

NUMERICAL SIMULATION OF CHANNEL INFILLING ASSOCIATED WITH DEFORMATION OF RIVER MOUTH BAR

Nobuyuki Ono¹, Keiji Kuroki¹, Kenji Ishimoto¹, Yoshimasa Ito¹ and Jae Hyeng Lee¹

Masuda port is located in both sides of the mouth of Takatsu River, the access channel of which passes behind a river-mouth bar. This study intends to develop a tool for examination of countermeasures against channel infilling which is very linked with deformation of river-mouth bar. First, the relation between the sand bar deformation and channel infilling has been examined for the river mouth area of Takatsu River through analysis of aerial photos, current and wave data, bathymetric survey data, and so on. As the results, two dominant processes of flushing sand bar due to flood and reformation of sand bar by waves are confirmed. Also, numerical simulations for the two dominant processes have been conducted and the reproducibility of the model has been examined.

Keywords: river mouth bar; sand bar; channel infilling; morphology change; flooding; waves and current

INTRODUCTION

River mouth is one of the most difficult regions to control sediment transport because of complex topography and forcing conditions of waves and current. Ports and channels located around river mouth are often affected by complex morphology change such as deformation of river mouth bar. This study intends to develop a numerical model to calculate waves, current, sediment transport and morphology change in the river mouth region. In this study, morphology change simulations around a river mouth bar have been carried out and the applicability of the model has been examined.

STUDY SITE

The study site is mouth of Takatsu River, which is a class A river and discharges into Japan Sea. The aerial photograph of the site is shown in Figure 1. In the river mouth, Masuda port is located in the both sides of the river mouth and Takatsu channel passes behind a river-mouth bar. The river mouth bar is presently formed between the training wall and the breakwater, and the sediment of the bar is mainly composed of fine sand of about 0.2mm in grain diameter. In Takatsu channel located behind the river mouth bar, channel infilling has often taken place and navigation troubles have sometimes taken place.

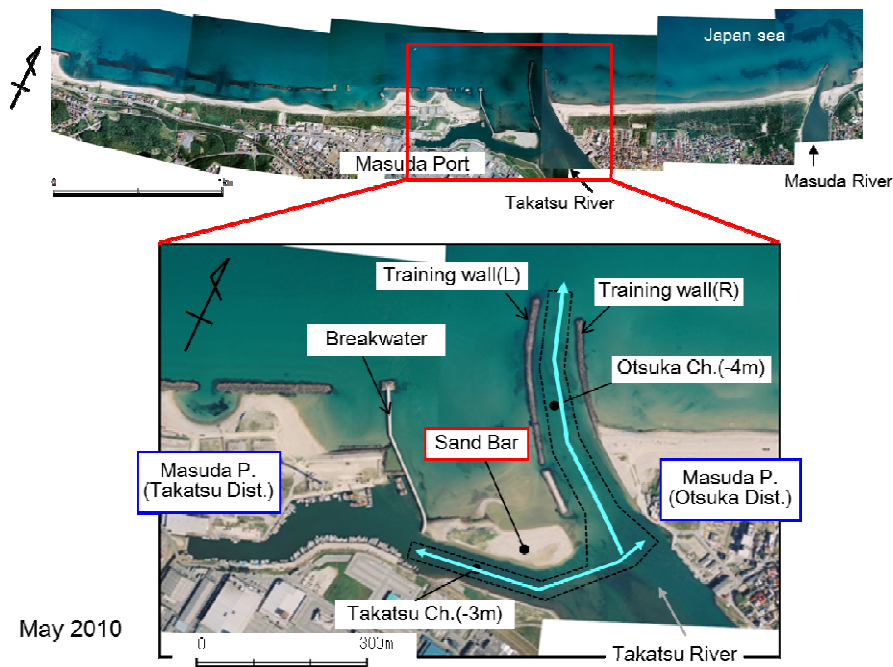


Figure 1. Mouth of Takatsu River, Simane Prefecture, Japan

¹ ECOH Corporation, 2-6-4, Kita-Ueno, Taito-ku, Tokyo 110-0014, Japan

Long-term transition of the sand bar shape

Figure 2 shows aerial photographs of the mouth of Takatsu River to describe long-term transition of the sand bar shape. In 1991, the sand bar was connected to the west coast. In those days, excavation of the sand bar was also carried out to prevent overflow in flooding (Uda, et. al., 1998). After 1994, detached breakwaters were constructed in the west coast of the river mouth and the root of the sand bar was gradually getting narrower. Under the situation, between 1999 and 2000, a heavy flooding happened and the sand bar was cut and the position of the bar moved onshore. After 2002, the breakwater in the left side of the sand bar was constructed and it has been gradually extended. In 2010, the training wall was also extended in the upstream direction. This study deals with the sand bar of 2010, which is perfectly disconnected from the west coast.

