AN INNOVATIVE TRAILING SUCTION HOPPER DREDGER WITH AFT-CENTER DRAG SYSTEM AND A WIDE SPAN DRAG-HEAD

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ABSTRACT

The new “Seiryu-maru” is a highly advanced multifunctional high-capability trailing suction hopper dredger with an oil recovery system. She is capable of three major functions: dredging of environmentally-friendly leveled dredging by thin layers; oil recovery - capable of handling low- to high-viscosity oil in the open sea, and accident control - prompt response in the event of an disaster such as large-scaled oil spill and earthquake, etc.

The vessel was ordered by the Chubu Regional Bureau of the Ministry of Land, Infrastructure and Transport (MLIT) of Japan and completed in March 31, 2005. Since then, she has been engaged in dredging work in Nagoya Port in Japan.

She has replaced the first-generation “Seiryu-maru”, which was a very conventional trailing suction hopper dredger with drag-arms on both sides. The new “Seiryu-maru”, however, has been completely changed from the old one in design but keeping the capacity of the mud hold unchanged. She is an outstanding vessel unparalleled in the world with regard to her basic concept of dredging systems. The dredging system is based on adoption of the world's largest-class wide span drag-head 7.2 m in width which permits high accuracy in leveled dredging without left-over, excessive or stripe dredging; while the old “Seiryu-maru” adopted the conventional drag-heads of 2.0 m width. Adoption of the ultra-wide drag head has resulted in a hull layout that accommodates a drag-ladder at the aft center of the vessel, a so called aft-center draghead system. In actual dredging operations in Nagoya Port, highly accurate dredging with a high mud concentration has been realized.

This paper shall present the results of comparison study in dredging efficiency between the old and the new “Seiryu-maru”, namely conventional side drag system versus aft-center drag system, based upon the measured data of dredging production, dredging cycle time and dredged bottom surface during the dredging trial. The finding was that the total dredging efficiency of the new dredging system achieved a level abt.35% higher than the old one.

Key words: Trailing suction hopper dredger, Environmental preservation, Wide span drag-head, Drag ladder, Aft-center draghead system, Dredging efficiency, Automatic control, Oil recovery system.

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1. INTRODUCTION

The new "Seiryu-maru" is the replacement for the trailing suction hopper dredger "Seiryu-maru" called the old Seiryu-maru herein, with an oil recovery system that was built in 1978. The new Seiryu-maru is a world unique multi-function trailing suction hopper dredger facilitating three functions, a dredging function to achieve environmentally friendly "thin layer" dredging, spilled oil recovery function adaptable for a wide range oil types from low to high viscosity in rough oceanic conditions, and a rescue function instantly deployable for hazards.

The new "Seiryu-maru" in this paper was completed on 31st March, 2005 and is owned by the Chubu District Port Construction Bureau of the Japan Ministry of Construction and Transportation. It is undertaking dredging work in the Port of Nagoya.

The basic design of the dredger was intended to facilitate a newly developed wide span drag-head of 7.2 meter breadth to realize high accuracy leveled dredging that minimizes left-over, excessive and stripe dredging profile compared with the old Seiryu-maru that was designed as a conventional trailing suction hopper dredger with drag arms at both ship sides. Accordingly the new Seiryu-maru became a very rare trailing suction hopper dredger in the world being an aft-center draghead type dredger with only one dragarm ladder at the cerntre of the ship's stern

This paper presents the overall dredging efficiency of the new dredger based on the data acquired in the actual dredging operation in the Port of Nagoya in comparison with those for the old Seiryu-maru. As a conclusion it was proved that the new dredger was 35% more efficient than the old one.

Photo 1. Over View Of New Seiryu-maru

2. OUTLINE OF THE NEW DREDGER

The basic design of the new dredger intended that the vessel to be equipped with the newly developed wide span drag-head of 7.2 meter span to realize high accuracy leveled dredging that minimizes left-over, excessive cut and uneven dredging profile. This compares with the old Seiryu-maru designed as a conventional trailing suction hopper dredger having drag arms, one each at the ship sides. Accordingly the new Seiryu-maru is a very rare trailing suction hopper dredger in the world being an aft-center drag type dredger with only one drag ladder at the center of the ship's stern .

In planning concepts for the new dredger, we started to review all the aspects of the operations of the old dredger including problems experienced in this old dredger, and extended discussions regarding the prospects for dredgers to be expected in future. Important points of the review and discussions are as followings.

(1) Dredging system to achieve highly accurate leveled dredging without left-over material, excessive or stripe dredging. Development for a wide span drag-head capable of preventing the sucking of water due to roughness of dredging bottom

(2) Development for a land discharging system for dredged mud instead of dumping directly to the sea from the viewpoint of the preservation of environmental conditions. Also, development for an overflow recycling system to improve loading efficiency of the mud hold.

(3) Development for an oil recovery system with high seaworthiness operable in a significant wave height of 2.5 meters. Development of a high efficiency oil recovering system to replace the conventional oil collecting boom

(4) Development of an oil recovery system operable for high viscosity oil balls and rubbish

(5) Study for a rapidly deployable rescue and hazard control system, helicopter deck, information and telecommunication systems, and other hazard control system.

(6) Application of integrated highly automated system for all aspects of the dredging operation including automation for dredging, mud dumping and oil recovery systems, as well as ship navigation and engine operation. Management for various data and information network for operation, video, safety managing, fault diagnosis and other data

2.1 Main Particulars

Length overall	104 meters
Length between perpendiculars	96.0 meters
Breadth (mold)	17.4 meters
Depth (mold)	7.5 meters
Draft (mold)	5.6 meters
Gross tonnage	4,792 tons
Trial speed	13.5 knots
Deadweight	3,579 tons
Mud tank capacity	1,700 m^3
Collecting oil tank capacity	1,500 m^3

2.2 New Technologies and Systems applied to the new Dredger

The new technologies applied to the new Seiryu-maru are as listed below.

(1) New dredging system and new wide span drag-head for highly accurate leveled dredging

(2) Dredged mud transfer system employed to discharge dredged mud to the mud discharge area with consideration for the preservation of the environment and high dredging efficiency

(3) Oil recovery system consisting of the oil collecting device having high seaworthiness and a water jet

(4) The oil collecting device capable of disposing spilled oil of high and low viscosities

(5) Hazard control system to achieve roles for hazard managing center

(6) Integrated automated control system for all facilities of the dredger including sub-systems for dredging, land discharging, navigation, oil recovery, engine operation and so on

Photo 2. Wide Span Drug Head

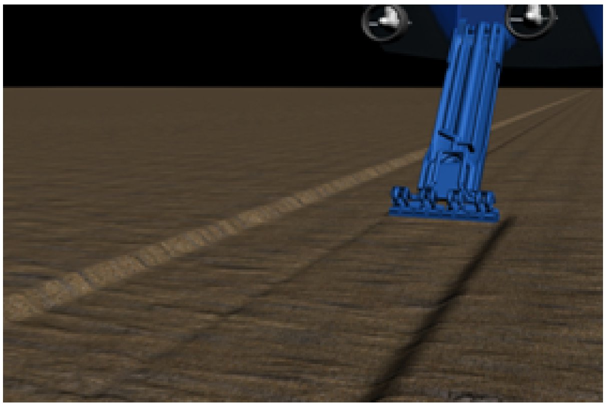


Figure 1. Concept for Wide Span Drug Head

2.3 Dredging System

The drag head is constructed as a single body having a span of 7.2 meters wide for leveled dredging profile. The drag head is divided into four sections to keep its contact with sea beds coping with unevenness of the sea bottom, thus preventing water suction caused by heaving of the drag head as a whole due to roughness of the sea bottom. This was a deficiency of the single body drag head with super wide span. As the result of the division of drag head by sections, high mud density and highly accurate dredging operation was achieved in the actual operation.

