

# SAFETY ASSESSMENT OF UNDERGROUND TANK AGAINST LONG-PERIOD STRONG GROUND MOTION - DEVELOPMENT OF EARTHQUAKE DISASTER WARNING SYSTEM USING REAL-TIME EARTHQUAKE INFORMATION-

# Tatsuya IWAHARA<sup>1</sup>, Tsukasa MITUTA<sup>1</sup>, Yuji HORII<sup>1</sup>, Kenji KATO<sup>2</sup>, Naoto OHBO<sup>2</sup>, Akira ISHII<sup>2</sup>, and Tomonori HAMADA<sup>2</sup>

Japan oil, gas and Metals National Corporation, Tokyo, Japan,<sup>2</sup> Kajima Corporation, Tokyo, Japan Email:iwahara-tatsuya@jogmec.go.jp,mitsuta-tsukasa@jogmec.go.jp,horii-yuji@jogmec.go.jp, katokenji@kajima.com,ohbo@kajima.com,ishii@kajima.com,hamadtom@kajima.com.

## **ABSTRACT :**

It will be difficult to prevent the damage of tanks caused by a large earthquake even if extreme care has been exercised. Therefore, tank checking priority information system against tank damage by liquid sloshing due to large earthquake is very effective.

In order to make earthquake disaster warning system against the tank damage by liquid sloshing, we developed a system that can quickly and real-time evaluate velocity spectrum using earthquake early warning information and earthquake data at the Akita Oil Storage Base.

This system processing flow is (1) Evaluation of arrival time and seismic intensity using earthquake early warning information. (2) Evaluation of potential tank damage by sloshing using earthquake early warning information. (3) Transmission of potential tank damage to a mobile telephone or an email. (4) Evaluation of potential tank damage by sloshing using earthquake wave data. (5) Transmission of potential tank damage to a mobile telephone or an email.

**KEYWORDS:** Long-period ground motion, oil storage tank, sloshing system, earthquake early warning information, earthquake observed data

## **1. INTRODUCTION**

Based on the damage assessment of tank in Tomakomai area due to the 2003 Tokachi-oki Earthquake (Hatayama 2003), the ground motion level for evaluating the sloshing height inside oil tank (hereafter called the ground motion level), which had been specified in the public notice of the Ministry of Home Affairs (Ministry of Home Affairs 1983), was revised in the public notice of the Ministry of Internal affairs issued on January 14, 2005 (The Ministry of Public Management, Home Affairs, Posts and Telecommunications 2005). According to the public notice, the ground motion level before the revision, which has been the same for all the regions in Japan, is used as the bottom level, and the ground motion level vary from the region to region with the highest one being almost twice as large as the bottom level. The ground motion level for a region is determined based on the observed ground motions in the same region by the Meteorological Agency of Japan. However, the highly satisfied accuracy has not been acquired because the ground motion depends on the local ground conditions.

Investigation was performed on the sloshing of large scale oil tank including underground one during the past large earthquakes, and it was confirmed that the analytical results significantly differed from the observed ones. Therefore, it has become necessary to improve the prediction accuracy of the ground motion employed for sloshing evaluation and study the occurrence possibility of long-period earthquake motions.

Long-period ground motions are caused by the specific characteristics in the magnitude of earthquake, epicenter location and geological structure through which seismic waves propagates. The observation of long-period ground motions was conducted to investigate if the geological structure at and around Akita oil tank site would cause remarkable long-period ground motions. Based on the investigation results, the faults in the objective area were clarified and long-period ground motions were calculated. The safety of underground oil tank regarding the sloshing was evaluated.

As the investigation result, no ground motion was confirmed to contain the periods of fundamental sloshing.



During Nihon-Kai-Chubu Earthquake, however, the sloshing was observed. Thus, seismographs were installed to study the occurrence possibility of long-period ground motions and accumulate related observed data.

A real-time sloshing evaluation system was developed to prevent disaster during large earthquakes, and the sloshing height could be evaluated in real time using the observed records.