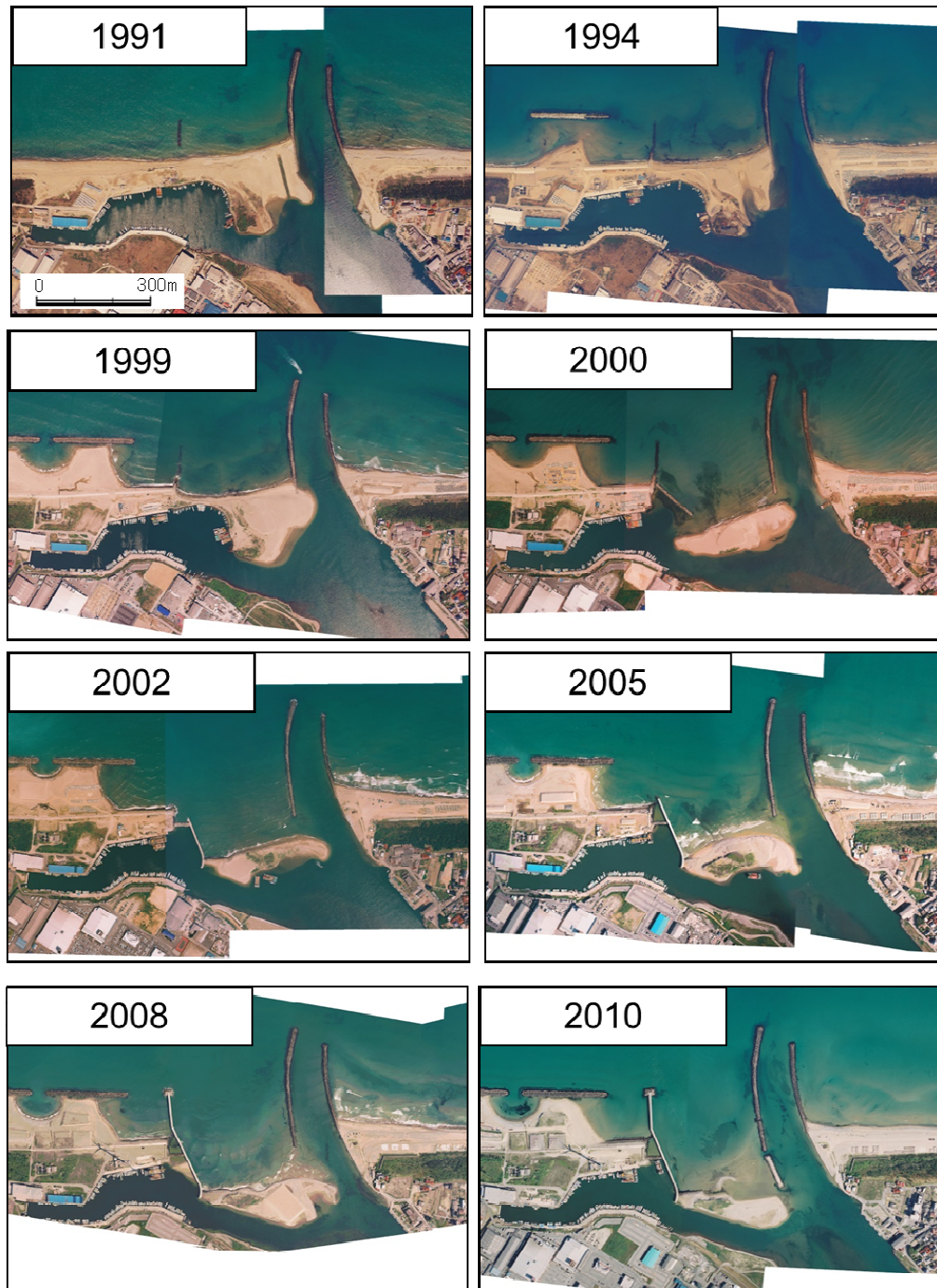


Figure 2. Transition of sand bar shape around the mouth of Takatsu River

Forcing conditions

The diagram on the top of Figure 3 is monthly-averaged daily mean discharge observed at Takatsuno, located 2.4 km upstream from the river mouth, and the bottom is monthly-averaged significant wave height observed at two nearest wave stations of Misumi and Hamada. It is found that seasonal variation of forcing condition is apparent in this site, where flooding is frequent in July and waves are low in summer and high in winter. The main wave direction in winter is from NNW to NNE and that of high waves greater than 2.5 m is NNW or N.

The diagram on the top of Figure 4 is monthly-maximum daily mean discharge and on the bottom is annual maintenance dredging volume of Takatsu channel and Otsuka channel. From the diagram on the top, it is confirmed that heavy flooding over 1000 m³/s in daily-mean discharge occurred three times during past 10 years. Corresponding to the heavy floods, the maintenance dredging volume in the next year increased. This indicates that the maintenance dredging volume or channel infilling volume tends to increase when heavy floods occur.

