# COMPARING METHODS FOR MEASURING THE VOLUME OF SAND EXCAVATED BY A LABORATORY CUTTER SUCTION DREDGE USING AN INSTRUMENTED HOPPER BARGE AND A LASER PROFILER

A Thesis

by

ARUN KUMAR MANIKANTAN

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

December 2009

Major Subject: Ocean Engineering

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Approved by:

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| Co-Chairs of Committee, | Robert E Randall |
| | David Brooks |
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# ABSTRACT

Comparing Methods for Measuring the Volume of Sand Excavated by a Laboratory Cutter Suction Dredge Using an Instrumented Hopper Barge and a Laser Profiler.

(December 2009)

Arun Kumar Manikantan, B.E., Mumbai University

Co-Chairs of Advisory Committee: Dr. Robert Randall
Dr. David Brooks

The research focuses on the various methods that could be used in the laboratory to determine the values of production from a model cutter suction dredge. The values of production obtained from different methods are compared to estimate the best value. The tests were conducted in an attempt to pave the way to find spillage from the cutter suction dredge. The development of these methods is useful for evaluating the sediment spillage and residuals during dredging. The more accurate the values of production the more accurate would be the values of spillage. For this purpose, the laboratory dredge carriage and dredge/tow tank located at the Haynes Coastal Engineering Laboratory at Texas A&M University is used. During the summer of 2007 and 2008, the laboratory dredge carriage was used to dredge sand ($d_{50}$ = 0.27 mm) in the sediment pit that is 7.6 m (25 feet) long, 3.7 m (12 feet) wide and 1.5 m (5 feet) deep. A laser profiler, a model hopper barge attached with pressure gauges, a flowmeter and density gauge aid in determining the production from the laboratory model of the cutter suction dredge were used. The before and after bathymetry measurements using a laser profiling system are used to determine the amount of sediment remaining after dredging. The hopper is instrumented with pressure gauges to measure the amount of sediment contained in the hopper. The laboratory dredge system has a magnetic flowmeter and nuclear density gauge that provide data to calculate the amount of sand delivered to the hopper. The difference between the sand volume from the before and after bathymetry is the amount of sand that is resuspended and subsequently resettles in the dredging area (residual) and the sand that is not picked up by the dredge (spillage). Many issues in laboratory testing were found during the course of testing and solutions were found. The production values are compared with reasoning as to why the differences occur. The results demonstrate the ability and difficulty of measuring the amount of material that is dredged and the amount of spillage and residuals that occurs during dredging.

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# NOMENCLATURE

$\omega_{cutter}$ = Cutterhead angular velocity....rad/s

$D_{cutter}$ = Diameter of cutter head....m (in)

$U_{suction}$ = Average suction pipe flow velocity....m/s (ft/s)

$\mathrm{C}_v$ = Concentration factor....-

$SG_m$ = Specific Gravity of mixture (sand and water)....-

$SG_f$ = Specific Gravity of fluid (water)....-

$SG_s$ = Specific Gravity of solids (sand)....-

$H_{velocity}$ = Velocity head....m (ft)

$Q_{suction}$ = Volumetric flowrate through suction / discharge pipe....$m^3/s$ ($ft^3/s$)

$V_{swing}$ = Cutterhead swing velocity....m/s (ft/min)

$g$ = Gravitational acceleration constant....$m/s^2$ ($ft/s^2$)

$V_{settling}$ = Settling velocity....mm/s (ft/s)

$I_m$ = Internal height of the hopper....mm (in)

$h$ = Draft of the hopper....mm (in)

$W_t$ = Total weight of the hopper....kg (lb)

$W_e$ = Weight of the empty hopper....kg (lb)

$W_i$ = Weight of the slurry in the hopper....kg (lb)

$\gamma_w$ = Specific Gravity of water....-

$V_d$ = Displaced volume of the hopper....cu.m (cu.yd)

$V_s$ = Volume of slurry in the hopper....cu.m (cu.yd)

$V_c$ = Volume of the cuboid....cu.m (cu.yd)

$V_p$ = Volume of the frustrum of a pyramid....cu.m (cu.yd)

$I_{mp}$ = Height of the frustrum of a pyramid....mm (in)