This paper firstly introduces the characteristics of the seismographs and the outline of the real-time sloshing evaluation system using the earthquake early Warning (E E W) information distributed by Japan Meteorological Agency. Then the observed ground motions are analyzed, and the occurrence possibility of long-period ground motions is discussed. In addition, the operating situation of the real-time sloshing evaluation system is introduced.

#### 2. OUTLINE OF REAL-TIME SLOSHING EVALUATION SYSTEM

Disaster prediction system has been established in many fields using the earthquake information such as magnitude and location. The real-time usage of observed records during earthquakes has been investigated to improve these systems. In these previous systems, however, the main purpose has been the data accumulation, and only the maximum acceleration, maximum velocity and SI value have been used (Kausaka 1998).

Recently, earthquake observation and data processing capability has been significantly improved and the internet usage has become mush easier. Under such circumstance, the real-time damage checking systems for bridges have been developed using the observed record during earthquakes, and are being adopted in earthquake observation for various civil engineering structures and liquefiable surface ground (Ohbo 2004). The damage prediction system of oil tanks has also been proposed, but it has been only the usage of other earthquake observation data processing system (Zama et al, 2002, Zama, 2004).

The sloshing inside tank occurs when the ground motion at the site contains the period which is the same as the fundamental period of tank sloshing. The tank sloshing period depends on the size and the amount of inside oil. For instance, the fundamental sloshing period of large tank with radius of 100m is around 10 seconds. Long period ground motions mainly arrive as the surface wave after the arrival of the main waves during large earthquakes, and there is a time lag after the main waves. Taking advantage of this time-lag characteristic, a real-time sloshing evaluation system was developed.

The outline of the real-time sloshing evaluation system, which uses the observed records by seismographs and the E E W distributed by Japan Meteorological Agency, is shown as the followings.

#### 2.1. Real-time sloshing evaluation system using observed records by seismographs

Sloshing is caused by the surface wave (long period ground motion) arriving after the main body waves.

Therefore, the occurrence of sloshing can be predicted to a degree by clarifying the earthquake faults which generate long period seismic motions. In addition, there is a time lag for the arrival of surface waves after the main body waves. Figure 2.1 displays the flow of processing and information transferring of the sloshing evaluation system using observed records by seismographs. The system consists of seismographs, processing system and evaluation system (Ohbo, 2005). The processing contents information and transferring items of each system are shown as the followings.

# Seismograph Processing system Measure intensity Measure intensity Report of magnitude Maximum velocity Evaluation system Sloshing evaluation on oil amount Evaluation of checking priority

1) Processing system

a) Seismograph informs the occurrence of

Figure 2.1 Flow of processing and information transferring of the sloshing evaluation system using observed records by seismograph.

# The 14<sup>th</sup> World Conference on Earthquake Engineering October 12-17, 2008, Beijing, China



earthquake.

- b) Maximum acceleration, maximum velocity and measure intensity are informed.
- 2) Evaluation system.
  - a) Sloshing period of tank is evaluated using the tank information prepared in advance.
  - b) Velocity response spectrum at a particular period is evaluated using the observed records.
  - c) The sloshing height of each tank is computed, and informed.

## 2.2. System improvement using E E W

By using the E E W distributed by Japan

Meteorological Agency (http: J M A, 2007), the

information of 'earthquake is coming' can be reported to the oil tank base before the arrival of the earthquake, and the corresponding management can be arranged and the safety of workers can be secured. In addition, the checking works can be quickly prepared if the sloshing occurrence can be predicted based on the above information. The functions of the system using only the earthquake early warning information before the start of the recording by seismographs are displayed as the followings.

As the E E W information, the occurrence time, epicenter and magnitude of the earthquake are distributed. Based on this information, the system can compute the possible intensity and the arriving time of the main waves and distribute the information to the PCs and cell phones of managers, and the manager in charge of announcement on the premises. Figure 2.2 shows the process flow.

The processing contents and information transferring items of the system are shown as the followings.

## 1) Processing system

- a) Prediction of intensity using magnitude and epicenter location of earthquake.
- b) Calculation of time duration before main waves comes.
- c) Report of the above results.

