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Paper No. 106. (quote when citing this article)
Eleventh World Conference on Earthquake Engineering
ISBN: 0 08 042822 3

DEVELOPMENT OF CITY GAS NETWORK ALERT SYSTEM BASED ON MONITORED EARTHQUAKE GROUND MOTION

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ABSTRACT

Tokyo Gas supplies city gas to 8 million customers around Tokyo metropolitan area and has social responsibility to secure safety even after big earthquake. To prevent gas-caused secondary disaster after earthquake, it is necessary to make prompt and reasonable decision. For this purpose, SIGNAL (Seismic Information Gathering Network Alert System) has been developed to support to make decision and has been in operation since June, 1994. One of SIGNAL's function is quick monitoring SI readings and seismic acceleration at 331 locations, acceleration waves at 5 locations and rising ground water levels at 20 locations considered most at risk from ground liquefaction, using a reliable radio network. This real-time earthquake data is linked to data bases of gas pipelines and ground conditions to give an accurate damage assessment, based on pipe damage experiences suffered in previous earthquakes. The assessment of damage to the gas network is useful for the rapid implementation of emergency work and in drawing up efficient and accurate restoration plans.

KEYWORDS

SIGNAL, Earthquake monitoring, Damage estimation, GIS, Geographic information system, City gas network, Wireless communication network.

INTRODUCTION

On January 17 1995, an earthquake of magnitude 7.2 occurred in the Osaka-Kobe and Awaji Island area, causing unprecedented damage especially in the city of Kobe. The city gas system was also damaged, with around 900,000 households gas-supply cut off to prevent secondary damage caused by gas leakage. In spite of a massive relief effort involving gas operators from the whole country, restoration work took nearly three months, renewing our awareness of the destructive force of earthquakes.

Tokyo Gas Co., Ltd. supplies city gas to eight million customers in an area of 3,100 km^2 centering on Tokyo, one of the most crowded cities in the world and the focus of a heavy concentration of political, cultural and economic functions (Fig. 1). We are aware that it is our duty to the community as a gas distributor to ensure public safety in the event of a major earthquake.

