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SEISMIC SHUTOFF CHARACTERISTICS OF INTELLIGENT GAS METERS FOR INDIVIDUAL CUSTOMERS IN JAPAN

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ABSTRACT: After the 1995 Kobe earthquake, countermeasures against earthquakes got higher priority than before. As one of such earthquake countermeasures, Tokyo Gas Co., Ltd. introduced an earthquake monitoring and rapid damage assessment system called SUPREME. This system has been under operation since 2001. The intelligent gas meters have been deployed for 9.8 million customers in the area where Tokyo Gas Co., Ltd. provides the service. The gas meter stops gas supply if earthquake motion exceeds a certain level. SUPREME has a subsystem to estimate the number of gas meters which stop gas supply because of an earthquake. However, the accuracy of estimation by this subsystem is not good because the characteristics of gas supply shutoff by intelligent gas meter are not very clear. In this study, to improve the accuracy of estimation, the characteristics of gas supply shutoff by intelligent gas meter are investigated based on shaking table tests and the questionnaire survey among employees of Tokyo Gas Co., Ltd.

KEYWORDS: intelligent gas meter, seismic shutoff, shaking table test, SUPREME

1 INTRODUCTION

The 1995 Kobe earthquake caused serious damages to various infrastructures and buildings in the highly populated area of central-western Japan. The gas system in this area was also seriously affected [1]. After this earthquake, countermeasures against earthquakes got higher priority than before. As one of such countermeasures, Tokyo Gas Co., Ltd. introduced an earthquake monitoring and rapid damage assessment system, SIGNAL (Seismic Information Gathering and Network Alert), with 331 SI-sensors in 1994. Expanding SIGNAL into a much denser seismic monitoring network with about 3800 SI-sensors, SUPREME (Super-Dense Real-time Monitoring of Earthquakes) has been under operation since 2001 [2]. The SI sensors measure the peak ground acceleration (PGA) and spectrum intensity (SI) at district regulator stations. The data from the network will be used for an early damage assessment of the city gas network of Tokyo Gas Co., Ltd. and the results will serve as important information for the decision making of the gas supply suspension.

The intelligent gas meters have been deployed for 9.8 million customers. The gas meter stops gas supply if earthquake motion exceeds a certain level (Fig. 1). It is designed to shut off gas supply if the peak acceleration is in the range of 200-250 cm/s^2. SUPREME has a subsystem to estimate the number of gas meters that shut off gas supply because of an earthquake. However, the accuracy of estimation by this subsystem is not good because the characteristics of gas supply shutoff by the intelligent gas

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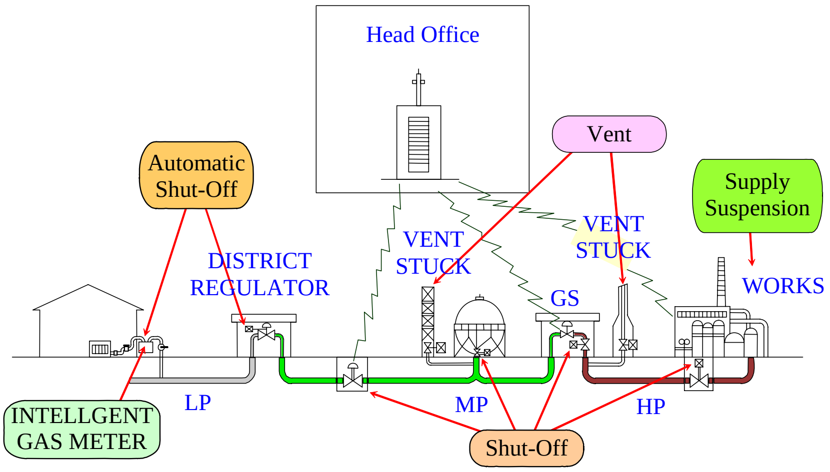


