SUPER HIGH-DENSITY REALTIME DISASTER MITIGATION SYSTEM

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SUMMARY

In order to achieve a more sophisticated real-time system of disaster mitigation, Tokyo Gas Co., Ltd., commenced preparation of what will be the world's most extensive ultra-high-density real-time seismic motion monitoring and disaster mitigation system in January 1998. Known as "SUPREME," the system employs the New SI (spectrum intensity) sensor and a district regulator remote surveillance system installed at about 3,600 locations in its supply area, which measures about 3,100 square kilometers. The New SI sensors utilize ultra-small acceleration pickups made with micromachining technology as well as central processing units (CPUs) and random access memory (RAM) units, and constitute a new kind of seismometer that is both high-performance and low-cost. They are capable of measuring SI and ground acceleration, recording six earthquake wave-form acceleration trends on three (XYZ) axes, detecting liquefaction based on knowledge of the changes in acceleration waves, and control of regulators by means of settings for SI or acceleration. Tokyo Gas intends to harness the system for high-precision estimates of damage and detection of liquefaction in real time, and for investigation of seismic shaking amplication at various points based on wave-forms for small and medium earthquakes.

INTRODUCTION

Tokyo Gas Co., Ltd. supplies gas to customers in metropolitan Tokyo area -- one of the world's most densely populated urban areas, and a major center of political, cultural and economic activity. We regard it as part of our responsibility to society as a gas supplier to assure safety even in the event of a major earthquake. Such preparations have long been an important concern of Tokyo Gas, and a range of hardware and software solutions is in place, including both the hardware of gas supply facilities and the software such as regulations or manuals relating to emergency response and efficiency of restoration work.

On 17 January 1995, an earthquake with a magnitude of 7.2 occurred directly under the Hanshin-Awajishima area of Japan. It resulted in unprecedented damage, especially in the city of Kobe, and subsequently became known as the “Great Hanshin Earthquake.” As shown in Table 1, it also caused considerable damage to city gas supply facilities, and particularly low-pressure pipelines. The results reconfirmed the immensity of the threat posed by earthquakes and also underscored the importance of emergency response systems for gas supply facilities in the event of an earthquake [Gas Industry Earthquake Countermeasures Study Report, 1996].

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Table 1: Damage to gas facilities in the Great Hanshin Earthquake

Item	Details
1. Damage to pipelines	Medium-pressure pipelines 106 cases of leakage Low-pressure pipelines 26,459 cases of leakage
2. Number of cases of supply suspension	About 860,000
3. Number of days required for complete resumption	85 days

The Great Hanshin Earthquake provided graphic proof of how difficult it is to gather information on damage immediately after an earthquake, in spite of the crucial importance of obtaining such information. As a means of resolving this difficulty, systems for real-time estimation of earthquake damage are being planned or constructed by several agencies. To the same end, Tokyo Gas launched development of the Seismic Information Gathering & Network Alert System (SIGNAL) [Shimizu, 1997] in 1986 and put it into operation in June 1994, about six months prior to the Great Hanshin Earthquake. With a view to achieving a higher level of safety in the event of major earthquakes, it began constructing another system in January 1998 for SUPer-dense REal-time Monitoring of Earthquakes (SUPREME). Based on installation of roughly 3,600 new seismometers (New SI sensors) over its supply area of roughly 3,100 square kilometers, the new system will feature the most intensive seismic monitoring of any in the world.

DEVELOPMENT OF THE NEW SI SENSORS

Micro-machining technology has made possible the adoption of ultra small acceleration pickups (manufactured by Sumitomo Precision Products Co., Ltd.), and the availability of low-cost, high performance CPU and RAM devices have resulted in the joint development together with Yamatake Co., Ltd. of a New SI sensor (see figure 1), which features high precision and high performance at a low price. The features are as follows:

Both Control and Measurement Functions, and Accommodation of Telemeter Equipment

The New SI sensors employ a voltageless relay contact point output for regulator shutoff, analog output of SI values and acceleration data for measurement, and an alarm (contact point output) for liquefaction. The analog output is of a highly general-purpose nature; it has an operational range of 4 - 20 mA to accommodate various kinds of telemeter equipment.

