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Evaluation of Turbidity Generated by Cutter Suction and Grab Dredgers

Jae Youll Jin[1], Won Oh Song[1], Jin Soon Park[1], Sung Eun Kim[1],
Young Min Oh[1], Ki Dai Yum[1] and Jae Kyung Oh[2]

1. INTRODUCTION

It is inevitable for dredging to increase the suspended sediment concentration (SSC) of the ambient waters in some degree, which has the potential to affect the coastal ecosystem in various manners. Thus, quantitative understanding of dredging-induced sediment loss is essential for the reliable environmental impacts assessment.

However, because the loss is influenced by various site- and case-specific conditions such as current velocity, seabed material, the type and class of the dredger, and operator's skill, the existing loss rates (e.g., Nakai, 1978; Kirby and Land, 1991; Lorenz, 1999) have no consistency as a general guidance.

Quantification of the loss is absolutely subject to field measurement of the dredging-induced plume. In other words, difference in the measuring instrument and method may yield large difference in the loss rate even though the remaining conditions are similar.

Considering the importance of simultaneous profiling of current and SSC, acoustic Doppler sensors are recognized as the best way for measuring the sediment flux although a rigorous *in-situ* calibration is required to estimate SSC from the acoustic backscatter intensity (e.g., Kraus and Thevenot, 1992; Tubman, 1995; Land et al., 1997; Land and Bray, 1998; Land and Jones, 2001).

This paper presents the rates of release of sediment caused by cutter suction dredgers and grab dredgers by using a vessel-mounted (VM) acoustic Doppler sensor system.

2. FIELD MEASUREMENTS

2.1 Sites and Target Dredgers

A total of 15 field campaigns has been conducted in four areas which were tentatively selected from tide- to wave-dominated coastal waters (Fig. 1). The mean spring tidal ranges of Gunsan and Sokcho are about 6.8 m and 0.3 m, respectively.

The capacity of the centrifugal pumps of the target cutter suction dredgers (CSDs) ranges from 4,000 to 20,000 hp. All the grabs are mechanical open clamshells and their volumes are 8 m^3 or 13 m^3.

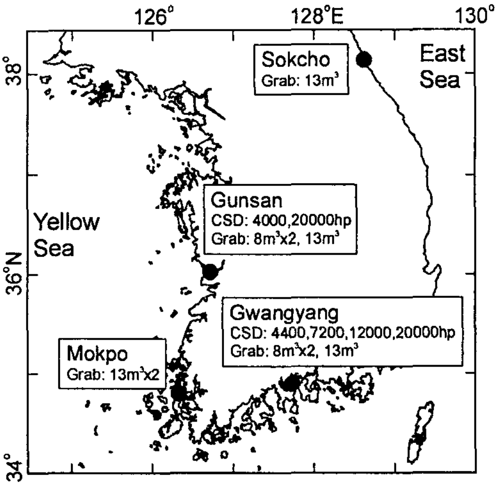

Fig. 1. Field experiment sites and target dredgers.

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[1] Corresponding Author : Jae-Youll Jin, Coastal and Harbor Engineering Laboratory, Korea Ocean Research and Development Institute, Ansan, Seoul 425-600, Korea, jyjin@kordi.re.kr

[2] Department of Oceanography, Inha University, Incheon 402-751, Korea

2.2 Configuration of VM ADCP Monitoring

A vessel-mounted acoustic Doppler sensor system was set up for this study (Fig. 2). The system consists of an 1.2MHz broadband Acoustic Doppler Current Profiler (ADCP) of RDI, multiparameter instrument (YSI6600) of YSI, echo sounder (PS-20R) of Kaijo, and DGPS (GPSIII) of Garmin.

As shown in Fig. 2, the acoustic method does not provide data in the upper and bottom blank zones where current and signal strength should be properly filled in the data processing procedure.