Figure 1. Outline of emergency control of natural gas supply system in Japan

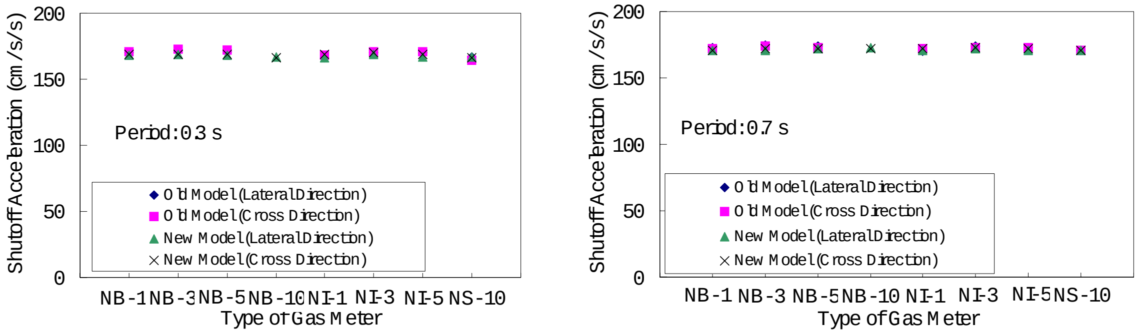


Figure 2. Shutoff acceleration of various types of intelligent gas meters conducted by producteers (Old model: until February 2003, New model: from February 2003)

meter are not very clear. Therefore, the subsystem sometimes overestimates the number of gas meters that shut off gas supply, and sometimes underestimates it.

In this study, to improve the accuracy of estimation, the characteristics of gas supply shutoff by the intelligent gas meter are investigated based on shaking table tests and questionnaire survey among employees of Tokyo Gas Co., Ltd.

2 INVESTIGATION OF SEISMIC SHUTOFF CHARACTERISTICS OF INTELLIGENT GAS METER BASED ON SHAKING TABLE TESTS

2.1 SHUTOFF CHARACTERISTICS UNDER SINUSOIDAL WAVE

Intelligent gas meters are designed to shut off gas supply if the acceleration in the range of 200-250 cm/s^2 is detected. The producteers of gas meter are conducting product tests. In the tests, gas meters are subjected to sinusoidal waves with the period of 0.3 s and 0.7 s. Figure 2 shows the average shutoff accelerations among various types of intelligent gas meters. This figure suggests that the shutoff acceleration does not depend on the type of gas meters. The shutoff acceleration under sinusoidal wave with the period of 0.3 s is almost equal to that under sinusoidal wave with the period of 0.7 s. However, in the product testing, only two periods are adopted as the period of the applied sinusoidal waves. Therefore, for a further investigation of seismic shutoff characteristics of intelligent gas meter, it is necessary to consider the shutoff acceleration of gas meters subjected to sinusoidal waves with various periods.