2) Evaluation system

- a) Spectrum prediction using epicenter location and magnitude information.
- b) Calculation of sloshing height using the predicted spectrum.
- c) Report of the above results

This system was developed based on the fact that the sloshing is caused by the surface waves (long period ground motion components) becoming predominant

after the arrival of main body waves.

# **3. DEVELOPMENT OF SYSTEM**

## 3.1. Outline of Akita oil storage base

Akita Oil Storage Co. Ltd was established in 1982, and the construction of four underground oil tanks were completed in the west-base area in 1989, six oil tanks in the east-base area in 1992, and four oil tanks and twelve underground tanks in 1995. The Nihon-Kai-Chubu earthquake of 1983 had not affected the underground tanks because no tank was completed then. The arrangement of



Figure 3.1 Location of tanks at Akita base



Figure 2.2 Flow of the system using E E W.



tanks and the basic information of tanks are shown in Figure 3.1 and Table 3.1, respectively (http: Akibi,).

# 3.2. Seismograph Installment and information distribution

Seismographs, which could record velocity wave of period until 20 seconds with high accuracy, were installed and the earthquake observation was started in October 2006. At the same time, the system started the distribution of trigger status information when seismographs start recording, and the distribution of the maximum acceleration/velocity and measured intensity after the arrival of the maximum amplitude to the cell phones and PCs of the

Table	Table 3.1 Basic tank information and fundamental period							
BASE	TVDE	Number	Height	Diameter	Sloshing			
DASE	TIL	Number	H(m)	D(m)	Period(s)			
	Under	4	18	00	10.1			
WEST	Ground	4	40	90	10.1			
	Ground	2	23.2	83.4	10.9			
	Ground	2	20.2	82.3	11.2			
EAST	Under Ground	8	48	97	10.6			

managers in charge of disaster prevention. The use of the ground motion information in disaster prevention was started.

# 3.3. Outline of the system using earthquake information

The trial operation of the real-time sloshing evaluation system using the observed records by seismographs during earthquakes (hereafter called disaster prevention system), was started in November of 2007.

In this system, the ground motions recorded by seismographs are processed in real time, and the sloshing height is computed instantly and the results are distributed to the managers in charge of disaster prevention. The fundamental functions of the system are as the followings.

- (1) When seismograph starts to record the ground motion, the trigger information is sent out and the start of the system is reported.
- (2) Within the same network, the earthquake information is automatically displayed on the screen of PC (Figure 3.2). The mark is displayed, and the color of the mark is corresponding to the degree of danger.
- (3) Earthquake information is distributed to PCs and cell phones.
- (4) The comparison results of sloshing height and tank height are distributed (Figure 3.3).







Figure 3.3 Display on cell phone.

# 3.4. Outline of the system using E E W information

The earthquake disaster prevention information could be provided before and after the seismic wave arrives at

# The 14<sup>th</sup> World Conference on Earthquake Engineering October 12-17, 2008, Beijing, China



Akita oil storage base during an earthquake. For the Akita oil storage base, the earthquakes that would cause long period ground motions are supposed to occur relatively far in the ocean, and the just-prior preparation of several tens of seconds becomes possible if the earthquake early warning information is employed.

In the use of the earthquake early warning information, an intensity prediction formulation was developed using the earthquake intensity information in by Japan Meteorological Agency for Akita-base and the surrounding areas, because it is necessary to predict the intensity at high accuracy.

The observed data by seismographs in east-base and west-base of Akita oil storage base was adopted. As for the site of municipal office of Oga, the intensity information by Japan Meteorological Agency was used because the observed data was not available. In addition, the observed intensity data (number of data is 531) obtained from

1926 to September of 2007 at Akita Local Meteorological Station, which is about 27km from the tank site, was employed. In the intensity prediction formulation, the distance attenuation equation was firstly evaluated using intensity data at Akita Local Meteorological Station which has large numbers of recorded data. Next, the distance attenuation equation for the tank base site was studied by revising the constant term through relative comparison of intensities with distance effects being corrected. Two types of distance attenuation formulations were evaluated through regression analysis. One is for earthquakes with epicenter depth being larger than 20km, the other is for those less than 20km. The dependency on the depth was considered in the formulation for the deeper



earthquakes with epicenter.

earthquakes. In addition, the correcting term (residual term) was evaluated to be dependent on epicenter location in order to take account of the difference in epicenter characteristic and wave propagation effects. As one example, Figure 3.4 shows the distribution of residual term for the earthquakes with epicenter depth being smaller than 20km. The detail of the evaluation is presented in reference (Kanda et al, 2006).

