INITIAL EXPERIMENTS AND DATA ACQUISITION FOR THE MODEL DREDGE CARRIAGE

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ABSTRACT

Resuspension of sediment from dredging operations is an important environmental topic. The Haynes Coastal Engineering Laboratory provides an exceptional environment to test dredge resuspension. The 2,045 square meter laboratory houses a 45.7 m long, 3.7 m wide, and 3 m deep dredge/tow tank with an additional 1.5 m by 9.1 m long sediment pit. Four water pumps provide the capability of pumping a total of 2,233 liters/s through the tank facilities. The laboratory is also home to a dredge carriage. The dredge carriage is mounted on the rails of the dredge/tow tank and is composed of a carriage, cradle, and ladder. A 10 cm suction by 7.6 cm discharge dredge pump is mounted on the carriage and a moveable upper vertical and lower articulating ladder has a 30 cm cutter for dredging sediment from the sediment pit.

The objective of this paper is to illustrate recent additions to the dredge carriage system. These additions include the installation of a hydrocyclone separator system onto the dredge carriage as well as the installation and calibration of optical backscatter sensors (OBS) onto the dredge ladder. Other instrumentation includes the addition of a nuclear density gauge, a magnetic flow meter, and the installation of cutter force gauges. Testing methods and results of the instrumentation are described and data from a trial simulation is reported. The sediment plume data will be used to calibrate a near-field sediment plume numerical model for a cutter suction dredge. This information will be valuable to dredging resuspension research and will help predict environmental impacts for specific dredging projects.

Keywords: Dredge carriage, dredge laboratory modeling, cutter performance, and sediment resuspension modeling.

INTRODUCTION

The resuspension of dredge material is an important environmental topic. The response to the environmental concerns instigated the use of environmental windows for dredging in the United States as well as contractual turbidity clauses associated with dredging projects in Europe. In order to control these issues, an international protocol between United States and European organizations was issued so that a standard process could be created to measure and evaluate turbidity measurements created by dredging operations (Burt and Clausner 2002).

Since the incorporation of dredging project monitoring systems, the generation of data in real-time has become a needed aspect of the dredging industry. Field work has attempted to quantify the amount of sediment released in real-time using a spatial correlation between ADCP (Acoustic Doppler Current Profiler) and OBS (Optical Backscatter Sensor) measurements. However, constraints such as spatial resolution and non-homogeneous sediment properties produced discrepancies when correlating the two types of measurement data (Aardoom and Mol 2004). These discrepancies could be minimized in a model scale setting.

Past work on the physical modeling of cutter suction dredging resuspension has also taken place. Physical model studies conducted at Texas A&M University (Brahme 1983; and Herbich and DeVries 1986) obtained resuspension data collecting samples during and immediately after cutting. Burger et al. (2006) was able to evaluate the path of a single particle in a physical model setting.

In September 2003, the Barrett G. Hindes Foundation established the Barrett G. Hindes Dredging Engineering Education Fund. These funds were dedicated to the construction of the dredge/tow carriage for the dredge/tow flume in the Haynes Coastal Lab at Texas A&M University. The purpose of the construction of a dredge/ tow carriage was to create a multi-purpose system that could be used to investigate multiple types of dredging scenarios as well as provide a towing apparatus for other marine experimentation.

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Randall, Edge and Cox (1998) defined the typical needs for dredging research in a laboratory setting. Thereafter, Glover (2002) and Glover and Randall (2004) reported on the design of a dredge/tow carriage for the dredge/tow flume in the Haynes Coastal Engineering Laboratory. A paper on the installation of the dredge carriage at the Haynes Coastal Laboratory as well as a report on the layout of the structural, mechanical, and initial electrical plans can be found in. Randall et al (2005). The objective of this paper is to provide information on the advances that have been made to the dredge carriage since the time of installation.

HAYNES COASTAL ENGINEERING LABORATORY

History

Texas A&M University received a grant from the National Science Foundation to help fund the construction of a new Coastal Research Laboratory. The Haynes Coastal Engineering Laboratory construction was completed in 2002 and dedicated in 2003. The facility houses both a shallow water wave basin with a directional wave maker and a dredge/tow flume and shown in Figure 1. The basic dredge tow carriage was installed in 2004 and the multi-directional wave maker was completed in 2005. Several model tests have been completed that include: modeling of oil spills, river bed meandering and scour, scour around bridge structures, modeling forces on strakes, and others.

Figure 1. View of the shallow water wave flume and the dredge/tow flume.

