In-situ loading test of wooden pile at Shinano River Ohkouzu old movable weir and discussion on foundation design

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ABSTRACT

The old movable weir at Shinano River Ohkouzu in Nagaoka city was demolished owing to aging of structure, after construction of the new movable weir. This study reports the rapid loading test results of wooden piles installed below the foundation of movable weir and discusses the design method of foundation. Ground survey clearly illustrated the geological structure of the ground and indicated the wooden piles of 13m in length below the pillar was supported by the dense sandy layer. On the other hand, the wooden piles of 7m in length at the channel was shown to be supported by the thin dense sandy layer. Ultimate bearing capacity of wooden pile was estimated by the in-situ rapid loading test of piles. It matched with the design value in case of the channel, but it was smaller than that in case of the pillar. The foundation design of the pillar was found based on the piled raft foundation theory. Wooden piles had maintained the integrity of material, although it was constructed before about 80 years.

Keywords: wooden pile, rapid loading test, foundation design, remains record preservation

1 INTRODUCTION

The old movable weir at Shinano River Ohkouzu in Nagaoka city was demolished owing to aging of structure after construction of the new movable weir. By boring survey, cavity was observed to distribute between the foundation of movable weir and the ground as shown in Fig.1. It is widely distributed below the foundation and the maximum height of cavity becomes 16cm. Since the development of cavity causes the reduction in vertical and horizontal bearing capacity of the foundation, the old movable weir is judged severely instable. This study reports the rapid loading test results of wooden pile which is installed below the foundation and discusses the design method of the foundation at the time. In addition, the health survey test result of wooden pile is indicated in the paper.

Fig. 1. Cavity distribution below weir foundation by boring core photographs.

2 PURPOSE OF SURVEY

The Shinano River Ohkouzu movable weir was constructed in 1921. However, it was severely damaged and mostly lost by flood in 1927. It is because the bed slope of channel was steeper than that of upstream side and the bed ground was unstable against channel erosion. The old movable weir was newly constructed in 1931 by providing countermeasure works of ground sill and sheet pile to prevent from scouring of bed ground. The weir structure had been safe for about eighty years against repeated floods. However, it was renewed owing to aging of the old movable weir. As the old movable weir was constructed in short time after the lost of the former weir by flood, the detailed design has not been found in past documents. From the remains record preservation viewpoint, the design and the current status of old movable weir needs to be investigated before it was demolished. This study mainly investigated the design of weir foundation. Since the weir foundation is supported by wooden piles, the ultimate bearing capacity and the integrity of wooden pile were intensively investigated.

3 STRATUM CONSTITUTION AND CONFIGURATION OF WOODEN PILES

Fig.2 indicates the data of boring No.1 and the

configuration of wooden piles in the water slapping portion between the weir columns. In soil boring log, there exist two stiff sandy layers. The wooden piles of 7m in length are supported by the thin sand layer, As1 which is distributed from 7.65-10.45m in depth. On the other hand, the wooden piles of 13m below the pillar are supported by the stiff sand layer of As1 distributed under 14.85m in depth. The ground survey technique was not developed as today, but the supported piles are well designed corresponding to the stratum constitution by construction experience.

Fig. 2. Geological structure and pile configuration.

Various tests were carried out on the shorter piles at the downstream side in the channel. By excavating the concrete foundation of 3m in thick, four piles below the foundation are employed for the tests. One is for static pull-out test and two are for rapid loading tests to evaluate ultimate bearing capacity. The last is for the

reserve. The integrity test was also conducted on piles.

The Ohkouzu movable weir is located on the artificial waterway. The ground shows a complex stratum constitution since topography of the site is a natural levee and a flood plain. Additional boring survey was conducted to investigate both the geological structure and the collapse area of the former weir lost by the flood in 1927. Fig.3 expresses the stratum constitution of cross section of the Shinano river at the former weir. Refilled ground is clearly observed over the collapse area of the former weir. B2 is the refill by countermeasure work and indicates the status of scoured ground by water stream. Since the cavity was observed in the wide range of the weir foundation and the channel, static and dynamic laboratory tests were performed to the soils sampled from As0 and Acs1 sandy layers. As the result, As0 layer is so loose and has the potential of liquefaction during earthquake. Since the Ohkouzu movable weir suffered 1964 Niigata earthquake, it is pointed out that As0 sandy layer is possible to cause the ground settlement due to excitation by the earthquake.

4 LOADING TESTS OF WOODEN PILES

In order to evaluate the bearing capacity of wooden pile, rapid loading test of piles was carried out. The test was conducted in a multi-cycle system that increased the drop height of plumb bob. The pile diameter is $\phi 200 \sim 220$ mm in the head diameter, $\phi 180$ mm in the tip diameter. Array of wooden pile was confirmed by measurement that it almost matches with the design arrangement of $2.0\text{m} \times 2.0\text{m}$.

4.1 Rapid loading test of pile

Fig.4 indicates an overview of the rapid loading test equipment. The plumb bob (600kg) is lifted to a predetermined height by the crane. Rapid loading is carried out by plumb bob's striking the pile top through the cushion material. An overview of the loading unit is shown in Tables 1 and 2.

