Present state of measurement of earthquake motion and nation-wide networking of seismographs at dam sites in Japan

by

Syuji TAKASU¹), Hitoshi YOSHIDA²), Yoshikazu YAMAGUCHI³), Takashi SASAKI⁴) and Kenji INAGAKI⁵)

ABSTRACT

The SMAC-type strong motion recorder was installed in the Sarutani Dam in the Kinki Region, Japan in 1957, and strong motion observation on dam structures under the jurisdiction of the MLIT, the Ministry of Land, Infrastructure, and Transport (formally the Ministry of Construction) had been started. Since the Niigata Earthquake in 1964, the necessity of strong motion observation has been widely recognized and the Ministry has been positively promoted the installation of seismometers in dams.

Nowadays, the 413 dams under the jurisdiction of the Ministry have seismometers and the high-density observation of earthquake records can be conducted. Furthermore, the network of observation of earthquake records at dam sites has been speeded, the 236 seismometers at 50 dam sites have been connected to the Public Works Research Institute (PWRI), presently the National Institute for Land and Infrastructure Management (NILIM).

This report describes the present state of earthquake data measurement at dams under jurisdiction of MLIT, the characteristics of collected data, and the outline of the dam-site seismograph network that is now being constructed.

KEY WORDS: Strong motion records, Dam, Seismometer, Network of observation of earthquake record

1. INTRODUCTION

Many large earthquakes struck Japan and caused severe damage on important infrastructures and private properties. Fortunately, no dams in Japan has suffered damage that threatened its safety, but clarifying and securing the earthquake safety of dams is one of the most important missions that must be faced in densely populated Japan. To respond to a strong demand for the advancement of evaluating methods of the earthquake safety of new and existing dams, it is important to study the characteristics of seismic motion at rock foundation and the dynamic behavior of actual dams based on observed records measured at various dam sites. Installing seismographs at dams have been speeded since the

 Group Leader, Hydraulic Research Group (HRG), Public Works Research Institute (PWRI),
1-6 Minami-hara, Tsukuba-shi, 305-8516,
JAPAN

2) Research Coordinator for Watershed Management, River Department, National Institute for Land and Infrastructure Management (NILIM), Ministry of Land, Infrastructure, and Transport (MLIT), 1 Asahi, Tsukuba-shi, 305-0804, JAPAN

3) Head, Dam Structures Research Team, HRG, PWRI

4) Senior Researcher, Dam Structures Research Team, HRG, PWRI

5) Researcher, Water Management and Dam Division, River Department, NILIM, MLIT

1995 Hyogo-ken Nanbu Earthquake (the Kobe Earthquake) and all dams have seismographs under jurisdiction of the MLIT now.

2. PRESENT STATE OF MEASUREMENT OF EARTHQUAKE MOTION AT DAMS IN JAPAN

(1) Background

The measurement of earthquake motion at dams began in 1957 when the Ministry of Construction (presently the MLIT) installed a SMAC-type strong motion seismograph at the Sarutani Dam to obtain data vital for dam safety management and to advance seismic resistant design. The installation of strong motion seismographs was promoted in response to a growing awareness of the need for strong motion observations following the Niigata Earthquake in 1964.

At the Kobe Earthquake in 1995, a lot of several strong motion records at dam sites were observed, but some dams near the earthquake faults didn't have seismometers, so the strong motion records at dam sites near the earthquake faults were not got unfortunately. The Ministry, therefore, decided to place the seismometers in all dam sites under its jurisdiction, and to replace the old-fashioned analog seismometers to the new digital seismometers. By the end of 2000, all dam got the seismometers.

(2) State of installation of strong motion seismographs

By the time of the Hyogo-ken Nanbu Earthquake, 443 strong motion seismographs were installed at 140 dams (MLIT's dams: 48, Water Resources Development Public Corporation's dams: 10, Subsidized prefectural dams: 82), but 1,152 have now been installed at 413 dams (MLIT's dams: 78, Water Resources Development Public Corporation's dams: 20, Subsidized prefectural dams: 315). Figure 1 shows the locations of the dams where the installation of strong motion seismographs has been completed, and Figure 2 shows changes in the number of strong motion seismographs in operation.