Shallow Water Basin

The 2,045 m^2 (22,000 ft^2) laboratory houses a 36.6 m long, 22.9 m wide, and 1.22 m deep (120 ft long, 75 ft wide, and 4 ft deep) wave basin with a multidirectional piston-type wave maker. The basin has a flat floor and can hold up to a depth of 4.0 ft (1.22) m of water. Ideal testing functionality of the shallow water basin includes studies on coastal facilities, shallow water mooring systems, and multi-directional random wave analysis.

Dredge/Tow Carriage and Dredge/Tow Flume

The dredge/tow flume provides an exceptional environment to test different types of dredging situations including cutterheads, suction heads, dragheads, and hopper disposal. Four axial flow pumps provide the capability of pumping 2,233 L/s (35,000 GPM) of water through the flume. Figure 2 illustrates the model dredge sitting on the Dredge/Tow Flume immediately after installation. The model dredge consists of a carriage, ladder, and cradle. The cradle moves the ladder side-to-side in the flume to simulate the swinging of a cutterhead dredge. The cradle can be removed from the carriage using the 2721 kg (3 ton) overhead crane and reinstalled when needed. The model dredge carriage posses both an upper vertical ladder as well as an articulating ladder at the bottom of the vertical ladder. This allows both vertical translation as well as an adjustable angle between 0 and 50 degrees with the horizontal. The cutter is attached to the end of the articulating ladder and the suction inlet is located directly behind the cutter. The towing carriage traverses on the steel flume rails using polyurethane rimmed steel wheels.

 

Figure 2. Dredge carriage sitting atop the dredge/tow flume (left) and the dredge ladder just above the sediment pit (right) at time of installation.

The dredge/tow flume is 45.6 m (149.5 ft) long 3.66 m (12 ft) wide, with a maximum water depth of 3.05 m (10 ft). The flume also contains a 7.56 m (24.8 ft) long by 1.52 m (5 ft) deep sediment pit that is ideal for dredging testing. The sediment pit can be covered during model towing operations, and the overhead crane can be used to lift the plates covering the sediment pit when dredging research will be taking place. There are also windows located in the region of the sediment pit. The windows are particularly useful in flow visualization studies around the cutter or suction head. The complete specifications for the Dredge/Tow Carriage and Dredge/Tow Flume are tabulated in Table 1.

Table 1. Specifications of the model dredge carriage.

Category	Characteristic
Maximum Carriage Speed	2 m/s (6.6 ft/s)
Total Dredge/Tow Carriage Weight	4545 kg (10,000 lb)
Cradle Weight	1364 kg (3,000 lb)
Ladder Weight	909 kg (2,000 lb)
Carriage Power	Two 3.8 kW (5 hp) motors
Cutter Power	7.5 kW (10 hp)
Pump Power	14.9 kW (20 hp)
Side to Side Cradle Motor Power	1.1 kW (1.5 hp)
Vertical Ladder Motor Power	1.1 kW (1.5 hp)
Articulating Ladder Position Motor Power	0.5 kW (0.8 hp)
Dredge Pump Flow Rate	Maximum 1893 LPM (500 GPM)
Dredge Pump Size	10.4 cm (4 in), suction; 7.62 cm (3 in), discharge
Control System	Ethernet PLC Automated and manual operation
Data Acquisition	Real-time display and data storage
Swing Travel	1.6 m (5.3 ft) on either side of flume centerline
Ladder Angle	0 to 50 degrees from horizontal

MODIFICATIONS TO THE MODEL DREDGE

Following initial installation and testing of the Dredge/Tow Carriage in 2005, additional modifications have been made to complete the model dredge carriage. These modifications include:

- Installation of a magnetic flowmeter and nuclear density gauge
- Purchase and installation of a Slurry Sand Separation System for the separation of sediment with water
- Completion of the data acquisition system for recording and transferring all data entries.
- Purchase of optical backscatter instruments for sediment resuspension measurements

- A hopper barge for storing dredged sediments is expected

The completion of these additions to the Dredge/Tow Carriage allows for dredging laboratory research to be conducted thoroughly and quickly, and is especially helpful when conducting resuspension studies. The following is a more in depth explanation of each of the additions mentioned above.

Magnetic Flowmeter and Nuclear Density Gauge

Figure 3 shows the setup of the flowmeter on the Dredge/Tow Carriage. The flowmeter is a Krohne IFC 090 K magnetic flowmeter. Output for the flowmeter is a 4-20 mA signal. The output data from the flowmeter is sent to the data acquisition system so that the flow of slurry or water can be monitored. The flowmeter is mounted inline in a vertical section of the 7.6 cm (3 in) discharge line. Calibration of the flowmeter was conducted using both standing and moving water.