The water recycling system to return top clear water in the mud holds to the drag head was introduced to improve operational efficiency further.

The adoption of wide ultra span drag head forced the layout of the vessel to be an aft-center draghead type. However this layout was the best for making good use of the advantages of the wide span drag head as well as every advantage of the side draghead type of dredgers.

The mud suctionwater line was designed to be of a single line system with one dredge pump, though a two line system with two pumps is the usual application for conventional dredgers.

Considering that no simultaneous operation of the mud discharge pump and the recycling pump is expected, one common pump is equipped for both the mud discharge line and the recycling line so as to reduce the number of the pumps. Accordingly, the number of mud water lines on the drag ladder is also reduced. Thus the piping was reduced to almost half of that in any conventional dredger, and maintenance work for the pump lines is also reduced accordingly.

Another advantage attained by adopting the aft-center drag layout is that the dredging paths match the ship's navigating paths resulting in improvements to the operational efficiency.

In the aft-center drag type dredger, the living quarters are usually arranged at the fore part of the ship considering the ship's trim and maintenance of the drag ladder. In the new Seiryu-maru the living quarters are arranged at the aft of the ship to ensure comfortable living conditions and avoiding the effect of vibrations and pitching because the new Seiryu-maru is to be deployed even in rough wave conditions for oil recovery and rescue work.

2.4 Oil Recovery System

The oil recovery system installed on the new dredger was developed to satisfy various requirements, such as oil recovery efficiency under rough sea conditions, performance for collecting spilled oil floating on the water surface, and performance for removal of high viscosity oil.

The oil recovery scoop was designed to be operable in wave conditions of 2.5 meter wave height. The targets for development of the above were achieved by the improvements made to the existing swirl type oil recovery scoop.

The improvements made to the existing swirl type are;

(1) To heighten the opening level for water in-take

(2) To increase water jet capacity at the lower part to improve water flow at the in-take

For the first time in the world an oil collecting system with a water jet was developed to increase oil collecting efficiency and installed on the new Seiryu-maru. In the case of the existing oil collecting system, oily water gathering around the in-take escapes and is not trapped by the collecting device because of turbulent waves at the in-take, thus the collecting efficiency became low.

The new system using the water jet with proper jet directions and properly adjusted jet forces improved oil collecting performance and total efficiency of the oil recovery system. The system installed on the new Seiryu-maru is a simple operation compared with the conventional oil collecting boom and is safe for navigation because no structural part is required for the oil collecting device.

In addition, a skipper type oil recovery system newly developed for the new Seiryu-maru was installed to scoop extremely high viscosity oil reflecting experiences in the large oil spill accident of the Russian vessel "Nakhodka".

Photo 3. Oil recovery system with water jet Oil collecting device

2.5 Hazard Control System

In addition to the dredging and oil recovery systems, the new Seiryu-maru is equipped with hazard control systems. A helicopter deck is installed for the first time as the dredger is owned by port authorities and is used for transporting staff and materials in the occurrence of large scale hazards or disasters. A hazard control room is provided which is equipped with modern IT systems (information and telecommunication technologies), including a video conference system and other systems, such as support system for information capturing, video and graphic information distribution network and support system for hazard control documentation.

Communication with the land facilities is through an INMALSAT, high speed wireless communication system that is able to send and receive video data as well as other digital data.

2.6 Advanced Automated Operation System

The automation system was installed based on the experienced systems having been introduced to the ex Seiryu-maru. Further improvement was made to the systems for the new dredger aiming at manpower saving, easy operation, operational safety, higher dredging efficiency, less burdening maintenance management. (Reference to the paper "Artificial Intelligence for Dredging Control of the Trailing Suction Hopper Dredger" 14th WODCON)

The centralized remote controls and automatic controls enable all operations to be carried out at the bridge including navigation, dredging, oil recovery, and engine control.

All aspects of operations to be carried out on board the dredger are monitored by a sensor base monitoring system. In addition to the monitoring system, the visual and acoustic monitoring system is completed with 40 sets of video cameras throughout areas of the new dredger without hindsight.

The centralized data managing system is employed covering 800 analogue inputs and 10,000 digital inputs which are captured at one second scanning time intervals and used for supporting a system of fault diagnosis, a remote fault diagnosis system, and data logging and reporting system for engine and deck parts.

The centralized data managing system also covers engine fault predicting data, dredging depth data at coordinates of a one meter lattice and video data by using the monitoring cameras as motion and static pictures. The illustration for layout of integrated automation system is as indicated in the Figure 2.

3. ANALYSIS FOR DREDGING EFFICIENCY

Following are reports for the overall dredging efficiencies obtained through the analysis of the dredging data acquired during actual dredging operations in the Port of Nagaya in comparison with those of ex Seiryu-maru. In the following item 3.1 we will describe differences of the dredging systems between the new and the ex Seiryu-maru. In item 3.2 we will summarize dredging efficiencies comparing those of the new and the ex Seiryu-maru.

3.1 Differences of the Dredging System

The table 1 shows the main particulars of the new and the ex Seiryu-maru.

Major differences of the dredging system between the new and ex Seiryu-maru are as follows (refer to sketch for illustration of differences of the new and ex Seiryu-maru in the Figure 3.).

(1) Propulsion system

A fully rotating propeller contributes to improvement of steering performance and eliminates the steering rudder used for the ex Seiryu-maru.

(2) Dredge and mud water line

The dredge and mud water line adopted is a one line system comprising one dredge pump and one drag arm for the new dredger instead of a two line system in the ex Seiryu-maru.

The dredging pipe installed in the drag arm in the new dredger is one 900 mm diameter instead of two 630 mm diameter pipes in the ex Seiryu-maru, thus mud water suction efficiencies increase as the result of the decrease of pressure losses in the pipe.

(3) Wide Span Drag Head

The span of the drag head is increased to 7.2 meters in the new dredger compared with 2x two meters in the ex Seiryu-maru. The drag arm is of an aft-center drag type rigidly connected to the ships hull so as to limit lateral movements instead the drag arms suspended by wire ropes allowing lateral movements in the ex Seiryu-maru.

(4) Common use for discharge pump and recycling pump

Capacity of recycling pump is increased significantly to 4,000 m^3/h in the new dredger compared with 1,800 m^3/h in the ex Seiryu-maru.

