Environmentally-friendly dredging in the Bisan-Seto Shipping Route

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Abstract: Japan's Bisan-Seto Shipping Route serves as both a key a route for domestic shipping between Osaka and Kyushu and as an international sea trade route. Between fiscal year 1963 and 1972, the Ministry of Land, Infrastructure and Transport implemented a government-controlled program to improve this sea route. Approximately 38.4 million cubic meters of solids, including bedrock, were dredged to increase the depth of the northern shipping route to –19 m, the southern and connecting shipping route to –13 m, and the Mizushima Shipping Route to –17 m.

The Ministry of Land, Infrastructure and Transtport performed every few years this dredging in response to the complex surrounding geography and tidal characteristics of the shipping route, which cause sediment build-up and reduce the functionality of the shipping route. The dredging involves barge-loading pump dredgers, with the dredged material loaded onto barges for transportation to disposal areas. This work lead to the overflow of turbid water from hopper of barges into surrounding sea areas, causing marine turbidity.

The most recent Bisan-Seto Shipping Route dredging program was carried out over a five-year period, from fiscal year 2001 through 2005. The program incorporated studies on environmentally-friendly dredging methods that do not generate turbidity, leading to the selection of a method that recirculates overflow water from the barge to the dredger suction inlet, and realized an approach to prevent the generation of turbidity without reducing dredging efficiency. The pump dredger was equipped with an operational control system, GPS, and a Christmas tree to handle sandbanks and wakes from passing ships, which tend to complicate loading operations.

This report describes the barge-loading pump dredger equipment used in the Bisan-Seto Shipping Route dredging program, along with the nature and conditions of the dredging work performed in fiscal year 2001.

Keywords: Route dredging, Environmental preservation, Overflow water recirculation, Recirculation pump, Barge-loading

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INTRODUCTION

With the growing awareness of environmental issues in recent years, environmental pollution such as turbidity resulting from offshore work has become subject to increasingly strict regulations.

The Bisan-Seto Shipping Route dredging program previously involved dredging using a cutter pump dredger and transporting the dredged material on a barge to a specified site for disposal. This process, however, resulted in the pollution of surrounding sea areas due to turbid water overflowing from the barge hoppers carried by the tides and spread over a distance of several kilometers.

This sort of environmental pollution under the dredging program was no longer justifiable beginning in fiscal 2001, and so steps to prevent the generation and spread of turbidity during dredging were made priority issues.

As soon as its involvement in the fiscal 2001 program was determined, Tomac Corporation examined a number of issues to resolve these problems and ultimately developed a recirculating barge-loading dredger that collected water overflowing from the barge and returned it to the dredger cutter suction inlet. The system developed was used in the dredging program and demonstrated its ability to perform as specified while preventing the previously serious problem of turbidity spreading into the sea.

This report describes the development of the recirculating barge-loading dredger, the equipment used, and the results obtained in operation.

DEVELOPMENT OF TURBIDITY PREVENTION METHODS AND OUTLINE OF VESSEL MODIFICATION

The program was intended to dredge sediment accumulating on the seabed created by the sand wave phenomena caused by the tides. The sediment piled up thinly and spread over a wide area combined with the particular characteristics of dredging a shipping route heavily used by large vessels led in the past to the use of a cutter pump dredger, with dredged material being transferred to a barge using a barge-loading system. This method resulted in turbidity spreading from around the dredger cutter and in water overflowing from the barge. The majority of turbidity was thought to originate from overflow water. Studies therefore focused on methods to prevent the release of turbid water from the barge directly into the surrounding sea.

Two methods considered for preventing the release of turbid water from the barge directly into the surrounding sea were (1) to lower a tremie pipe from the barge into the sea to discharge overflow water naturally, and (2) to pump up the overflow water and discharge it close to the dredger cutter to be forcibly sucked up and recirculated together with the dredged material. One concern with method (1) was that the tremie pipe diameter would not be sufficiently large to discharge large volumes of turbid water, and so some turbid water would still overflow around the barge. There were also concerns that this method would not be sufficiently effective in preventing turbidity generation, as, depending on the tremie pipe discharge depth, turbidity could rise to the sea surface again. Method (2) was thought to be more effective in preventing turbidity generation, as it forcibly sucked up turbid water. Method (2) was therefore employed.