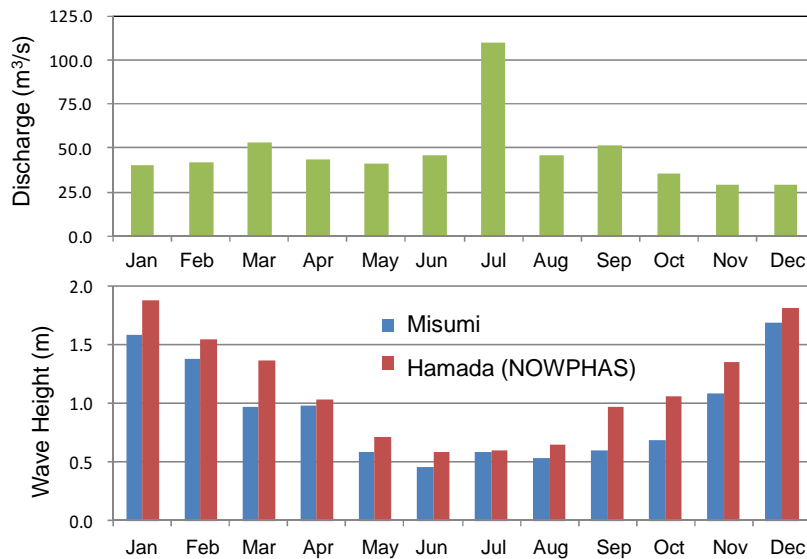


Figure 3. Monthly-averaged daily mean discharge (2000-2010) at Takatsuno (top) and monthly-averaged significant wave height (2000-2011) (bottom)

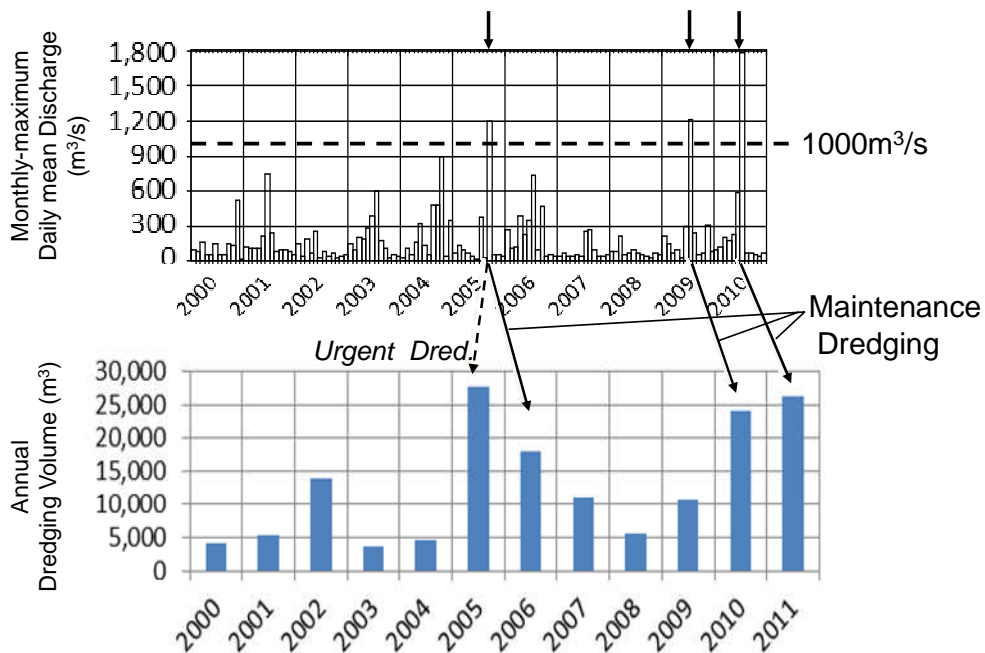


Figure 4. Monthly-maximum discharge (top) and annual maintenance dredging volume (bottom)

CHANNEL INFILLING PROCESS

Morphology change when flooding at July 2010

In the study site, massive deformation of the sand bar was caused by floods in 14 July, 2010. Figure 5 shows photographs of the sand bar before and after flooding of July, 2010. Figure 6 shows hydrograph of the flooding. The peak discharge of the floods is $2,700\text{m}^3/\text{s}$.

From Figure 5, it is found that the heavy flooding has flushed half of the sand bar. It is also found that the area between the sand bar and the training wall has opened widely and the flushed sand has deposited in the offshore.

After the floods, the river mouth bar tends to be gradually recovered by sequential wave action. Channel infilling in Takatsu channel was occurred in January, 2011. It is considered that the infilling is caused by the onshore sand transport due to high waves, through the widely opened area of the river mouth bar.