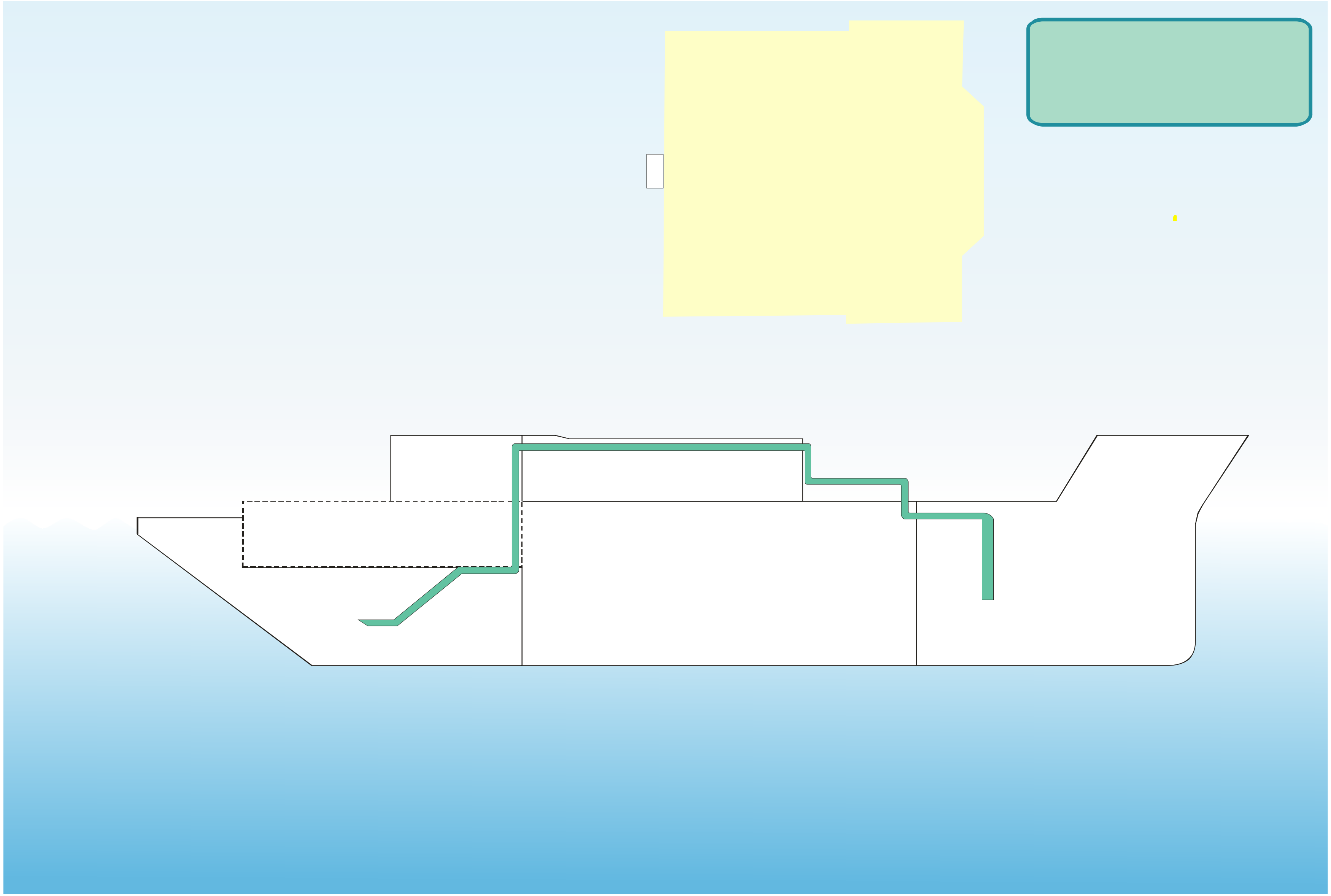


Table 1. Comparison Table for Main Particulars between New Dredger and ex Seiryu-maru

No	Item	Ex Seiryu-maru	New Dredger
1	Length overall	94.9 m	104 m
2	Breadth (mold)	16.0 m	17.4 m
3	Depth (mold)	7.2 m	7.5 m
4	Full load draft	5.6 m	5.6 m
5	Gross tonnage	3,256 GT	4,792 GT
6	Mud Hold	1,700 m^3	1,700 m^3
7	Max dredging depth	22 m	21 m
8	Speed	13.3 kt	13.5 kt
9	Main engine	3,000 PS×2 sets	2,860 kW×2 sets
10	Propulsion	(CPP＋Rudder)×2 sets	Fully rotating propeller× 2 sets
11	Bow thruster	CPP type 300 kW× 1 set	CPP type 600 kW× 1 set
12	Dredging speed	3～4 Kt	3～4 Kt
13	Dredging pump	4,100 m^3/h×17 m×2	8,000 m^3/h×17 m×1
14	Drag arm	Inner diameter 620 mm×2 Two side drag type	Inner diameter 900 mm×1 Aft-center drag type
15	Type of drag head	California type Width 2.0m×2 sets	Wide edge type Width 7.2m×1 set
16	Recycling and discharge pump	900 m^3/h×27m×2 sets (at recycling)	4,000m^3/h×22m/ 8,000m^3/h×17m×1 (recycling/ discharge)
17	Jet pump	500 m^3/h×75m×2 sets	1,000 m^3/h×75m×2 sets
18	Oil recovery system	Swirl type×2 sets Slope plate type×2 sets	Swirl type×2 sets skipper type×2 sets
19	Recovery oil tank	1,450 m^3	1,500 m^3
20	Hazard control system		Helicopter deck, Hazard control center, Communication and information system

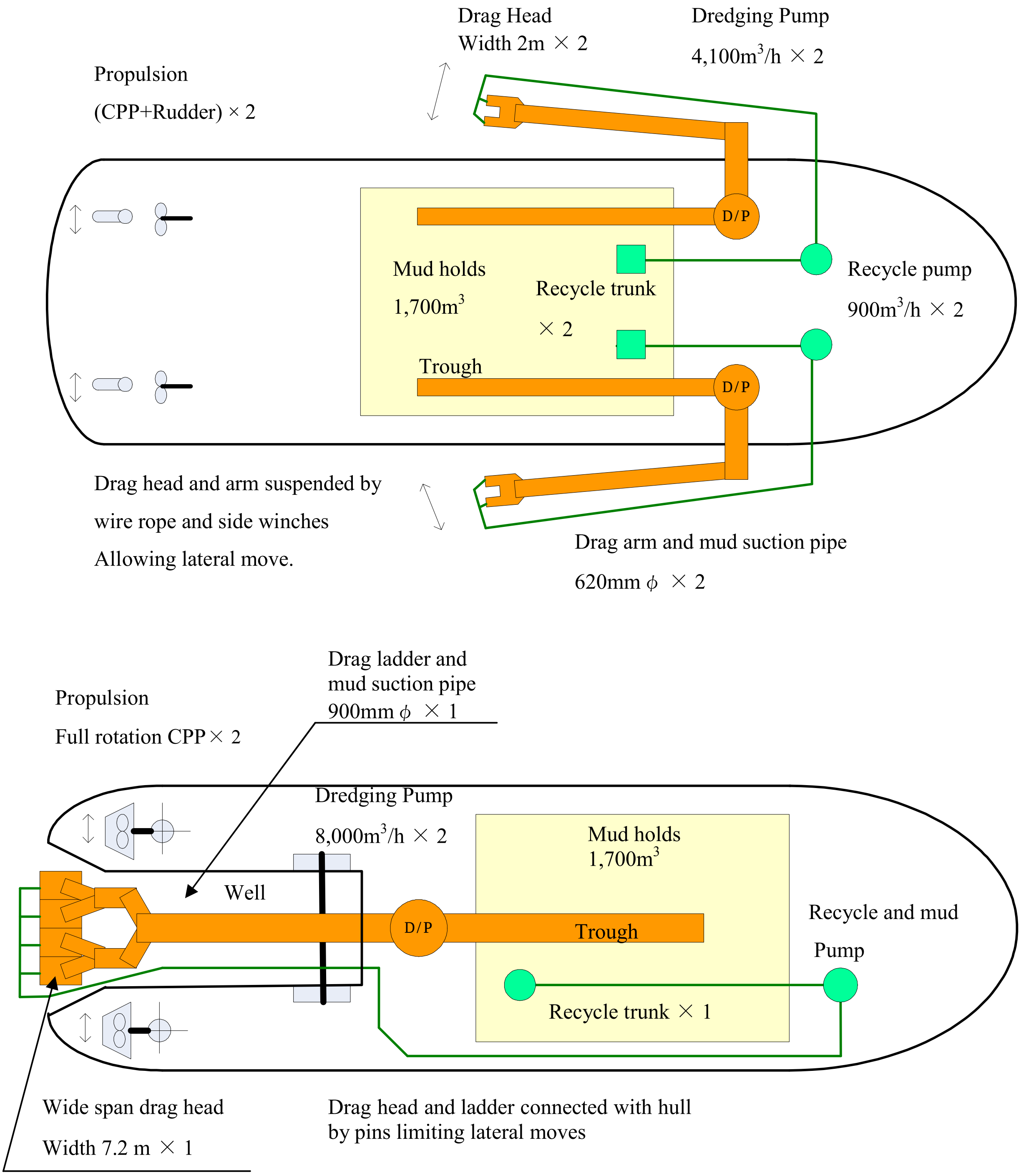


Figure 3. Illustration for differences of the new and ex Seiryu-maru.

