A new technology for earthquake disaster prevention
New SI sensor and SUPREME

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The New Spectral Intensity (SI) sensor is an intelligent yet inexpensive seismometer comprising an ultra-compact acceleration pickup based on micro-machining technology, a CPU, and RAM. The sensor is able to measure spectral intensity and acceleration, record the acceleration waveforms of six earthquakes in the X-, Y- and Z-directions, detect ground liquefaction through changes in acceleration waveforms, and produce outputs that can be used to control equipment at adjustable SI/acceleration settings.

Tokyo Gas Co., Ltd. is currently installing about 3,600 of these New SI sensors over a service area of about 3,100 km^2 with the aim of developing a high-density, real-time seismographic disaster prevention system called SUPREME (SUPer-dense REaltime Monitoring of Earthquakes).

THE STRATEGY FOR EARTHQUAKE DISASTER PREVENTION

Metropolitan Tokyo is the world's most crowded urban area, and it contains an excessive concentration of political, cultural, and economic functions. A vital part of our mission to supply gas to this area is the assurance of customers' safety even during big earthquakes. In recognition of this crucial challenge of guarding against major earthquakes, we have taken various measures to protect gas supply facilities and have developed emergency response systems for efficiently restoring facilities when necessary.

A strong local earthquake of magnitude 7.2 struck the Hanshin area and the island of Awajishima on January 17, 1995, causing devastating damage to the city of Kobe in particular. A great deal of damage was suffered by the low-pressure gas supply system, as listed in Table 1. We were once again forced to recognize the threat of earthquake damage and the importance of an emergency response system for the low-pressure gas supply system in earthquakes.

A major challenge thrown up by this earthquake is the collection of information on the damage immediately after the event; though very important, this is in practice difficult. In an effort to meet this challenge, some companies are planning or implementing the development of a real-time earthquake damage estimation system. Our company announced SIGNAL (Seismic Information Gathering Network Alert System) in 1986, and brought it into actual use in June 1994, just six months prior to the Kobe earthquake. In order to further enhance the degree of protection it offers, we have now begun developing SUPREME using about 3,600 of the New SI sensors.

Table 1 Damage to city gas supply facilities caused by the Hanshin-Awaji Earthquake

Item	Description
Damage to gas pipes	Number of medium-pressure gas pipes damaged : 106 Number of low-pressure gas pipes damaged : 26,459
Number of customers at which gas supply was interrupted	About 860,000
Number of days required for full recovery	85

DEVELOPMENT OF NEW SI SENSOR

Advances in micro-machining technology have allowed us to use a low-cost acceleration pickup manufactured by Sumitomo Precision Products Co., Ltd. and miniature high-performance CPUs and RAM to develop, in a joint effort with Yamateke Co., Ltd, a new highly functional high-precision SI sensor at half to one-third of the conventional cost. (Fig. 1 and Photo 1) The main features of this new sensor are described below.

(1) Measurement and control functions

The sensors are used to shut off city gas pressure

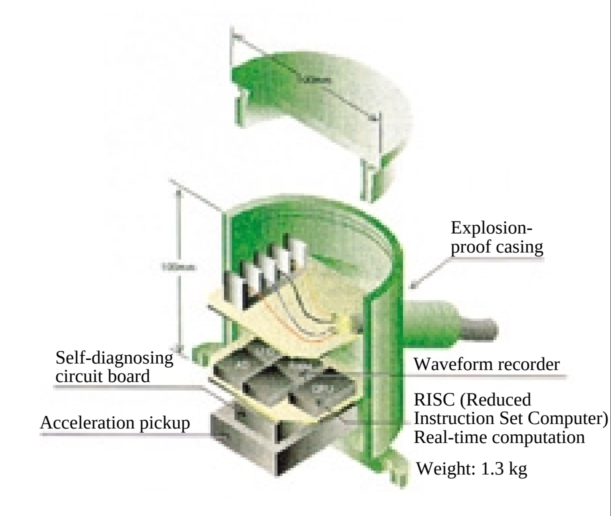

Fig. 1 Construction of New SI sensor

Photo 1 New SI sensor

regulators (or district regulators) if seismic motion is detected. For the control of such regulators, the sensor produces a non-voltage relay-type output, analog SI and acceleration outputs, and a liquefaction alarm output. Spectral intensity correlates strongly with the degree of damage to structures in an earthquake, and it is calculated by averaging the velocity response spectrum of a one-mass damping system for natural periods from 0.1 to 2.5 seconds (which is the usual range of natural periods of major structures).