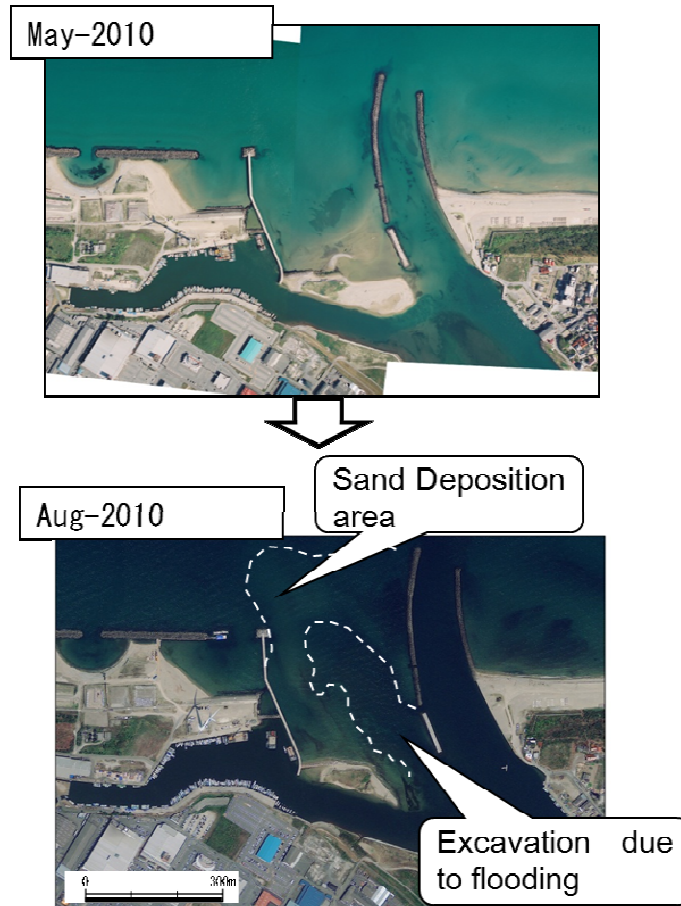


Figure 5. Deformation of the sand bar before and after the heavy flooding

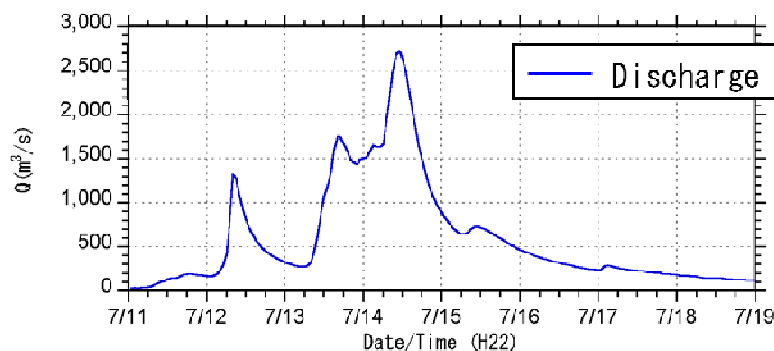


Figure 6. Discharge of the flooding at 14 July, 2010

Cross-sectional change of the river mouth bar

Figure 7 shows cross-sections on the line L200, which runs on the center of the sand bar. The cross-sections on the middle of Figure 7 is comparison between May 2004 and Apr 2005, when flooding over 1000 m³/s in daily-mean-discharge did not occur in this period. The cross-sections on the bottom of Figure 7 is comparison between Apr 2005 and Apr 2006, where a heavy flooding occurred with the peak discharge over 3000 m³/s as shown in hydrograph on the top of Figure 7, erosion of the sand bar crest and accumulation in the Takatsu channel were induced in case with a heavy flooding.

Consequently, the channel infilling process in the mouth of Takatsu River can be explained as follows. At first, the crest of the sand bar is flushed offshore by a heavy flooding. Then the flushed sand once deposited offshore moves onshore by waves, inducing the channel infilling due to sediment transport through the widely opened area after flooding.