3.2 Methods for comparing dredging efficiency

3.2.1 General

The most important factor for evaluating dredging efficiencies is dredged soil volumes in a certain period of time. The dredged soil volumes are calculated by multiplying the number of dredging cycles in a certain time by dredged soil volumes for each dredging cycle. In another words, since number of dredging cycles in a certain period is inversely proportional to a dredging cycle time, dredged soil volume in a certain period is proportional to a ratio of dredged soil volume per dredging cycle and dredging cycle time (Dredged soil volume per dredging cycle/Dredging cycle time).

For the purpose of evaluating dredging efficiencies, we mainly colleted and analyzed the data in relation to the above mentioned ratio.

Further, for evaluating evenness of the dredged sea bottom and excessive dredging, the depths of the sea bottom at cross points of a 10 meter lattice were measured.

3.2.2 Conditions of the dredging site and dredging method

Particular aspects of conditions at the dredging site and dredging methods in which the new and ex Seiryu-maru were deployed are as follows.

(1) The dredging work was intended to maintain depths of the navigation channels in the Port of Nagoya and to deepen them further. To pursue the intended purpose above, it was required to dredge while keeping evenness of the sea bottom and eliminating excessive dredging. These two requirements are particularly important in the recent situation because soil discharging areas have become less available.

In order to eliminate excessive dredging thin layer dredging procedures were adopted, that is, the dredging work was carried out in thin layers of 30 cm.

(2) No overflow during dredging work, and no dumping of dredged soil into the sea

To prevent pollution of the sea water with dredging, no overflow and no dumping into the sea during dredging is allowed. Discharging of the dredged mud is made to the mud transfer barge moored near the reclamation site using the land discharge system onboard. Therefore it is required in view of improving dredging efficiencies that dredged soil volumes should be as high as possible without causing any overflow. To prevent any early overflow and to prolong the continuous dredging time, the recycling system is also in operation returning clear water in the top of the mud holds to the drag head.

3.2.3 Data for comparing dredging efficiencies

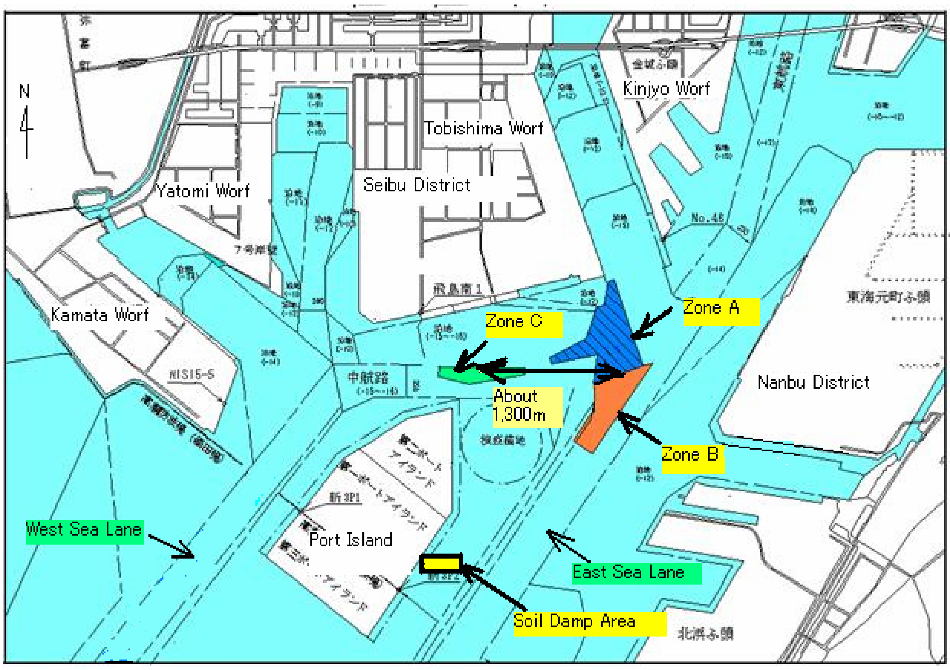
We used the dredging data obtained during dredging work of the new and ex Seityu-maru at three dredging zones in navigation channels of the Port of Nagoya for comparing dredging efficiencies. Fig. 4 indicates the mapped area around the dredging sites.

(1) Data for dredging work recorded in the daily report

The subject data includes the all day dredging data, starting and finishing time, and dredged soil volumes for respective dredging cycles obtained for the three dredging zones. Dredging time and dredging cycle time (time difference between the starting time of two consecutive dredging operations) were also calculated using the data mentioned above.

(2) Administrative survey data

The survey data for the sea bottom at the completion of dredging work for dredging zone A (dredged by the new dredger) and zone B (by ex Seiryu-maru) were used The data were taken at cross points of a 10 meter lattice.



Dredging zone	Dredger	Term for data capturing	Number of dredging cycle	Remarks
Zone A	ex Seiryu-maru	2004/12/1 ～ 2005/2/25	287	・soft mud ・irregular shape zone
	New Seiryu -maru	2005/5/9 ～ 2005/8/5	400	
Zone B	ex Seiryu-maru	2004/4/1 ～ 2004/9/15	252	・soft mud ・standard shape zone
Zone C	New Seiryu-maru	2005/4/4 ～ 2005/9/30	242	・sand silt ・narrow area zone

Figure 4. Site Map (Port of Nagoya , Japan)

3.3 Comparison of dredging efficiencies

The table 2 shows the results of the analysis undertaken for the comparison of the dredging efficiencies of the dredging work for the navigation channels of the Port of Nagoya. Fig. 5 indicates the frequency distributions for various data including dredged soil volumes in the dredging work for zone A.

3.3.1 Dredging operation hours

(1) Records for the operation hours in the dredging log were used for counting dredging operation hours. The dredging operation hours are time lengths between the start time for lowering the drag arm at the dredging site and the time for completion of raising the drag arm upon achieving a full load in the mud holds.

(2) The results of counting the operation hours were in the case of the ex Seiryu-maru 27.6 minutes on average and for new dredger 33.4 minutes. This means the operation hours of the new dredger is longer by 5.8 minutes on average.

(3) It is assumed that the increase of the operation hours for the new dredger was the result of the larger capacity of recycling water which made the time for filling the mud holds longer. Accordingly the time and distances utilized for effective dredging increased the share in dredging cycles with increasing dredged soil volumes.