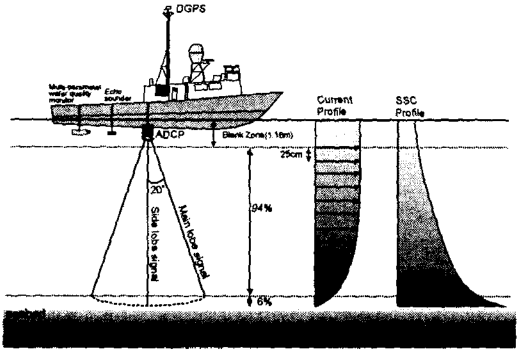


Fig. 2. Vessel-mounted ADCP system and effective profiling range of RDI's ADCP (1.2MHz).

The cruise monitoring tracks were determined by considering the position of dredgers, current speed and direction. Where current direction is distinct, sediment flux was measured along a rectangle track at the downstream of the dredger (Fig. 3(a)). The two sides normal to the current direction were fixed to be long enough to include the plume and sort out the background concentration later. And their distances from the cutter and grab were about 40-50 m, and 150-200 m, respectively. However in Sokcho Harbor and Gunsan Outer Port where the currents are weak and/or the directions fluctuate, the dredgers were surrounded by the tracks (Fig. 3(b)).

The cruising speed of the system was about 2 m/s. Temporal and spatial intervals of the ADCP profiling which is dependent on the water depth were 2-4 s and 4-8 m, respectively. Position data from the DGPS were logged in the ADCP software every 2 seconds. Sampling intervals of the PS-20R and YSI6600 are 1 and 2 seconds, respectively.

In addition to this continuous cruise monitoring, the vertical profiles of optical turbidity, temperature and salinity were measured with the YSI6600 as well as seawater sampling at selected points on the tracks for the calibration of ADCP's signal strength.

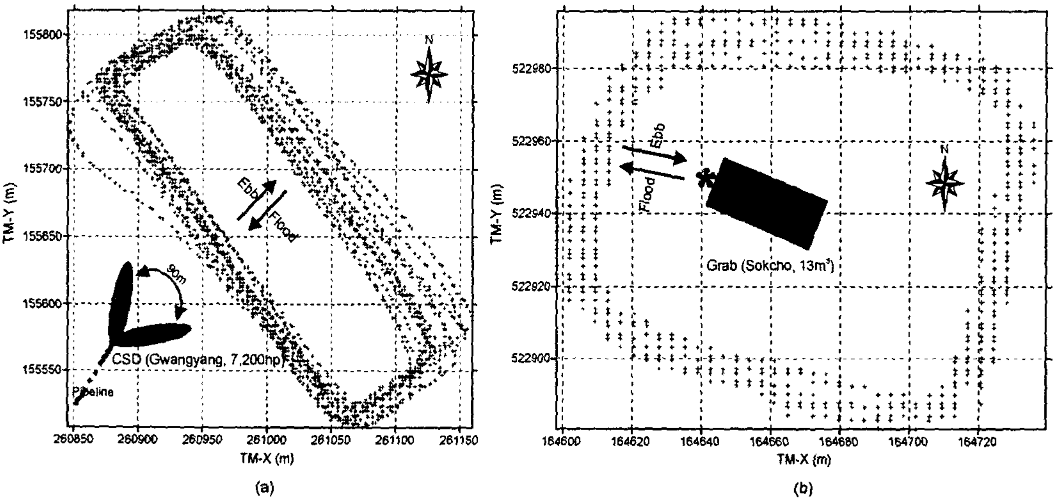


Fig. 3. VM ADCP monitoring tracks at the sites where current directions are distinct (a) and fluctuate (b).

3. PROCEDURES FOR EVALUATION OF SEDIMENT LOSS RATE

3.1 Calibration of ADCP Backscatter

The intensity of acoustic backscatter from the each layer is logged as non-dimensional counts referred to as reflected signal strength indicators (RSSI).

Typical results at the downstream of the dredger in ebb period near Gunsan Outer Port are shown in Fig. 4, in which RSSI counts were converted to decibel by the software WinRiver® provided by RDI with the ADCP.

Current speed along the northern east-west side near to the center of the main channel is relatively strong beyond 0.7 m/s, but only about 0.1 m/s along the line from the point Ⓐ to Ⓑ in the cruise direction.