(3) Standard installation method of seismographs at dams

Strong earthquake motion observations at dams play an important role in dam safety management and studies of the response of the dam to strong motion in bedrock. Therefore, in principle, installation of seismographs is done at the base and at the crest of each dam in the maximum cross section. But because differing responses appear at bridges and pier structures on dam crest, installing seismographs at these locations is avoided generally. Table 1 shows a breakdown of strong motion seismograph installation locations. Dam base mainly means the gallery near the base of concrete dams or the gallery beneath the impervious zone of rockfill dams. Other locations include rim grouting tunnels, water intake systems, and management offices. Data observed at foundations under the dam include reflected waves from on the dam body. Therefore, installation of seismographs on the downstream free field is recommended¹⁾.

The components measured by a seismograph are set of course as 2 horizontal components and 1 vertical component. Vibration of dam body occurs most easily at right angles to the dam axis because of the vibration characteristics of dams. Therefore, the directions of the horizontal components are, in principle, right angles to the dam axis and the dam axis direction.

Earthquake observations are normally performed in trigger mode; the seismographs are all linked and begin recording simultaneously when a certain standard value is exceeded. In general, trigger seismograph is located at dam base.

Strong motion seismographs that are now installed at dam sites include analog type seismograph and digital type seismographs. Figure 3 shows the state of installation of analog type and digital type seismographs. Initially, most were analog type equipped with a moving pendulum to record earthquake motion on paper, but most of those now in use are digital type that converts earthquake motion to electrical output that is then digitized by an AD converter and recorded on an IC card etc. In the case of new installation, only digital type seismographs are now selected.

3. CHARACTERISTICS OF ACCELERATION AT ROCK FOUNDATION OF DAM SITE

Two reports about the collection of observed acceleration data at dam sites by the PWRI were published in January, 2001. The first report²⁾ is about the information of the locations and the specifications of seismographs in each dam at the time of 2000. The second report³⁾ summarizes the acceleration data and spectrum, and information of earthquakes. The number of records dealt with in this report is 2,960 collected in from 1966 to 2000.

In this paper, the characteristics of horizontal acceleration records in dam foundations have been examined based on records of observed earthquake data. Dams under the jurisdiction of the MLIT were all constructed on rock foundations. The S-wave velocities of dam foundations are therefore, expected to be at least 1,000 m /sec.

The 143 sets of, 286 in total of horizontal acceleration records were used in this study. These data were collected during earthquakes with a magnitude of 5 or more and observed at an epicentral distance of 200 km or less. Figure 4 shows the distribution of the earthquake epicenters and Figure 5 shows the relationships of the magnitude, hypocenter depth, and peak acceleration with the epicentral distance. The distribution of observed results is relatively dispersive.

Figure 6 shows the relationship of the epicentral distance with the peak acceleration. The data are shown with the presumption values by the attenuation relationship equations by Fukushima et al.⁵⁾ and An-naka et al.⁶⁾ These two attenuation relationship equations are based on the data mainly collected on hard soil foundation. The data of dam sites seem to be small as compared with the presumption values.

Figure 7 shows acceleration response spectra. And,

Figure 8 shows acceleration response magnification spectra.

Figure 9 shows acceleration response spectra for different epicentral distances. Figure 10 shows acceleration response magnification spectra obtained by dividing acceleration response spectra by the peak acceleration values. In order to investigate the characteristics of the relatively strong motions, the data shown in these figures are reduced data observed earthquakes of a magnitude 6 or more and within 100 km of the epicentral distance. The number of extracted data is 122. The peak value of response magnification spectrum is about 2 for all earthquake magnitude and epicentral distance, and the peak values mostly appear within the periods of 0.1-0.2s. The response magnification spectrum decreases rapidly for the period over 1 sec, and the larger earthquake magnitude is, the smaller the decreasing rate of the response magnification spectrum according to the period is.