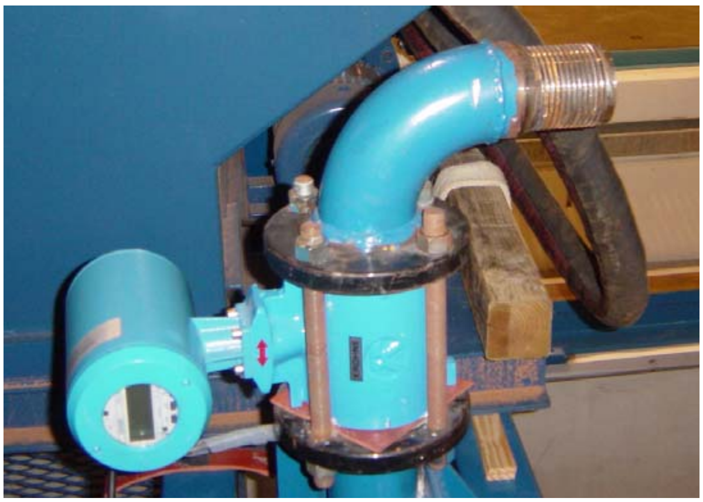

Figure 3. Magnetic flowmeter installation on the dredge/tow carriage.

The nuclear density gauge (Figure 4) installed on the Dredge/ Tow Carriage is an Ohmart Vega DSG radiation based density measurement system. The system contains a gamma-based density gauge with a sealed Cesium 137 source in a source holder with a scintillation detector. The density gauge is clamped on the 7.6 cm (3 in) vertical discharge pipe just below the flowmeter. The density gauge output is a 4 to 20 mA signal. Calibration of the density gauge was completed by using a sand filled tube. The sand filled tube was inserted into the discharge pipe and the instrument reading was adjusted to the 2.65 specific gravity of the sand in the pipe.

Figure 4. Ohmart Vega DSG nuclear density gauge.

Dredge Slurry Separation System

A fluid processing unit was also ordered and installed on the Dredge/Tow Carriage. The unit is a Tri-Flow model 300 fluid processing unit (TFI-300) and is designed to have a storage tank of up to 1136 liters (300 gallons). A picture of the unit can be seen in Figure 5 as well as the unit's location on the dredge carriage. The TFI-300 is able to handle separation of solids and water at a pumping load of up to 454 liters per minute (120 gallons per minute). The discharge pump can also act as a "bottom agitator" if allowed to pump back into the tank.

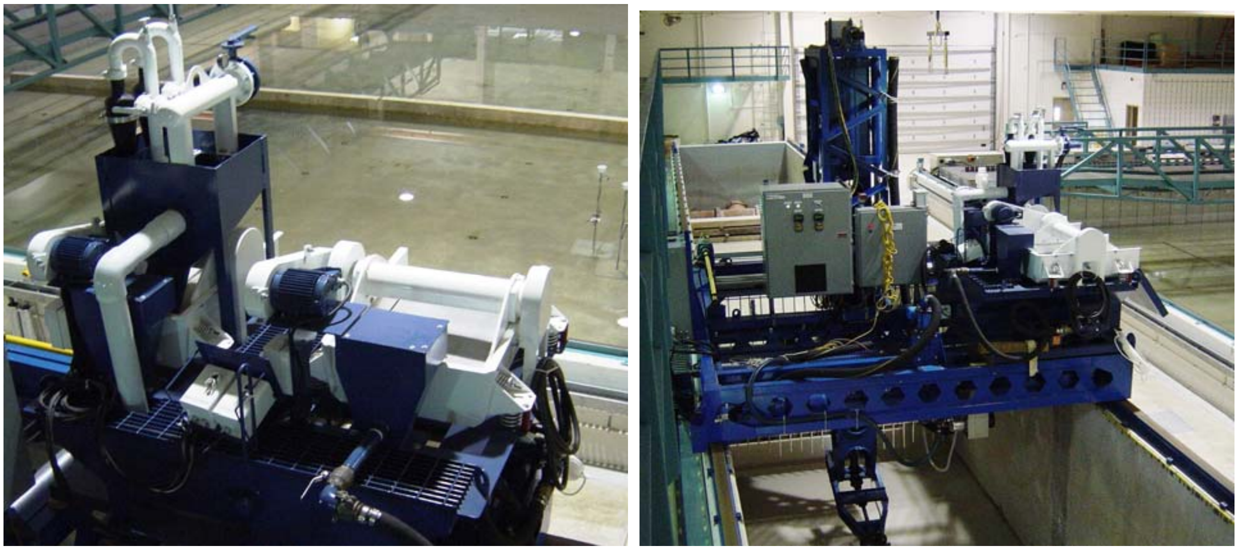

Figure 5. Dredge slurry separation system (left) and mounting setup on the dredge/tow carriage (right).

