

# DEVELOPMENT OF SUPER HIGH-DENSITY REAL-TIME DISASTER MITIGATION SYSTEM FOR GAS SUPPLY SYSTEM

Yoshihisa SHIMIZU<sup>1</sup>, Eisuke ISHIDA<sup>2</sup>, Ryoji ISOYAMA<sup>2</sup>, Kenichi KOGANEMARU<sup>1</sup>,  
Wataru NAKAYAMA<sup>1</sup>, Fumio YAMAZAKI<sup>3</sup>

## ABSTRACT

With the 3,700 New SI sensors installed throughout its service area (3,100km<sup>2</sup>), Tokyo Gas has started to develop its super high-density real-time disaster mitigation system "SUPREME" for gas supply systems. Immediately after an earthquake, seismic data from the New SI sensors is relayed to the main system where extremely precise estimates of the damage are made on the spot. Damage estimation consists of making an estimate of the surface distribution of seismic motion that takes account of the site amplification factor, and making an estimate of damage to the pipeline network that takes account of factors such as the types of the pipes, the topography of the area, and the liquefaction conditions.

## Introduction

Tokyo Gas has started to develop its super high-density real-time disaster mitigation system "SUPREME" (Fig.1). This system is designed to measure seismic and relevant data using New SI sensors installed in 3,700 district regulators throughout the gas service area (3,100km<sup>2</sup>). SUPREME, which is designed to provide a higher level of protection against earthquakes, has been developed from the earlier Seismic Information Gathering and Network Alert System (SIGNAL). SIGNAL, a system which was developed by Tokyo Gas and is used by the company today, provides estimates of damage incurred based on information relayed from 332 SI sensors sited throughout the network.

The New SI sensors used with SUPREME are compact, economically priced seismometers created with the help of micro-machining techniques. The current plan is to provide SUPREME with the capacity to make precise estimates of damage using data from the New SI sensors, and to display liquefaction detection data and monitored pressures immediately after an earthquake has occurred. In addition, during normal times, the system will also make use of small seismic waves to analyze the site amplification factor of various points in the service area and to utilize this information into a zoning map.

Real-time damage estimation based on dense seismic data in SUPREME consists of an

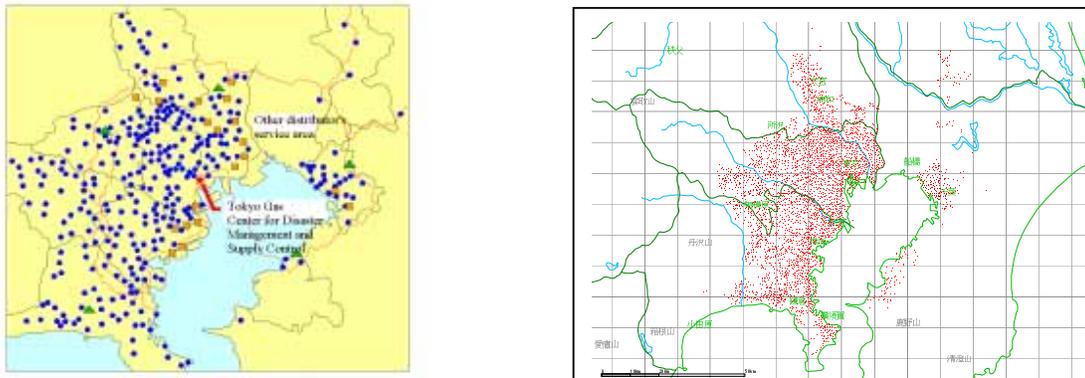
---

<sup>1</sup> Center for Disaster Management and Supply Control, Tokyo Gas Co., Ltd., Japan

<sup>2</sup> Earthquake Disaster Mitigation, Japan Engineering Consultants Co., Ltd.

<sup>3</sup> Institute of Industrial Science, The University of Tokyo, Japan

estimate of the surface distribution of seismic motion and liquefaction that takes account of the site amplification characteristics, along with an estimate of damage to the pipeline network that takes account of factors such as the types of the pipes and the topography of the surrounding area. To this end, site amplification factor in all areas must first be ascertained. To ascertain the site amplification factor in all areas, Tokyo Gas has established a geographic information system (GIS) comprising 50,000 boring data and precise topographical types from throughout the service area.