$I_{mc}$ = Height of the cuboid....mm (in)

# CHAPTER I

# INTRODUCTION

## 1.1 Organization

The Haynes Coastal Engineering Laboratory hosts a Dredge Tow Tank where the experiments were conducted for measuring the production of the spillage of sand resulting from a model cutter suction dredge. Different methods were used so as to calculate the production resulting from the model cutter suction dredge. The thesis starts with introducing the facility at Texas A&M University where the experiments were conducted. This section is followed by a literature review, which encompasses the previous research and discusses the results. The different dredging parameters and scaling laws applicable to the experiment are discussed in Chapter III. The various equipments available at the laboratory and their usability are discussed in chapter IV. Chapter V describes the experimental setup procedure and chapter VI discusses the different methods of calculating the dredge production, the instrumentation used on the hopper barge and the laser profiler. Finally the thesis describes the experimental data and discusses the results from all four different types of dredge production calculations used in the experiment.

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This thesis follows the style of Journal of Dredging Engineering.

## 1.2 Introduction

The quantification of the amount of material dredged has always been very difficult. The resuspension, spillage and turbidity are a few of the many reasons why the quantification becomes difficult. In this experiment, various types of attempts have been made to quantify the amount of sand dredged, and the quantities are compared which helps to determine the approximate quantity of sand removed, using a cutter suction dredge.

The dredge/tow tank facility at the Haynes Coastal Engineering Laboratory (Figure 1) at Texas A&M University has been utilized for this purpose. The installation of the basic dredge tow carriage in Haynes Laboratory was completed in 2005. Several model tests have been conducted and finished in this laboratory dredge/tow tank, including: modeling of simulated oil spills, scouring around bridge structures, modeling forces on strakes, resuspension of dredged material by cutter suction dredge, effect of debris on dredging production, measurement of cutter force, operation of bed levelers and others. The laboratory houses a state-of-the- art model cutter suction dredge. The model dredge comprises of a carriage, ladder, and cradle. The entire assembly is mounted rails attached to the tow tank walls. The model cutter suction dredge, as shown in Figure 2, is supported by a carriage that runs on the rails of a 45.72 m (150 ft) long, 3.657m (12 ft) wide, and 3.353mt (11 ft) deep dredge/tow flume. The 0.3 m (12 in) cutter is mounted on an articulating ladder, attached to a vertical ladder that runs transverse to the carriage. The upward and the downward movement of the cutter are facilitated using the vertical and articulating ladder.

The towing carriage traverses on the steel flume rails using polyurethane rimmed steel wheels along the top of the tow tank side walls, while the cradle moves in a direction perpendicular to the movement of the carriage. The vertical ladder is on the upper side while the articulating ladder is in the lower side of the carriage. These allow both vertical translation and an adjustable angle of the lower ladder between 0 and 50 degrees with the horizontal, respectively. The cutter is attached to the end of the articulating ladder and the suction inlet is located directly behind the cutter.  The dredge/tow tank also has an additional 7.62 m (25 ft) long by 1.524 m (5 ft) deep sediment pit. The sediment pit is covered when the experiments are not using the sediment pit. A maximum of 2.233 L/s (35,000 GPM) of water can be pumped through the flume using the four axial flow pumps. For a dredging production test, the tow tank is filled with up to 6 feet of water.  The specifications of the carriage are tabulated in Table 1.

