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SEISMIC SHUTOFF CHARACTERISTICS OF INTELLIGENT GAS METERS IN MULTISTORY BUILDINGS BASED ON ACTUAL EARTHQUAKE DATA AND GIS

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ABSTRACT : To prevent secondary disasters due to strong earthquakes, Tokyo Gas Co., Ltd. has introduced an earthquake monitoring and rapid damage assessment system called SUPREME, which has a subsystem to estimate the number of gas meters' shutoff. In a previous research, a shutoff rate estimation model of gas meters for wooden houses was constructed. The effect of seismic response of multistory buildings were not considered in the study. Hence, the estimation method of shutoff rate of gas meters in multistory buildings is considered in this research based on the actual earthquake data of the 2005 North-western Chiba Earthquake. First, the response acceleration at each floor of a multistory building is estimated using ground motion records and a simplified response model. Second, the height of building is obtained from a 3D GIS data. Then, the relationship between the estimated response accelerations and the actual shutoff rate is compared to demonstrate the accuracy of the proposed method. The result shows the possibility of grasping the shutoff rate of gas meters in various buildings from the earthquake ground motion recorded at a nearby district regulator.

KEYWORDS: Intelligent Gas Meter, Seismic Shutoff, Multistory Building, 3D GIS

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 3900 SI-sensors, SUPREME (Super-Dense Real-time Monitoring of Earthquakes) has been under operation since 2001 [2]. The data from the network is used for an early damage assessment of the city gas network of Tokyo Gas Co., Ltd. and the results serve as important information for the decision making of the gas supply suspension.

The intelligent gas meters have been deployed for all the customers in the area where Tokyo Gas Co. provides the service. The gas meter stops gas supply if earthquake motion exceeds a certain level. It is designed to shut off gas supply if the peak acceleration is in the range of 150-250 cm/s^2. The seismic shut off characteristics of intelligent gas meters were investigated by shaking table tests [3]. The relationship between the observed peak ground acceleration (PGA) by SUPREME and the shutoff rate of gas meters were evaluated based on actual earthquake data [4]. According to the results of these studies, the observed PGA by SUPREME can be utilized to estimate the number of shut off gas meters just after an earthquake occurrence.

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The methodology proposed by Yano *et al.* [4] does not consider the effects of amplification of seismic motion by structural responses. Only the dataset of gas meters installed for wooden houses (1- or 2-story buildings) was used to obtain the relationship between the PGA and the shutoff rate. The acceleration is, in general, amplified because of structural response, and then the gas meter installed on a higher floor is subjected to stronger shaking than that on a ground floor. The gas meters on higher floors may shut off gas supply although the gas meters on lower floors are not activated. Hence, the effects of structural response during an earthquake should be considered properly to apply the methodology in real situations.

In this study, the estimation method of shutoff rate of gas meters in multistory buildings is considered based on the actual earthquake data from the 2005 North-western Chiba Earthquake. The response acceleration at each floor is estimated using ground motion records and a simplified response model. Then, the relationship between the estimated response accelerations and the actual shutoff rate is compared to demonstrate the accuracy of the proposed method.

2. RELATIONSHIP BETWEEN THE PGA AND SHUTOFF RATE OF INTELIGENT GAS METERS INSTALLED FOR WOODEN HOUSES

The North-western Chiba earthquake occurred on July 23, 2005 (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. About 12,000 customers telephoned Tokyo Gas to ask how to restore gas supply.

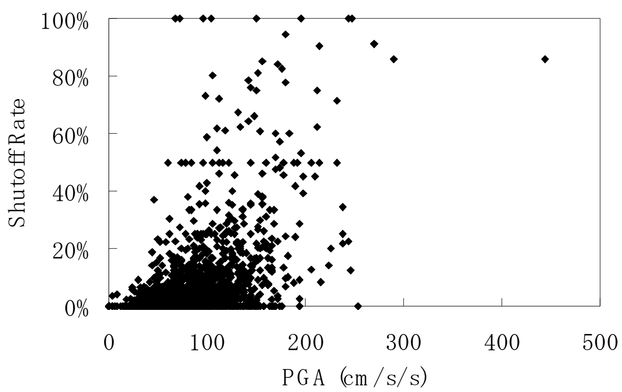


Figure 1. Relationship between the PGA and shutoff rate of intelligent gas meters installed at wooden houses in the 2005 North-western Chiba earthquake

Tokyo Gas Co., Ltd. has introduced various disaster measures. One of the services is called Station 24 (ST24), which connects each intelligent gas meter and Tokyo Gas with telephone communication. Tokyo Gas can observe gas leakage based on this system. The shutoff archives of intelligent gas meters can be collected with telecommunication using ST24 network.