The range of the acceleration pickup is ±2,000 gal, so the sensor is able to measure the acceleration of Hanshin-Awaji-class earthquakes, and its resolution is 1/8 gal making it suitable for use as a seismometer. Further, an accuracy of ±5% is achieved by incorporating temperature compensation with a built-in thermometer. The sensor produces an alarm output that can be triggered at adjustable SI and acceleration settings.

(2) Seismogram storage function

The sensor is able to store seismograms for later use for research and in taking earthquake disaster prevention measures. The acceleration waveforms in the X-, Y- and Z-directions of six earthquakes are saved in built-in memory, in decreasing order of SI, along with header information such as year, month, date, and time. The sampling period is 1/100 second, and acceleration waveforms are recorded for a total of 50 seconds — 25 seconds before and after the time of maximum SI. Figure 2 shows the acceleration waveform of an earthquake on January 14, 1998 with the epicenter in southern Ibaraki Prefecture, as recorded in Konan epicenter, Minato Ward, Tokyo.

(3) Liquefaction detection function

In estimating earthquake damage, it is of crucial importance to know whether the ground liquefies or not. Conventionally, large-scale boring was required to

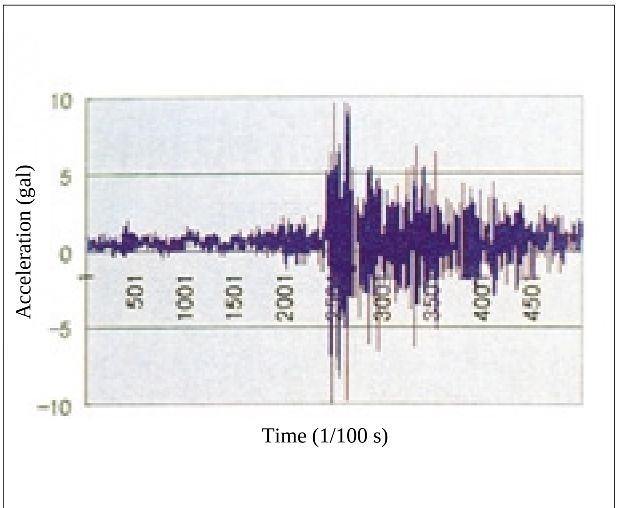

Fig. 2 Acceleration waveform of earthquake on January 14, 1998 as recorded in Konan, Minato Ward, Tokyo

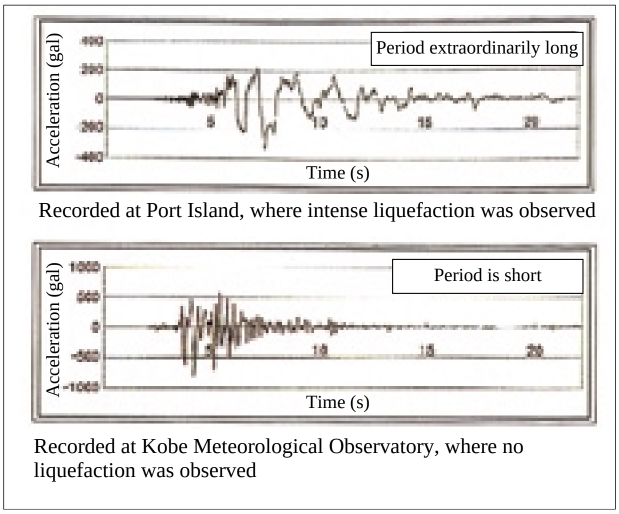

Fig. 3 Acceleration waveforms of the Hanshin-Awaji Earthquake

determine the probability of liquefaction. This new sensor, however, is able to sense whether liquefaction occurs based on changes in acceleration waveforms. Figure 3 compares the acceleration waveform of the Hanshin-Awaji Earthquake as recorded at Port Island with that taken at Kobe Meteorological Observatory. As is clear from the figure, the period of the waveform at the island, where liquefaction took place, is longer than that at the liquefaction-free observatory.