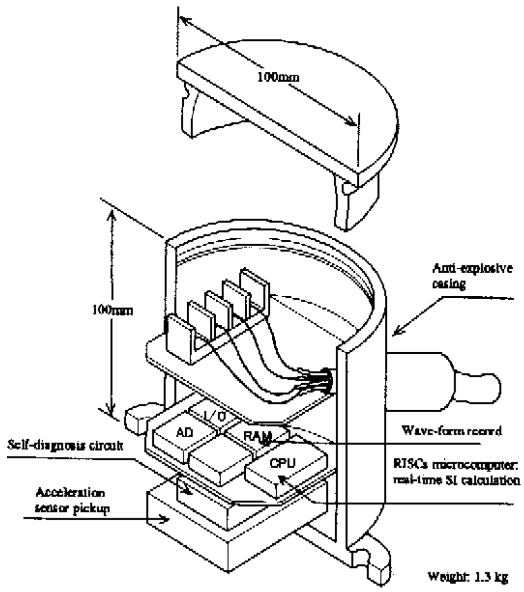

Figure 1: New SI sensor

The sensors are capable of measuring acceleration from plus 2,000 Gal to minus 2,000 Gal, and with a precision of less than plus or minus 5 percent. Moreover, the setting for issuance of alerts can be changed (in addition, the SI and acceleration settings can be selected as desired).

Wave-form Data Storage

The New SI sensors are also equipped for storage of the earthquake wave-form data to permit their use in the formulation of disaster mitigation countermeasures and in related research. The data are stored on an internal memory together with header information for items such as six earthquake wave-forms on the X, Y, and Z axes, (listed beginning with the highest SI value) and the dates of occurrence. The sensors have a recording data sampling time of 1/100th of a second, a resolution of 1/8th of a Gal, and a wave-form recording duration of 50 seconds (from plus to minus 25 seconds) per seismic wave, centered around the wave with the highest SI value. Figure 2 shows the acceleration wave-form data actually stored for an earthquake which struck in the southern part of Ibaraki prefecture on 14 January 1998.

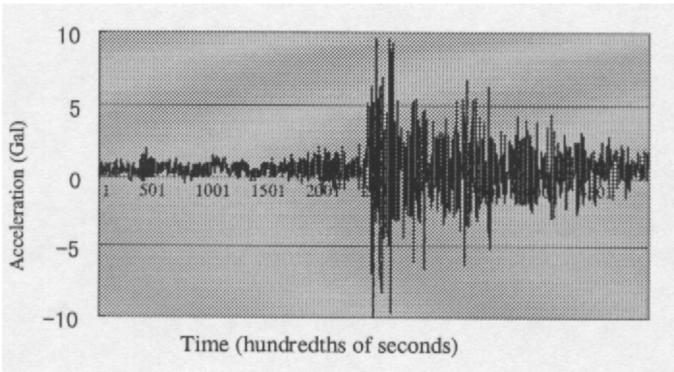

Figure 2: Seismic data, 1998/1/14 (Konan, Minato ward)

Self-diagnosis

The SI units are equipped with a constantly available self-diagnostic function in the interest of more reliable action. In the event of abnormality, the situation can be promptly apprehended by abnormal output to the tele-metering device.

Liquefaction Judgment

Data on ground liquefaction are extremely important for estimating damage. Conventionally, the acquisition of such data has required large-scale boring. The New SI sensors make a judgment on the presence or absence of liquefaction from the changes in the acceleration wave-forms, and therefore make it extremely simple to apprehend ground liquefaction. As shown in Figure 3, the wave-form period for Port Island, where ground liquefaction occurred in the Great Hanshin Earthquake, is clearly longer than that for the Kobe Marine Meteorological Station.

The New SI sensors judge that ground liquefaction has occurred when the four conditions shown below have been met in respect of acceleration (A max), SI value, estimated displacement (D; $2SI^2$/A max) [Towhata, Park, Orense and Kano, 1996], and estimated period (T), based on the change in seismic wave-form. The estimated period is equated with the time interval as defined by zero-cross, i.e., the time required for the wave-form trend measured by the sensor to cross the zero line.