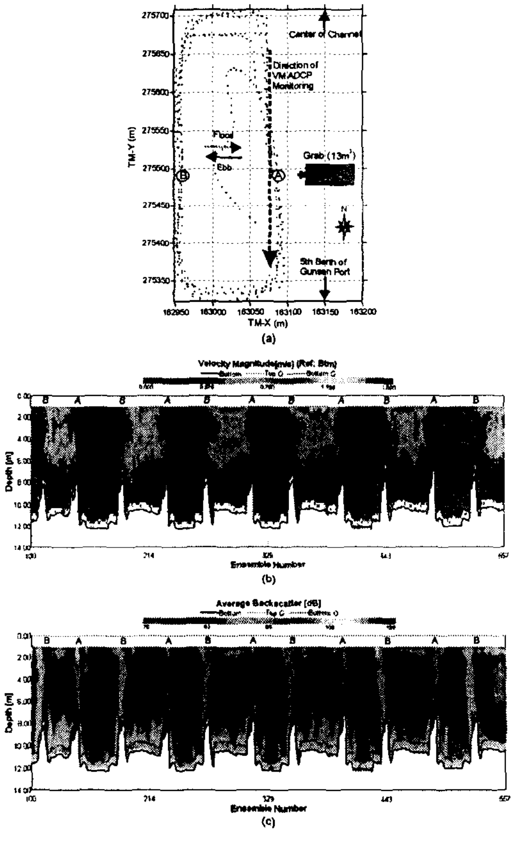


Fig. 4. Primary results of the VM ADCP monitoring; (a) *monitoring track*, (b) *profiles* of current speed and (c) acoustic backscatter intensity.

The profile of backscatter intensity (dB) indicates the evolution of the plume generated by the grab dredging. That is, the plume width and signal intensity close to Ⓑ is broader and weaker than those close to Ⓐ, which is the result of the advection and lateral diffusion in the distance of about 125 m.

An additional rigorous calibration procedure is required to obtain reliable SSC from RSSI which is influenced by several parameters including the transducer's unique conversion factor from RSSI counts to dB, the shape of beam spreading, water absorption of acoustic energy, attenuation and absorption of acoustic energy due to SSC and particle size (Puckette, 1998; DRL software Ltd., 2002).

A commercial software, Sediview® developed by DRL software Ltd through about 10-year research (Land et al., 1997; Land and Bray, 1998; Land and Jones, 2001), was used. Essential data for the calibration of RSSI count to SSC with Sediview® are the profiles of temperature, salinity and SSC concurrently measured with ADCP profiling.

Furthermore, in order to obtain SSC profile, additional calibration of the YSI6600's optical backscattering sensor (OBS) of which the output unit is nephelometric turbidity units (NTU) is required. A sample result of the OBS *calibration with SSC of the seawater sampled on* the track is shown in Fig. 5(a).

After the OBS calibration, RSSI counts are calibrated by the iterative method of Sediview® to provide optimal relation as shown in Fig. 5(b).

A typical sample of the sectional distribution of calibrated SSC along the Ⓐ side of Figure 4(a) is shown in Fig. 6.

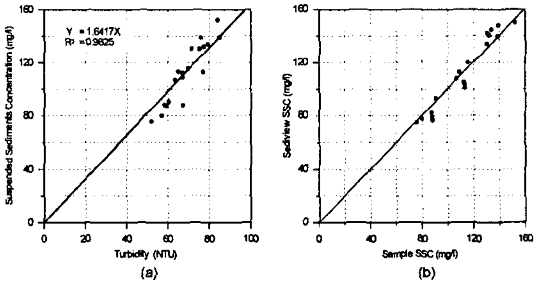


Fig. 5. Samples of the OBS NTU (a) and ADCP RSSI (b) calibrations.

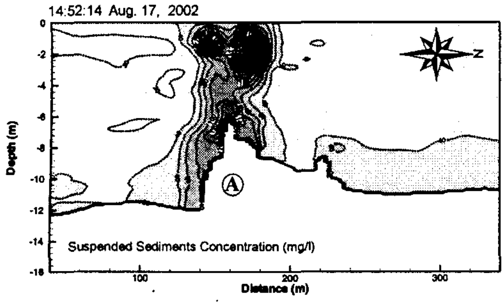


Fig. 6. Sectional distribution of SSC calibrated by Sediview®.