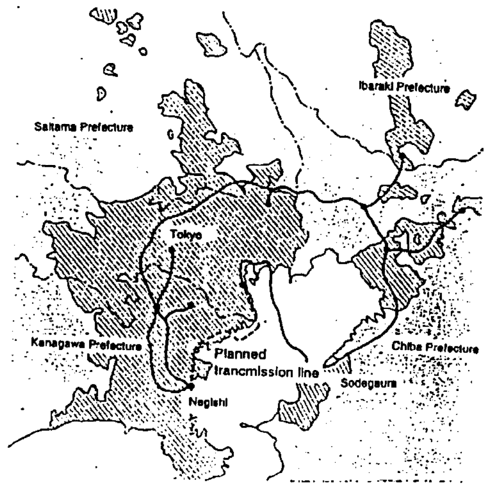


Fig. 1. Tokyo Gas Co., Ltd. Service Area

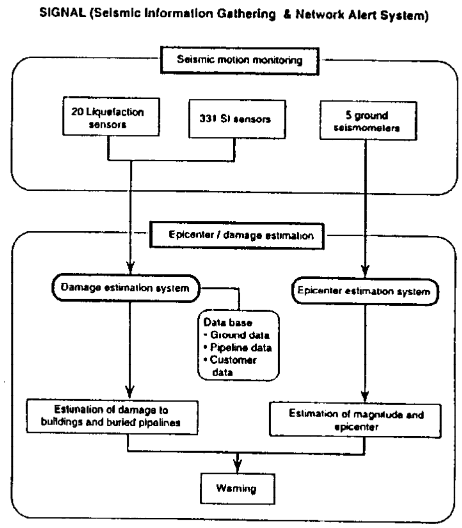


Fig. 2. Overall system configuration

In order to prevent secondary gas-related damage at the time of an earthquake, it is necessary to shut off gas supplies to the heavily damaged areas rapidly. For this reason, Tokyo Gas has set up a system of area blocks, which allows gas supplies to be shut off block by block depending on the extent of damage. (15 medium pressure blocks, 100 low pressure blocks). However, rapid decisions on shutting of supplies depend on accurate information being available on the extent of damage to the gas-pipeline network in each block immediately after the earthquake. It is very difficult, though, to gain an overall picture of the damage immediately after a major earthquake, with telephone lines, road traffic etc. either cut off or severely congested. In fact there were delays in ascertaining the extent of damage to buried pipes after the Great Hanshin earthquake, which in turn impeded emergency work and restoration work planning.

We, therefore, installed a system known as SIGNAL (Seismic Information Gathering & Network Alert system) and operation started in June 1994, with 356 seismic sensors installed across the service area, allowing damage to pipes to be assessed by combination of earthquake data sent on-line (via radio circuits, the most reliable method during earthquakes) with a databases of ground and pipeline information. SIGNAL is capable of completing a damage assessment within 10 minutes of an earthquake, allowing decisions on shutting off gas supplies to the heavily damaged areas as part of the emergency work following a major earthquake to be taken rapidly. It is also now possible to plan restoration work in a short period of time after an earthquake, based on this damage assessment data, and restoration work can be speeded up by a faster response to outside offers of help, and a more rapid securing of pipes and other materials.

CONFIGURATION OF SIGNAL

SIGNAL is made up of three sub-systems: a seismic motion monitoring system, an epicenter estimation system, and a damage assessment system. It also includes a data bank of basic data on the ground and the pipe system. The overall configuration of the system is shown in Fig. 2.

Basic data base

Basic data on ground conditions, consumers and pipelines have been entered into a data base using our mapping system data, based on a grid with cells measuring 250m E-W by 175m N-S (80,000 cells overall). As the size of earthquake vibrations is greatly affected by ground conditions, the data collected by each of the 331 SI sensors (Katayama, et al., 1988) are made to represent the seismic motion in similar ground around the sensor, with the service area microzoned according to ground conditions and the areas to be represented by each sensor determined in advance. Ground types are classified by topography into upland and alluvial plain types; the latter is further subdivided into three categories according to the natural frequency of the ground, giving a total of four ground types.

Another factor exacerbating damage is ground liquefaction. Therefore, the depth of the liquefaction layer around each SI sensor is calculated in advance for each grid cell. Data on pipe types, total length of each diameter of pipe, and numbers of consumers are also entered for each cell.

Seismic motion monitoring system (Fig. 3)

SIGNAL monitors seismic motion in the Tokyo Gas service area using earthquake sensors installed at 356 locations. Fig. 4 shows the locations of earthquake sensors. The system is extremely reliable even in earthquake situations, as data from each sensor are sent by a microwave radio transmitter used exclusively for that sensors. First, SI sensors are installed at 331 locations to measure the SI value and maximum acceleration of the seismic motion. In order to estimate epicenter and magnitude, ground seismometers are installed at five locations in the surrounding areas. The seismometers are installed at depths of 20--40m in the engineering base rock layer, and the meters continuously measure and transmit 3-directional component acceleration waves. In order to assess the occurrence and extent of ground liquefaction, liquefaction sensors (Shimizu, et al., 1992) are also installed at 20 sites considered to be at high risk from ground liquefaction.