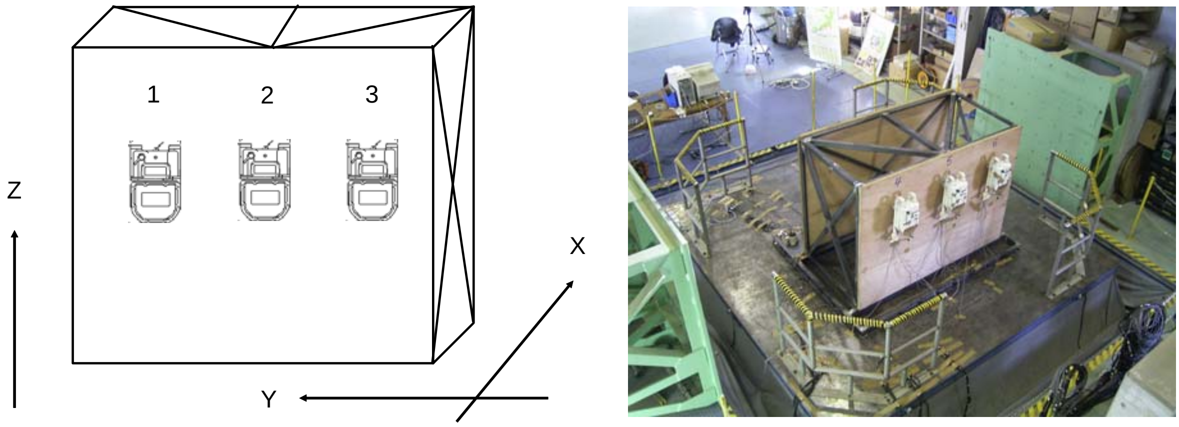


Figure 3. Shaking table test of intelligent gas meters

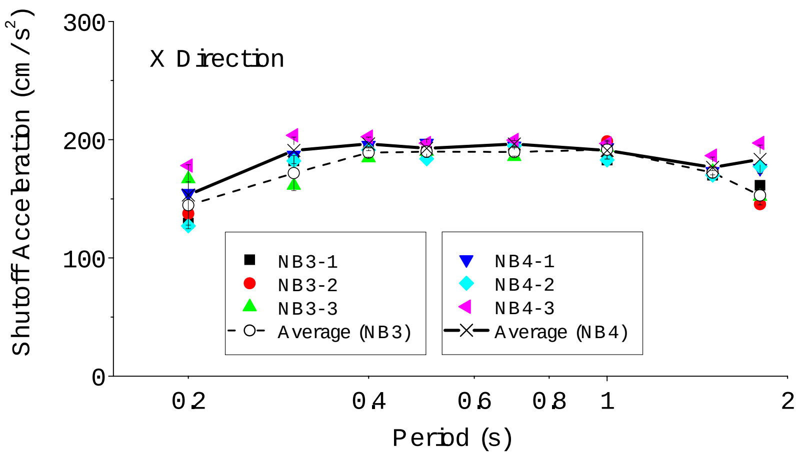


Figure 4. Shutoff accelerations with respect to the periods of sinusoidal waves applied to the X direction

In this study, a series of shaking table tests of intelligent gas meters was conducted. The shaking table possessed by Pipeline Technology Center, Tokyo Gas Co., Ltd. was employed in the experiment. The sinusoidal waves with the period of 0.2-1.8 s were applied to the gas meters fixed on the wall (Fig. 3). The amplitudes of sinusoidal waves increase with the interval of 5 cm/s^2. The change of power voltage associated with the shutoff by gas meter was detected, so that the time when the gas meter shut off gas supply could be identified exactly. Two types of gas meters, which are NB-3 and NB-4, were used in the experiment. Three gas meters of each type were subjected to excitation.

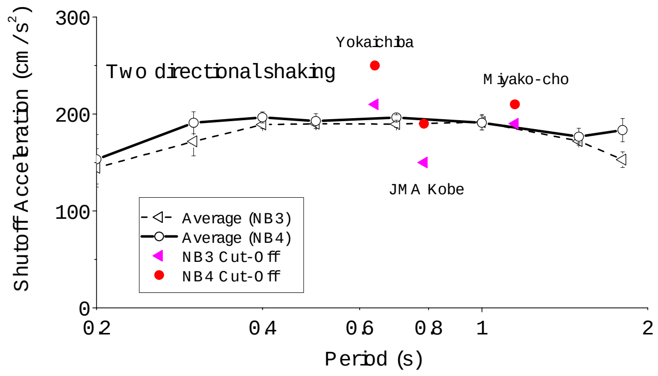
Figure 4 shows the relationship between the period of applied sinusoidal waves and shutoff accelerations of intelligent gas meters. According to the figure, the shutoff accelerations with the periods of 0.2 s and 1.8 s are a little smaller. However, the shutoff accelerations with the periods of 0.3-1.5 s are almost constant, and the shutoff acceleration is about 190 cm/s^2. The difference between the shutoff acceleration of NB-3 type gas meter and that of NB-4 type was not observed in the period range, but the shutoff acceleration of NB-3 type is smaller than that of NB-4 type when the period of sinusoidal wave is equal to 1.8 s.