(I) Amax > 100 gal
(II) SI value > 20 kine
(III) D > 10 cm
(IV) T > 2 sec

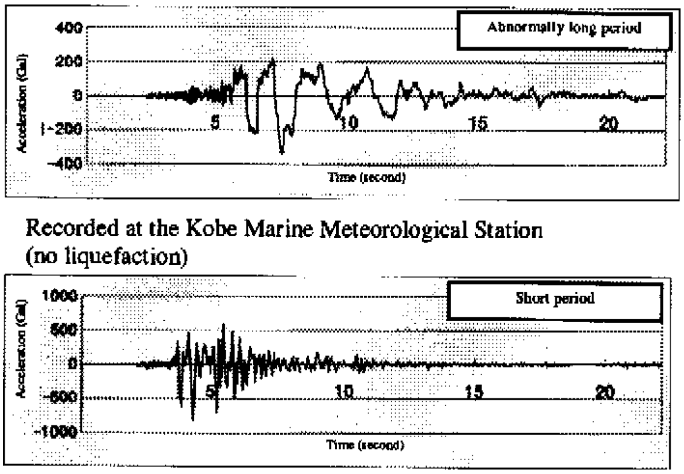

Figure 3: Seismic wave-forms for the Great Hanshin Earthquake

Figure 4 shows the results of the analysis of wave-forms and liquefaction judgment in the case of 70 past earthquakes. Among these 70 earthquakes, those which actually caused liquefaction were as follows (with areas of liquefaction noted in parentheses): the Central Sea of Japan Earthquake (Aomori, Hachirogata, and the Tsugaru Bridge), the Great Hanshin Earthquake (Amagasaki, Kobe harbor, Port Island, and the East Kobe Bridge), Superstition Hill (Wildlife) [Matasovic and Vucetic, 1993], and the Niigata Earthquake (Kawagishi-cho). Use of this newly developed measurement technique will enable determination of liquefaction in real time with an accuracy approaching 100 percent.

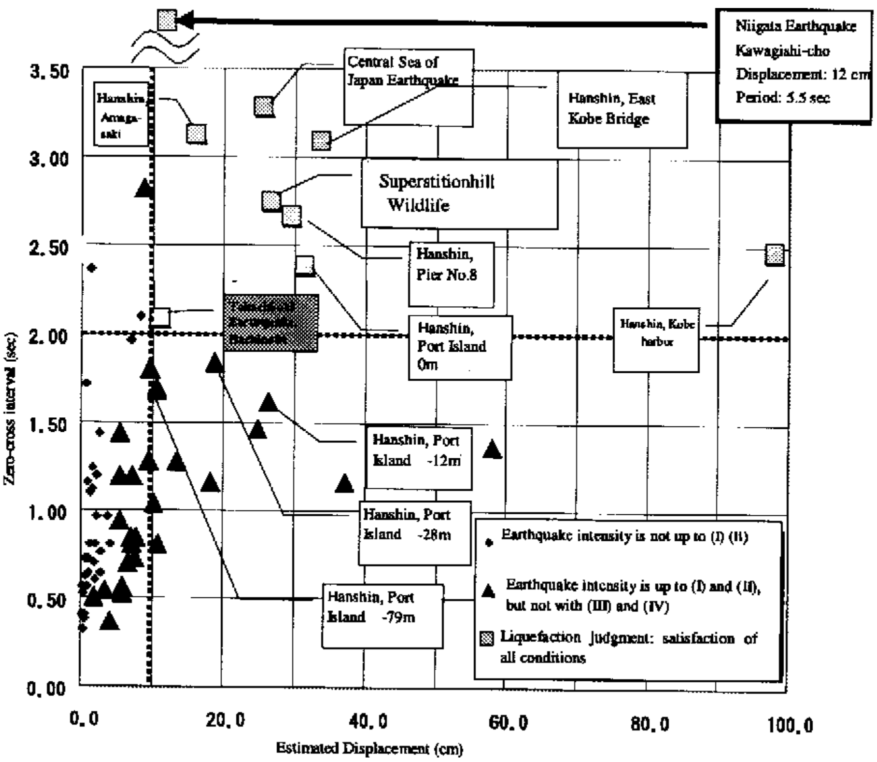

Figure 4: Results of liquefaction judgment

DEVELOPMENT OF THE SUPER HIGH-DENSITY REALTIME DISASTER MITIGATION SYSTEM (SUPREME)

