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Risk Management Of The Yodogawa River During The Hanshin-Awaji Earthquake

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1. Introduction

The Yodogawa River suffered unprecedented damage from the Hanshin-Awaji earthquake of January 17, 1995. In particular, the lower reaches of the river were severely damaged, as such areas were close to the focus of the earthquake and ground was weak. Along the waterfront of Torishima, Konohana-ku, Osaka City in particular, ground was liquefied by the strong earthquake motion and levees that lost bearing support were depressed as much as three meters. Fortunately, the areas were not subjected to the worst situation of sea water flooding from full tide of Osaka Bay, but urgent repairs were necessary for restoration of the damaged levees. While various problems were encountered to prevent secondary disasters that were feared directly after the earthquake, and to restore the damaged levees within a very limited period, restoration of the levees of the Torishima were completed in March 1996. In this paper, I will mainly discuss the risk management of the Yodogawa River after the Hanshin-Awaji Earthquake, primarily focusing on the action taken to restore the damaged levees at Torishima.

2. General Description of the Hanshin-Awaji Earthquake 1)

(1)Description of the Earthquake

On January 17, 1995 at 5:46 A.M., an earthquake of magnitude 7.2 with a focus located at the northern part of Awajishima Island, Hyogo Prefecture, occurred. Strong shocks were recorded in wide areas from the west to the east of Japan, and were centered in the Kinki District. According to the announcement of the Osaka Meteorological Station, shocks with a seismic intensity of six to seven were recorded in Kobe and Sumoto, and intensities of five in Kyoto, Hikone and Toyooka. A seismic intensity of four was recorded in Osaka. Buildings and structures were destroyed by this earthquake at various places, with damage concentrated in the Hanshin areas and Awajishima Island, and fires broke out one after another. Railroads, including Shinkansen, local and private lines, and subways in Kobe City, were significantly damaged and had to shut down. Express highways and elevated national road bridges collapsed, and the land traffic network was cut into pieces. In addition, utilities, including electricity, gas, water and telephone lines were severely damaged, severely impacting city life for a long period of time. The

Meteorological Agency started to investigate the collapsed buildings immediately after the earthquake, and on February 7, 1995 published the results obtained from investigations of areas affected by intensities of seven. This was the first event where a seismic intensity of seven occurred since the intensity scale had been established by the Meteorological Agency after the Fukui Earthquake of 1948.

(2)Characteristics of the Earthquake

It is known that there are a number of active faults, such as the Rokko Thrust, the Ikomayama Fault, and the Arima-Takatsuki tectonic line, in areas adjacent to Hanshin District. The focus of this earthquake is located at Hokutan-cho in the northern part of Awajishima Island that has the Nojima fault. There are indications that this fault moved about 1,000 years ago, and it is presumed that it belongs to the Rokko Thrust. For this reason, Kobe and other cities of Hanshin District stretching over the Rokko Thrust were seriously damaged. According to the Meteorological Agency, the number of aftershocks from the main shock of December 31, 1995 totaled 2,361, and of these 389 were strong enough to be felt. The peak acceleration of earthquake motion observed by the Kobe Marine Observatory was 818 gals in a horizontal direction and 332 gals in the vertical direction. In areas where the seismic intensity of seven occurred, a peak horizontal acceleration between 600 and 800 was measured. A distribution area map of the main shock and aftershocks is shown in figure 2-1. The peak accelerations obtained from the records by the Oyodo Seismograph Station, located on the left bank of the lower reaches of the Yodogawa river, approximately 6.5 km to the river mouth, are as shown in Table 2-1.

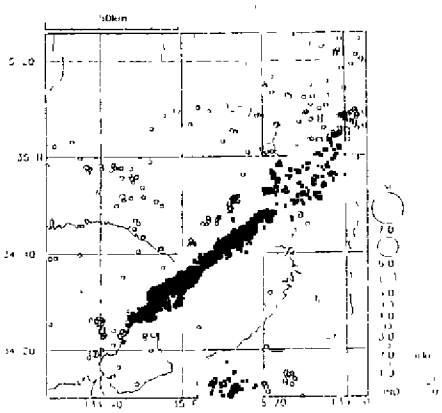

Fig. 2-1 Distribution Area Map of the Main Shock and Aftershocks

Table 2-1 Peak Accelerations Observed at the Oyodo Seismograph Station (unit in gal) 2)

Measuring Point	Longitudinal Direction on the bank	Transverse Direction on the bank	Vertical Direction
Ground below the bank	203	221	239

(3)Distinctive Features of Damage

Damage caused by this earthquake extended over the entire areas of Hanshin District, with Hyogo Prefecture being the hardest hit. Particularly, damage in the northern part of Awajishima Island and the cities of Kobe, Ashiya, Nishinomiya and Takarazuka, close to the focus, was very disastrous