The TFI-300 is composed of the 1136 liter (300 gallon) tank, a scalping shaker, a mud cleaner consisting of two 10.2 cm (4 in) hydrocyclones mounted on a drying shaker, a mud gun, two 5.1 cm by 7.6 cm (2 in by 3 in) closed coupled centrifugal pumps, and solid slides to deliver solids to holding bins. The TFI-300 is 157.5 cm (62 in) wide, 226 cm (89 in) long, and 233.7 cm (92 in) in height. The total weight empty is 1225 kg (2700 lb), and the total weight full is 2858 kg (6300 lb).

In order to install the system, a few modifications were necessary that included the installation of mounting rings on the Tri-Flow unit so that the unit could be easily lifted on and off the Dredge/Tow Carriage. Other modifications included the addition of an exit valve and the addition of a connection between the dredge pump hose and feeder hose. The installation of a 480 volt power supply on the Dredge/Tow Carriage was also necessary for powering the Tri-Flow unit.

Optical Backscatter Sensors

Optical backscatter sensors (OBS) have been used to increase sampling densities of RSS (resuspended sediments) in-situ measurements for many years. The sensors function by emitting infrared light and measuring the transmission. In this case, the cross sectional area (A) rather than the mass concentration governs how much light is backscattered. The infrared radiation is quickly attenuated by water, therefore the infrared beam does not travel large distances. This allows the OBS sensor to measure very exact point locations in the range of 2.5 – 20.3 cm (1 – 8 in).

The OBS sensors have a nearly linear response to particles in turbid water. Figure 6 demonstrates the linear characteristics of the sensor and also displays the nonlinear characteristics as particulate matter becomes too concentrated. Most aquatic applications utilize the linear section of the OBS so that the single equation can be used:

$$C=AV+B \tag{1}$$

where C is the resuspended sediment (RSS) concentration, V is the optical backscatter (OBS) voltage, and A and B are regression coefficients.

The OBS sensor that is used to record turbidity measurements in the tow tank is the OBS-3+ sensor as shown in Figure 7. The sensor contains a high intensity infrared emitting diode (IRED), four photodiode detectors, and has a turbidity range of 0-4,000 nephelometric turbidity units (NTU's).

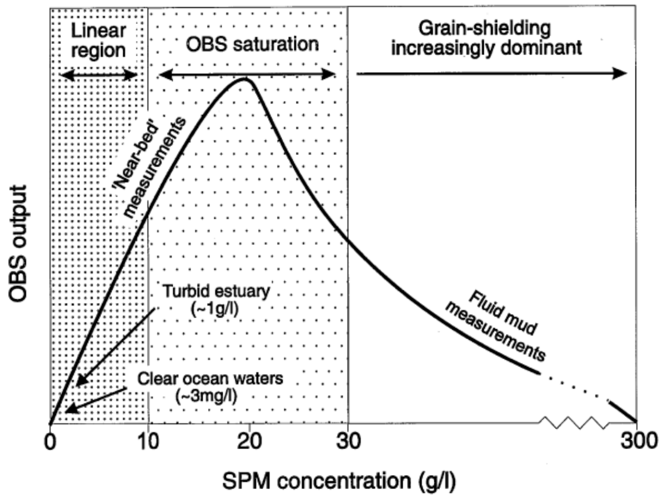

Figure 6. OBS response to suspended particulate matter (Downing, 2005).

Figure 7. Picture of the OBS-3+ sensor.

The IRED provides a beam with a half power point location at 50 degrees in the axial plane and 30 degrees in the radial plane. The operation of the OBS-3+ sensors is controlled using a Campbell Scientific CR10X data logger. The time required to obtain an accurate point measurement is less than one second.

