DAMAGE TO RIVER DIKES

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ABSTRACT

Among the rivers damaged by the earthquake, two most severely damaged along the Yodo-gawa River are described. In the left levee, the settlement exceeded 2 m for a length of 1.4 km, with a maximum settlement of 3 m. Sand boils were observed extensively on the ground surface near the damaged dikes. Holocene sandy soil with an SPT *N*-value of 10 or less existed in the upper part of the subsoil profile. These facts indicate that liquefaction of the soil was the major cause of the embankment damage. The cyclic stress ratio required to cause liquefaction was 0.30 as determined from cyclic triaxial tests on undisturbed samples.

Key words: earthquake damage, liquefaction, river dike (IGC: D7/E8/E6)

INTRODUCTION

Flood control river dikes suffered extensive failure. Damage to the dikes consisted of cracking, settlement, lateral spreading and slumping.

Table 1 summarizes the damage to the rivers administered by the central government. The damage was observed on six rivers, amounting to 32 sites and a total length of 9,290 m. The most severely damaged were the dikes of the Yodo-gawa, which, flowing through Osaka, is the largest river in the Kansai area. The Yodo-gawa is not however the closest river to the epicenter. At most of the damaged sites, sand boils were observed on the ground surface near the dikes. Major damage to the Yodo-gawa is described in the following sections of this paper. For details about the location, refer to ref. 1).

TORISHIMA DIKE AT YODO-GAWA

A length of 2,000 m (kilopost 0.2–2.2 km) of the Torishima Diike, the left levee of the Yodo-gawa, was severely damaged. The dike was designed to protect against the high sea tide of 5.2 m above mean sea level. The core of the dike was a soil embankment, and the river side surface was protected by concrete parapet wall, the design height of which was 8.1 m from the sea level. The rear slope and the top were faced with concrete blocks and asphalt pavement, respectively.

Photograph 1 shows the damage and Fig. 1 shows the maximum settlement of the embankment crest due to the shaking. The cross section is illustrated in Fig. 2. The concrete parapet at the top of the levees tilted and settled. The parapet slid about 8 m into the river. The embankment also settled and cracked severely. The settlement exceeded 2 m on the kilopost 0.5–1.9 km, with a maximum of 3 m. Sand boils along the fissures were observed on the ground surface along the dike. Lateral movements and heaving of the ground surface occurred in the residential area where the ground elevation was low. These facts suggest that soil liquefaction triggered the damage.

Figure 3 shows the soil profile along the right dike and Fig. 4 shows the cross section at the 1.4 km kilopost site. These figures were drawn based on boring data obtained after the earthquake, in February and March, 1995. As shown in these figures, the dike is underlain by the Holocene deposit with a thickness of about 30 m, called the Umeda Layer. The deposit consists of, from the top, the upper sandy layer (As2), clay layer (Ac) and the lower

Table 1. Summary of damage to river dikes

River	Location	Number of damaged sites	Total length of damaged sites (in m)
Yodo-gawa	Osaka Pref.	18	6,590
Kanzaki-gawa	Osaka Pref.	1	30
Ina-gawa	Hyogo Pref.	3	610
Mo-kawa	Hyogo Pref.	5	680
Kako-gawa	Hyogo Pref.	3	1,180
Yura-kawa	Kyoto Pref.	2	200
(Total)		32	9,290

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(a)

(b)

Photo. 1. Damage to the Torishima Dike: (a) Before the earthquake (Looking downstream from the 1.7 km site; the Yodo-gawa mainstream is on the right hand side.); (b) After the earthquake (Looking downstream from the 1.4 km site)

sandy layer (As1). The thickness of the Holocene deposit decreases downstream. The As2 layer is also divided into the upper sublayer (As2-2) and the lower sublayer (As2-1). The SPT N -value is less than 10 in the As2-2 layer, and more than 10 in the As2-1 layer. The sand boils observed after the quake are considered to have been ejected from the upper sandy layer.

Figure 5 shows the grain size distribution of the As2-2 layer. Average of the mean grain size and fines content are 0.2-0.3 mm and 20%, respectively. Cyclic undrained triaxial compression tests were made on samples obtained from the depth of 8.0-8.6 m (As2-2 layer) of the 1.4 k-3 borehole (see Fig. 4). The double tube twist sampler with an inner diameter of 70 mm and an outer diameter of 97 mm was used in the sampling. The samples obtained were frozen at the sites and then carried to a laboratory. The test results are presented in Fig. 6. The cyclic stress ratio, $\sigma_d/2\sigma_c'$ (σ_d : deviatoric cyclic axial stress; $2\sigma_c'$: effective confining stress), required to cause 5% axial strain in 20 cycles, is about 0.30.

Fig. 1. Settlement of the Torishima Dike

Fig. 2. Cross section of the Torishima Dike

Fig. 3. Soil profile along the right dike

Fig. 4. Cross section and soil profile of the Torishima Dike at kilopost of 1.4 km

Fig. 5. Grain size distribution of the upper sandy layer, As2, at Torishima

NISHIJIMA DIKE AT YODO-GAWA

A 750 m length (kilopost 1.2–2.0 km) of the right levee, located just opposite the damaged Torishima Dike, was also damaged. Although the structure of the dike was similar to that of the Torishima Dike, there was no damage to the parapet. Only the embankment slope

failure occurred in the rear slope. The crack that developed at the crest was about 20 to 150 cm wide and its subsidence amounted to 1.2 m (Photo. 2). The toe of the damaged slope displaced about 1 m. Sand boils were observed near the toe. The cross section of the failed embankment together with the boring data and the soil profile is presented in Fig. 7. At the 1.7 k–4 boring loca-

Fig. 6. Liquefaction test results for the upper sandy layer, As2-2, at Torishima

Photo. 2. Damage to the Nishijima Dike (Looking downstream from the 1.7 km site; the Yodo-gawa mainstream is seen on the left hand side. The water seen in the right hand side is a tributary river.)

Fig. 7. Cross section and soil profile of the Nishijima Dike at kilopost of 1.7 km

tion in this figure, the embankment material seems to have penetrated into the upper sandy layer (As2). This may indicate that the embankment slope failure was induced by the loss of shear strength in the As2 layer, probably due to liquefaction. In Fig. 7, however, no distinct difference in the SPT N -value was observed between both sides of the levee; one side failed but the other side did not fail.

Figure 8 plots the results of cyclic undrained triaxial tests on samples obtained from the As2-2 layer. The cyclic stress ratio, $\sigma_d/2\sigma'_c$, required to cause 5% axial

Fig. 8. Liquefaction test results for the upper sandy layer, As2-2, at Nishijima

strain in 20 cycles, is about 0.31, which is almost equal to that obtained at Torishima. No clear difference in the grain size distribution of the As2-2 soil was observed between the two sites.

CONCLUSIONS

Among the river dikes damaged by the earthquake, data for two most severely damaged sites along the Yodo-gawa River were presented in the paper. The maximum settlement of the embankment was 3 m. Sand boils were observed at most of the damaged sites. Geotechnical survey and laboratory tests conducted immediately after the event revealed that there existed Holocene sandy soil with SPT N -value of 10 or less in the upper part of the subsoil profile. These facts indicated that liquefaction of the foundation soil was the major cause of the damage to the embankment.

ACKNOWLEDGEMENT

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REFERENCE

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