2.2 SHAKING TABLE TESTS USING ACTUAL SEISMIC MOTIONS

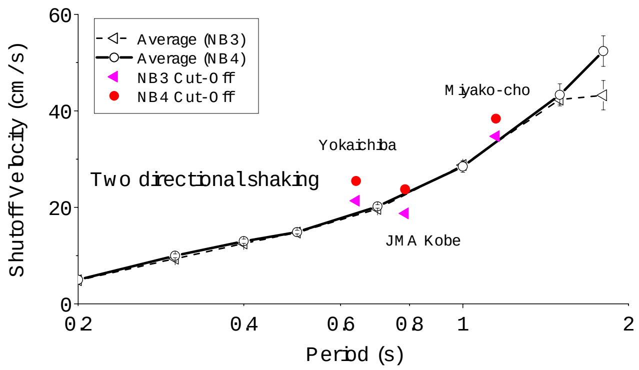
To evaluate the characteristics of seismic shutoff of intelligent gas meters revealed in the previous section, four sets of actual seismic motion records were used as input motions in the shaking table tests: 1) the Kobe Marine Observatory record of Japan Meteorological Agency (JMA) in the 1995 Kobe earthquake, 2) the K-NET Tomakomai record in the 2003 Tokachi-Oki earthquake, 3) the K-

Table 1. The number of intelligent gas meters which shut off gas supply during the shaking table test

	JMA Kobe		Miyako-cho, Tokyo Gas		K-NET Yokaichiba	
PGA (cm/s^2)	NB-3	NB-4	NB-3	NB-4	NB-3	NB-4
130	0	0	-	-	-	-
150	3	0	-	0	-	-
170	3	0	0	0	0	0
190	-	3	3	2	1	0
210	-	-	-	3	3	1
230	-	-	-	-	-	1
250	-	-	-	-	-	3



(a) Shutoff acceleration

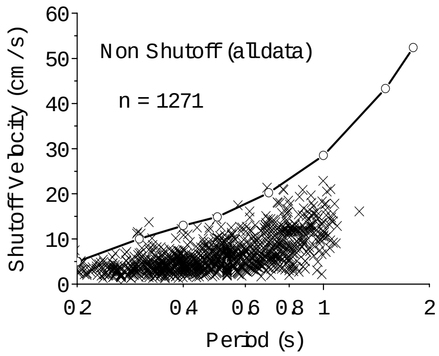


(b) Shutoff velocity

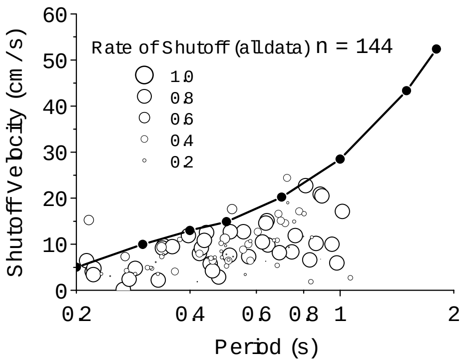
Figure 5. Comparisons of the shutoff accelerations and the shutoff velocities between under seismic motions and sinusoidal waves

NET Yokaichiba record in the North-eastern Chiba Prefecture earthquake (April 11, 2005), and 4) the Miyako-cho Tokyo Gas seismic observation station record in the North-western Chiba Prefecture earthquake (July 23, 2005). The Tomakomai record was selected as the typical long-period record. On the contrary, the K-NET Yokaichiba record was employed as the short-period seismic motion. The applied peak ground acceleration (PGA) of the record, which is obtained as the resultant of two horizontal components, was scaled to be 130-250 cm/s^2.

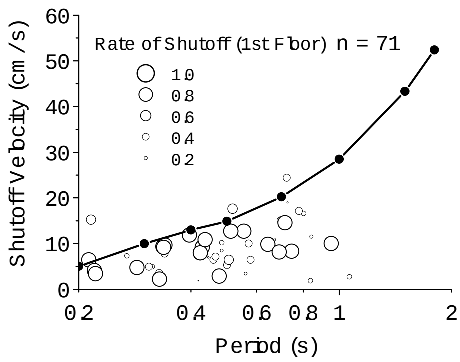
Table 1 shows the number of gas meters which shut off gas supply because of ground shaking. It should be noted that the K-NET Tomakomai record whose PGA is equal to 130 cm/s^2 could not be applied to the shaking table because of the limitation of actuators. Therefore, the result under the K-NET Tomakomai record is not listed in Table 1. The gas meters did not shut off gas supply under the



(a) Non-shutoff



(b) Rate of shutoff (all data)



(c) Rate of shutoff (1st floor)

Figure 6. Relationship between the period of seismic motion and the PGV allocated to the responders of the questionnaire survey

non-scaled K-NET Tomakomai record (PGA = 87.2 cm/s^2). According to the result, the NB-3 gas meters shut off gas supply under smaller seismic motion than NB-4 gas meters especially under the JMA Kobe record.