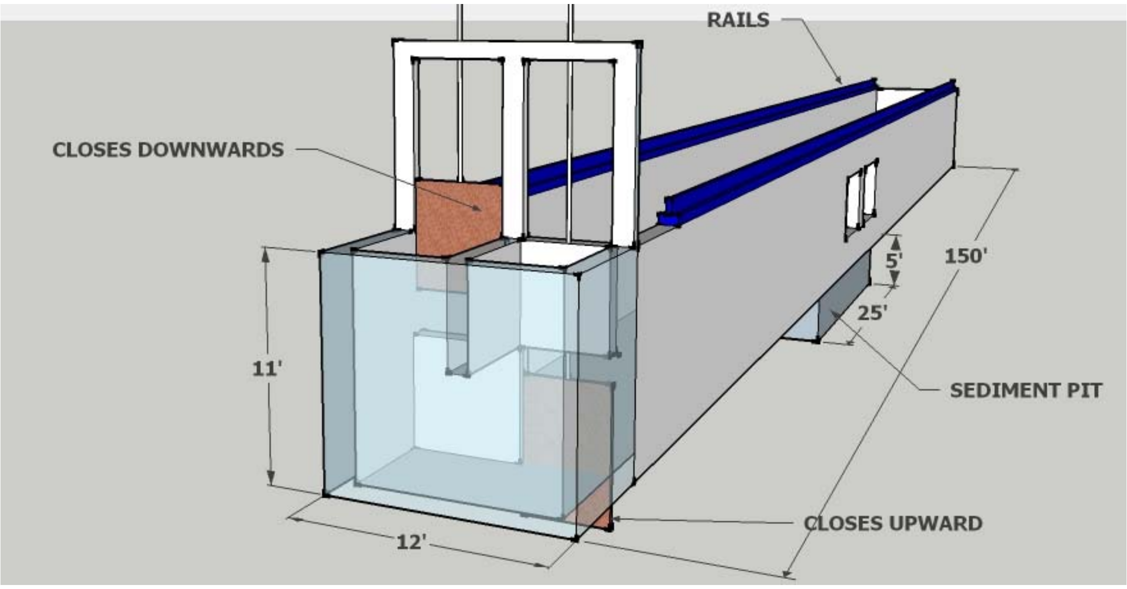


**Figure 1:** *A 3-D sketch of the dredge tow tank.*

**Table 1:** *Specifications of the model dredge carriage*

| **Category** | **Characteristic** |
|---|---|
| Maximum Carriage Speed | 2 m/s (6.6 feet/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 feet) on either side of flume centerline |
| Ladder Angle | 0 to 50 degrees from horizontal |

**Figure 2:** *Different views of carriage mounted on the rails of the tow tank with cutter seen in the bottom (right).*

Apart from the testing of production from the model cutter, the facility is used for efficient testing of different drag heads, suction heads, cutterheads, and hopper placement of dredged material. Real time experiments like studies on the effects of bed leveling on model turtles or of mangrove roots on production have been simulated in the dredge/tow tank.

A sand/water separation system was also installed on the Dredge/Tow Carriage. The Tri-Flo model 300 sand/water separation unit is designed to have a storage tank with a capacity of 1136 liters (300 gallons). The system is able to handle separation of solids and water at a pumping load of up to 454 liters per minute (120 gallons per minute). If allowed to pump back into the tank, the discharge pump can also act as a "bottom agitator". A 1136 liter (300 gallon) tank, a scalping shaker, a mud cleaner consisting of two 10.2 cm (4 in) hydro cyclones 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 comprise the sand/water separation system. It is 157.5 cm (62 in) wide, 226 cm (89 in) long, and 233.7 cm (92 in) in height. The total empty weight is 1225 kg (2700 lb) and the total full weight is 2858 kg (6300 lb).

A magnetic flow meter and a nuclear density gauge are additional instruments on the carriage, and they facilitate measuring the instantaneous flow and specific gravities of the slurry, respectively. The laboratory also has a model hopper barge that is used to study the production. The hopper is instrumented with pressure gauges to study the production of sand from the model cutter suction dredge. This process is accomplished using draft measurements. The laboratory also has a Laser profiler that is used to calculate the volume of sediments dredged by knowing the before and after bathymetry of the sediment pit.

# CHAPTER II

# LITERATURE REVIEW

Tests were conducted using a cutter suction dredge on the Corpus Christi Ship Channel on a clay sediment bed by Huston and Huston (1976). They concluded that the level of turbidity increases in the immediate vicinity of the cutter and the increased levels of turbidity (variable) are due to an increase in the suspension of fine grained material created from cutter turbulence. The variability of the turbidity is inconsistent in the immediate vicinity of the cutter, possibly due to cutter generated turbulence which increases the turbidity at higher rpm. This inconsistency could also be influenced by the variability of the material being dredged and/or the suction velocity. They also concluded that very little turbidity created by the cutter rises into the water column (9 to 12 m deep). This is proven by the fact that no substantial visible surface turbidity was observed.