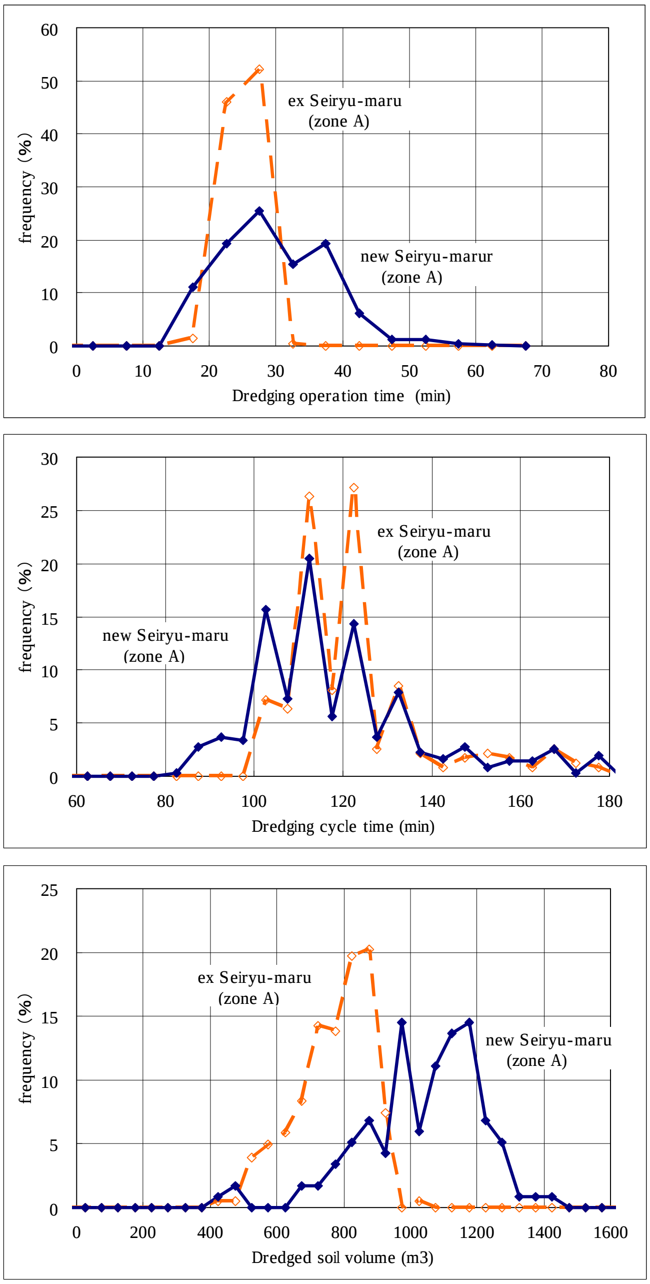


Figure 5. Frequency Distribution for Dredging Time, Dredging Cycle Time, Dredged Soil Volume

3.3.2 Dredging cycle time

(1) Dredging cycle time means the time interval between the starting time of consecutive dredging operations including time for sailing to soil discharge areas, discharging of soil to the areas, and returning to the next dredging position following the end of actual dredging operation. Since the recorded cycle time sometimes includes down time due to large vessels navigating in the dredging area, we chose and averaged cycle time of three hours or shorter which was assumed to contain the least amount of down time for avoiding other vessels.

(2) In the case of analyzing the data for zone C which was 1,300 meters apart from other dredging zones as indicated in the Fig. 4, the additional time required for navigating this distance was considered.

(3) As the results, dredging cycle time was 123.8 minutes on average for ex Seiryu-maru and 119.2 minutes for the new dredger. It was confirmed that the cycle time for the new dredger was 4.6 minutes or about 4 % shorter than that for the ex Seiryu-maru. Fig. 5 also indicates the same result as mentioned before.

(4) It is thought that the fully rotating propellers installed on the new dredger contributed to easier steering with a smaller turning radius during mooring operations associated with the mud transfer barge and during dredging operations. Consequently the cycle time became shorter by 5 minutes or about 5 %.

Even though the dredging time of new Seiryu-maru in one cycle became longer by 5.8 minutes when compared with that of the ex Seiryu-maru, the cycle time of the new dredger was shorter by 5 minutes or 4 % as mentioned above.

The captains of the new dredger commented that the turning of the new dredger was easier, without drifting the dredger position, and commented that approach and mooring to the mud transfer barge became much easier and speedier.

Table 2. Summary for Results on Comparison of Dredging Efficiency

	Item		ex Seiryu-maru		New Seiryu-maru	
1	Dredging work area		zone A	zone B	zone A	zone C
2	Target dredging depth		-15m	-15m	-15m	-15m
3	Soil kind in dredging area		Silt	Silt	Silt	Sand silt
4	Assumed mud density (t/m^3)		1.32	1.32	1.32	1.46
5	Estimated dredging area (m^2)		295,800	319,200	295,800	200,000
6	Features of dredging zones	Shape	Irregular shape	Near right angle standard shape area	Irregular shape	(1)smaller area (2)inclined wall channel
		Features	(see note 1)		(see note 1 and note 2)	1,300m apart (see note 3 and note 4)
7	Data capturing periods		2004/12/1～2005/2/25	2004/4/1～2004/9/15	2005/5/9～2005/8/5	2005/4/4～2005/9/30
8	Dredging cycles		287	252	400	242
9	Average actual dredging time in one cycle （min.）		27.6	27.5	30.5	38.2
	Weighted average		27.6		33.4	
10	Average dredging cycle time （Minute）		123.0	124.8	119.0	119.7 (excluding time for 1300m navigation)
	Weighted average		123.8		119.2	
11	Average dredged volume in one cycle (m^3)		770.8	777.4	1036.6	993.0 (γm=1.32 Converted value）
	Weighted average		774.5		1007.2	
12	Administrative survey data after dredging in the zones (see note 5)			Average depth 15.40 (m) Standard deviation 0.22 (m) Targeted ratio for 15m or shallower points : 7.5 (%)	Average depth 15.35 (m) Standard deviation 0.18 (m) Targeted ratio for 15m or shallower points : 2.2 (%)	

Note 1. New Seiryu-maru took over from the ex Seiryu-maru to complete remaining work in this zone including finish dredging work.
Note 2. New Seiryu-maru was put into actual work two months after its completion, though it seemed a little premature then.
Note 3. Because of different soil kind in this zone (sand silt), dredging cycle time in this zone was comparatively longer than those in other zones.
Note 4. The zone was 1,300m apart from other zones, so sailing time to the soil discharging site was longer than other zones.
Note 5. Depth data measured at cross points of a 10 m lattice.

3.3.3 Dredged soil volume

(1) Adjustment was made to the data so as to compare dredged soil volume data on an equivalent basis, regardless of dredging zones, using soil volume data recorded in the dredging work log.

The dredged soil volume was estimated using displacement data for the dredger and data for the mud hold volume obtained from draft sensors and sounding sensors in the mud holds as indicated in the Fig. 6.

Densities of the sea bottom soil significantly affect the estimation accuracy of dredged soil volumes. The densities we used for the estimation for the new dredger and the ex Seiryu-maru are listed in the table 3.

Among the mud density data obtained this time, only zone C was 1.46 (t/m^3) which was different from those of other zones. However dredged soil volumes for zones C were re-calculated based on the mud density in zone A and B of 1.32 (t/m^3).

(2) As indicated in the table 2, average dredged soil volume in the case of the ex Seiryu-maru is 774.5 (m^3) compared with that of the new dredger of 1007.2 (m^3). It was evaluated that the dredged soil volume of the new dredger is 30 % (1007.2/774.5=1.30, 130 %) more than that of the ex Seiryu-maru.