The recirculating system involved partitioning the barge hopper to install a tank to collect the turbid water, which was then pumped out and discharged close to the dredger cutter. The vessels modified were a 7,000-kW large-scale dredger, the *Chiyoda-maru*, owned by Tomac, together with 2,000-m^3 capacity box barges.

Modifications to the *Chiyoda-maru* Dredger

The dredger was capable of pumping up to a distance of 6,500 m, but only the ladder pump was used in this operation, without using the onboard main pump, as the barge-loading system only required transferring dredged material to the barge positioned alongside the dredger. The modifications made to convert the dredger to the barge-loading system are described next.

Recirculation pump

A new recirculation pump was installed on the dredger to recirculate the turbid water from the barge.

(1) Type

Pumps considered included a submarine pump and a fixed centrifugal pump, but a low-lift fixed-position centrifugal pump was ultimately used following comparisons of capacity for the turbid water collection tank to be installed in the barge and the costs involved for different installation locations. A new pump was manufactured and installed on the deck of the dredger.

(2) Pumping capacity

A total maximum water pumping capacity of 8,000 m^3/h was provided in conjunction with the ladder pump.

(3) Drive unit

An inverter control system was used for the drive motor, as this was able to cope with flow-rate fluctuations caused by variations in the concentration of the mixture being pumped.

(4) Inlet pipe

The recirculation pump inlet pipe consisted of a 650-mm-diameter rubber hose with a remotely controlled check valve to prevent flow backward at the inlet.

(5) Outlet pipe

The outlet pipe had a diameter of 550 mm and was connected via the ladder to the turbidity prevention cover fitted to the top of the cutter.

(6) Lifting gear

The recirculation pump inlet end had to be positioned in the barge collection tank when the barge was moored alongside, and so an inlet-pipe-lifting gantry was installed to enable the inlet pipe to be rotated and raised using an electric winch. The inlet pipe was also successfully stowed aboard the dredger when the barge was separated. The lifting gear is shown in Figure 1.

Figure 1. Recirculation pump inlet-pipe-lifting gear.

(7) Generator

Two 400-kVA mobile generators were installed, as the existing generator capacity was insufficient to power the two 230-kW recirculation pumps.

(8) Miscellaneous

A priming pump was installed on the inlet side of the recirculation pump, and air bleed valves were fitted to the inlet and outlet pipes. These were fully remote-controlled. The operation control system for the newly installed recirculation pump equipment enabled centralized control and monitoring from the dedicated control panel to ensure safe and efficient operation.

Barge-loading system

A new barge-loading system was installed to transfer dredged material to the barge.

(1) Spreader pipe

It was essential to load dredged material into the barge hoppers uniformly to ensure safe operation of the barge. However, the need to move the barge frequently alongside the dredger would reduce work efficiency, and so modifications were made to the spreader pipe used to discharge dredged material into the barge. The spreader pipe was changed from a fixed to a raising/lowering type, allowing the loading position to be adjusted by remote control. Remotely controlled butterfly valves were also added to both sides of the spreader pipe tip to increase the loading rate by adjusting the dredged material discharge rate.

(2) Barge mooring equipment

An auto-tensioning winch and universal fairleaders were installed to cope with movement of the barge caused by waves and shipping wakes and changes in draft when loaded, to ensure safe operation while moored alongside the dredger.

Turbidity-prevention Cover

The cutter pump dredger uses a cutter to excavate sediment from the seabed and sucks this up together with seawater. This means that material around the cutter is easily stirred up, and discharging the recirculated water close to the cutter would result in the disturbance of a large amount of material, spreading turbidity over the surrounding area. The turbidity-prevention cover shown in Figure 2 was therefore fitted to the top of the cutter, and the recirculated water was discharged inside this cover.

Figure 2. Turbidity-prevention cover on cutter.

The main details of the recirculating barge-loading dredger after modification are shown in Table 1.

Table 1. Main details of the *Chiyoda-maru* dredger.