4. DAM SEISMOGRAPH NETWORK

Because the observed data are very valuable and indispensable for the investigation of seismic resistance of dams, the MLIT have been made a periodical collection of the data observed at dams under its jurisdiction. Now, the dam offices should report the earthquake records to once a year and the information of observation system in the event of new installation or updating of seismographs to the NILIM, the MLIT. The detailed format is fixed for the report and the data in fixed format is sent to the NILIM by floppy disks.

The MLIT is connecting seismographs installed at dams in a network to construct a system that can monitor earthquakes in real time for responding to demand of earthquake disaster management. The dam seismograph network is connected by the direct microwave circuit, and enables quick collection of not only the maximum acceleration values but also time-history acceleration data. This network system is now monitoring 50 dams of the MLIT.

This system consists of earthquake information

monitoring parts and a data base system. Figure 11 shows the outline of the network system, and Figure 12 shows a sample screen on a display terminal.

(1) Monitoring

The seismograph network monitors earthquakes by connecting a server at the NILIM with relay devices installed at each dam using microwave circuits which is dedicated to the MLIT.

(2) Data base

The database consists of basic information of dam, information of seismograph, earthquake information and measure data. The following is the actual examples of the items in database.

a) Basic information of dam

Dam height, dam length, latitude, longitude, epicentral distance, dam type, slope gradient, etc.

b) Seismograph information

Seismograph model number, specification of seismograph, installation position, installation elevation, etc.

c) Earthquake information

Occurrence time, epicenter location, depth, magnitude, etc.

d) Measure data

Components, peak acceleration, number of samples, number of data, etc.

(3) Function and operation

At the instant that a seismograph at a dam detects an earthquake, the peak acceleration and the measured seismic intensity of the earthquake are transmitted through relay devices to the NILIM database. When the earthquake information arrives at the NILIM from a dam relay device, a message that an earthquake has occurred is displayed on a terminal screen at the same time as an alarm is sounded. And this system automatically starts the collecting of earthquake records from dams nearby the dam that firstly send a data. The dam seismograph network is connected to other seismograph networks⁶⁰ for national facilities related rivers and roads, and is sharing data such as the peak acceleration and measured SI value etc.

The shared information is utilized for immediate expectation of disaster occurrences such as the ground liquefaction the damage of bridge etc. Some kind of digital data such as the peak accelerations opens public through the Internet.

For maintaining of system functions, the state of the system is constantly monitored once a day by confirmations of the soundness of each relay device, and by checking of the existence of untransmitted earthquake data.

5. FUTURE PLANS

The researches on evaluation methods of seismic safety of dams have been conducted using data are accumulated in the PWRI and the NILIM.

According as the system to collect the observed earthquake data from jurisdictional dams has been completed and networking of seismographs has been progressing, the related researches are expected to be advanced. Future plans for the seismograph network include cooperating with prefectural governments to link the network to seismographs at all prefectural dams in order to create a more precise, more highly concentrated earthquake motion monitoring environment.

The networking of seismographs enables quick collection of the earthquake information. The network is, therefore, counted on to make a big contribution to supporting an efficient and appropriate initial emergency action: evaluating the need for inspections of managed facilities, predicting the state of damage etc. immediately after the earthquake when little information is available.

It is, moreover, very important to share earthquake information each other in organizations responsible to the disaster prevention.

And the collection and accumulation of recordings of actual seismic data are essential to researches on the dynamic analysis methods of dams. Therefore, one of important subjects of the network is linkage to the database of detailed data of foundation and dam material for the precise estimation of earthquake motion distribution and dam behavior.

When the networking of seismographs of all dams under jurisdiction of the MLIT, the collection data by the NILIM through the network will be take the place of the report of earthquake data form dam offices to the NILIM. For improvement of the reliance of the network system, the supervising function of system should be strengthened to be preventing the functional trouble and deterioration.