Model Hopper Barge

A model hopper barge (Figure 8) has been designed and is awaiting construction. The barge is 6.1 m long by 3.4 m wide by 1.5 m deep (20 ft long by 11 ft wide and 5 ft deep) and the hopper internal dimensions are 4.9 m long by 2.1 m wide by 1.5 m deep (16 ft long by 7 ft wide by 4 ft deep). The hopper is being constructed with 3/32 steel plate and the total internal volume is 14.1 m^3 (18.5 yd^3). For a slurry velocity of 3 m/s (9.8 ft/s), the estimated pumping time until full is 57 min for overflow and 17 min for no overflow. The hopper barge floats on the water in the tank and is attached to the carriage. The hopper is positioned over the sediment pit in the dredge/tow tank and the bottom door is opened to return the sediment to the pit. Draft measurements are used to determine the weight of slurry in the hopper.

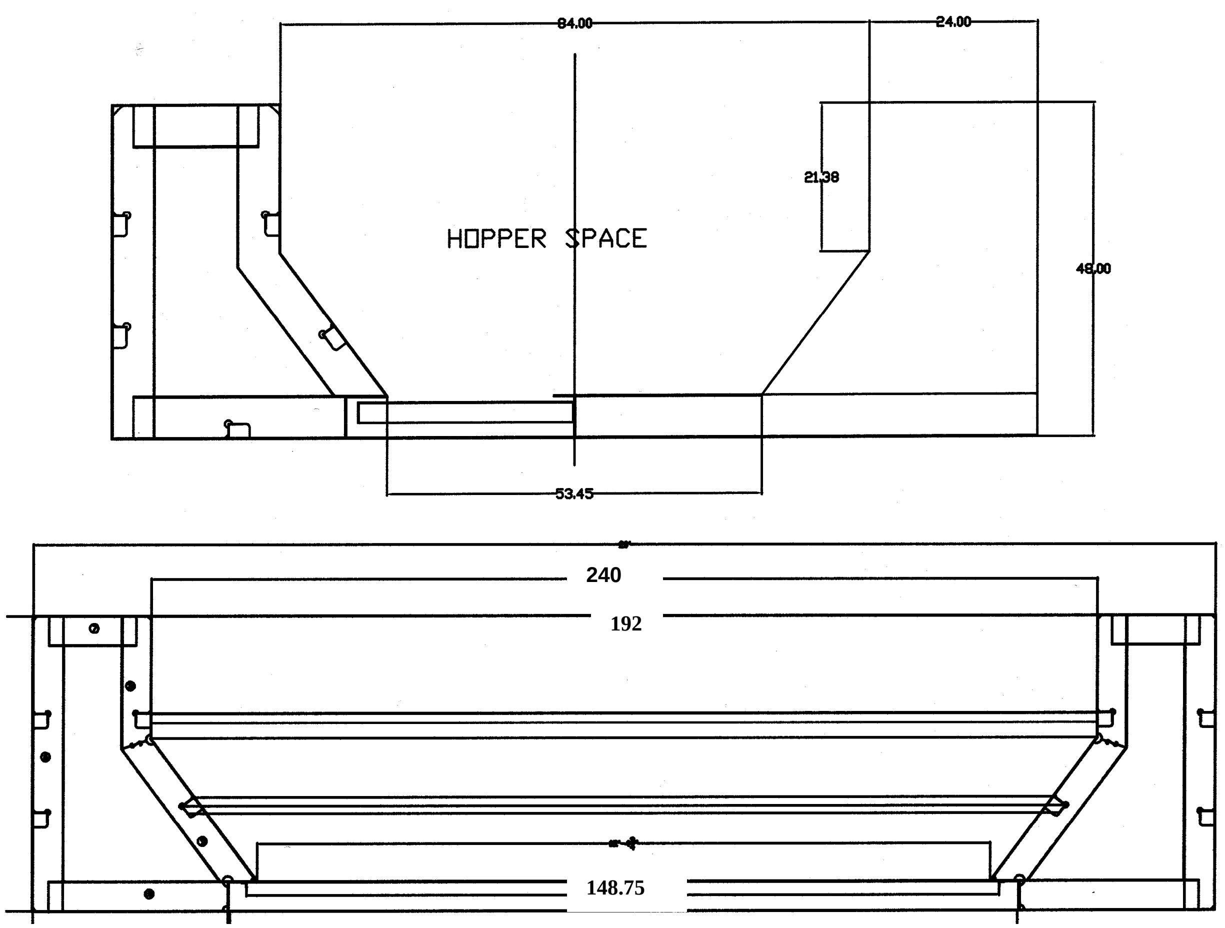

Figure 8. End (top) and side (bottom) views of hopper barge. All dimensions are in inches (multiply by 2.54 to get centimeters).