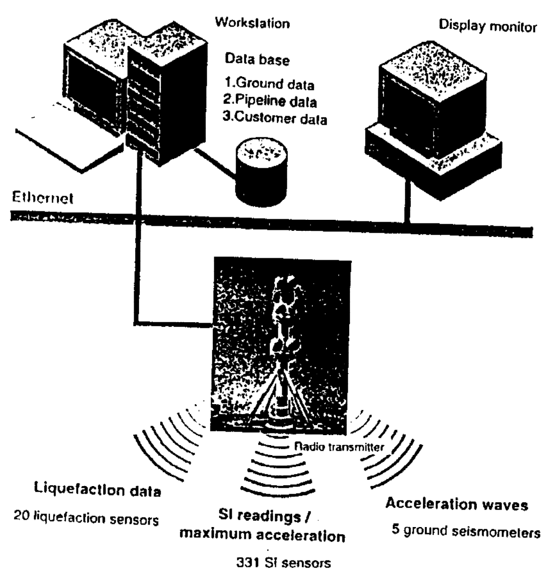


Fig. 3. Seismic motion monitoring system

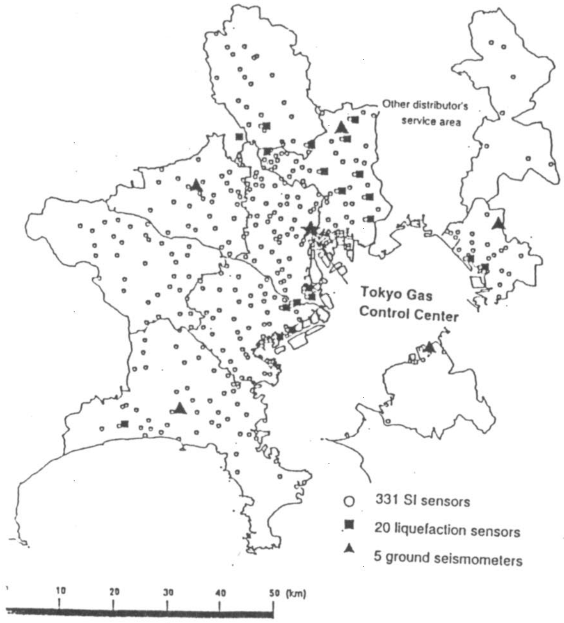


Fig. 4. Locations of seismic sensors

Damage estimation system

Damage in low- and medium-pressure blocks is assessed on the basis of data sent from the SI sensors (Yamazaki, et al., 1994).

The first step in damage estimation is the calculation of standard damage ratios and liquefaction depths for each grid cell, based on input of the SI values measured at each of the 331 locations. As similar ground types are considered to give identical responses, the SI values for each cell are taken to be the readings from the nearest SI sensor in the same type of ground. Standard damage ratios are calculated from an empirical formula based on records of past earthquake damage, with SI readings as a function. Exacerbation of damage due to liquefaction is taken into account by factoring ground liquefaction into the standard damage ratio, according to the depth of the liquefaction layer. Finally, the number of damage sites for each grid cell is determined by multiplying the total buried pipe length, after correction for pipe type and diameter, by the modified damage ratio. From the estimated number of damage sites for each cell, the number of damage sites in low- and medium-pressure blocks are assessed, forming a basis for decisions on whether emergency shut-off of supply is necessary.

Epicenter estimation system

Since data on the epicenter location and earthquake magnitude can be obtained within a very short time, such data is ideal for drawing up subsequent emergency response plans. Estimating the epicenter (Noda, et al., 1993) is carried out in real time, using acceleration waves transmitted continuously from ground seismometers in five locations. First the initial time for P-waves and S-waves is calculated and compared with the theoretical and observed motion times to minimize error in determining the epicenter location. Magnitude is calculated based on the Meteorological Agency formula.

It is also possible to estimate damage from the epicenter location and earthquake magnitude calculated by the epicenter estimation system. In this case, damage is assessed by calculating SI values for each point, using an attenuation damping formula to factor in the distance from the epicenter.