Herbich and Brahme (1983), conducted studies on conventional and unconventional dredges, their dredging techniques, turbidity generation and ways to improve these dredges so as to reduce the environmental impact. Turbidity is also one of the results of the sediments that have not been picked up by the dredge (resuspension). The authors have discussed turbidity and its effects (physical, chemical and biological) on the environment, turbidity generation, turbidity generation potential of sediments and prediction of turbidity due to different dredges. Finally, the authors have suggested methods to reduce the turbidity in various dredges using different techniques. According to the authors, given a set of conditions, the dredging equipment, skill of the operator and the type of dredge create different levels of turbidity. The cutterhead dredge is the most commonly used dredge in the United States, and the typical solid contents of the sediments pumped is 10 to 20 percent by volume, for a pipeline size that varies from 15 cm to 112 cm (6 in to 44 in). Most of the resuspension for the cutter suction dredge occurs in the vicinity of the cutter. The rate of cutter rotation, the vertical thickness of the dredge cut, the velocity (horizontal) of the cutter moving across the cut, and the skill of operator greatly influence the amount of resuspension. Field data for sediment resuspension was collected under low current conditions, and the concentrations in the vicinity of the cutter (3m) are highly variable (as much as 10s of grams per liter). These concentrations are observed to decrease exponentially towards the surface and are in the order of a few hundred milligrams per liter at distances of a few hundred meters from a cutter. An improperly designed cutter creates greater turbulence which in turn affects resuspension. Excessive cutter rotation speed also tends to throw the sediments away from the cutter.

Resuspension from a cutter suction dredge is a process wherein some amount of the dredged material is suspended back into the vicinity of dredging. Schroeder (2009), discusses, the 3Rs of dredging namely Resuspension, Release and Residuals. Resuspension, is defined, as the dislodgement and dispersal of sediments into the water column where finer sediment particles and floccus are subject to transport and dispersion by currents, and residuals are defined as the sediments dislodged but not removed by dredging, which falls back (spillage), or settles in or near dredging foot print and forms a new sediment layer. Resuspension is often characterized by dispersion of sediment (turbidity). Herbich (2000) discusses the resuspension of sediments during the dredging operation and indicates that the factors causing dispersion depends upon the type of dredge, method of dredging and the environmental conditions. But the degree of resuspension is largely governed by the size of sediment particles being dredged. Extremely fine particles have a higher tendency to go into suspension as they are supported by buoyancy. He also talks about the composition of solids and water mixture which gives us an approach to measure the volume of solids in the hopper. The composition of the mixture is the ratio of the volume of solids to the volume of the mixture. Concentration by volume of solids in a mixture, $C_v$, is the ratio of volume of solids to volume of mixture and is expressed as

$$C_v = \frac{SG_m - SG_f}{SG_s - SG_f} \tag{1}$$

where, $SG_m$ $SG_s$ and $SG_w$ are the specific gravities of the mixture, solids and water respectively.

Glover and Randall (2004), based on previous model studies, develop grounds for scaling the model dredge operating parameters at the Texas A&M University's Reta and Bill Haynes '46 Coastal Engineering Laboratory. They have demonstrated how the similitude criteria can be used in an actual model dredge study. Performance of a model dredge depends on the extent to which the kinematic, dynamic and geometric similarities are attained between the model and the prototype. Hypothetical model studies on a cutter suction dredge were conducted to show how effectively the similitude criteria could be used. For this purpose, numerous model studies were reviewed, such as model dredge studies, flow visualization studies, model cutterhead studies, flow field studies and sediment pick up behavior, cavitations and cutterhead dynamics. The scaling laws for modeling the hydraulic dredging operation were reviewed and suggest that the best method to model the dredge in a laboratory facility is based on the sediment pick up behavior. It also suggests that the velocity fields must all be scaled in accordance with the geometric scale ratio and normalized to the sediment settling velocity. Experiments are conducted on the model dredge facility to determine the effect of swing speeds on the production for a given cutterhead design, and the swing speeds are varied and all other parameters are kept constant. It was found that the higher swing speeds result in lower production because of spillage. Also, some of the recorded quantities, such as the cutterhead forces, cutterhead power and pump characteristics like the pump power, head and slurry specific gravity, are not easily scalable. However, the effect of the swing speed on these parameters can be observed. One of the limitations observed here was that the dynamic similarity cannot be attained simultaneously with the hydraulic similarity. This would mean if the cutterhead speeds and the swing speeds are increased, so as to obtain similarity with respect to cavitation, then, the similarity due to sediment pick up behavior would have to be compromised.