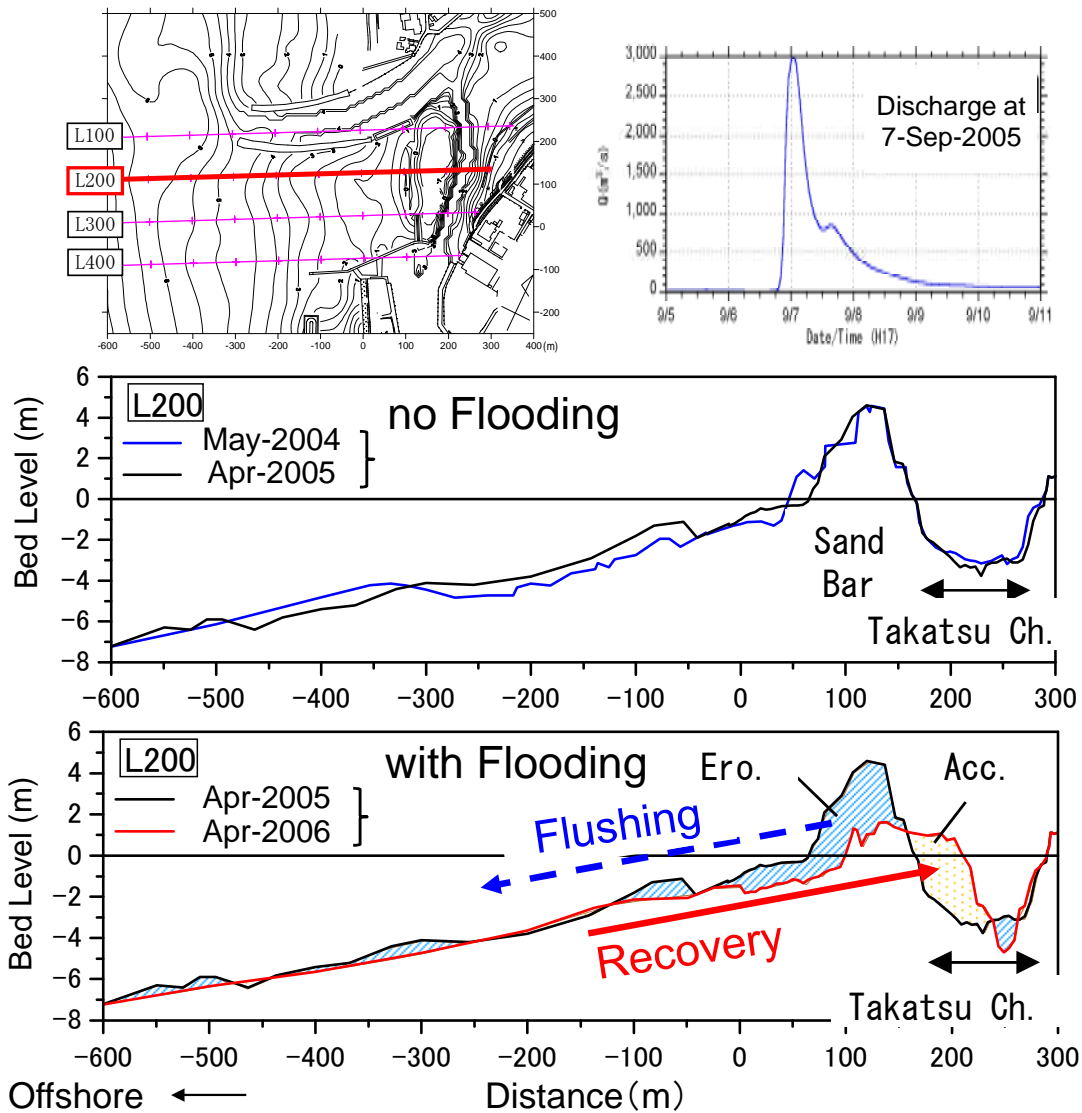


Figure 7. Change in cross-section profile with and without flooding over 1000m³/s in daily mean discharge

NUMERICAL SIMULATION

Model setup

Two dominant processes of channel infilling in the mouth of Takatsu River have been confirmed through analysis of bathymetric data. One is sand-bar deformation due to flooding and the other is morphology change due to wave starting from the topography after flooding.

In order to reproduce the deformation of river mouth bar and the resultant channel infilling, numerical simulations have been carried out for the two dominant processes of flushing sand bar due to floods and the onshore sand transport due to waves. The numerical model applied in this study is based on a depth-averaged model computing 2-D circulation including interacting waves and currents, sediment transport, and morphology change. The sediment transport rates of bed load and suspended load are calculated by van Rijn formulas (1985), and advection-diffusion transport model is implemented for calculation of suspended load.

The computational domain consists of the area of 2650 m x 2950 m including the river mouth, the topography of which is approximated by 10m meshes. For structure condition, the breakwater and training wall set as non-permeable cells, and reflection coefficient is set as 0.9 for the breakwater.

For simulation with flooding, the time-series of river discharge shown in Figure 6 is given at the upstream boundary of the computational domain and tide level of the open boundary of sea area is set as a constant value of MSL. For simulation with waves, three wave conditions of summer, autumn, and winter are employed taking seasonal wave characteristics into account.

Sand bar deformation by flooding

Simulation results are presented below. Figure 8 shows the simulated current velocity at the peak discharge and Figure 9 shows time-series of current, depth, and water level on the point A and point B shown in Figure 8. In Figure 9, the time series of current speed at Pt A show similar variation to the given discharge, and the peak speed is about 3 m/s. Also, the depth has rapidly changed during the second peak to third peak of the current, indicating that flushing sand bar occurred in the short period. The photograph in Figure 9 is taken at the time of peak discharge. The water level of the photograph is the same level as the crown height of the wharf. Time-series of water level at Pt. B show that the model well reproduced the rising water level during flooding.

Figure 10 shows the net depth change of the flooding simulation. The depth change is characterized that the sand bar is pushed out in the offshore direction due to strong current. The sediment moved by the strong current is deposited near the offshore end of the training wall with semi-circular shape. The shape of deposited sediment is quite similar to the photograph in Figure 5. Also, in the east half of Takatsu channel, accretion in channel takes place because of passing strong current on the area opened by flushing.