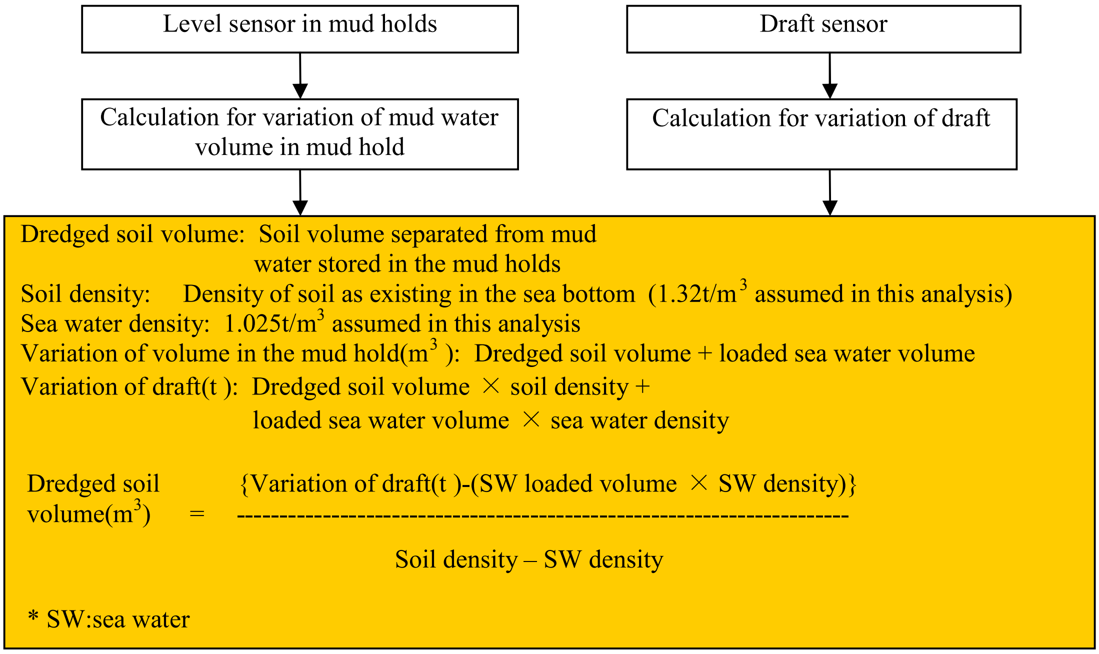


Figure 6. Explanation for Calculation of Soil Volumes

Table 3. Sea Bottom Soil Density

Items	Ex Seiryu-Maru(Zone A and B) new Seiryu-Maru (Zone A)	new Seiryu-Maru (Zone C)
Soil density apparent (t/m^3)	About 1.32	1.46
Sea water density (t/m^3)	1.018	1.025
Compensation factor	1.0	(1.46-1.025) ／ (1.32-1.018) =1.44

3.3.4 Comparison of dredging profiles

(1)Comparison on measured data for dredging profile

Dredging profiles for the sea bottom in the two dredging zones having similar areas (about 300,000 m^2) were compared based on the data measured as the administrative report at the cross points of every 10 meter lattice upon completion of dredging work carried out respectively by the ex Seiryu-maru and the new vessel. Fig. 7 indicates the profile of zone B dredged by the ex Seiryu-maru, and Fig. 8 indicates that of zone A by the new dredger.

Fig. 9 indicates summary of the comparison for the profiles in the Zone A and B.

In the dredging by the ex Seiryu-maru in the past, the problem with stripe dredging often happened because the drag heads (only 2m in width) tended to drop into the ditches which were made by the previous dredge.

The problem in the ex Seiryu-maru in respect to stripe dredging was one of the reasons to adopt wide span drag heads in the new dredger.

By comparing the bottom profile after dredging work for the aspects of unevenness and significance of excessive dredging, we intended to prove effectiveness of the wide span drag head.

(2)Results for comparison of the bottom profile

(a) Unevenness

① As seen in the section of the sea bottom, there were a lot of unevenness at the bottom surface. About 40 cm in height in the case of the ex Seiryu-maru, while about 20 cm in height for the new dredger.

② Standard deviation for the variations of the heights for uneven parts is 0.22 for the ex Seiryu-maru and 0.18 for the new dredger. The variation for the new dredger is smaller than that for the ex Seiryu-maru. (Note: The standard deviations were calculated for 3000 cross points of the 10 meter lattice.)

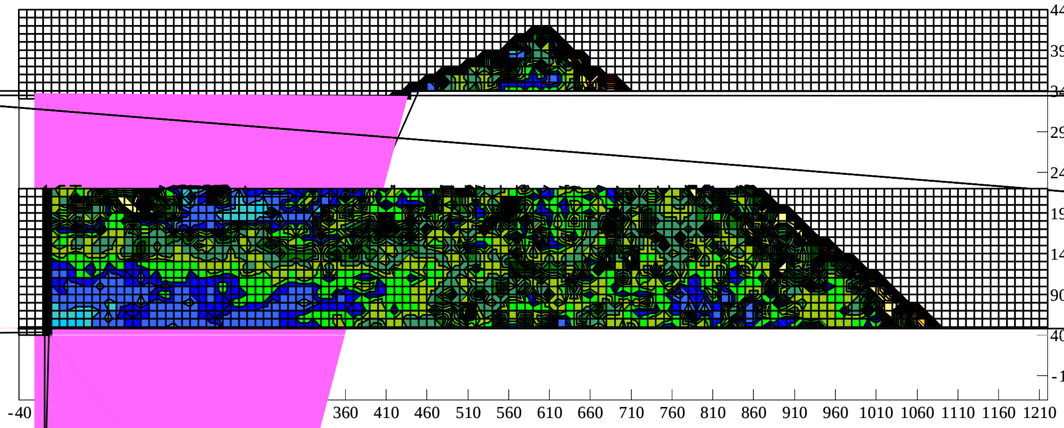
If the height of most prominent part is assumed to be within 3σ, the height of most prominent part in the case of ex Sriryu-maru is 64 cm, and that of the new dredger is 54 cm, which means the height of the most prominent part reduced by 12 cm in the new dredger.

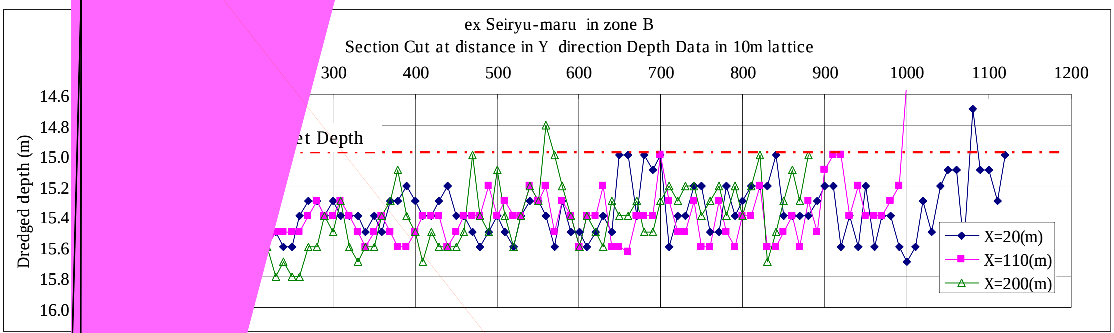
③ Numbers of points of sea bottom shallower than targeted depth of 15 meters after dredging was 229 in the case of ex Seiryu-maru, however it was reduced to 66 in the new dredger (by counting 3000 cross points in the every 10 meters lattice.)