Vessel dimensions		Ladder pump	x1
Length	77.0m	Pipe diameter	850/850mm
Beam	18.4m	Pumping capacity	8,000m^3/h
Depth	4.6m	Pumping head	18m
Maximum dredging depth	32.0m	Output	750kw
Swing winch	x2	Recirculation pump	x2
Output	175kw	Pipe diameter	650/550mm
Lifting capacity	25～35t	Pumping capacity	4,000m^3/h
Lifting speed	25～9m/min	Pumping head	10m
Christmas winch	x1	Output	230kw
Output	200kw	Cutter	
Lifting capacity	25t	Rotation speed	0～26rpm
Lifting speed	12m/min	Output	1,000kw

A Christmas system was used instead of spuds to ensure efficient movement of the dredger during operation and to cope smoothly with shipping wakes.

Barge Modifications

The box barge used in the dredging work was fitted with bulkheads on both ends of the hopper to create tanks for temporarily holding overflow water. The recirculation pump inlet was installed in one of the water tanks, but both tanks were connected by a pipe to allow recirculated water to be drawn from both tanks. Screens were fitted to the bottom of the bulkheads with 1-mm-meshes to prevent materials flowing from the hopper to the water tanks. These modifications enabled hopper overflow water to be recirculated efficiently.

Figure 3 shows water being sucked from the barge water tanks by the recirculation pump.

Figure 3. Barge water tanks.

DREDGING WORK DETAILS

The fiscal 2001 dredging program was conducted as shown below using the recirculating barge-loading dredger.

3.1 Dredging work outline

- Program: Fiscal 2001 Bisan-Seto Shipping Route (Inosakinotsugai area) Dredging Program
- Work contracted by: Land, Infrastructure and Transportation Ministry, Shikoku Regional Development Bureau
- Dredged volume: 167,000 m^3
- Work period: April 24, 2001 to October 31, 2001
- Location: Offshore from Sakaide-shi, Kagawa-ken
  As shown in Figure 4, the dredging area was located close to the Seto Ohashi bridge spanning the Seto Inland Sea, and covered the northern shipping route and north-south connecting shipping route of the Bisan-Seto shipping routes.

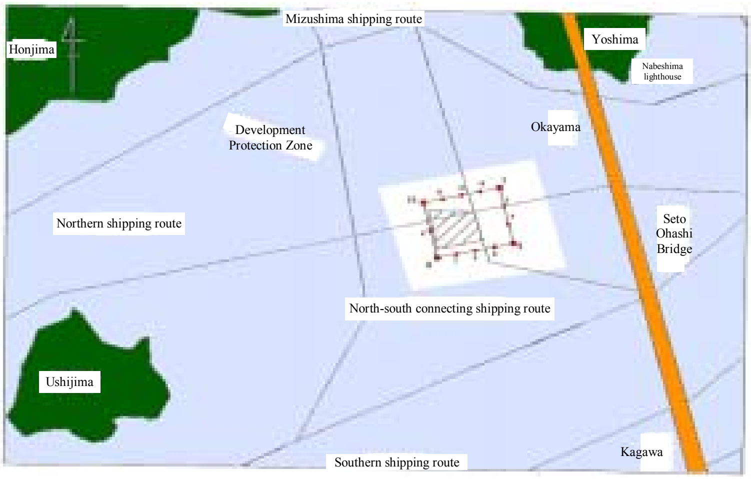

Figure 4. Dredging area map.

Working Vessels

Table 2 lists the working vessels used in the dredging program.

Table 2. List of vessels used.

Name	Class, Capacity	Number	Units	Purpose	Remarks
Chiyoda-maru	7,000kw	1	Vessels	Dredging	Barge-loading and water recirculating system
Anchor handling boat	736 kW, 35-t lifting	1	Vessels	Dredging	
Pusher boat	1,470-kW class	3	Vessels	Dredged material transporting	
Pusher boat	2,200-kW class	2	Vessels	Dredged material transporting	
Hopper barge	Box type, 2,000-m^3 class	5	Vessels	Dredged material transporting	Overflow water recovery system
Watch boat	370-kW class	3	Vessels	Safety observation	
Diving boat	50 kW, 5-t lifting	2	Vessels	Underwater surveying, tidal observation	
Survey ship	184 kW	1	Vessels	Post-dredging surveying	
Traffic boat	275 kW	2	Vessels	Water quality monitoring, staff transportation	

Dredging Operations

The procedures for dredging operations are as shown below.

(1) The dredger is guided to and positioned at the dredging location using GPS.

(2) The barge is moored alongside the dredger.

(3) The ladder pump is operated.