Damage was characterized by loss of life, the destruction of buildings, and the severe damage to utility lines because the earthquake occurred directly below major cities. Public structures constructed of concrete, such as roads, river facilities, and port and harbor facilities were also severely damaged. The number of dead and missing was over 6,000, and damaged houses and buildings totaled more than 430,000. The utility lines were restored, first with electrical systems within six days, then with telephone lines after two weeks, but about three months were needed for restoration of water and gas lines. Secondary disasters became a problem, as had happened in the past after the Kanto Plain Earthquake and the Southwest Offshore Earthquake in Hokkaido-fires broke out concurrently at various places, increasing the damage from the earthquake. According to an investigation made by the Fire Defense Agency, there were 294 separate fires, and a total of 7,500 houses were burned. In addition to the interruption of railroads and traffic, life saving activities and transportation of materials were badly obstructed by heavy traffic congestion In the Kinki Regional Construction Bureau, some of the employees and their families were killed or injured. Facilities such as office buildings, living quarters, roads, rivers, shore protection and erosion control dams under the control of the bureau were also severely damaged.

3. Outline of Damage to the Yodogawa River

(1)Overall Damage Conditions

The seismic intensity announced by the meteorological station immediately after the main shock was "four" for Osaka and "five" for Kyoto. It is understood that concrete structures will not be damaged with the intensity of four. Therefore, at first it was thought there would be damage in some areas within Kyoto Prefecture. However, it became clear during the progress of emergency inspections that damage was worse, not in Kyoto, but in Osaka Prefecture, and that the downstream areas were severely damaged. A total of 19 places along the Yodogawa river were damaged to the extent that disaster relief works were authorized for shore protection, levees and other structures. Of these, 16 projects were for levees, with a total length of pproximately 5,660 meters. Among such damaged levees, 14 places totaling 5,270 meters in length were in the lower reaches of the river within 9 km of the river mouth. The damaged areas in the lower reaches of the Yodogawa river are shown in figure 3-1. Typical damage to the levees is represented by depression of the entire structure, settlement of the top, crosswise cracks, and collapse or bulging of bank protection.

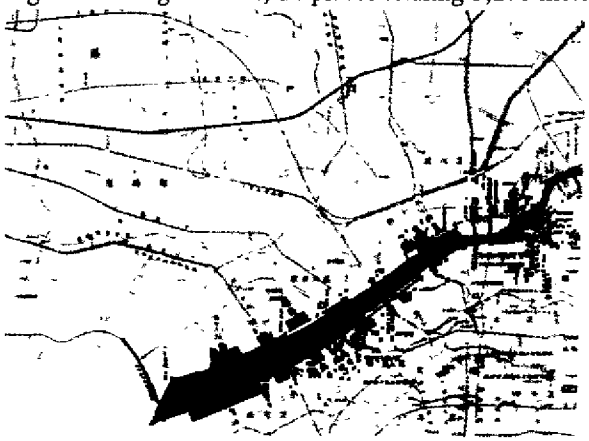

Fig.3-1 Dameged Levee in Lower Reaches of the yodogawa River

(2)Damaged Conditions of Torishima Levee

Damage was severe at the downstream areas near the focus. In particular, the waterfront areas of Torishima, Konohana-ku, Osaka City on the left riverbank were depressed for a length of over 2 km and to a maximum depth of 3 meters. Longitudinal profiles of the depressed levee are shown in figure 3-2. Even after the earthquake, the levee at the lowest point was still at an elevation of OP + 3.5 m, and leaks were not found in the structure, so it was not feared that secondary disasters such as sea water flooding or collapse of the structure might occur. Damaged conditions of the Torishima Levee is shown in photographs 3-1 through 3-3. In areas adjacent to damaged levees traces of mud pumping were noted at a number of points. These were noted not only within the levee structure but also in the river bed. Such traces of the mud pumping within the depressed levee structure were also observed in excavation inspections. In Torishima district, a super embankment was being constructed next to the damaged levee before the earthquake occurred. Various gauges were buried in ground in order to monitor variations appearing in the ground due to construction of the embankment. A rapid rise of pore water pressure was recorded in these gauges For this reason, it can be presumed that the ground was liquefied in this area due to strong earthquake motion