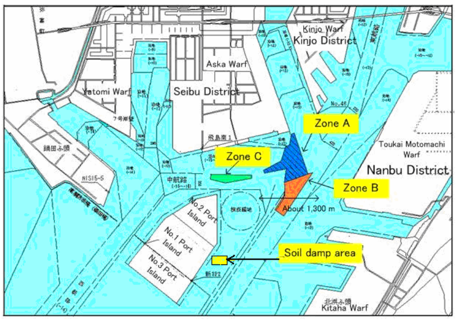
④ It can be concluded that the use of the wide span drag head resulted in the improvement to the dredged profile.

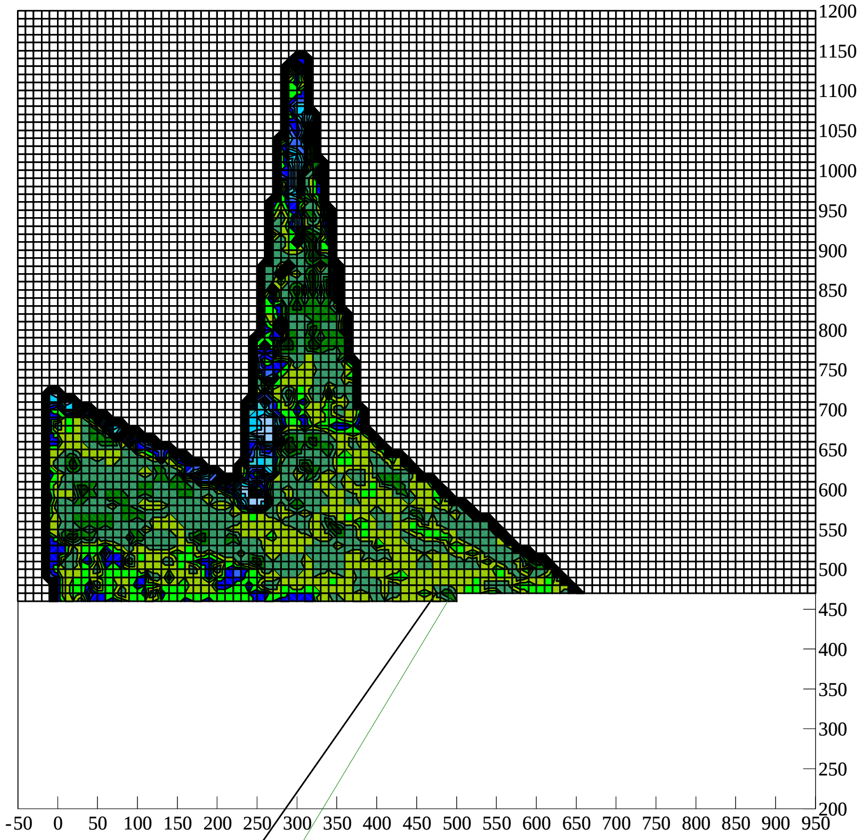
(b) Excessive dredging depth

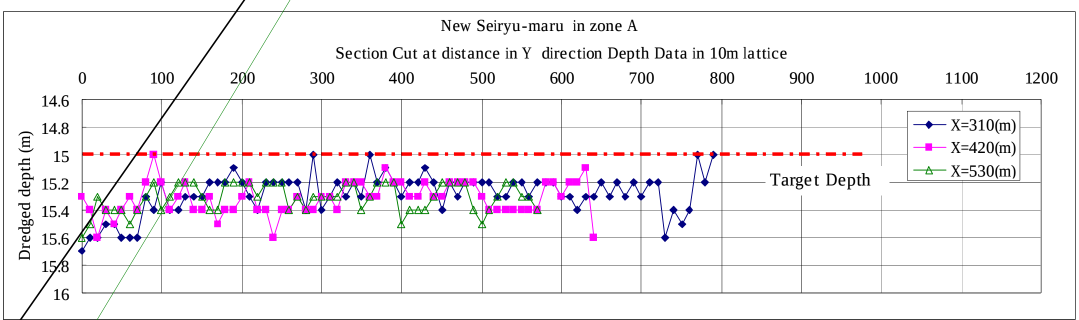
The average dredging depth in the case of the ex Seiryu-maru is 15.4 meters against the targeted dredging depth of 15 meter compared with 15.35 meters in the new dredger, which means excessive dredging depth was improved by 5 cm in the new vessel.

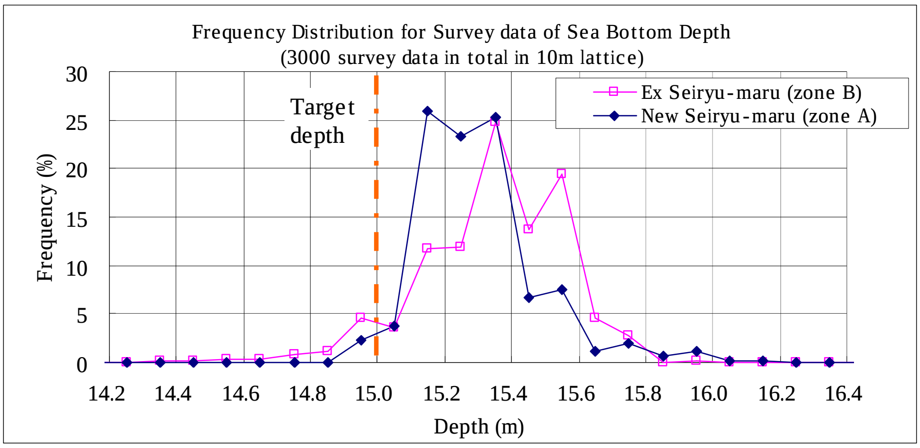

440
390
340
290
240
190
140
90
40
-10
-40
360 410 460 510 560 610 660 710 760 810 860 910 960 1010 1060 1110 1160 1210


ex Seiryu-maru in zone B
Section Cut at distance in Y direction Depth Data in 10m lattice
300 400 500 600 700 800 900 1000 1100 1200
Dredged depth (m)
14.6
14.8
15.0
15.2
15.4
15.6
15.8
16.0
X=20(m)
X=110(m)
X=200(m)


Kinjo Warf
Kinjo District
Aska Warf
Yatomi Warf
Seibu District
Zone A
Zone C
Toukai Motomachi Warf
Nanbu District
Zone B
About 1,300 m
No.2 Port Island
No.1 Port Island
No.3 Port Island
Soil damp area
Kitaha Warf


1200
1150
1100
1050
1000
950
900
850
800
750
700
650
600
550
500
450
400
350
300
250
200
-50 0 50 100 150 200 250 300 350 400 450 500 550 600 650 700 750 800 850 900 950


New Seiryu-maru in zone A
Section Cut at distance in Y direction Depth Data in 10m lattice
0 100 200 300 400 500 600 700 800 900 1000 1100 1200
14.6
14.8
15
15.2
15.4
15.6
15.8
16
Dredged depth (m)
Target Depth
X=310(m)
X=420(m)
X=530(m)



	Ex Seiryu-maru	New Seiryu-maru
	zone B	zone A
Average dredged depth (m)	15.40	15.35
Standard deviation (m)	0.22	0.18
Number of data measured as point of cross 10m lattice	3061	2957
Minimum depth (m)	14.40	15.00
Maximum depth (m)	16.00	16.20
Ratio of points no deeper than 15m (m)	7.5	2.2
Number of points no deeper than 15m	229	66

Figure 9. Summary for the Sea Bottom Profile after dredging

3.3.5 Averaged operational data for equipment relating to dredging operations

We analyzed the averaged data representing the operation of the equipment relating directly to the dredging work. The data subject to this analysis was that collected during running of the dredging pump at the sampling rate of 1 to 2 seconds intervals. The data collected was averaged for evaluation.