(4) The recirculation pump inlet is positioned in the barge water tank and started.

(5) The ladder is lowered to the specified depth, and the cutter is started to begin dredging. The loading system is controlled during dredging to ensure that dredged material is loaded uniformly onto the barge. The operation is monitored to ensure that water does not overflow from the water tanks. Views of the dredging operation are shown in Figures 5 and 6.

Figure 5. Overall view of the dredging operation.

Figure 6. Dredged material being loaded onto the barge.

(6) Once the dredged material has been fully transferred to the barge, dredging is stopped, and the amount of solids in the hopper of the barge is inspected.

(7) The barge is separated from the dredger, and the entire process is repeated.

PROBLEMS ARISING DURING DREDGING AND CORRECTIVE ACTION

As this was the first time the recirculation method had been used for dredging, a number of different problems arose during operations, but appropriate corrective action were successfully taken to ensure that work was completed safely and efficiently. Details are shown in Table 3.

Table 3. Main problems and corrective action during dredging.

Problem	Corrective action	Results
① Dredging work stopped due to barge recirculation water tanks becoming full.	• Increased recirculation pump capacity • Monitored the dredged mixture discharge using monitoring camera	• Work efficiency was improved by reducing dredging stoppage time and increasing continuous dredging time.
② Fast tides at certain times hindered anchor repositioning and vessel maneuvering.	• Tidal data used to plan operations at times with minimal tidal effects x	• Work efficiency was improved by an increase in operating time due to reduced work stoppages.
③ The mixture solids settled the discharge pipe when density increased.	• Concentration of the mixture settlement phenomenon controlled by adjusting dredging layer and loading equipment height	• Work efficiency was improved by allowing dredging at constant swing speed.
④ Time losses when separating from dredger due to differences in pusher boat performance	• Assistance using dredger swing operation and anchor handling boat	• Separating from dredger subsequently conducted safely and smoothly.
⑤ Smooth recirculation hindered by material blockage of screens on barge bulkheads.	• Increased number of screens	• Work efficiency was improved by allowing continuous loading.

DREDGING RESULTS

Dredging Performance

Table 4 shows the breakdown of operation time and dredging performance for the fiscal 2001 program.

Dredging was conducted using the recirculating system to ensure environmental protection by preventing the overflow of turbid water directly into the surrounding sea from the barge hoppers. This entailed time losses of 8% for water drainage. It is therefore considered essential to incorporate measures in the future to reduce the proportion of time required for water drainage, switch barges more efficiently, and increase the proportion of dredging time as much as possible.

Table 4. Breakdown of operation time and dredging performance.

Operation time composition (%)			Dredging capacity (m^3/h)
Dredging time	Drainage time	Barge switching time	
75	8	17	340

- Dredging time: The time required for dredging with operation of the ladder pump
- Drainage time: Dredging stoppage time to prevent water overflow from barge recirculation water tanks
- Barge switching time: The time taken to switch barges from completion of the dredging material loading to one barge until the start of loading to the next one

- Dredging capacity (m^3/h): Total volume of dredged material/total dredging time

Turbid Water around Dredging Area

Water quality was monitored around the dredging area while dredging was in progress. Turbidity was measured using a turbidity meter, with measurements taken at 15 locations within an area extending up to 2,000 m from the dredger. Two measurements were taken at each location: 2 m below sea level and 2 m above the seabed. These measurements showed no noticeable turbidity created throughout the entire dredging period, and operations were not stopped at any time as a result of turbidity. This demonstrates that dredging using the recirculation system was extremely effective in preventing turbidity.

CONCLUSION

The Bisan-Seto Shipping Route situated in Japan's Seto Inland Sea serves an extremely important role as both an international and domestic shipping route. The Ministry of Land, Infrastructure and Transport implemented a large-scale program to dredge the route every few years to maintain its usefulness.

The Bisan-Seto Shipping Route dredging program demanded safe and efficient dredging amid the difficult conditions created by fast tides and the congested shipping traffic; however, dredging was conducted for the first time on this occasion using a recirculating barge-loading dredger, which successfully prevented the generation and diffusion of turbidity without reducing dredging performance.

The results of this dredging operation are believed to form a model case for Bisan-Seto Shipping Route dredging operations, while taking into account environmental considerations through the use of a recirculating barge-loading dredger.

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