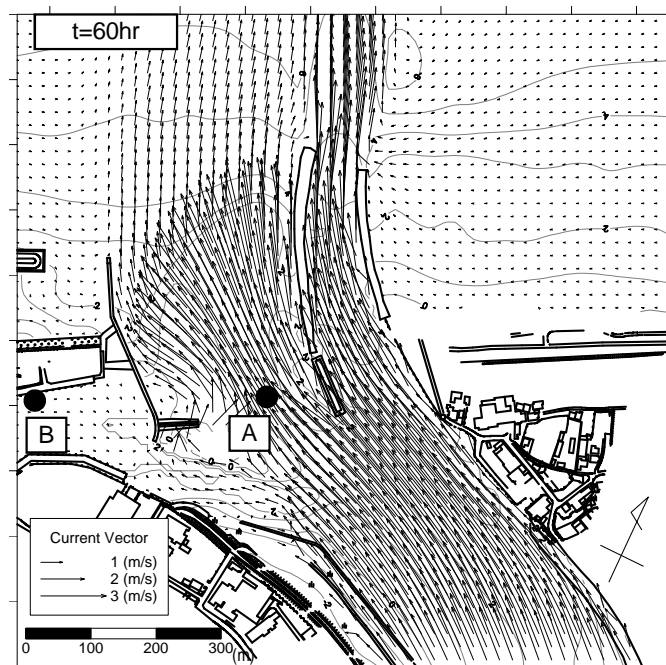


Figure 8. Simulated current velocity at the peak discharge

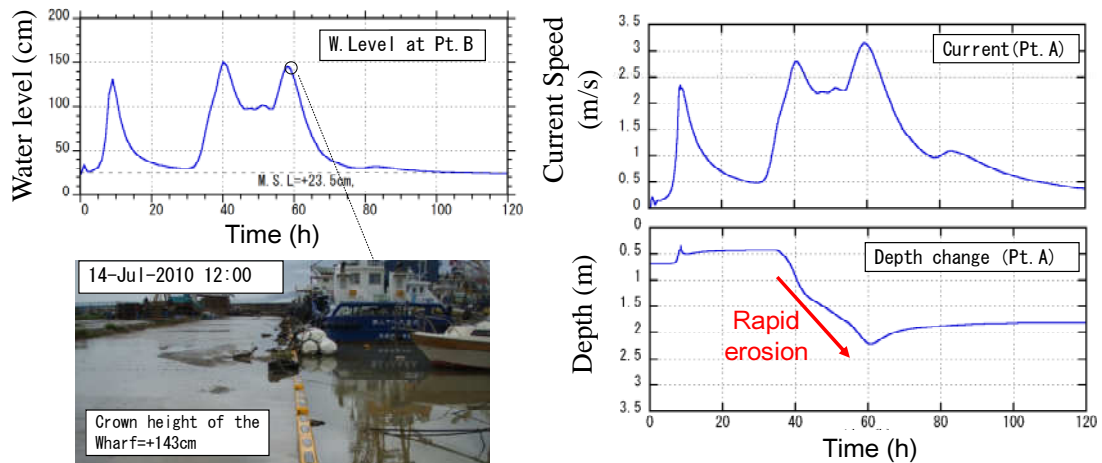


Figure 9. Simulated time-series of current and depth on the sand bar, and water level in the port area

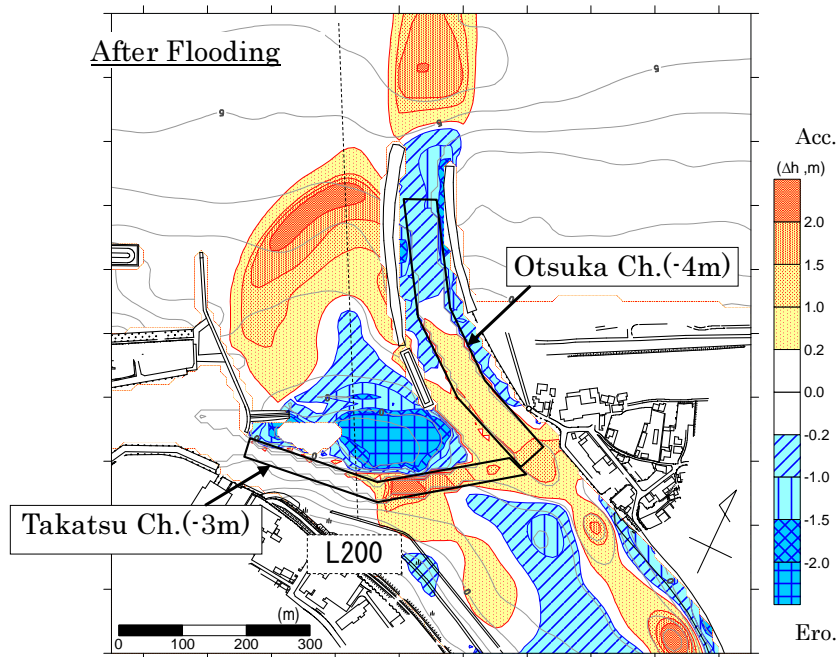


Figure 10. Net depth change after flooding

Sand bar deformation by waves

Sand bar deformation by waves is also simulated with the topography after flooding as the initial condition. In the simulation with waves, recovery process after flooding has been simulated where three wave conditions of summer, autumn, and winter are employed taking seasonal wave characteristics into account. The wave conditions of summer, autumn, and winter are 1.1m, 2.3m, and 3.1m in wave height, and 6.3s, 7.7s, and 8.3s in wave period, respectively. The representative waves are determined as probability of 10 % exceedance in each season and the wave duration in the simulation is determined as the total wave energy flux is equivalent to that of observation. The wave direction is set as NNW for all wave conditions, and the ordinal river flow ($=50 \text{ m}^3/\text{s}$) is given at the inflow boundary.