EXAMPLES OF SYSTEM APPLICATION BASED ON CASE ANALYSIS

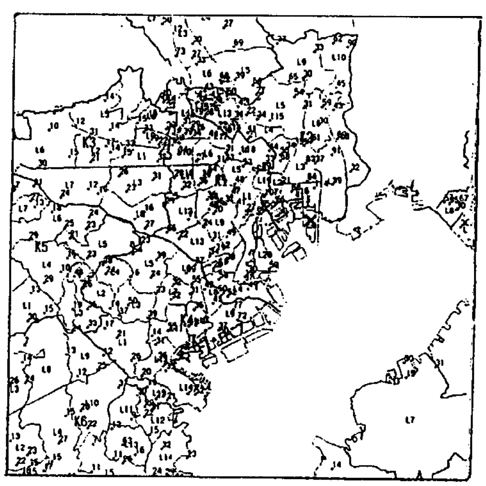
Another major function of SIGNAL is damage simulation. The SI values for each of the 331 locations is calculated for a given set of earthquake conditions according to the attenuation damping formula, and the SI readings obtained are used to activate the SIGNAL database and damage estimation system, thus making possible case analysis of earthquake damage in each area.

Since the installation of SIGNAL, this case analysis function has been utilized in the annual disaster prevention training, making this training more realistic than before by supplying specific data on damage for each area.

The example given here is an analysis of a typical, hypothetical case of an earthquake with an epicenter below the mouth of the Arakawa River, based on the Ansei Edo earthquake of 1855 (magnitude 7.0, epicenter depth 20km).

Fig. 5 shows the distribution of the 331 SI readings obtained by simulation, and Fig. 6 shows the results of damage estimation based on these readings. These damage estimates give the total number of damage sites for each low-pressure block. This map is output approximately 10 minutes after the occurrence of an earthquake, allowing rapid assessment of the extent of damage in each block, thus forming the basis for decisions on cutting off supplies and allocation of resources for emergency and restoration work.

Based on the damage estimates, a separate Restoration Planning System is activated to determine post-earthquake restoration strategy, which in turn makes possible a rapid response to offers of help from other gas distributors or other authorities, as well as efficient issuing of restoration reports to government agencies and the press.



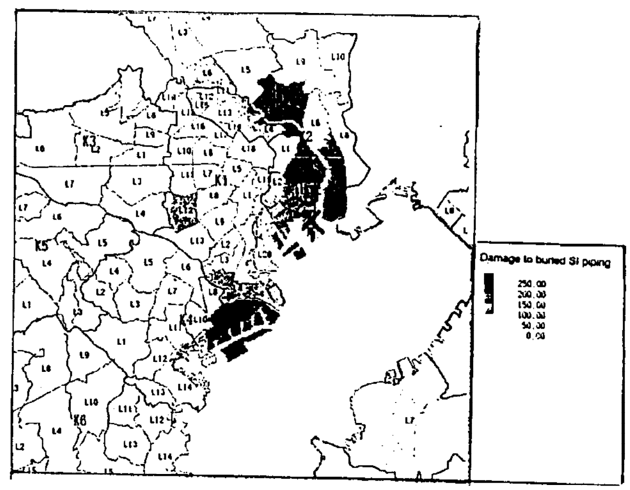


Fig. 5. SI-Value Distribution in Case Analysis

Fig. 6. Damage Estimation by Low-pressure Block in Case Analysis

CONCLUSION

Rapid and accurate decision-making on shut-off of gas supplies after an earthquake is needed to prevent the occurrence of secondary accident. SIGNAL (Seismic Information Gathering Network Alert System) was developed to assist in this decision-making. This system comprises 331 SI sensors, 20 liquefaction sensors, and 5 ground seismometers which provide data for monitoring of seismic motion after an earthquake. A detailed data base for ground conditions, buried pipes, building and structures, liquefaction risk, and damage ratio for buried pipes after earthquakes was prepared to estimate damage of pipe based on the monitored SI values. The system has been operating since June 1994.

SIGNAL is also linked to a separate Restoration Planning System, allowing instant implementation of restoration work after an earthquake.

The accuracy of damage assessment is expected to be improved further through collection and analysis of seismic motion and damage in the Great Hanshin earthquake, as data are added or revised.

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