Figs. 5 and 6 express the obtained load-displacement

Fig. 3. Geological structure of cross section of the Shinano river at the former weir.

relationships by rapid loading tests. The static load-displacement relationship is analyzed by dynamic analysis for each loading step. The obtained static load-displacement relationship is exhibited in those figures as Frapid. Two test results are summarized in Table 3, in which P_u and R_u expresses the maximum load and the load of 10% displacement in pile diameter, respectively. R_y expresses the yielding point of the load-displacement relationship in both logarithms for Figs. 5 and 6.

Fig. 4. Overview of rapid loading test of wooden pile.

Table 1. Specification of rapid loading test equipment.

Name	Specification	Quantity
Plumb bob	600kg	1
Cushion	φ315mm	1
Leader	φ65mm*4, height 4.2m	1
Cap of pile head	φ200-300mm	1
Crane	25tonf	1

Table 2. Specifications of pile used for analysis.

Pile	wood	Unit weight	5.92kN/m ³
Pile diameter	178mm	Primary wave speed	4948m/s
Pile length	6.4m	Elastic modulus	8548MN/m ²
Pile material	pine		

Table 3. Results of rapid loading tests.

item	No. 1	No. 2
Maximum drop height, h (m)	2.85	2.70
Maximum load, Frapid (kN)	383	386
Maximum ground resistance, R_{soil} (kN)	401	417
Maximum converted resistance, R_{ult} (kN)	332	333
Maximum displacement, S_{max} (mm)	30.6	32.1
Residual displacement, S_r (mm)	15.1	14.1
First limit resistance, R_y (kN)	195	206
Second limit resistance, R_u (kN)	245	279
Ultimate resistance, P_u (kN)	335	333

Table 4. Discussion on bearing capacity of wooden pile.

Weir	length	13m	diameter	0.24m	Measured bearing pile	$R_{u*1.2/3}$
	Required resistance /pile	245kN	Computed resistance /pile	166kN	Measured friction pile	$R_{u*1.2/4}$
channel	length	7m	diameter	0.18m	Measured bearing pile	105kN /pile
	Required resistance /pile	69kN	Computed resistance /pile	71kN	Measured friction pile	79kN /pile

Fig. 5. Load-displacement relationship in rapid loading test, No1.

Fig. 6. Load-displacement relationship in rapid loading test, No.2.

4.2 Discussion on foundation design

In the design guideline of the Shinano river Ohkouzu movable weir, the bearing capacity of wooden piles are set as 490kPa for pile tip resistance and 14.7kPa for pile skin friction resistance. Those design magnitudes were determined by practical experience in series of construction work of old movable weir. It is, however, unknown about the background of these design methods. Table 4 indicates the trial computation on ultimate bearing capacity based on the design method of old movable weir. In case of channel, the bearing capacity of pile is computed as 70.5kN per pile and it matches with that of design requirement of 68.6kN per pile. On the other hand, bearing capacity becomes 166kN per pile in case of weir pillar and it is found out much smaller than that of the design requirement of 245kN per pile. The design guideline denotes the mechanism of pile foundation systems to support the movable weir is the synergy effect of pile and ground in resistance force. The resistance of sheet pile was also taken into account in the design although it was not quantitatively estimated. It means the design guideline of the Shinano river Ohkouzu movable weir

introduces the concept of raft foundation into the assessment of bearing capacity.

Japanese specifications for highway bridges in 2012 indicates the bearing capacity of pile is defined as the load at 10% displacement in pile diameter. The factor of safety is set as 3 for bearing pile and 4 for friction pile. The results of rapid loading tests are converted based on the Japanese specifications for highway bridges in 2012 as shown in Table 4 by considering the correction coefficient of 1.2 for loading tests. The design magnitudes of bearing capacity comparatively give good estimation for field loading tests of piles. In case of the bearing capacity formula of Meyerhof, bearing capacity becomes 163kN per pile and provides the greater magnitudes than those of field loading tests.

5 INTEGRITY OF WOODEN PILE

Fig.6 indicates the wooden pile pulled-out after the rapid loading test. The dimensions of the pile such as diameter at various points and length are exhibited in the figure. The position of pile corresponds to the ground depth by adding 2.8m of the foundation height. The photo of pile shows the attachment is installed to the pile tip. The cone type attachment made of mortar is used for driving piles into ground. Material tests for density, strength and deterioration degree were performed immediately after pulling out. The pile sounds to maintain the integrity from its appearance.

To examine the internal state of pile, the pile was divided into pieces of 0.5m and used for various material tests. Results of needle penetration test and unconfined compression test are indicated in Fig. 8. Although rotting to the core portion is in progress in the pile head, strength of pile was maintained after 80 years

Fig. 7. Status of pulled-out wooden pile.

Fig. 8. Needle penetration test of pile.

from the construction. While the strength was reduced in the core portion of pile and the portion in clayey ground, the pile can be judged as healthy enough.

6 CONCLUSIONS

The conclusions are summarized as follows.

- (1) Stratum constitution of the Ohkouzu old movable weir was investigated by boring surveys. The backfill section of river bed after the collapse of former weir was clarified. Furthermore, the wooden piles below the movable weir was clarified as bearing piles supported by sand layers.
- (2) Rapid loading tests of piles were conducted to survey the bearing capacity and the design concept. The guideline of the design was found to be rational in comparison with test results. The concept of raft foundation was already introduced into the design.
- (3) Wooden pile was healthy although it elapsed 80 years from the construction.

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