Figure 11 shows wave induced current velocity by the winter wave and Figure 12 shows the simulated net depth change between the topography just after flooding and that of the end of winter. From these results, it is confirmed that the onshore current is induced in the widely opened area

between sand bar and the training wall and the offshore deposited sand is transported onshore by the wave induced current leading to the channel infilling behind of the sand bar.

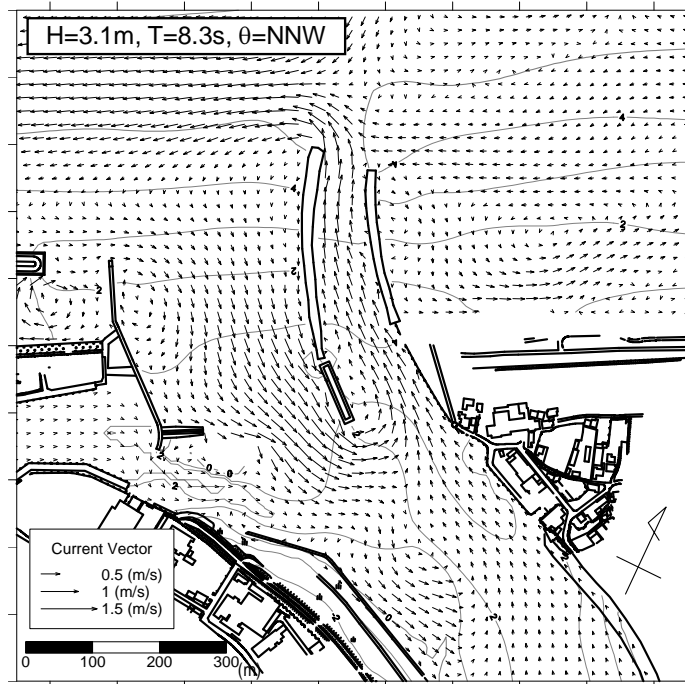


Figure 11. Wave-induced current velocity

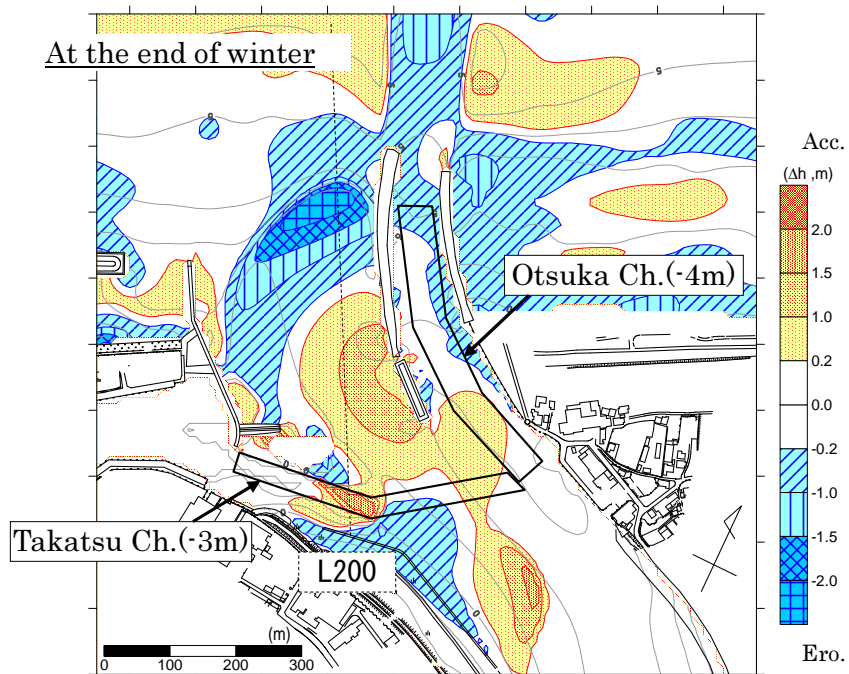


Figure 12. Cross-section profiles with heavy floods

Cross-sectional change of the river mouth bar

Figure 13 shows the simulation results of cross-section profiles on the line passing on the bar (L200) as shown in Figure 10 or Figure 12. The morphology change shown in Figure 13 indicates a process that the topography after flooding has recovered toward like the original profile. Also, the

Takatsu channel behind the river mouth bar has been gradually filled. Thus, the model showed good applicability by simulating a consecutive process of river mouth bar deformation, such as flushing by floods, recovery by waves, and the resultant channel infilling.