Burger, Vlasbom and Talmon (2005) conducted experiments at the Delft University to improve the cutterhead design so as to minimize the spillage, which would help increase production. The efficiency of the cutterhead varies based on the type of bed being dredged. Experiments are conducted to observe the amount of spillage for various speeds of the cutterhead and solutions are recommended based on the observations. The experiment consists of a prototype whose size compared to the working model is a ratio of 1:8 with the cutterhead shaft at an angle of 45 degrees. The experiment focuses on mixture formation processes while dredging a rock/hard clay bed. A prototype bed that would replicate similar effects while dredging rock/hard clay bed is prepared by weakly cemented gravel of density 2650 $\mathrm{Kg/m^3}$.The results show that production increases with an increase in rotational speed but decreases with further increase in speed. The reason for the first phenomena is observed as low rotational speed leads to the accumulation of particles at the lowest point of the cutterhead due to the dominance of gravitational force. The second phenomena where there is a reduction of production with higher rotational speed is explained as an increase in centrifugal force, which leads to particles being thrown away from the cutter. This also necessitates an increase in pump capacity to capture the remaining particles by maintaining a constant suction flow. With the above results, a graph for optimum cutterhead speed and optimum pump capacity for a given cutterhead dimension is drafted. The article further concludes that low efficiency of the cutterheads can be improved by redefining the pump capacity and cutterhead dimensions based on the graph.

Palermo and Randall (1990) investigated the overflow characteristics of a hopper, to load the hoppers economically. The resource agencies have put restrictions on the overflow. However, the need for restriction or data that technically supports overflow need to be found. Palermo and Randall (1989) recommended the development of techniques that would predict the potential load gain in hoppers and scows. This knowledge would provide guidance on when the overflow could potentially achieve load gains. Also, they recommend the development of equipment to aid in the retention of material in the hopper and scows. Miller, Palemro, and Groff (2001) studied the hopper overflow for the Delaware River, wherein they have sampled the hopper inflow to analyze the grain size distribution, particle size distribution of fines and chemical concentrations. Similar analysis in the experiment could render a basis for the estimate of the percentage of sand removed during dredging. Hopper contents are also sampled here so as to know the concentrations of suspended solids. Studies of this nature necessitate the need to know the amount of sediments dredged into the hopper.

Fortino (1966) describes the pneumatic and electrical methods to measure the flow of the dredged materials from the pump. This method can be used to measure the sediments in the hopper Over the years, many attempts to measure the amount of sediments in the hopper have been made. Armstong and Grant (1977) designed a float that was used to measure the sediment in a hopper to determine the pay load of a trailer suction dredge. This measurement device is mechanical and gives a continuous record of the dredged sediments in the hopper, based on the relative density for which it is set. Rokosch, Van Vechgel and Van der Veen (1986) investigated the challenges to measure the optimum load for mixed loads. Mixed load is a combination of settled and suspended materials. They examined the 'Displacement and Pressure' based measurements and found that the total load and suspended material in a mixed load can be separately determined. This result can be used to determine the continuation of loading the material in the hopper. A different approach was used by Meyer et al (1986) to measure the sediments in the hopper. They stated that dredge displacement is insufficient to measure optimum load for fine sediments as it fails to determine the distribution of load from fore to aft of the hopper. They suggested the use of a gamma emitting probe that helps to show material build up in the hopper as a function of time for fine sediments. It also determines the distribution of load throughout the hopper. However, this method is inadequate to measure the load for fine grained sediments, but it is adequate enough for sandy sediments.