Left: SIGNAL ● : SI sensors, ■ : Liquefaction sensors, ▲ : Base rock accelerometer  
 Right: SUPREME 3,700 New SI sensors

Figure 1. Distribution of SI sensors in SIGNAL and SUPREME

In this paper, the main features of SUPREME and its utilization will be introduced. We will also explain the flow of real-time estimation of damage and describe the way in which the site amplification factor is prepared.

## Features of SUPREME and Its Utilization

### New SI Sensors

Tokyo Gas has installed SI sensors in district regulators since 1986 to facilitate automatic shutoff in the event of an earthquake. The company is currently replacing these obsolescent SI sensors to New SI sensors. The new sensors are ultra-compact high-performance seismometers that have been developed with the help of techniques that were not available when the original sensors were developed. The New SI sensors incorporate the following features and functions.

- Ultra-compact: Acceleration detection unit, CPU and RAM incorporated with the help of micro-machining techniques
- Low cost: 1/2 - 1/3 of the cost of a conventional seismometer
- High-precision SI calculation: Carries out real-time high-precision measurement of SI and maximum acceleration values
- Liquefaction detection: Uses the world's first real-time seismometer-based liquefaction monitoring technology

- Self-diagnostic: Carries out self-diagnostic and warns of malfunctions in acceleration pickups, electrical circuits, etc.
- Control: Closes shutoff valves, etc. on the basis of combined SI and maximum acceleration values
- Waveform record: Records three-component acceleration waveforms

Tokyo Gas has been in the process of installing the new type of sensor in all its district regulators since fiscal 1997 and expects to have installed a total of 1,800 sensors by the summer of 2001.

### **Collection of Earthquake Data Using Public Telephone Lines**

Since the remote monitoring units used by the new disaster mitigation system to collect seismic data utilize the public telephone lines used at normal times to monitor day-to-day control instruments, such as pressure gauges and gas leak detectors (Fig. 2), there is an inevitable increase in the demand placed on these lines and congestion will occur when a big earthquake happens. The earthquake remote monitoring system (Disaster mitigation DCX) has been developed to minimize this problem.

There will be many alerts dialing from district regulators, in the event of big earthquake, such as power cuts, liquefaction alerts and regulator shut-off. The Disaster mitigation DCX incorporates a function that enables it to assemble and transmit the alerts in the event of an earthquake to reduce a number of dialing. The results of simulations carried out on the basis of the Great Hanshin Earthquake shows that it requires about only 20 minutes to collect all the necessary data.

### **SUPREME Utilization**

Immediately after an earthquake has occurred, SUPREME combines SI values, maximum acceleration values, and liquefaction alerts transmitted from the super high-density New SI sensors with GIS system data such as gas pipeline network, topographical and ground data, and uses it to make an extremely precise estimate of the damage incurred. The damage is also ascertained by raw data collected from sensors such as the pressure gauges installed in district regulators. Furthermore, by checking the operation of all automatic shutoff valves, quick emergency response can be realized.

Under usual circumstances, the analysis of ground amplification characteristics is carried out using waveform data from the New SI sensors (Fig. 3). The results are incorporated into the ground zoning plan with the result that the distribution of seismic motion which can be estimated more precisely in the event of a major earthquake.

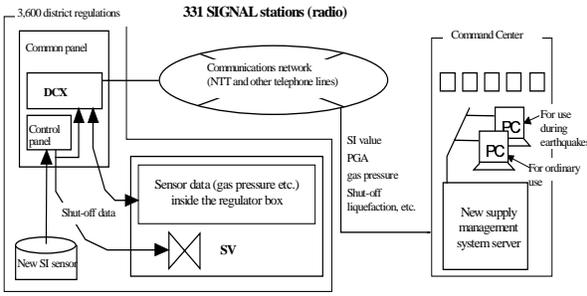


Figure 2. Composition of SUPREME

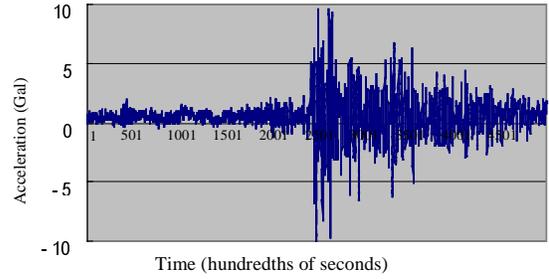


Figure 3. Seismic data, 1998/1/14 (Konan, Minato ward)