The sensor monitors changes in the acceleration waveform and determines that liquefaction has occurred when the maximum acceleration A_{max}, SI, estimated displacement $D = 2SI^2/A_{max}$, and estimated period T meet the conditions given below, where the estimated period T is defined as the interval between consecutive crossings of the zero-acceleration line, or the zero-cross period.

(Ⅰ) $A_{max} > 100$ gal
(Ⅱ) SI >20 kine
(Ⅲ) D > 10 cm
(Ⅳ) T > 2 seconds

Figure 4 plots the results of a liquefaction analysis carried out on the seismic waveforms of 70 past earthquakes. The observatories at which liquefaction was found to have occurred were the following: Hachirogata in the Nihonkai-Chubu Earthquake; Amagasaki, Kobe Port, Port Island (0 m), and Higashi Kobe Bridge in the Hanshin-Awaji Earthquake; Wildlife in the Superstition Hill Earthquake; and Kawagishi-cho in the Niigata Earthquake. In all of these cases except that of Hachinohe in the Tokachi-Oki Earthquake, it would have been possible to determine the occurrence of liquefaction in real time at almost 100% accuracy using this new measuring method. For the first time in the world, the technology is available for detecting liquefaction at low cost.

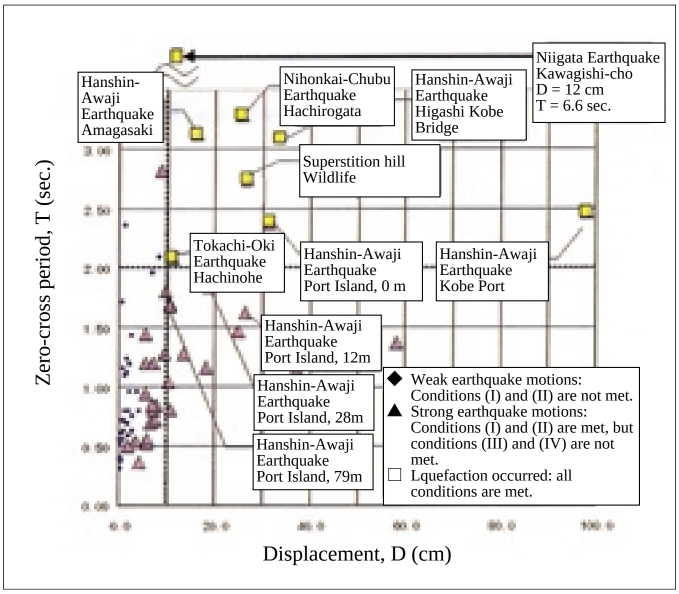

Fig. 4 Results of check for liquefaction

DEVELOPMENT OF SUPREME

This company has been operating SIGNAL using 331 seismogram stations. (Fig. 5) Drawing on the lessons of the Hanshin-Awaji Earthquake, we began implementing SUPREME as a development of SIGNAL, using 3,600 New SI sensors spread over a service area of about 3,100 km^2 in January 1998. Figure 6 shows a map of all New SI sensors after installation, and Fig. 7 illustrates the overall system configuration. Based on this system, installing New SI sensors and DCXs (remote monitoring units) are installed at district regulators (city gas pressure regulators within service areas) will make it possible to monitor SI, PGA (peak ground acceleration), and city gas pressure, and also to broadcast liquefaction alarms and shut off regulators, with a resolution of one detection unit per 0.9 km^2. In this type of configuration, the system will have the following applications:

(1) High-accuracy estimation of earthquake damage by combining high-density SI measurements with gas pipe network data in service areas, soil condition data, and landform data provided by GIS (Geographic Information System).