3.2 Calculation of Sediment Loss Rate

If y-axis is denoted to monitoring line faced with the cutter or grab with a distance, L(m), then the sediment loss rate due to dredging operation, Q_L (kg s^{-1}) can be described as

$$Q_L = \int_0^B\int_0^H (c_L - c_{LB})\cdot u_L \, dzdy \qquad (1)$$

where, c_L and c_{LB} are total and background SSCs at (L,y,z) respectively, z is vertical coordinate, u_L is x-component of current speed, B and H are the length of monitoring line and water depth, respectively.

Cautious understanding of SSC distribution should be taken when selecting background SSC. For example, the SSC beyond 40 mg/l in the lower layer of the north part of Fig. 6 has no concern with the plume.

Actually the sectional distribution of SSC cannot be represented as that of a certain time. Thus, it is assumed that the time of the system's passing the center of the line can represent the section time considering that it takes only about 2-3 minutes for the line monitoring.

The loss rate, Q_L, can be said as the rate of release of sediment per unit time (RSUT). The rate of release per unit volume of dredging (RSUV, kg m^{-3}) is also obtained by dividing RSUT with dredging rate (m^3 s^{-1}).

4. RESULTS

4.1 Plume Shape

The increase of SSC and evolution of the plume shape depend on various site- and case-specific conditions although it is well known that the sources of a CSD and grab dredger are the seabed and whole water column, respectively.

Typical shapes of the plumes caused by the CSD (20,000 hp) at Gwangyang and grab (13m^3) dredger at Mokpo are shown in Fig. 7. The background SSCs of the both sites are about 30 mg/l, while the core SSC increases up to about 200 mg/l in the CSD plume and 100 mg/l in the grab plume, respectively. It is well shown that the core of the CSD plume migrates because of the swing distance (70-120m) of the cutterhead.

Sediment plumes were measured on the tracks surrounding the grab dredger at Sokcho and the CSD at Gunsan Outer Port, too. However, as shown in Fig. 8, the current directions of both sites highly fluctuate, which means that their RSUT and RSUV may be overestimated because the sediments passed out the tracks flow in, and then pass out again the surrounded area. Thus, it is appropriate to provide only the increase of SSC in such areas.

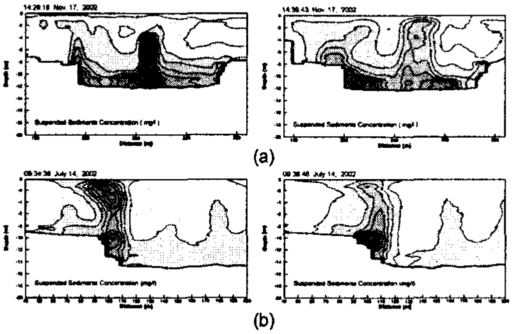


Fig. 7. Sample cross-sectional distribution of SSC at 40-50 m downstream of a CSD at Gwangyang (a) and grab dredger at Mokpo (b).

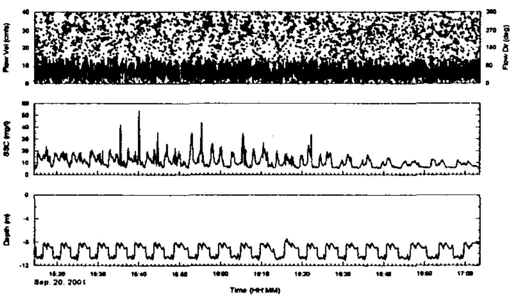


Fig. 8. Depth-averaged current speed, direction, SSC, and water depth on the track surrounding the grab dredger at Sokcho.