### Preparation of Ground Amplification Database

For more precise damage estimation by SUPREME, the database of ground amplification characteristics was prepared. We analyzed the relationship between ground boring data and ground amplification characteristics using the seismic waveforms obtained by K-NET, and 50,000 points boring data. We estimated the ground amplification characteristics on each boring point and interpolated to prepare surface ground amplification characteristics in a 50m mesh.

### Relationship between Average S-wave Velocity and the Amplitude of SI Values Based on K-NET Data

To study the relationship between boring and geographical data and ground amplification characteristics, we analyzed the relationship between the amplitude of SI values based on data obtained from K-NET and the average velocity of an S-waveform calculated from PS logging data. Our analysis showed that the following equation using travel time averages down to a depth of 20m (Tamura et al., 2000) is the best way to estimate ground amplification.

$$\text{Log}_{10}\lambda = -0.785 \log_{10} (AVS20) + 2.18 \quad (1)$$

where  $\lambda$  is the SI value amplitude, and AVS20 is the average S-wave velocity (m/s) based on travel times down to depths of 20m. We defined the standard base rock as an average S-wave velocity of 600 (m/s). The following travel time-based equation was used to calculate the average.

$$AVS20 = \sum_j h_j / \sum_j (h_j / V_{s_j}) \quad (2)$$

Where  $V_{s_j}$  is the S-wave velocity (m/s) of layer  $j$ ,  $h_j$  is the thickness (m) of layer  $j$ ,  $\sum_j$  is the aggregate of all layers  $j$  down to a depth of 20m. Fig. 4 shows Eq. (1) and the relationship between SI value amplitude based on observation records and average S-wave velocity based on travel times down to a depth of 20m at strong-motion observatory in Yokohama. The equation itself has been devised on the basis of K-NET records but even when using the Yokohama records, a correlation coefficient was as large as 0.65.

## Estimation of Average S-wave Velocity Using Boring Data

The following equations were used to estimate average S-wave velocities from N values and soil type (Japan Road Association, 1996), using boring data obtained from about 50,000 points around the service area.

$$V_{sj} = 100 N_j^{1/3} \text{ (clayey soil, } 1 \leq N_j \leq 25) \quad (3)$$

$$V_{sj} = 80 N_j^{1/3} \text{ (sandy soil, } 1 \leq N_j \leq 50) \quad (4)$$

Where  $N_j$  is the N value at each depth  $j$ , and  $V_{sj}$  is the estimated S-wave velocity (m/s). Fig. 5 compares the actual average S-wave velocities obtained from PS logging at 150 strong motion observatory of Yokohama with average S-wave velocities estimated on the basis of N values and soil types. Both data showed good fit (correlation coefficient of 0.87).

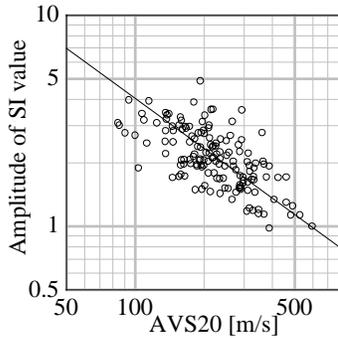


Figure 4. Relationship between SI amplitude and AVS

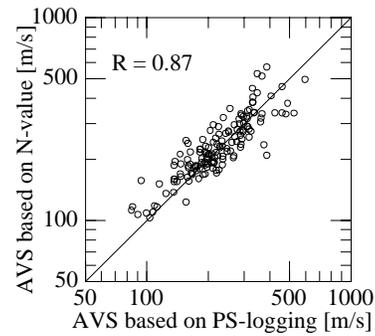


Figure 5. Relationship between AVS based on PS logging and AVS estimated

## Method for the Surface Interpolation of SI Value Amplitudes

As mentioned above, we obtained amplification factor at each boring point using Eqs. (2), (3) and (4). Using interpolation method, we estimate continuous distribution of SI value amplitudes. We used the following equation for the method.