DATA ACQUISITION SYSTEM

Previous discussion of the data acquisition system for the Dredge/Tow Carriage can be found in Randall et al. (2005). However, modifications and additions to the system have made the operation of the dredge carriage more functional and easy to use. The data acquisition system is run through a graphical user interface on a standard PC and is able to access a manual operating station as well as all of the necessary drives needed to run the Dredge/Tow Carriage. A picture of the manual operating station along side the dredge automation PC can be viewed in Figure 9. The PC is also able to record data from the installed gauges and simultaneously record information from the OBS sensors. A final addition to the system involves the addition of programmable dredging simulations, able to be replicated using the graphical user interface (GUI) shown in Figure 10.

Figure 9. Manual control system (left) next to PC automation system (right).

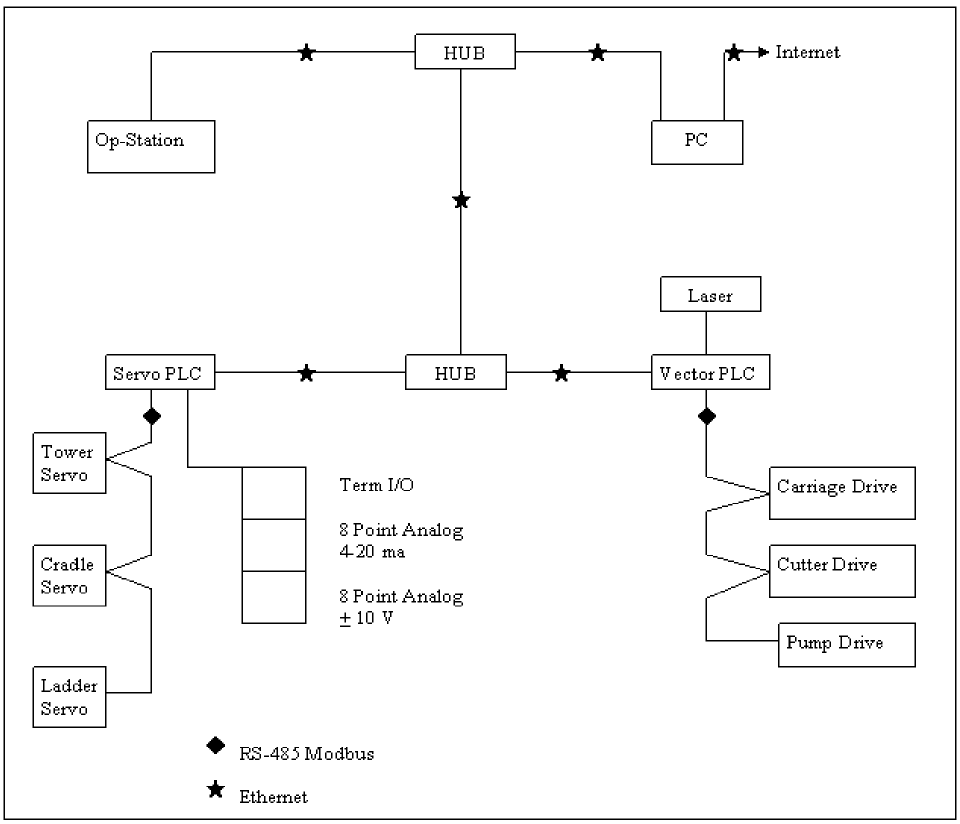

Figure 10. The dredge carriage graphical user interface.

Figure 11 displays the schematic of the data acquisition system and the individual components associated with the operation of the dredge carriage. The graphical user interface (GUI) is located in the personal computer (PC), however, it is important to note that the control of the carriage can be manually controlled from the operator station location. In manual or GUI controlled modes, hubs relay and obtain information to/from the servo and vector programmable logic computers (PLC). The Servo PLC's control and obtain data for the tower, cradle, and ladder movements. The Vector PLC controls and obtains data for the movement of the carriage, cutter and pump movements. Data for the horizontal position of the carriage along the tank is obtained through the Vector PLC via a laser (Figure 12).