Table 1. Sediment loss rates caused by the operation of CSDs and grab dredgers

Type & Class of Dredger		ID[1]	Weight Composition (%)[2]				Sediment type[3]	U[4] (m s^{-1})	ΔC[5] (mg l^{-1})	DR[6] (m^3 h^{-1})	RSUT (kg s^{-1})	RSUV (kg m^{-3})
			Gravel	Sand	Silt	Clay						
CSD (hp)	20,000	CGY3	0.0	7.0	67.4	25.6	Z	0.09	17.3	1007.0	1.85	6.60
		CGS1[7]	0.0	93.0	6.6	0.5	S	0.23	10.4	1997.7	2.37	4.27
	12,000	CGY1	0.0	22.4	52.2	25.4	sZ	0.09	14.6	1690.7	3.14	6.70
	7,200	CGY2	0.1	38.7	41.7	19.5	(g)sM	0.05	2.8	463.9	0.30	2.36
	4,400	CGY4	5.3	23.9	53.8	17.0	gM	0.18	9.0	400.0	1.50	13.50
	4,000	CGS2	0.1	8.2	69.6	22.1	(g)M		37.0	412.9		
Grab (m^3)	13	GGY1	0.7	30.0	48.7	16.0	gmS	0.04	5.2	175.5	0.13	2.65
		GGS2[8]						0.10	44.2	58.1	3.05	188.87
		GMP1	0.0	44.8	44.6	10.6	sZ	0.62	10.5	248.8	6.85	99.06
		GMP2	0.9	71.7	21.2	6.2	(g)mS	0.06	12.3	255.0	0.46	6.50
		GSC1	0.2	71.3	25.0	3.5	(g)mS		5.8	200.0		
	8	GGY2[8]						0.25	6.9	77.8	2.09	96.59
		GGY3	1.4	21.0	55.0	22.6	(g)sM	0.16	17.0	133.3	3.01	81.35
		GGS1[8]						0.13	39.1	81.8	2.46	108.23
		GGS3	0.0	48.0	42.4	9.6	sZ	0.05	67.0	150.1	1.49	35.75

1) CGY and CGS mean the CSDs at Gwangyang and Gunsan. GMP and GSC mean the grab dredgers at Mokpo and Sokcho.
2) For dredged bottom sediment. Diameters of class boundaries from gravel are 2mm, 62.5μm and 4μm.
3) According to the classification of Folk and Ward (1957)
4) Average of section-mean
5) Average of averaged SSC increases in plume sections
6) Dredging (production) rate
7) Operated at 12,000hp for the monitoring period due to the problem of one of the three centrifugal pumps
8) Dredging after crushing the sedimentary bedrock

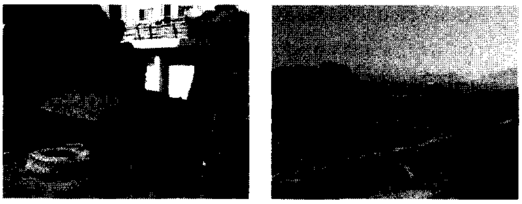
4.2 Sediment Loss Rates

The more the number of cycle times of the VM ADCP monitoring is, the higher the reliability of evaluated loss rates should be. However unfortunately, the number of cycle ranging 5 to 25 was limited by several restrictions including frequent stop of dredging operation, tidal phase and location of the CSD pipeline.

Cycle-averaged loss rates at 40-50m downstream of the cutters and grabs are summarized in Table 1. The results show that the loss rates by grab dredging are much higher than those by CSD operation as reported in previous studies (Nakai, 1978; Kirby and Land, 1991; John et al., 2000).

In cases of the CSDs, the increase of SSC is about 3 to 55 mg/l. Their RSUT and RSUV are about 0.3-3.1 kg/s and 2.4-13.5 kg/m^3, respectively. It is also recognized that the rates are dependent on current speed and the type of bottom sediment rather than the pump capacity.

The increase of SSC resulting from the operation of mechanical open grab dredgers ranges 5 to 67 mg/l, the RSUT and RSUV are 0.15-6.9 kg/s and 3-189 kg/m^3, respectively.



(a) (b)

Fig. 9. Hammer weight for crushing the bedrock (a) and dredged rock fragments on the barge at GGY2 (b).