# CHAPTER III

# SCALING LAWS

## 3.1 Review

This chapter describes the scaling relationships between operating parameters for the hydraulic dredge model studies. The degree of geometric, kinematic and dynamic similarity determines the usefulness of the hydraulic model dredge. Glover (2002) studied the modeling of a model dredge facility in a laboratory. Even though the process of modeling is extremely difficult, researchers have tried to isolate the different processes. Evaluation of the scale effects is determined by different model scales. Sometimes the models are as close as possible to the prototype, where in the errors due to scale effects are minimized. Scales of 1:10 or sometimes 1:6 are better for model dredging studies. According to Glover and Randall (2004), based on previous model hydraulic dredge studies, the scaling laws can be divided into the following three categories:

i. Similarity based on the sediment pick up behavior
ii. Similarity based on the cavitation during the cutting process
iii. Similarity based on the Froude or Reynolds number

It is stated that all of the above criteria cannot be satisfied by using one set of operating parameters. It is well proven by researchers, such as Slotta (1968), J oanknecht (1976), Brahme (1983), Herbich and Herbich (1983), and Burger (1997) that the similarity based on the sediment pick up behavior is the most effective one. To model the hydraulic dredge based on the Froude or Reynolds number or on the cavitation during the cutting process requires parameters such as higher speeds (cavitation) and excessive cutting swing speeds. These parameters are not realistically attainable in the laboratory.

Slotta (1968) developed relationships by dimensionless analysis of the cutterhead and suction pipe parameters. The following equations were found to accurately correlate the data for volumetric flow rate, suction velocity and cutterhead speeds.

$$\left[\frac{\omega_{cutter} D_{cutter}}{U_{suction}}\right]_{\text{model}} = \left[\frac{\omega_{cutter} D_{cutter}}{U_{suction}}\right]_{\text{prototype}} \tag{2}$$

$$\left[\frac{\omega_{cutter} \sqrt{Q}_{suction}}{\left(H_{velocity}\right)^{\frac{3}{4}}}\right]_{\text{model}} = \left[\frac{\omega_{cutter} \sqrt{Q}_{suction}}{\left(H_{velocity}\right)^{\frac{3}{4}}}\right]_{\text{prototype}} \tag{3}$$

In another instance, Joanknecht (1976) uses scaling of cutter forces without taking sediment pick up, production or cavitations into consideration to model the prototype. The equations are:

$$\left[\frac{V_{swing}}{\sqrt{g D_{cutter}}}\right]_{\text{model}} = \left[\frac{V_{swing}}{\sqrt{g D_{cutter}}}\right]_{\text{prototype}} \tag{4}$$

$$\left[N_{cutter} \sqrt{\frac{V_{swing}}{g}}\right]_{\text{model}} = \left[N_{cutter} \sqrt{\frac{V_{swing}}{g}}\right]_{\text{prototype}} \tag{5}$$

Glover and Randall (2004) also states that for a similarity between the scale model and prototype to be attained, with respect to the sediment pick up behavior, the velocity fields must be normalized to the sediment settling velocity after the velocity fields are all scaled with the geometric scale ratio. Herbich and Brahme (1986) showed that the velocity field scaling factor depended on volumetric flow rate as opposed to velocity at the suction inlet as Slotta (1968) stated. Thus, the equation (2) was rewritten as equation (6).

$$\left[\frac{N_{cutter}D_{cutter}}{V_{settling}}\right]_{\text{model}}=\left[\frac{N_{cutter}D_{cutter}}{V_{settling}}\right]_{\text{prototype}} \tag{6}$$

Equation (6) is derived from the fact that a velocity field relative to the cutterhead is created which interacts with the velocity fields created by the cutterhead rotation and suction. The velocity field relative to the cutterhead is created due to the swing speed of the cutterhead. Herbich and Brahme (1983) arrive at Equation 7, based on studies, with dimensionless velocity field plots, which show that the velocity field was more a function of the volumetric flowrate through the suction pipe. When the settling velocity of the model and the speed of the cutterhead are known, the model flow rate, swing speed and cutterhead rotation speed can be scaled based on equations (6), (7), and (8).