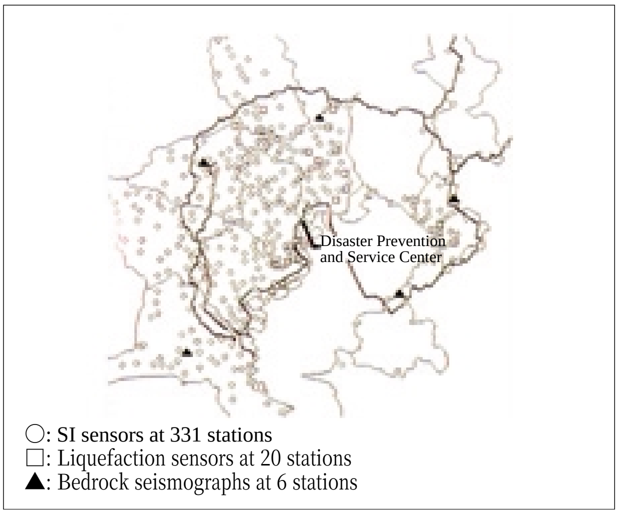

Fig. 5 Map of SIGNAL SI sensors

(2) Determination of seismic motion amplitude at 3,600 stations through analysis of seismic waveform data continually accumulated from small- and medium-size earthquakes and GIS data. This data will be useful in zoning service areas and optimizing emergency responses.

(3) High-accuracy earthquake damage estimations and properly targeted emergency responses through real-time, high-density detection of liquefaction.

High-density acceleration waveforms collected for small- and medium-size earthquakes will be recorded on CD-ROMs and published about once a year.

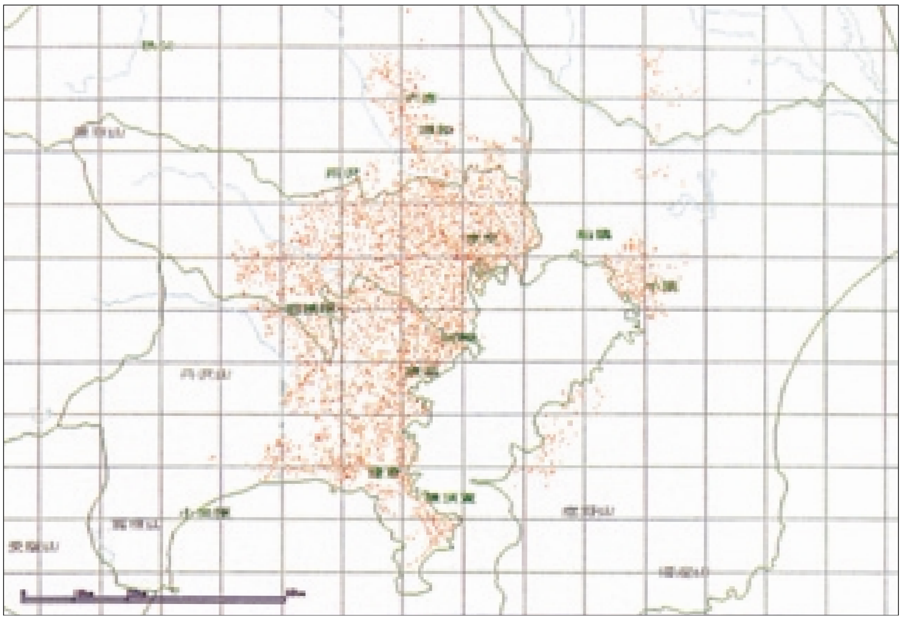

Fig. 6 Map of SUPREME New SI sensors

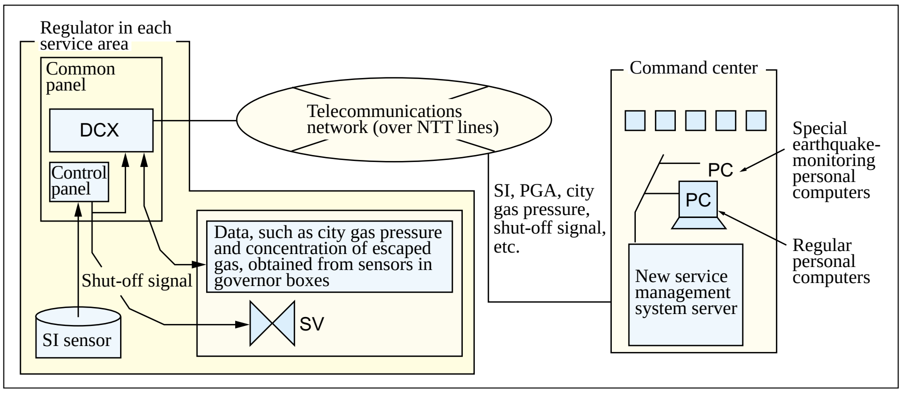

Fig. 7 Configuration of new real-time earthquake-disaster prevention system (SUPREME)