REFERENCES

1) Y. Yamaguchi, T. Iwashita: Earthquake Motions at an Embankment Dam Site and an Estimation Method of Incident Seismic Waves Using the Observations, Proceeding of the 32nd Joint Meeting of UJNR Panel on Wind and Seismic Effects, pp. 253-262, 2001 2) Y. Yamaguchi, T. Iwashita, J. Matsuura: Seismometers Installed in the Dams Under the Jurisdiction of the Ministry of Land, Infrastructure and Transport, Technical Memorandum of PWRI, No.3768, 2001.

3) Y. Yamaguchi, T. Iwashita: Earthquake Motion at Rock Foundation and Response of Embankment Dams by Acceleration Records at Dams in Japan, Technical Memorandum of PWRI, No.3780, 2001.

4) Fukushima et al.: Shimizu Tech. Res. Bull., Vol.10, 1-11, 1991 (in Japanese)

5) An-naka et al.: 19th JSCE Earthquake Engineering Symposium, 129-132, 1987 (in Japanese)

6) H. Sugita, T. Hamada: Development of Real-time Earthquake Damage Estimation System for Road Facilities, 7th U.S-Japan Workshop on Earthquake Disaster Prevention for Lifeline Systems, 1997

Location	Number of Seismographs	Ratio (%)
Dam base	400	34.7%
Dam crest	426	37.0%
Free field	290	25.2%
Other	36	3.1%
Total	1152	100.0%

Table 1 Seismograph installation locations



Figure 1 Distribution of dams where seismograph installation is completed



Figure 2 Changing number of seismographs



Figure 3 Transition of number of analog type and digital type seismographs



Figure 4 Distribution of earthquake epicenters



Figure 5 Relationship of magnitude, hypocenter depth, and peak acceleration with epicentral distance



Figure 6 Relationship of epicentral distance and peak acceleration



Figure 7 Acceleration response spectra (dam base, horizontal)



Figure 8 Acceleration response magnification spectra (dam base, horizontal)



Figure 9 Acceleration response spectra by epicentral distance interval of 20km (average, dam base, horizontal)



Figure 10 Acceleration response magnification spectra by epicentral distance interval of 20km (average, dam base, horizontal)