Figure 5 compares the results of shaking table tests under sinusoidal waves and those under actual ground motion records. The period of seismic motion was determined by Eq. (1).

$$T = 2\pi PGV^{*}/PGA^{*} \qquad (1)$$

where *T* is the period of seismic motion. *PGA** and *PGV** are the peak ground acceleration and the peak ground velocity by the resultant of two horizontal components, respectively. Figure 5 illustrates the shutoff accelerations and shutoff velocities when all the three gas meters shut off gas supply under seismic motion. According to the figure, the shutoff acceleration under the K-NET Yokaichiba record is larger than that obtained under sinusoidal waves. As is mentioned before, the K-NET Yokaichiba record was selected as an example of short-period record. The peak ground acceleration is dependent on the short-period components of ground excitation. This indicates that the intelligent gas meters may not be sensitive to the short-period ground motions. With respect to the shutoff velocities of gas meters (Fig. 5(b)), the results obtained from the seismic motions coincide with those obtained from sinusoidal waves. The PGV does not depend on the short-period components of ground motion, so the results under the K-NET Yokaichiba record show good agreement with those under sinusoidal waves.

3 QUESTIONNAIRE SURVEY ON SEISMIC SHUTOFF OF INTELLIGENT GAS METERS

On July 23, 2005, the North-western Chiba Prefecture earthquake occurred (M_{JMA} = 6.0). The Tokyo Metropolitan area suffered from this earthquake, and the lifelines, especially, train services and road traffic networks ceased their functions. The intelligent gas meters perceived the seismic motion, and some of them shut off gas supply. In order to reveal the effects of seismic motion to the shutoff behavior of intelligent gas meters, the questionnaire survey was conducted for employees of Tokyo Gas Co., Ltd. In the questionnaire, the responders were asked to answer the address of residence, what floor they live on, and whether the gas meter stopped due to the earthquake or not.

From the addresses of responders, the seismic intensity was allocated using the nearest record of SI-sensors deployed by Tokyo Gas Co., Ltd. In SUPREME, the spectrum intensity (SI) and the PGA recorded by SI-sensors can be monitored and gathered at an early stage of the earthquake. Therefore, these two seismic indices were adopted in the analysis. The SI was converted to the PGV using the relationship by Tong et al. [3] shown in Eq. (2).

$$SI = 1.18PGV \tag{2}$$

The period of seismic motion was determined by Eq. (1). Figure 6(a) shows the relationship between the period of seismic motion and the PGV for the gas meters that did not shut off gas supply. Figure 6 (b) and (c) show the relationships between the period and the shutoff velocities of the gas meters. The size of the symbol means the rate of shutoff by gas meters in Fig. 6(b) and (c). The rate of shutoff was calculated based on the all data (located within 500 m from the nearest seismic observation station) of the questionnaire survey in Fig. 6(b). Figure 6(c) shows the rate of shutoff calculated from the results of the responders who live on the 1st floor of an apartment building or in two or one storied house. In Fig. 5, the results of the shaking table test using the sinusoidal waves are also illustrated.

According to the figure, the symbols that show the non-shutoff gas meters are mainly concentrated in the lower part of the line drawn from the results of the experiments. The symbols in Fig. 6(b) spread out comparing with those in Fig. 6(c). This is because the seismic responses of the buildings affect the behavior of shutoff characteristics of intelligent gas meters. This suggests that the effects of the structural response to seismic motion should be considered to predict the number of shutoff gas meters.

4 CONCLUSIONS

In this study, to investigate the characteristics of seismic shutoff of intelligent gas meters, a series of shaking table tests were conducted. According to the results, the characteristics of seismic shutoff of gas meters estimated by applying sinusoidal waves coincided with the results of experiments under actual seismic records. The questionnaire survey to reveal the characteristics of seismic shutoff during the 2005 North-western Chiba Prefecture earthquake was also conducted among the employees of Tokyo Gas Co., Ltd. The results of the questionnaire survey were compared with those of the shaking table tests. To predict the number of intelligent gas meters that shut off gas supply, the seismic response of structures should be considered in a proper manner.

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