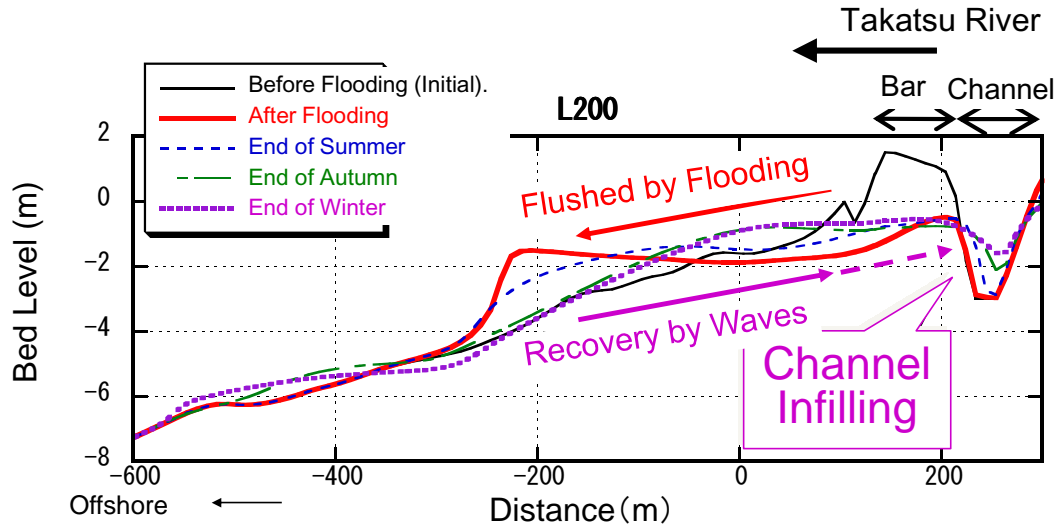


Figure 13. The simulated cross-section profiles on L200

Estimation of Channel infilling volume

Finally, channel infilling volume has been estimated and compared with the record of dredging volume. Figure 14 shows the result of comparison between actual dredging volume and simulated infilling volume for Otsuka channel, Takatsu channel, and both channels. The simulated volume for both channels show good agreement with the actual volume.

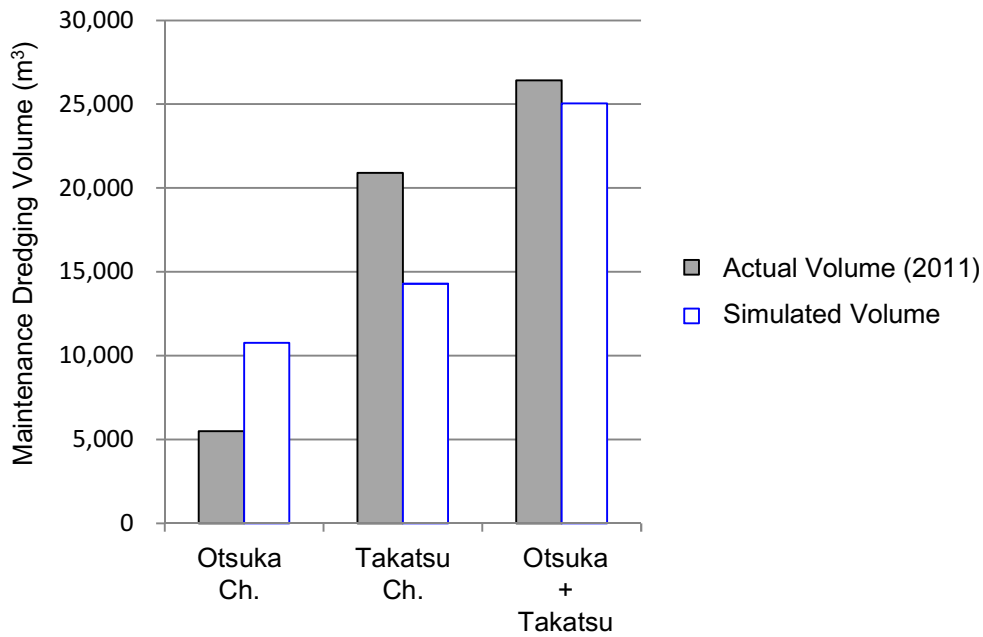


Figure 14. Comparison between actual dredging volume and simulated infilling volume

CONCLUSION

In this study, channel infilling process around the mouth of Takatsu River has been analyzed by available data and simulated numerically for the process strongly associated with the sand bar deformation. Main conclusions of the study are as follows.

1. By analyzing the available field data, two dominant processes are clarified for morphology change at the mouth of Takatsu River. One is flushing the sand bar by heavy flooding, and the other is the onshore sand transport by waves through the area opened by flushing.
2. Morphology change in flooding event has been successfully reproduced for the processes of flushing sand-bar, rising water-level in the port, and so on.
3. Morphology change by waves has been successfully reproduced for the recovery of sand-bar and resultant channel infilling by taking seasonal waves into account.

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