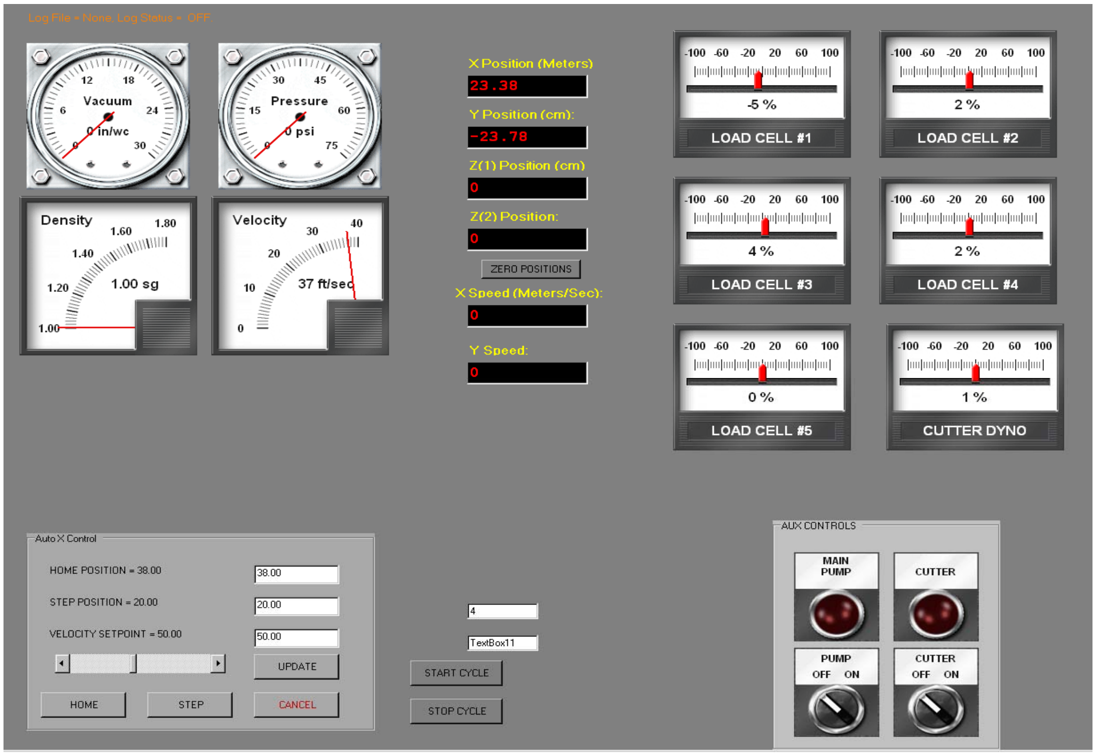

Figure 11. Schematic of the data acquisition and control setup for the dredge/tow carriage.

Figure 12. Picture of the horizontal position laser mounted on the dredge/tow carriage.

Initial Data Acquired from the Dredge/Tow Carriage

In order to test the functionality of the Dredge/Tow Carriage a dredging scenario was programmed into the data acquisition and control system. The scenario is executed by a user pressing the "start cycle" button on the graphical user interface (GUI). When the button is pressed the dredge/tow carriage is instructed to conduct a series of moves. During these operations all gauges on the dredge/tow carriage are acquiring data in real time. The data is written to a file and subsequently plotted. Sampling frequency is conducted at 8Hz.

Figure 13 shows the real time position of the carriage and cradle while Figure 14 displays data on the density flowing through the nuclear density gauge and the velocity recorded from the flowmeter. Figure 15 plots information from four OBS sensors recording a turbidity cloud.

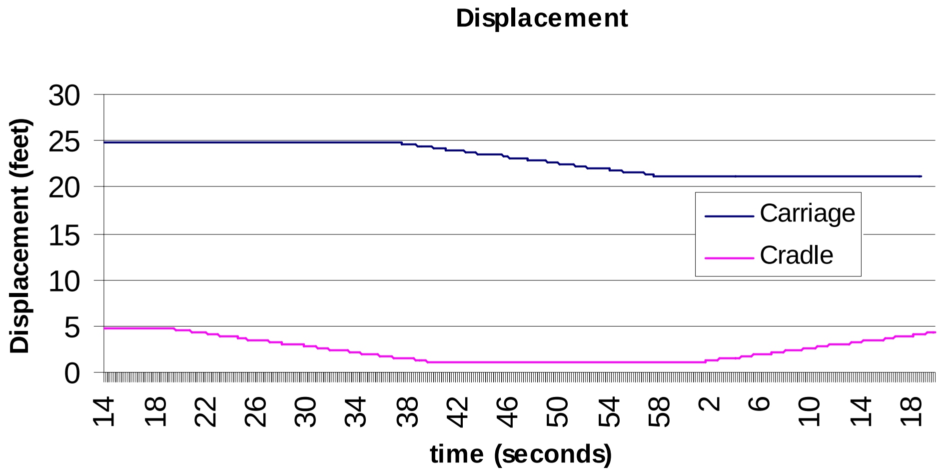

Figure 13. Position data for the carriage and cradle.

