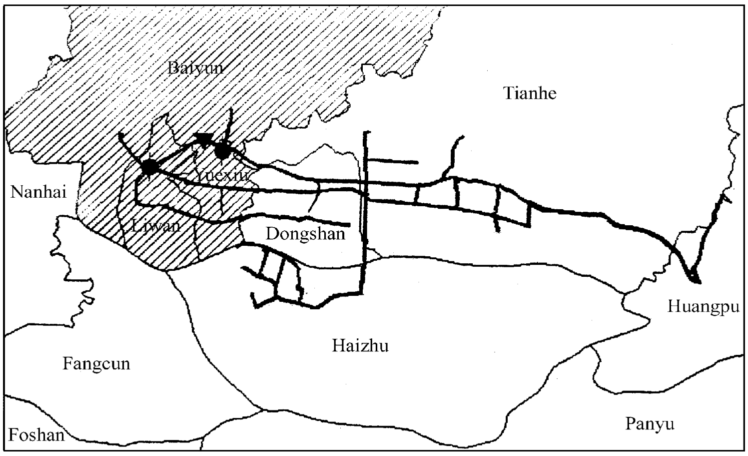

Fig. 5 Prediction of affected pipes and regions

Table 2. Affected area and population

Region Name	Area(km^2)	Population	Density(person/k m^2)
Baiyun	47.279	700500	671
Liwan	7.843	545480	45456
Yuexiu	5.291	479080	53231

4 CONCLUSIONS

GIS technique is a modern means which can applied in many fields. It aims at the problem solving. The paper studied the application of GIS in disaster research. It's a meaningful attempt.

REFERENCES

1.Taylor, D. R. Fraser, 1991, Geographic Information System.
2.Keith C. Clarke, 1997, Getting Started with Geographic Information Systems
3.Jie Yu, Fuling Bian, GIS in Prediction of Earthquake Disaster, GIS & REMOTE SENSING: Research, Development & Applications, Geoinformatics'96 Proceedings, U. S. A., 1996, pp.564-569
4.Zheng, Ding and Wolfgang Kainz, An approach using fuzzy set theory in natural resource analysis, Spatial Information Technology Towards 2000 and Beyond, Geoinformatics'98 Conference Proceedings, 1998, Beijing, pp. 299-307