A noteworthy and significant result of this study is that sediment loss generated by grab dredging after crushing the bedrock covered with sediments is very high up to about 200 kg/m^3 (Fig. 9), which has not been reported. These higher loss rates are presumably responsible for the rock fragments which prevent the grabs from being tightly closed, consequently cause high spill of sediments and low production rates below 100

m^3/h. As the result, site GG2 having the highest loss rate of 188.9 kg/m shows the lowest production rate of 58.1 m^3/h.

Both current speed and sediment type, of course, have large effect on the loss rate of grab dredging. The RSUV of 99 kg/m^3 at GMP1 should be responsible for the high current speed of about 62 cm/s, and that of 81 kg/m^3 at GGY3 for the high fraction of fine sediment.

As described above, it is thought to be reasonable to provide only SSC increase where the sediment flux method may yield serious error due to very low current speed and the fluctuation of current direction. The averaged-increases of the plume-section at GSC1 in Sokcho harbor and CGS2 in Gunsan Outer Port are 6 mg/l and 37 mg/l, respectively.

5. CONCLUSIONS

Dredging-induced sediment losses into the ambient waters at 15 sites in 4 areas have been evaluated based on the sediment flux through intensive field measurements with a VM ADCP system.

The major results of this study can be summarized as follows:

1) The rate of release of sediment per unit volume of dredging associated with the operation of cutter suction dredgers ranges 2.4 to 13.5 kg/m^3.
2) The rate of release of sediment per unit volume of dredging due to the operation of grab dredgers ranges 2.7 to 188.9 kg/m^3.
3) The loss rate largely depends on current speed and grain composition of the bottom sediment.
4) Mechanical grab dredging after crushing the bedrock covered with sediments cause very high loss rate up to about 200 kg/m^3.
5) Where the current direction fluctuates, sediment flux method may overestimate the loss rate, so it is reasonable to provide the increase of SSC.

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REFERENCES

DRL Software Ltd., 2002. Sediview version 3 available March! *Sediviews, Issue 2, February.*

John, S.A., Challinor, S.L., Simpson, M., Burt, T.N. and Spearman, J., 2000. Scoping the assessment of sediment plumes from dredging, *Pub. No. CIRIA C547,* Construction and Industry Research and Information Association of the UK.

Kirby, R. and Land, J.M., 1991. The impact of dredging - A comparison of natural and man-made disturbance to cohesive sediment regimes, *Proc. of CEDA Dredging Days,* Amsterdam, the Netherlands.

Kraus, N.C. and Thevenot, M.M., 1992. The plume measurement system (PLUMES): First announcement, *Tech. Note, DRP-1-06,* US Army Engineer Waterways Experiment Station, Vicksburg.

Land, J.M., Kirby, R. and Massey, J.B., 1997. Developments in the combined use of acoustic Doppler current profilers and profiling siltmeters for suspended solids monitoring, *Cohesive Sediments,* N. Burt, R. Parker and J. Watts ed., John Wiley and Sons.

Land J.M. and Bray, R.N., 1998. Acoustic measurement of suspended solids for monitoring of dredging and dredged material disposal. *Proc. 15th World Dredging Congress,* World Dredging Association, Las Vegas, the USA.

Land, J.M and Jones, P.D., 2001. Acoustic measurement of sediment flux in rivers and near-shore waters, *7th Federal Interagency Sedimentation Conf.*

Lorenz, R., 1999. Spill from dredging activities, *Proc. Øresund Link Dredging and Reclamation Conf.*

Nakai, O., 1978. Turbidity generated by dredging projects, *Proc. 3rd United States-Japan experts meeting, EPA-600/3-78-084.*

Puckette, P.T., 1998. Evaluation of dredged material plumes Physical monitoring techniques, *Tech. Note, DOER-E5,* US Army Engineer Waterways Experiment Station, Vicksburg.

Tubman, M.W., 1995. Plume measurement system (PLUMES) technical manual and data analysis project, *Tech. Rep., DRP-95-1,* US Army Engineer Waterways Experiment Station, Vicksburg.