Analytical study toward the building of an evaluation technique for local scour around a highway bridge foundation

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1. Introduction

Situations often occurred where torrential rains with intensifying severity and increasing frequency in recent years caused scour damage to piers and the road functions were lost for a long period (Photo 1). The effects on a bridge associated with scour are considered to be dependent on the structural conditions of the bridge as well as on the conditions of a river shape, etc. in the location of bridge construction as well, e.g. such as a bent river channel[1].

On the other hand, in hydraulic model experiments conducted by our Division in the past, it was clarified that the local scour shape, etc. around piers were affected by the mode of installation of the piers themselves and the bed protection works[2] used as the protective measures against the scour of a riverbed or bank protection works in association with the installation of the piers.

This paper reports the applicability of the method of evaluation for scour by using semi-three-dimensional flow analysis, toward the establishment of techniques for risk evaluation and verification of effects in order to proceed with scour protection measures more effectively for existing bridges.

Photo 1: Pier damaged by scour

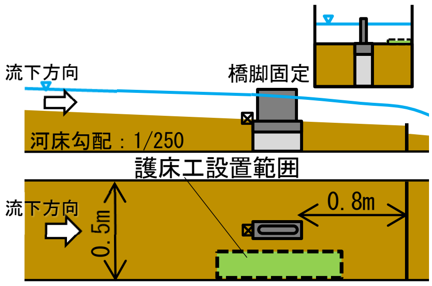

Fig. 1: Overview of an experimental model

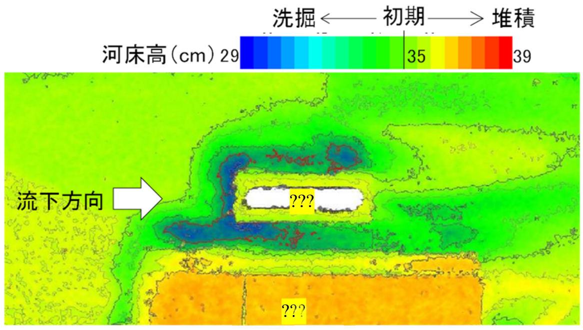

Fig. 2: Riverbed shape after completion of the passing of water

2. Effects of bed protection works on local scour around piers

(1) Overview of existing experiments subject to analysis

Fig. 1 shows an experimental model for hydraulic model experiments subject to reproduction analysis. In this experimental model, bed protection works are arranged adjacent to the pier, by referring to actual examples of scour damage. Note that in the case of this experiment, the pier model is secured to the bottom surface of the waterway, for the purpose of grasping the situation of scour around the pier depending on the conditions of installation of the bed protection works, thereby ensuring that no subsidence or fall by leaning will occur as a result of the progression of scour. Also, the experimental flow rate is set to 5 L/s, assuming the situation of the river in ordinary times (static scour flow rate).

Fig. 2 shows, as the experimental result, a contour diagram of the riverbed shape after completion of the passing of water. An overall tendency can be confirmed that the riverbed degradation ranges are connected from the front surface of the bed protection works to the front surface of the pier, as though crossing the waterway obliquely. Among other things, in the range in the vicinity of the pier (front surface and both sides), great riverbed degradation occurred to the point equivalent to the footing lower end (29 cm).

(2) Reproduction by means of semi-three-dimensional flow analysis

In order to grasp the scour depth of a pier and its range by means of an analytical technique, an analytical model is required that enables reproduction of three-dimensional and complex hydraulic phenomena around the pier such as downward flow and horseshoe vortex (Fig. 3). However, three-dimensional flow analysis involves a large computation load, and there are few examples of its application to actual rivers extending over a wide range[4]. Therefore, in this study, considering deployment to the practical work of road management in future as well, it has been determined that semi-three-dimensional flow analysis shall be used that considers the three dimensionality of flow, by expanding the planar (longitudinal/transversal) two-dimensional flow analysis that is frequently used in the practical work of river management.

Various proposals have been made to the method of evaluation of the three dimensionality of flow. In this study, an analytical method[5] has been used, that can consider the vertical distribution of the flow velocities in the longitudinal and transversal directions (differences in the flow velocities on the water surface and bottom surface) and the flow in the vertical direction (upward flow, downward flow), by solving the vorticity equation and the equation of flow velocity in the vertical direction. Note that, for the sake of comparison, we have also carried out an analysis in the case of an assumption of hydrostatic approximation (general assumption that is applied in the flow regime analysis in the practical work of river management) without considering the flow in the vertical direction by using the analytical method as it is.

Here, the pier and bed protection works have been expressed by setting the fluid occupation rate[6] instead of an obstacle cell, and to express riverbed fluctuations, a general planar two-dimensional riverbed fluctuation analytical technique has been applied[7], which uses the equilibrium sediment transport formula, etc.

The result of analysis is shown in Fig. 4. As compared with the experimental result (Fig. 2), the magnitude of the depth of scour that occurs on the front surface side of each of the pier and bed protection works is slightly excessive. However, the result that roughly reproduces the experimental result has been obtained, such as the tendency of riverbed degradation in the direction from the front surface of the bed protection works to the front surface of the pier (oblique direction) and the large local scour in the range in the vicinity of the pier (front surface and both sides).

Note that, in the case of the assumption of hydrostatic approximation, the result was significantly different from the experimental result, in terms of the scour depth and scour range.

3. Conclusion

By means of the non-hydrostatic semi-three-dimensional flow analysis that enables the three dimensionality of flow to be expressed reasonably by expanding the planar two-dimensional technique, the existing experimental result could roughly be reproduced. In future, we plan to verify the applicability in the case of changing the river channel shape or the conditions of arrangement of the pier and bed protection works, thereby clarifying the conditions of road bridges having a high risk of sour damage and elucidating the mechanisms of scouring, etc., and at the same time to summarize the findings, etc. that will serve as a reference when the road administrator takes scour protection measures by means of analytical techniques.

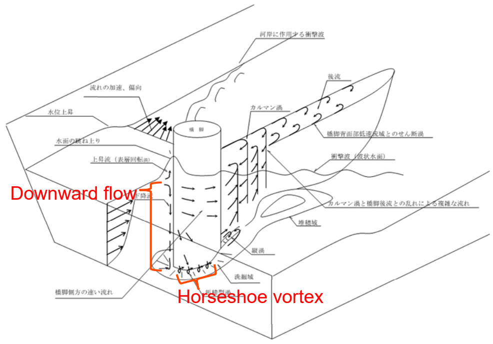

Fig. 3: Hydraulic phenomena that are caused by the pier with additions to 4)

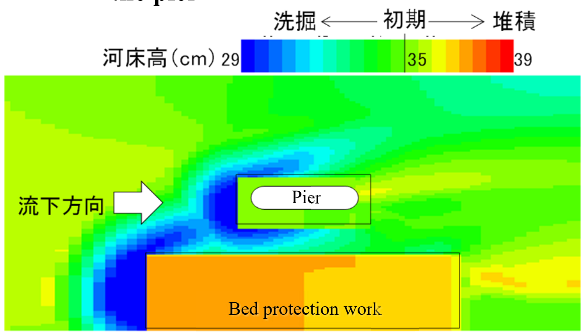

Fig. 4: Result of reproduction by means of riverbed fluctuation analysis

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