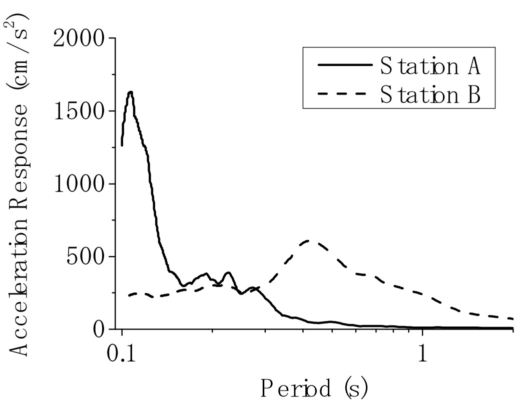


Figure 2. Comparison of response spectra with 5% damping ratio at two seismic observation stations

In this study, about 200,000 shutoff archives were collected after the 2005 North-western Chiba earthquake. The number of shutoff gas metes, which was collected by ST24, is 10,175. Using the archives and the seismic records from SUPREME, the relationship between the seismic motion indices and shutoff rate of intelligent gas meters were evaluated.

In order to eliminate structural response, the shutoff archives of wooden houses were selected. Then, the gas meters whose distances from the nearest seismic observation stations are shorter than 500 meters were used to reveal the relationship between the PGA and seismic shutoff rate of intelligent gas meters (Fig. 1). As the PGA becomes larger, the shutoff rate also becomes larger. However the shutoff rate has a broad range with respect to the PGA. The characteristics of seismic motion might affect the shutoff rate of intelligent gas meters. Figure 2 compares the response spectra with 5% damping ratio at two seismic observation stations. The PGA at station A is 246.0 cm/s^2, and no gas meters out of 8 shut off gas supply. The PGA at station B is 217.0 cm/s^2, and all gas meters (The number of collected data is 3.) shut off gas supply. According to Fig. 2, the peak period of response spectrum at Station A is much shorter than that at Station B. The gas meters are not sensitive to the short-period motion [3], and hence no gas meters shut off gas supply at Station A.

Although the shutoff rate of gas meters spreads widely with respect to the PGA, the results shown in Fig. 2 include the effects of spatial distribution of seismic motion in an actual environment to some extent. The intelligent gas meters are tested to shut off gas supply with respect to the peak acceleration by manufacturer, and that is also validated by shaking table tests in our previous study [3]. Hence, the PGA is employed to estimate the shutoff rate of intelligent gas meters after earthquakes.

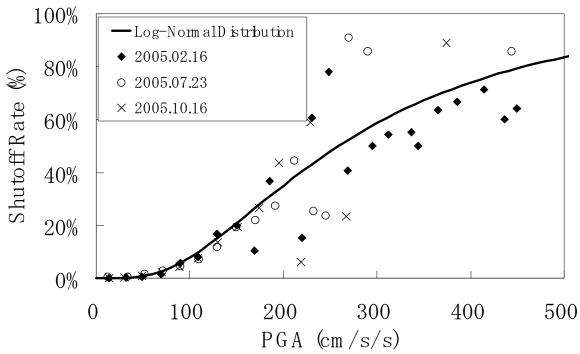


Figure 3. Estimation curve of shutoff rate of intelligent gas meters constructed by Yano *et al.* [4]

Floor	Shutoff	Non-Shutoff
12F	1	0
11F	0	0
10F	3	0
9F	1	3
8F	1	6
7F	0	4
6F	1	2
5F	1	4
4F	0	4
3F	0	3
2F	0	3
1F	0	3

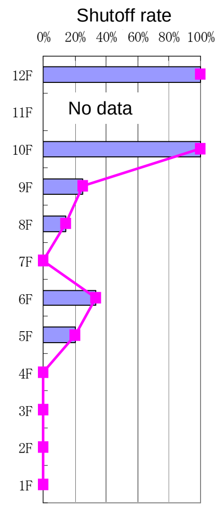


Figure 4. State of seismic shutoff of intelligent gas meters installed in the 12-story building after the 2005 North-western Chiba earthquake (Chuo ward, Chiba city)

The shutoff rate of gas meters was assumed to follow the log-normal distribution and the mean and standard deviation were determined by a regression analysis [4]. Although the logistic distribution was also employed to show the shutoff rate of gas meters, the accuracy was not good enough to give a reasonable estimation. Figure 3 shows the results of estimation curve of shutoff rate. In addition to the 2005 North-western Chiba earthquake, the shutoff rates for two other earthquakes are also plotted in the figure.

3. SEISMIC SHUTOFF OF INTELLIGENT GAS METERS IN MULTISTORY BUILDINGS

So far, the seismic shutoff characteristics of intelligent gas meters installed for wooden houses are discussed. The effects of structural response due to earthquakes are considered to be negligible for the gas meters in 1- or 2-story buildings. As for multistory buildings, the seismic motion on higher floors is amplified because of structural response.