The comparison for the equipment's operational data was made for 55 available readings for the ex Seiryu-maru during dredging operations in the zone A, and 117 readings for the new dredger taken in the same operating condition as the ex Seryu-maru. Operating data collected during the dredging operations in other zones was treated as reference data.

Fig. 10 shows the data indicating significant differences between the two dredgers.

We studied mechanisms or reasons for improvements to dredging efficiency (30 % improvement) achieved in the new dredger as mentioned above in relation to the operation data for the equipment shown in the Fig. 10.

(1) Due to the increased flow rate of the recycling system the running time of the dredging pump until full loading of the mud holds became longer, thus dredged soil volumes were increased as the result of longer dredging pump running time. Though there was an increased flow rate of the recycling system, on the other hand the decrease in

the mud suction rate, increased dredging time as the effects of the longer dredging pump running time resulted in higher dredging efficiencies.

(2) In the new dredger, because of the wider drag head and drag ladder which limits lateral movement of the drag head, the drag head does not slide sideways even with humps on the sea bottom and can dredge these hump parts, which is difficult in the case of the conventional drag head and drag arm system.

(3) One large drag head and single dredge line in the new dredger instead of two small drag heads and two dredge pipes in the ex Seiryu-maru decreased the pressure loss for suction and the effective suction pressure was increased resulting in the increase of dredging soil volumes.

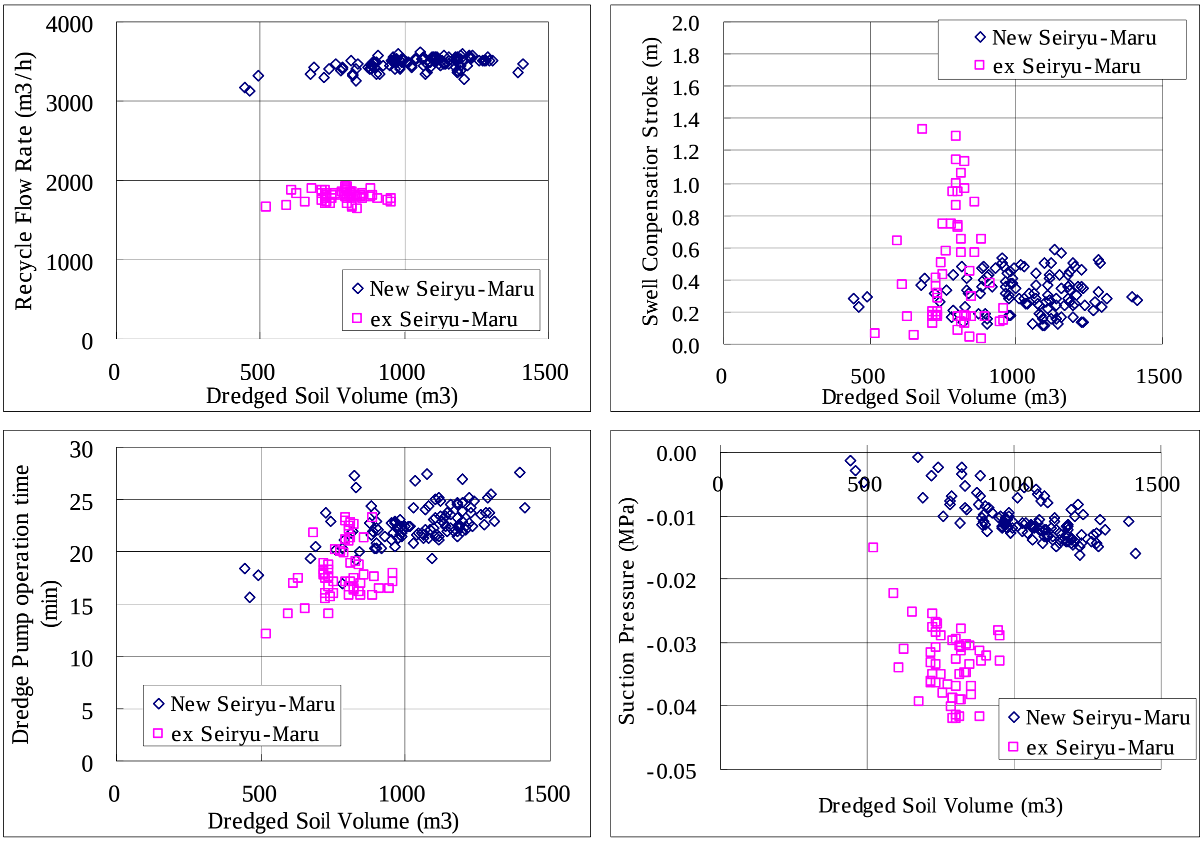


Figure 10. Averaged Operational Data (for selected items indicating significant changes)

3.4 Comparison of integrated dredging efficiencies

In order to summarize the discussions for the respective factors affecting the dredging efficiencies, integrated dredging efficiencies were studied.

3.4.1 Comparison of dredging efficiencies in certain periods

The most important evaluation point for the dredger is the volume of dredged soil produced in a certain term. The dredged volumes in certain periods are to be calculated with the formula below.

Total dredged soil volume(m^3) in period concerned

= Dredged soil volume in one cycle × Cycles in period concerned

= Dredged soil volume in one cycle ×{Total allowable dredging time / Dredging cycle time}

The comparison between the new and ex Seiryu-maru can be done assuming the value of ex Seiryu-maru in Table-4 to be 1.0 as follows, where K is the dredging periods,

Yearly dredged soil volume of the ex Seiryu-maru = 1.0 × (K/1.0) = K

Yearly dredged soil volume of the new dredger = 1.3 × (K/0.98) = 1.354K

From the calculation above, the yearly dredged soil volume of the new dredger is assessed to be 35.4 % higher than that of the ex Seiryu-maru.

Table 4. Resulted Comparison Data for Efficiency

Item	Ex Seiryu Maru	New Seiryu Maru	Improvement (%)
Dredging soil volume per cycle	774.5(m^3)	1007.2(m^3)	1.30 (30% increase)
Cycle time	123.8 (Minutes)	119.2 (Minutes)	0.96 (4% shorter)
Lessening of excessive dredging depth	Average finished depth 15.40m (Target depth 15m)	15.35m less excessive dredging by 5cm	5 % less for dredging thickness of 1 meter (subject to conditions of dredging site)

3.4.2 Effects of excessive dredging

It was confirmed that in addition to the effect on dredged soil volumes, excessive dredging depth by the new dredger was 5 cm lower than that of the ex Seiryu-maru, therefore, the soil discharge area was assumed to be used more efficiently. Taking the example of the dredging in Higashi-Port area II the total area was 300,000 m^2. 5 cm less excessive depth is worth an additional 15,000 m^2.

4. CLOSING

It is a widely accepted notion that the 21st century is the Asian century and rapid economic growth is expected. Getting along with the trend in the Asian area, ports in Japan are expected to achieve important roles.

In the situation surrounding the ports of Japan, the roles of the new dredger for maintenance of navigation channels and environment preservation have become more significant.

The new dredger is a versatile vessel with the most advanced systems for dredging, oil recovery and hazard control as described in this paper. We expect the new dredger will bloom and its real values contribute to port maintenance work, prevention of sea pollution, and port security.

In closing the paper we would like to express our thanks to all the persons and organizations who cooperatively worked with us.