Figure 11 System configuration of the real-time dam seismograph network system

UNICE.							
IYE I	ダム地震計画	日録収集システム					
	7 × 16 × 11 1	0 ** ** * * * * * *					
中維装置	感音器	観測年月日	囊度	ダム軸	上下流	給直	加速度F
1021	天籁中央	2002-03-25 22:58:55.330	1.7	0018	0010	0005	地震夠
41.21	應設監査庫	2002-03-25 22:58:55.330	0.9	0003	0003	0003	地震角
和潮	ダムサイト左岸	2002-03-25 22:58:55.330	1.0	0006	0005	0004	地震角
最 大 加 速 度 由維証要	:情報表示 	細測年月月	(加速度単位) 四度	:gel) 耳ム論	下法	松市	加速度F
1030	天臻中央	2002-03-25 22:58:55,330	1.7	0018	0010	0005	발태(
44.31	底段影響廊	2002-03-25 22:58:55,330	0.9	0003	0003	0003	警部
44.34	ダムサ小左岸	2002-03-25 22:58:55.330	1.0	0006	0005	0004	管報の
温井	天蓮右岸	2002-03-25 22:58:46.000	1.9	0010	0004	0001	警部
温井	天建中央	2002-03-25 22:58:46.000	2.0	0012	0005	0003	警部
温井	天壤左岸	2002-03-25 22:58:46.000	1.8	0008	0006	0001	1994 Fr
温井	點查應下部減給	2002-03-25 22:58:46.000	0.1	0001	0001	0000	管報任
温井	點資廠中断中央	2002-03-25 22:58:46.000	1.1	0004	0001	0001	警報
温井	點查應下部中央	2002-03-25 22:58:46.000	0.1	0001	0000	0000	管報
8911	天壤水位計案	2002-03-25 22:58:36.270	1.0	0003	0001	0002	警報
3761	1F點查應入口	2002-03-25 22:58:36.270	1.4	0005	0005	0003	管報
野村	左岸リムトンネル	2002-03-25 22:58:36.270	1.2	0004	0003	0003	管報
39FF1	中段監査廊	2002-03-25 22:58:36.270	1.8	0012	0007	0002	管報
新畫根	底設整査廊	2002-03-25 18:04:42.000	4.7	0093	0090	0092	警報 (
新豊根	底設監査廊	2002-03-25 18:04:42.000	4.7	0093	0090	0092	警報
新島根	應設監査廠	2002-03-25 18:04:42.000	4.7	0093	0090	0092	管報任
新豊根	底設監査廊	2002-03-25 18:04:42.000	4.7	0093	0090	0092	警報
新島根	應設監査廊	2002-03-25 17:24:14.000	4.7	0093	0090	0092	管報
新量根	應設監査廊	2002-03-25 17:24:14.000	4.7	0093	0090	0092	い いっち いっち いっち いっち いっち いっち いっち いっち いっち いっ
					0000	0000	www.eD/
	中國其實 和調 相調 相調 相調 相調 相調 相調 相調 相調 相調 相	中華民王 委会名 解析 万味中寺 解析 万法与中 解析 万人ウ小左州 日本 万人ウ小左州 日本 万人ウ小左州 日本 万人ウ小左州 日本 万人ウ小左州 日本 万大ウ小左州 「日本 万大ウ・万米 「日 「日本 「日本 日本 「日本 日本 <td>中華区学 所設有 1000000000000000000000000000000000000</td> <td>中華区支 第第単の 新香菜 新香菜 新香菜 新香菜 189 万葉中市 5002-03-62 52656.530 1-3 189 万法中市 5002-03-62 52656.530 1-3 189 万法中市 5002-03-62 52656.530 1-3 189 万法中市 5002-03-62 52656.530 1-3 199 万法学生 5002-03-62 52656.530 1-3 199 万米市 2002-03-62 52666.530 1-3 194 万能学生 2002-03-62 52666.530 1-3 194 大部長田市町市 2002-03-62 52666.530 1-3 194 北京田市町市<</td> 2002-03-62 52666.530 1-3 194 日気気気気気気気気気気気気気気気 1-3 1-4 194 日気気気気気気気気気気気気気気気気気気気気 1-3 <td>中華文字 委会会 知道年月月日 予算 グスト 解析 255525 2020-07-55 255656-500 0.3 0.9 00003 解析 2555255 2020-07-55 255656-500 0.9 00003 0.9 00003 解析 2555255 2020-07-55 255656-500 1.0 00005 日本 第第第 25257 25525 25525 1.0 00005 日本 第第第 25257 1.0 00005 1.0 00005 日本 第第第 25257 1.0 00005 1.0 00005 日本 第第第 25257 1.0 00005 1.0 00005 日本 1.0 1.0 00005 1.0 00005 1.0 00005 温井 1.0 1.0 00005 1.0 00010 3.8 1.0 00005 温井 1.0 1.0 1.0 00005 3.8 