Figure 4 shows the example of seismic shutoff of gas meters in a multistory building after the 2005 North-western Chiba earthquake. The condominium is 12 storied, and located in Chiba City. The shutoff rate on higher floors is larger than that of lower floors because the seismic motion was amplified due to structural response. According to the dataset collected in this study, all the 11 gas meters of wooden houses near this apartment building were not activated during the earthquake.

Hence, it is important to consider the effects of structural response to estimate the number of gas meter shutoffs in an actual environment.

To achieve the objective, a simplified method to estimate the response acceleration at each floor was considered in this study. In Japan, various kinds of 3D GIS data are developed in urban areas. The heights of buildings can be obtained from those datasets. However, the structural information to conduct a seismic response analysis is difficult to get. Based on this background, the response acceleration of multistory buildings is estimated using the seismic record at a district regulator and the heights of buildings in this study.

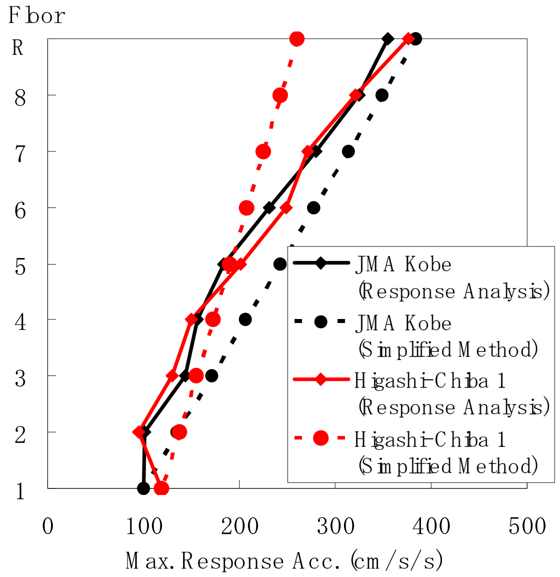


Figure 5. Estimation of the maximum response acceleration on each floor for an 8-story RC building

Assuming an N-story building exists, the predominant period of the building, T, can be estimated as $0.06N$ s for a reinforced concrete (RC) structure [5]. Then, the response acceleration at the roof of the building, Acc_N, is estimated as

$$Acc_N = \beta \cdot u_N \cdot S_A(T) \tag{1}$$

where $S_A(T)$ is the response acceleration spectrum when the period of SDOF is equal to T. u_i is the assumed 1st mode shape at the roof of the i-th story, and β is the participation factor of the 1st mode. u_i and β are described as

$$u_i = \sin\left(\frac{i}{N} \cdot \frac{\pi}{2}\right) \tag{2}$$

$$\beta = \sum_{i=1}^{N} m_i \cdot u_i \Big/ \sum_{i=1}^{N} m_i \cdot u_i^2 \tag{3}$$

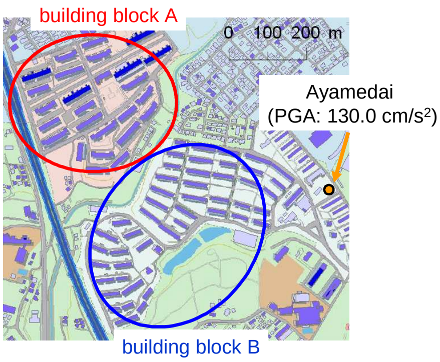
where m_i is the mass of the roof at the i-th story, and all the masses are assumed to be uniform.

The response acceleration at the ground floor is assumed to be equal to the PGA recorded by an accelerometer on the ground. Then, the response acceleration on the floor of the k-th story, Acc_k, is interpolated as

$$Acc_k = (Acc_N - PGA) \cdot \frac{k-1}{N} + PGA \tag{4}$$

The damping ratio of RC structures is assumed to be 5 % in this study.

Figure 5 shows the comparisons between the results of seismic response analysis and those of the simplified method proposed in this study. The numerical model of an 8-story RC building [6] is employed to compare the results, and the input ground motions used were recorded at Japan Meteorological Agency (JMA) Kobe during the 1995 Kobe earthquake and at Higashi-Chiba 1 regulator of Tokyo Gas during the 2005 North-western Chiba earthquake. The JMA Kobe record was scaled to PGA equal to 100 cm/s^2 to conduct a seismic response analysis. The maximum response acceleration obtained by the simplified method gives a reasonable estimation, however, the number of input ground motions and numerical structural models employed in the study is not large enough to demonstrate the accuracy quantitatively.



building block A (11-story)

Floor	Shutoff	Non-shutoff	Response Acc. (cm/s^2)
11	1		181
10	2		176
9		1	171
8		1	166
7		1	161
6		2	155
5		4	150
4		1	145
3		2	140
2		2	135
1			130