## 4. OPERATION RESULTS OF THE SYSYTEM

#### 4.1. Long period ground motions observed at the oil tank base

The earthquake observation was started in October of 2006, and the ground motions during 62 earthquakes have been observed until the end of June of 2008. Table 4.1 shows the list of the earthquake. Figure 4.1 and 4.2 show the velocity waves and Fourier spectra for Event-1 (Chisimarettou-Oki earthquake) and Event-10 (Iwate-Miyagi-Nairiku earthquake) with long period ground motions being observed, respectively. At the Akita oil storage base, it is confirmed that there had been long period

Table 4.1 Lannquake Event Information								
Event No.	Origin Time	Longitude	Latitude	М	Depth (km)	Epicentral Distance (km)	Intensity	Predicted Intensity
1	2007:01:13	155.100	46.900	8.2	30	1454	1	-
2	2007:03:25	136.685	37.220	6.9	11	403	1	-
3	2007:07:16	138.608	37.557	6.8	17	278	2	-
4	2007:10:31	145.487	19.223	7.1	216	2315	0	-
5	2007:11:26	141.757	37.303	6.0	44	330	0	-
6	2008:04:17	140.233	39.042	5.8	166	98	1	1
7	2008:05:08	141.607	36.227	7.0	50	433	1	1
8	2008:05:12	103.500	31.100	7.9	10	3406	0	0
9	2008:05:19	132.480	42.473	5.9	569	680	0	0
10	2008:06:14	140.880	39.028	7.2	8	128	4	3

Table 4.1 Earthquake Event Information

ground motions with period of 6-10 seconds, which are the sloshing periods of some tanks. And the ground motions during Niigata-Chuetsu earthquake, which occurred soon after the start of the observation, was also observed, and the components with period of 3-7 seconds were confirmed which displays the possibility that the



components of the same period might be predominant in the seismic waves propagating in Nihon-Kai coast.



#### 4.2. Operation of earthquake disaster prevention system using observed data by seismographs

The earthquake disaster prevention system was installed on October 24, and the operation was started at the same time. The distribution of evaluated results are started when the measured intensity is larger than 1. Table 4.2 represents the list of the earthquakes when magnitude is larger than 5.8. During these earthquakes, the system was started. Only the information when the intensity at the tank oil base is equal to or larger than 1 was distributed to the interested persons.

The distributed information during Iwate-Miyagi-Nairiku earthquake of June 14, 2008 is shown in Figure 4.3. The occurrence time of the earthquake is 8:43:46, and the system distributed the information that P wave arrived at 8:44:08, the maximum acceleration and intensity at 8:44:45, and the checking priority information of tank at 8:47:20.

#### 4.3. Operation of earthquake disaster prevention system using E E W information

The trial operation of the system using earthquake early warning information was started in March of 2008. The



system was started during the earthquakes with the predicted intensity shown in Table 4.2. In this system, the

secondly distributed data among the earthquake early warning information is used to evaluate possible intensity and time-lag. In this table, it can be confirmed that the predicted intensity agrees well with the intensity at the tank base in two earthquakes. However, the intensities are different in these two earthquakes. This is because of the error in the earthquake

magnitude information secondly distributed in earthquake early warning information. Now, the system is independent of the earthquake disaster prevention system using the observed records by seismograph, and the merged system of the two systems are planning to be developed.

#### 5. Conclusions

In order to establish damage warning system of large oil tanks at Akita oil storage base due to sloshing during large earthquakes, a system being able to process observed velocity waves in real time was developed. The main completed items and the obtained results are as the followings.

1. Seismographs were installed at Akita oil storage base to investigate the possibility of the arrival of long period ground motions, and the earthquake observation was started.