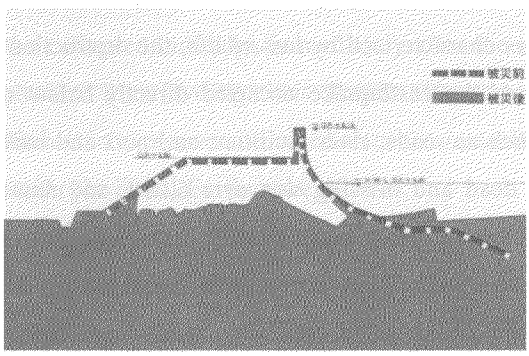

Fig.3-2 Cross Section View of Dameged Torishima Levee

Photo3-1～3 Damaged Conditions of the Torishima Levee

4. Actions Taken After the Earthquake

(1)Actions Immediately After the Earthquake

a)Attendance of Employees

Since the earthquake occurred very early in the morning, it was necessary to call up employees immediately. In areas adjacent to the lower reaches of the Yodogawa river, all means of transportation were interrupted and roads were full of vehicles. As it is a general rule, observed in any case of earthquake with a seismic intensity of four, that all river facilities are supposed to be immediately inspected, many employees had reported for work voluntarily before they were called up. The Keihan Railway, which is a main traffic means to the Yodogawa Work Office, was interrupted for a short time, but was restored at around 7:10 A.M., one and a half hours after the main shock. Therefore, employees living in areas close to the office and in Kyoto could report to the office. Approximately 80% of the employees were able to report to the office on the day of the main shock. It was 10 days later, on January 27, that all employees could be present at the office.

b)Setting Up Emergency Headquarters

Operating procedures in an event of disaster have been predetermined. This is the "Yodogawa River Emergency Headquarters Operating Plan." 3) Since earthquakes occurred rarely in the Kinki District in recent years. this plan consisted mainly of countermeasures for damage from storms and floods. The plan was not adequate for earthquakes, and this was one of the major reasons calling for reconsideration of the plan. The city of Hirakata, where the Yodogawa Work Office is located. also experienced strong shocks. Power failed. but lighting was quickly restored with a backup system. However, power-operated doors to the office building and rolling doors to the garage were not operated. Therefore, these doors had to be forced open by employees. As steel furnishings did not fall down in the office building (except for a TV set and some documents), office work was not interrupted significantly. The office was organized for the No. 1 Warning system at 6:30 A.M., as soon as the first group of employees reported to the office. As emergency inspections progressed it became clear that the levees at the lower reaches of the river had been significantly damaged. At 9.55 A.M. the No. 1 Warning system was upgraded to No. 2 system. As the extent of the damage became clear, an emergency system was announced at 17:30 on the next day, in order to devote all office functions for the disaster. At the same time, emergency relief vehicles were dispatched to the site patrol the levee and to accelerate emergency relief work, and a field emergency office headed by the Assistant Head was set up.

c)Gathering and Conveying Information on Damage

In order to conduct emergency inspections of the river directly after the earthquake, instructions were issued to all field offices However, it took a long time for field office employees to report to their office because of interruption or confusion regarding transportation. It was a little after 8:30 A.M. that all field offices received these instructions. In the Fukushima Field Office, responsible for the lower reaches of the

river near the focus, some employees could not report for work. Therefore, two inspection teams were dispatched from the main office to help conduct emergency inspections.

Through these emergency inspections, it became clear that areas in Kyoto Prefecture were little damaged, but that areas within Osaka Prefecture and in the lower reaches of the river were significantly damaged, and that the entire levee at the waterfront of Torishima was heavily depressed over a long distance. It was decided to take aerial photographs to determine existing conditions of the river after the main shock, but airplanes and helicopters were not available. A Cessna was secured in the afternoon of the day and vertical photographs of the lower reaches were successfully taken. Fortunately, the only means of communication, the multiple-radio communication system used exclusively by the Ministry of Construction, was safe and no communication troubles were experienced. Satellite communication vehicles were assigned to the field and all existing conditions of emergency relief work on the Torishima Levee were conveyed to the Yodogawa Work Office, Kinki Regional Construction Bureau and the Ministry of Construction starting January 18.

d)Prevention of Secondary Disasters

The existing levees at the waterfront of Torishima were depressed for a long distance, but fortunately a tsunami did not occur and there was no sea water flooding. However, emergency relief vehicles were dispatched to the site and patrol of the levee was made on a 24-hour basis, especially at times of high tides twice a day, as it was feared that the damage could be extended because of leaks.

As it was necessary to stockpile sand bags to be ready for leakage, a sand bag making vehicle was also dispatched to the site. In addition, illumination and drainage pumping vehicles were dispatched, since work had to be done also in the night and crews had to be ready for leakage. The levee was severely damaged, but fortunately no leakage was observed even at high tide. Because houses and factories were densely constructed in areas adjacent to the Torishima Levee, and there were no access roads to the levee for restoration work, a construction access road was also constructed.

e)Assistance Organizations

In an event of disaster, many personnel and a lot of materials and equipment are required all at once. It was decided that all organizations of the Ministry of Construction would cooperate and give a helping hand for this earthquake. The Yodogawa Work Office also received a lot of assistance in the form of personnel, materials and equipment from other regional construction bureaus.

f)Response to Questions from the Public

Since the day of the main shock, a number of inquiries were received from the residents relating to possible failure of the Torishima Levee and possible floods. Since the lower reaches located at sea level, and leaks had been frequently noted in the embankment, feelings of uneasiness had been raised among the residents, and leaks of the water system were often misunderstood to be flooding from the river. The

Work Office answered all inquiries and assured residents that the levee would never collapse.
The damage to the Yodogawa river was unprecedented in the long history of flood control of this river. However, the Yodogawa river had a little news reporters' interest at first because of the significant damage to Kobe and its adjacent areas.