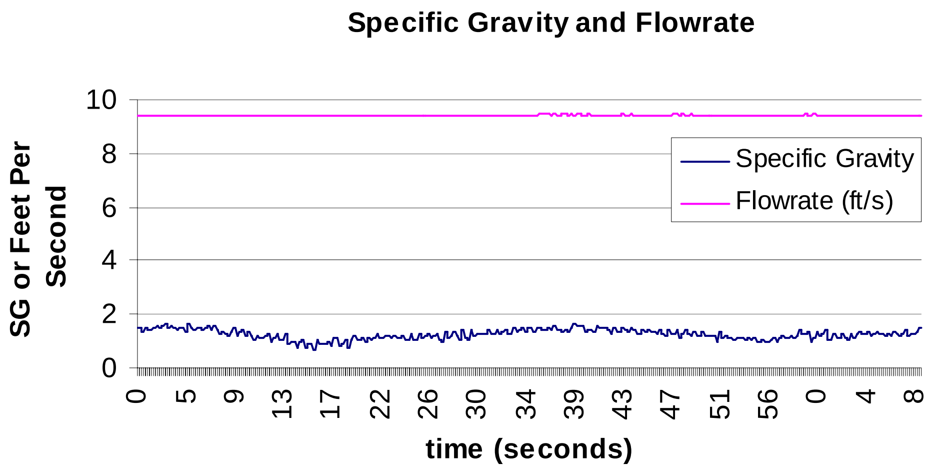

Figure 14. Example specific gravity and flowrate data recording.

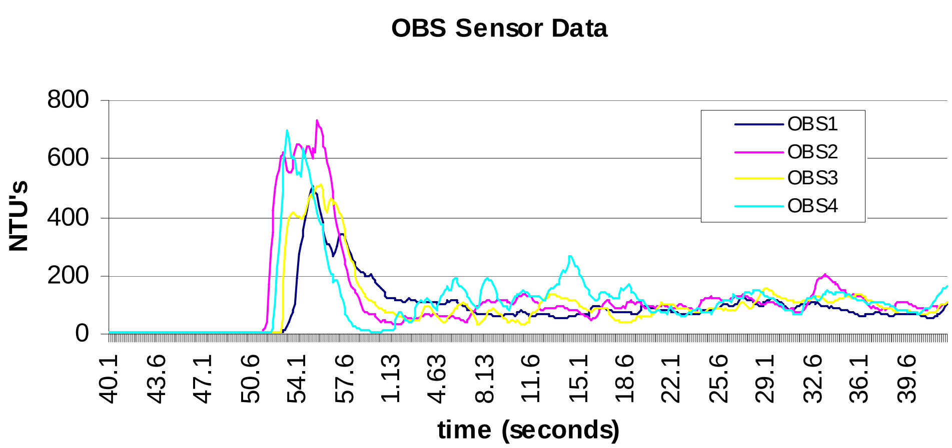

Figure 15. OBS turbidity data from four OBS sensors.

CONCLUSIONS

The data collected from the Dredge/Tow Carriage at the Haynes Coastal Engineering Lab will be beneficial for understand the resuspension of sediment created during cutter head dredging operations. Gauges on the Dredge/Tow Carriage were shown to be functional and provide real time data for dredging research. The ability to control the Dredge/Tow Carriage from a PC allows for repeatable experiments in a laboratory setting and provides a more accurate method to identify the source term for a cutter suction dredging operation. The possibilities for future studies using the Dredge/Tow Carriage are widespread and some of the research options for which the Dredge/Tow Carriage can be used are:

- New draghead and cutterhead design
- Flow around dragheads and cutterheads
- Turbidity or resuspended sediment generated by dragheads, cutterheads, and clamshell buckets.
- Reverse slurry flow through draghead for capping
- Effect of water jet assisted cutting for cutterheads and dragheads
- Hoppers used for capping with pump-out through draghead
- Modification of dragheads and cutterheads for minimizing effects on marine life
- Bank height effects on sediment flow to cutterhead
- Dredge cutter cutting of sediments
- Measuring production of model dredge

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donated the magnetic flowmeter and Ohmart Inc. donated the nuclear density gauge. Steel Processing Inc. is in the process of construction a hopper barge for the facility.