Table 4.2 List of earthquakes during which the system is started

Event	Origin	Longitudo	Latitude	М	Sloshing	Intensity	Predicted
No.	Time	Longitude			Hight(m)		Intensity
6	2008:04:17	140.233	39.042	5.8	0.01	1	1
7	2008:05:08	141.607	36.227	7.0	0.02	1	1
8	2008:05:12	103.500	31.100	7.9	0.04	0	0
9	2008:05:19	132.480	42.473	5.9	0.00	0	0
10	2008:06:14	140.880	39.028	7.2	0.21	4	3

Intencity : 4 Max. Acc. : 64.3 Gal

Lonk	Damage	Topl: No	Sloshing	Sloshing
Lank	Level	Talik NO.	period (s)	Hight (m)
1	1	TK-25	6.35	0.21
2	1	TK-26	6.35	0.21
3	1	TK-23	11.50	0.16
4	1	TK-24	11.51	0.16
5	1	TK-22	11.20	0.16
6	1	TK-11	10.61	0.20
7	1	TK-06	10.61	0.20
8	1	TK-12	10.61	0.20
9	1	TK-05	10.61	0.20
10	1	TK-07	10.66	0.20
11	1	TK-10	10.66	0.20
12	1	TK-01	10.19	0.19
13	1	TK-04	10.19	0.19

Figure 4.3 Tank checking priority information.

2. Using the observed records by seismographs, the sloshing of tank was evaluated, and an earthquake disaster prevention system was developed which is able to inform the checking priority of the oil tanks when long period seismic wave arrives, with the margin in height of tank being used as evaluation index.

- 3. Intensity prediction formulation at Akita oil storage base was developed using the earthquake early warning information, and an earthquake disaster prevention system was established.
- 4. Since the start of the operation of the earthquake disaster prevention system, several tens of earthquakes have been observed, and the evaluated results were distributed to the cell phones and PCs, and the validity of the system was confirmed.

The improvement of the system has been planned in order to use the observed data and earthquake early warning information more efficiently. It is also necessary to establish a system which could be operated in the frame of the disaster prevention manual prepared at the oil storage base.

#### REFERENCES

Hatayama, K., (2006), Long-Period Strong Ground Motion and damage to Oil Storage Tanks due to the 2003 Tokachi-Oki Earthquake, International Workshop on Long-Period Ground Motion Simulation and Velocity Structures, Earthquake Research Institute, University of Tokyo, 73-78

Ministry of Home Affairs (1983), No.119 in notification (in Japanese).

The Ministry of Public Management, Home Affairs, Posts and Telecommunications (2005), No.30 in



notification(in Japanese).

- Kousaka, M., Kojima, S., and Ohbo, N., (1998), Earthquake Damage Estimation System for City Gas Supply System, The 10th Earthquake Engineering Symposium, pp.3507-3512 (in Japanese).
- Ohbo, N., Yamanobe, S., and Kutsuna, K., (2004), Developments of real-time damage evaluation system of civil structures, Proceedings of the Symposium on application of real-time information in disaster management, pp.39-42(in Japanese).
- Zama, S., Hatayama, K., Yoshida, S., Kawano, K., Sekine, K., and Maruyama, H., (2002), Building a Real Time System for Evaluating Oil Storage Tank Damage due to Earthquakes in Petroleum Stockpiling Base, Journal of High Pressure, pp.26-37(in Japanese).
- Zama, S., (2004), Seismic Hazard Assessment for Liquid Sloshing of Oil Storage Tanks due to Long-Period Strong Motions in Japan, 13th World Conference on Earthquake Engineering, Paper No. 3200.
- Ohbo, N., and Kato, K., (2005), Development of Real-Time Sloshing Evaluation System, Proceedings of the Mini-Symposium on technology for mitigation of sloshing damages for large tank, pp.15-18(in Japanese).
- http://www.jma.go.jp/jma/indexe.html
- http://www.akibi.co.jp/index.html.
- Kanda K., Nasu, T., Miyamura, M., and Kobori, T., (2006), Application of Earthquake Early Warning System to Construction Site., 4th World Conference on Structural Control and Monitoring, pp.1-8,