(2)Review of Primary Principles for Restoration of Levees

a)Prevention of Secondary Disasters

One of the most important actions to be taken immediately after occurrence of a disaster is the prevention of secondary disasters. After this earthquake, damage was expanded further by fires. For disasters associated with rivers, tragic secondary disasters have often been caused by floods after earthquakes, as seen in the flood which occurred after the Fukui Earthquake. As described earlier, the Yodogawa river was fortunately saved from the worst scenario, but the levee had to be continuously monitored until restoration work was finished to a certain level to assure that leakage would not result in increased damage.

b)Earlier Restoration

It was estimated that the flood season could arrive at the discharge basin of the Yodogawa river about five months after the earthquake. All the necessary restoration work on the damaged portions had to be finished by that time. It was decided to complete all restoration work at 18 locations other than the Torishima Levee prior to the arrival of flood season, although the schedule could be very tight.
The Torishima Levee was seriously damaged and it was necessary to improve ground conditions prior to reconstructing the levee. Since it was estimated that a certain time period will be necessary to complete restoration, it was decided to perform the work in three separate phases. It was determined to accommodate the flood season of 1995 with a temporary levee to be completed by the end of March 1996, although this schedule was also very tight.

c)Preventing Similar Disasters in the Future

One of major factors causing damage to the levee was the liquefaction of the ground. The ground in the lower reaches of the Yodogawa river consists of loose sand alluvial deposits 10 meters thick. Since this sand layer was liquefied due to the strong shocks, it can be presumed that the levee settled because of loss of bearing support Therefore, it was considered necessary to take steps to prevent ground liquefaction to preclude similar failures from repetition. Such measures were discussed by a technical committee formed of personnel with academic backgrounds.

d)Action Toward Construction of Super-embankment

The levee at the lower reaches of the Yodogawa river is extremely important for protection of the major city. Its breakage is absolutely not allowed. For this reason, a wide embankment that will never collapse,

even if overtopped, has been under construction since 1987. (In Japan these are called "super embankments.") The Torishima Levee had a three-face concrete covering with a parapet on the center prior to being damaged, but it was decided to eliminate the parapet and employ an earth structure up to the crown so that the levee could be modified to a super-embankment in the future.

e)Consideration of the Environment

Rivers and streams are important open spaces that have remained in urban areas. They play an important role for assuring charm and peace of mind for the public. The style of the old Torishima Levee appeared to the public as a great bulkhead separating the river from the public. The parapet has been eliminated from the design of the new levee, and the levee has been provided with a gentle slope on the side facing the river to assure easy access for people who may desire to lounge on the river side. As the lower reaches of the Yodogawa river are in an area that may encounter high tides, it is generally necessary to cover all surfaces of the levee with concrete blocks. However, utmost efforts are being made to provide an earth cover with sodding for the benefit of the public.

(3)Emergency Relief Work 3)

a)The First Stage Emergency Relief Work

As it was necessary to secure a levee in a short time period to prevent secondary disasters such as inundation caused by heavy rains and floods under the first stage emergency relief work, embankment was first constructed to the height of the old control access road prior to the damage. This embankment was completed on January 30. It took a long time to remove the concrete pieces of the collapsed levee, and it was decided to break them up and pack them in sand bags and to reuse them as foot protection instead of cobbles. Soil materials for embankment construction were first taken from material intended be used for construction of the Torishima Super-embankment, but later were transported by sea from islands in the Setonaikai Sea

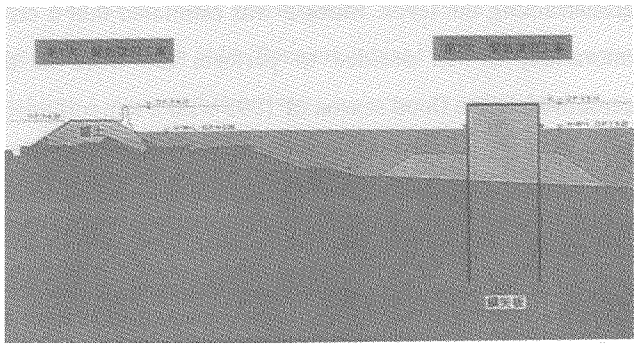

Fig.4-1 Cross Section View of Emergency Relief Word