Outline of the Super High-density Real-time Disaster Mitigation System (SUPREME)

Since the Great Hanshin Earthquake, numerous agencies have constructed systems for high-density monitoring of seismic motion and real-time damage estimation. Tokyo Gas is already operating the Seismic Information Gathering & Network Alert System (SIGNAL) based on installation of seismometers at 331 locations (see Figure 5). To raise the level of safety from disasters even higher, it embarked on construction of what will be the world's most extensive system for SUPer-dense REal-time Monitoring of Earthquakes (SUPREME) through installation of about 3,600 seismometers (New SI sensors) over its supply area, which measures about 3,100 square kilometers, beginning in January 1998. Figure 6 shows the distribution when all of the New SI sensors have been installed.

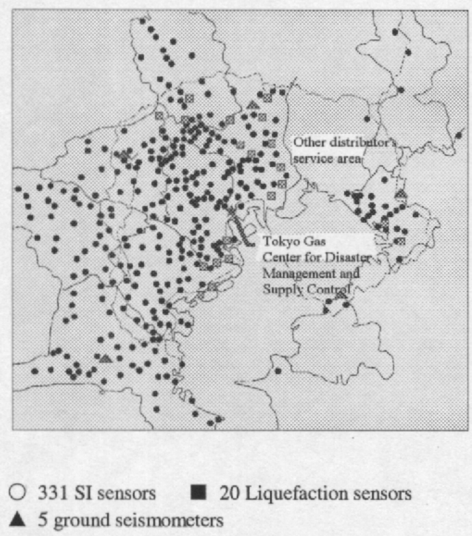

Figure 5: SI sensors in SIGNAL

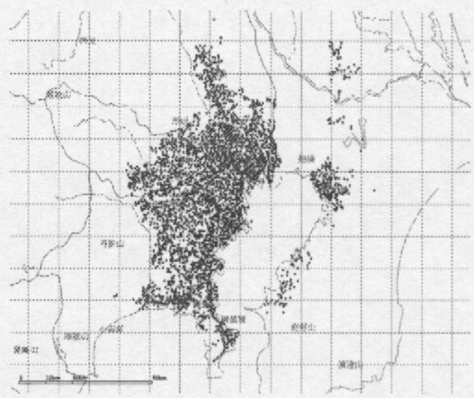

Figure 6: New SI sensors in SUPREME

Figure 7 shows the structure of the super high-density real-time disaster mitigation system. Tokyo Gas is currently taking the opportunity presented by replacement of the former SI regulator shutoff sensors to install the New SI sensors and district regulator remote monitoring system (DCX) in about 3,600 district regulators. The linkage of this equipment with the command center through communications circuits will enable observation, and remote monitoring at the center, of various control items at the roughly 3,600 points in the supply area of roughly 3,100 square kilometers (for an average of one point every 0.9 square kilometers). These items include the SI value, PGA, pressure, regulator shut-off status, and liquefaction alert data.