0000-07-55 2.5 0.0 1.0 00010</td> <td>中華区学 所設有 日月日 百匹 万人 上下客 1889 2585258 000-00-56 252685.500 1.3 0018 0010 1889 2585258 000-00-56 252685.500 1.0 0000 0000 1889 2585258 000-00-56 252685.500 1.0 0000 0000 1889 2585258 000-00-56 22685.500 1.0 0000 0000 1899 2585258 2000-00-56 22685.500 1.0 0000 0000 1898 2582-00 2000-00-56 22685.500 1.0 0000 0000 1898 2582-00 2582-586.500 1.0 0000 0000 1898 2582-00-55 2268-50.00 1.0 0000 0000 0000 1898 2582-00-55 2268-50.00 1.0 0000 0001 0001 0001 1898 2582-00-55 2268-50.00 1.3 0000 0001 0001 0001 0001 0001 0001 0001 0001 0001 0001 0001 0</td> <td>中華区支 第第一次第年希 (第第一次第年希 (第第一次第年希 (第第一次第年希 (第第一次第年希 (第第一次第年希 (第二次)) 安全(第二次) (第二次) 中華(第二次) (第二次) 中華(第二次) (第二次) 中華(第二次) (第二次) 中華(第二 (第二次) 中華(第二 (第二次) 中華(第二 (第二次) 中華(第二 (第二次) 中華(第二 (第二次) 中華(第二 (第二 (第二次) 中華(第二 (第二 (第二)) 中華(第二 (第二)) 中華(第二) 中華(第二) 中華(第二) 中華(第二) 中華(第二) 中華(第二) 中 (第二) 中 (第二) 中 (第二) 中 (第二) <</td>	中華区学 所設有 1000000000000000000000000000000000000	中華区支 第第単の 新香菜 新香菜 新香菜 新香菜 189 万葉中市 5002-03-62 52656.530 1-3 189 万法中市 5002-03-62 52656.530 1-3 189 万法中市 5002-03-62 52656.530 1-3 189 万法中市 5002-03-62 52656.530 1-3 199 万法学生 5002-03-62 52656.530 1-3 199 万米市 2002-03-62 52666.530 1-3 194 万能学生 2002-03-62 52666.530 1-3 194 大部長田市町市 2002-03-62 52666.530 1-3 194 北京田市町市<	中華文字 委会会 知道年月月日 予算 グスト 解析 255525 2020-07-55 255656-500 0.3 0.9 00003 解析 2555255 2020-07-55 255656-500 0.9 00003 0.9 00003 解析 2555255 2020-07-55 255656-500 1.0 00005 日本 第第第 25257 25525 25525 1.0 00005 日本 第第第 25257 1.0 00005 1.0 00005 日本 第第第 25257 1.0 00005 1.0 00005 日本 第第第 25257 1.0 00005 1.0 00005 日本 1.0 1.0 00005 1.0 00005 1.0 00005 温井 1.0 1.0 00005 1.0 00010 3.8 1.0 00005 温井 1.0 1.0 1.0 00005 3.8 0000-07-55 2.5 0.0 1.0 00010	中華区学 所設有 日月日 百匹 万人 上下客 1889 2585258 000-00-56 252685.500 1.3 0018 0010 1889 2585258 000-00-56 252685.500 1.0 0000 0000 1889 2585258 000-00-56 252685.500 1.0 0000 0000 1889 2585258 000-00-56 22685.500 1.0 0000 0000 1899 2585258 2000-00-56 22685.500 1.0 0000 0000 1898 2582-00 2000-00-56 22685.500 1.0 0000 0000 1898 2582-00 2582-586.500 1.0 0000 0000 1898 2582-00-55 2268-50.00 1.0 0000 0000 0000 1898 2582-00-55 2268-50.00 1.0 0000 0001 0001 0001 1898 2582-00-55 2268-50.00 1.3 0000 0001 0001 0001 0001 0001 0001 0001 0001 0001 0001 0001 0	中華区支 第第一次第年希 (第第一次第年希 (第第一次第年希 (第第一次第年希 (第第一次第年希 (第第一次第年希 (第二次)) 安全(第二次) (第二次) 中華(第二次) (第二次) 中華(第二次) (第二次) 中華(第二次) (第二次) 中華(第二 (第二次) 中華(第二 (第二次) 中華(第二 (第二次) 中華(第二 (第二次) 中華(第二 (第二次) 中華(第二 (第二 (第二次) 中華(第二 (第二 (第二)) 中華(第二 (第二)) 中華(第二) 中華(第二) 中華(第二) 中華(第二) 中華(第二) 中華(第二) 中 (第二) 中 (第二) 中 (第二) 中 (第二) <

Figure 12 Example of screen shot of a seismograph network information terminal