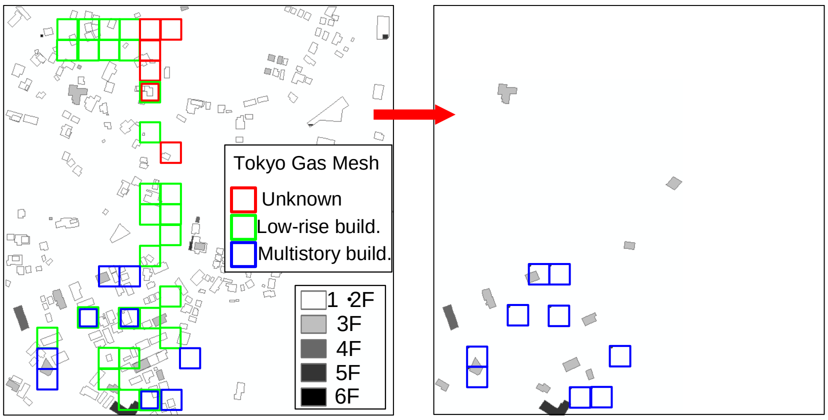
building block A (5-story)

Floor	Shut off	Non-shutoff	Response Acc. (cm/s^2)
5	7		271
4	1		236
3	1	7	200
2		6	165
1		9	130

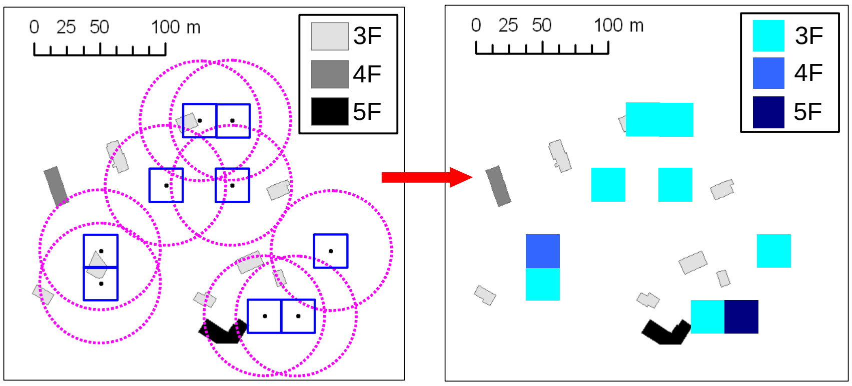
building block B (5-story)

Floor	Shutoff	Non-shutoff	Response Acc. (cm/s^2)
5	2	1	271
4	3	2	236
3	4	2	200
2		2	165
1		9	130

Figure 6. Seismic shutoff of intelligent gas meters in multistory buildings after the 2005 North-western Chiba earthquake and estimated response acceleration on each floor



(a) Extraction of multistory buildings from meshed data and 3D GIS



(b) Assignment of the number of stories of a building to the meshed data

Figure 7. Adjunction of the number of stories of a building to the meshed data developed by Tokyo Gas using a 3D GIS data

The simplified method proposed in this study was applied to the results of gas meter shutoffs after the 2005 North-western Chiba earthquake. Figure 6 shows the state of seismic shutoff of gas meters after the earthquake and the estimated maximum response acceleration for multistory buildings. The number of stories of buildings was estimated using the heights of buildings extracted from 3D GIS data named MAPCUBE [7]. The height of each story was assumed to be 3 m in this study. Two apartment blocks are illustrated in the figure, and the nearest seismic observation station is Ayamedai, where the recorded PGA was 130.0 cm/s^2. More gas meters shut off gas supply on higher floors. The response accelerations on the floor where the gas meter was activated are estimated larger than about 175 cm/s^2 in these cases.

Tokyo Gas Co., Ltd. has developed the building dataset in the area where they provide the service. In the mesh with the size of 25 m x 25m, the number of customers and the building type (multistory or low-rise building) are stored. Combining the building dataset with the 3D GIS, the number of stories can be added to the mesh (Fig. 7). First, only the meshes categorized as multistory buildings and the buildings whose estimated number of stories is equal to or larger than 3 were extracted from the two datasets (Fig. 7(a)). Then, the number of stories of the nearest building from the center of the mesh is registered to the meshed data (Fig. 7(b)). Using the earthquake records, the simplified response model for multistory buildings and the revalidated meshed data, the state of seismic shutoff of gas meters in multistory buildings can be estimated after an earthquake.

4. COMCLUSIONS

The methodology to estimate the condition of seismic shutoff of intelligent gas meters in multistory buildings was considered using a simplified response model and 3D GIS data. The results of simplified response model show good estimations to some extent although the number of examples is still limited. The accuracy of the proposed methodology should be investigated with more case studies in real situations.

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