$$y = \frac{\sum_i ((1/r_i^2) \cdot y_i)}{\sum_j (1/r_j^2)} \quad (5)$$

where  $y$  is an estimated value,  $y_i$  is the value obtained at boring point  $i$ ,  $r_i$  is the distance (m) between point to be estimated and boring point  $i$ , and  $\sum_i$  is the aggregate for boring points  $i$  used in the interpolation calculation. In this case, we have substituted  $y_i$  for  $\log_{10}\lambda$  of the SI value amplitudes of each boring point found using Eq. (1). In the present calculation, we have categorized two broadly-defined topographical groups, high ground and low ground, and interpolated separately for the two groups. The calculations have been carried out on a 50m mesh basis but to ensure that valley areas are not overlooked, if a single mesh is deemed to be a valley on a 25m mesh basis, then it is also treated as a valley on the 50m mesh basis, thereby somewhat exaggerating the valley feature. Fig. 6 shows the topographical groups in the service area. We

also used the nearest five points of the same geographical feature for interpolation calculation. The interpolation calculation results for the whole of the Tokyo Gas service area are shown in Fig. 7.

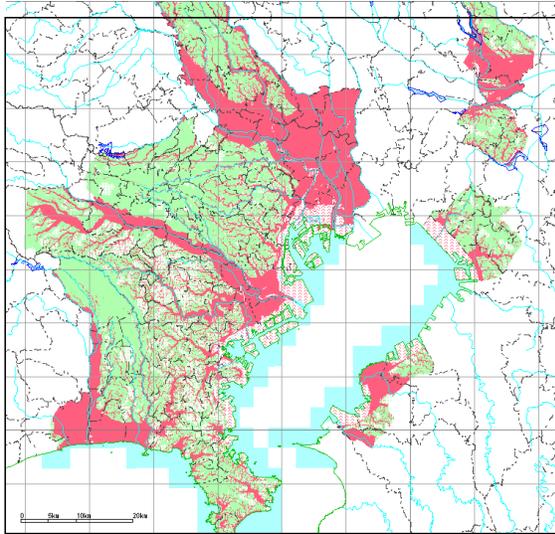


Figure 6. Topographical divisions in Tokyo-gas supply area

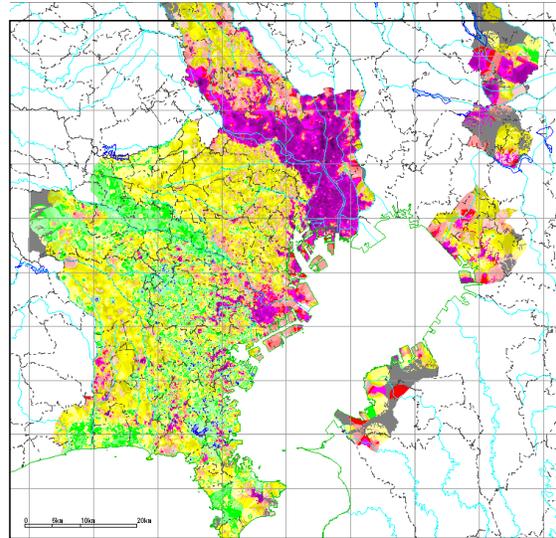


Figure 7. SI amplitude in Tokyo-gas supply area

### Conclusion

This completes our introduction of Tokyo Gas's new real-time disaster mitigation system "SUPREME". Tokyo Gas's wealth of ground and topographical data was also used to study a method of preparing database of surface ground amplification using GIS. From here on, we will be looking to utilize individual case studies to obtain more precise ground amplification characteristics, to increase the efficiency of real-time damage estimation and to expand the use of SUPREME.

### References

- Japan Road Association: *Design Specifications of Road Bridges; Part V: Seismic Design*, (and associated Explanation), 1996 (in Japanese)
- Tamura, I., F. Yamazaki, K.T. Shabestari: "Estimation of ground amplitudes based on average S-wave velocities calculated using K-NET earthquake records", Proceedings of the 55th Annual Technology Presentation, 2000 (in Japanese)