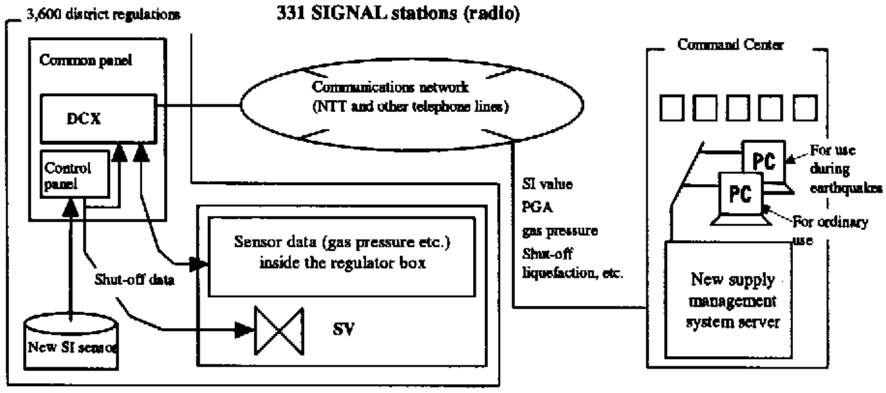

Figure 7: Composition of SUPREME

Approach to System Utilization

- The SI values, which are measured in ultra high density, and the GIS, which includes information on gas pipelines, soil and geography of the gas supply area, are used to make highly accurate estimations of the damage caused by an earthquake.

- Analysis of the yearly wave-form data on small and medium earthquakes in combination with GIS data will make it possible to determine the seismic shaking amplication at each of the roughly 3,600 points. Such information can be reflected in zoning plans and assist optimization of the setting of values for automatic shutoff of district regulators.

- In the event of a major earthquake, the system will not only automatically shut off the district regulators but also enable the command center to confirm the operation of the shutoff equipment. This will contribute to a more prompt and sure response to emergency situations.

- It is possible to monitor the gas pressure during critical events at approximately 3,600 points. Losses in gas pressure during an earthquake are indications of potential damage, and can be used to make early estimates of the extent of damage. Not only can realtime estimates of damage to major facilities be made, but a system is now being developed for the swift and accurate detection of actual damage.

- Detailed, realtime detection of liquefaction allows highly accurate estimates of damage, and the rapid execution of emergency measures

Release of Seismic Data

Data from 31 of the major points in the SIGNAL earthquake monitoring network are transmitted to Nippon Hoso Kyokai (NHK) and other mass media organs as well as public administrative institutions such as the Tokyo Metropolitan Government. Beginning in September 1996, it was decided to release data from all 331 SIGNAL points through Internet within a very short time after occurrence in the case of earthquakes with a magnitude of 3 or more, in order to contribute to emergency response and research by numerous institutions (see Table 2). In addition, Tokyo Gas is promoting the sharing of data and research results with governmental bodies that are taking active approaches to real-time disaster mitigation. The transmission of data from the 331 SIGNAL points to the Yokohama municipal government beginning in 1998 is a part of this policy.

Table 2: Release of SIGNAL data through Internet

♦ Objective • Promotion of research for disaster mitigation through sharing of seismic data • Active use for initial mobilization ♦ Items of data release (for earthquakes occurring within the service area and having a magnitude of at least 3) • Earthquake name, time of occurrence, and epicenter • Location of the seismometer (name of location, latitude, and longitude) • SI value and maximum acceleration ♦ URL http//www.toyko-gas.co.jp Posted at the bottom of the Tokyo Gas web site

The new SUPREME real-time disaster mitigation system will record wave-form data (six earthquake wave-forms on three axes, listed from the highest SI value) for small and medium earthquakes at some 3,600 points. Earthquake wave-forms entail an immense load of data which cannot be collected in real time. However, the company plans to release data stored by CD-ROM once a year.

CONCLUSION

Real-time disaster mitigation came to the fore in the aftermath of the Great Hanshin Earthquake, and systems for real-time monitoring of seismic motion and damage estimation have since been installed or planned by many agencies. In SIGNAL, Tokyo Gas constructed one of the first systems of this type, and was commended for its foresight with selection for the 1996 Award for Civil Engineering and Development given by the Japan Society of Civil Engineering. In order to raise the level of safety from disasters even higher, Tokyo Gas began construction of a new SUPREME system for disaster mitigation based on installation of roughly 3,600 New SI sensors and a DCX system for remote monitoring of district regulators in January 1998.

It is hoped that the future will bring a sharing of seismic and geophysical data obtained from the systems of Tokyo Gas (i.e., the SUPREME disaster mitigation system and SIGNAL) and the systems of other agencies, the promotion of related research by numerous institutions, and a sharing of the research results by all concerned.

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