$$\left[\frac{Q_{suction}}{\left(D_{cutter}\right)^{2}V_{settling}}\right]_{\text{model}}=\left[\frac{Q_{suction}}{\left(D_{cutter}\right)^{2}V_{settling}}\right]_{\text{prototype}} \tag{7}$$

$$\left[\frac{V_{swing}}{V_{settling}}\right]_{\text{model}} = \left[\frac{V_{swing}}{V_{settling}}\right]_{\text{prototype}} \tag{8}$$

Glover and Randall (2004), also state that the dynamic scaling of cutting forces depend upon bed sediment compactness ratio, dynamic scaling of particle settling velocities, void ratio, material density and cohesive / adhesive properties. However, finding these parameters is a major challenge for researches attempting to calculate sediment scaling.

## 3.2 Scaling of the Model Hydraulic Dredge at Texas A&M

The model cutter suction dredge at Texas A&M, where the experiments were conducted, is modeled using the similitude criteria. Here, again, the sediment pick up behavior is the basis of the scale laws, while the median grain size and the geometric scale ratio decide the basis of operating parameters. A chart for selecting the model dredge operating parameters is used for the selection of geometric scale. The resulting operating parameters for the model are known if the prototype grain size is known. The data used to plot the charts are calculated from the equations (6), (7), (8). A deviation from the model grain size would necessitate the calculation of the model to a prototype velocity scale based on relative settling velocities.

Table 2 shows the parameters of the prototype and the model with a scale of 1:6.

**Table 2**: *Parameters of the model dredge at the facility, (scale of 1:6)*

| **Parameter** | **Prototype** | **Model** | **Scale** |
|---|---|---|---|
| Cutter Diameter | 183cm (72in) | 30.5cm (12in) | 1:6 |
| Water Depth | 12.2m (40feet) | 3.35m (11feet) | Not scaled |
| Depth of Cut | 91.4cm (36in) | 15.2cm (6in) | 1:6 |
| Sediment Diameter | 0.2mm | 0.1mm | Not scaled |
| Settling Velocity | 22.7mm/s | 8.8mm/s | 0.388 |
| Suction Diameter | 61cm (24in) | 7.62cm (3in) | 1:8 |
| Suction Flow rate | 113,562LPM (30,000GPM) | 1223LPM (323GPM) | 0.011 |
| Cutter RPM | 40 | 124 | 3.104 |
| Max Swing Speed | 50cm/s (20in/s) | 19.7cm/s (7.76in/s) | 0.388 |

The model dredge is designed on the basis of the hydraulic similarity between the model and the prototype. This ensures kinematic similarity, which means, according to scaling laws, the model dredge will geometrically pick up the same amount of material as that of the prototype. Cavitation coefficients and cutting forces restrict the dynamic similarity of the dredge.

# CHAPTER IV

# EQUIPMENT DESCRIPTION

## 4.1 Laser Profiler

An optically safe laser mounted on an aluminum frame is used to aid the quantification of sediments removed during the dredging process. The laser translates in the longitudinal (x) and lateral (y) horizontal directions, as it takes the depth readings in the “z” direction. The laser measures a distance (depth, z) of 200 to 1000 mm with a resolution of 0.02 - 0.5 mm with an error of +/-2 mm. The laser, in this case, is programmed to take depth readings at every 5 mm and 20 mm x and y increments, respectively. The maximum reach of the laser is an area of 5000 mm by 2500 mm. Pictures of the laser on the aluminum frame are shown in Figure 3.

(a) (b)

**Figure 3:** *Profile laser (a), the laser mounting system (b).*

Current Position relative to User Origin
X -.091 Y 271.831 Z 616.064

Command Position
X 5000.0 Y 2500.0

Grid Spacing
X 5
Y 20

Current Position relative to system home
X -.091 Y 270.725

(c)

**Figure 4:** *Laser Profiler User interface with the laser (c).*

The laser continuously measures the depth and stores the readings in the form of both a Notepad (.dat) and a text file (.txt). The interface between the user and the Laser profiler is as shown in Error! Reference source not found.. The parameters, like the X and Y increments, absolute positions and the relative positions of the laser head, can be adjusted using the interface. The .dat file is an input to a *MATLAB* code that is used to calculate the volume of the dredged sediment.

## 4.2 Model Hopper Barge

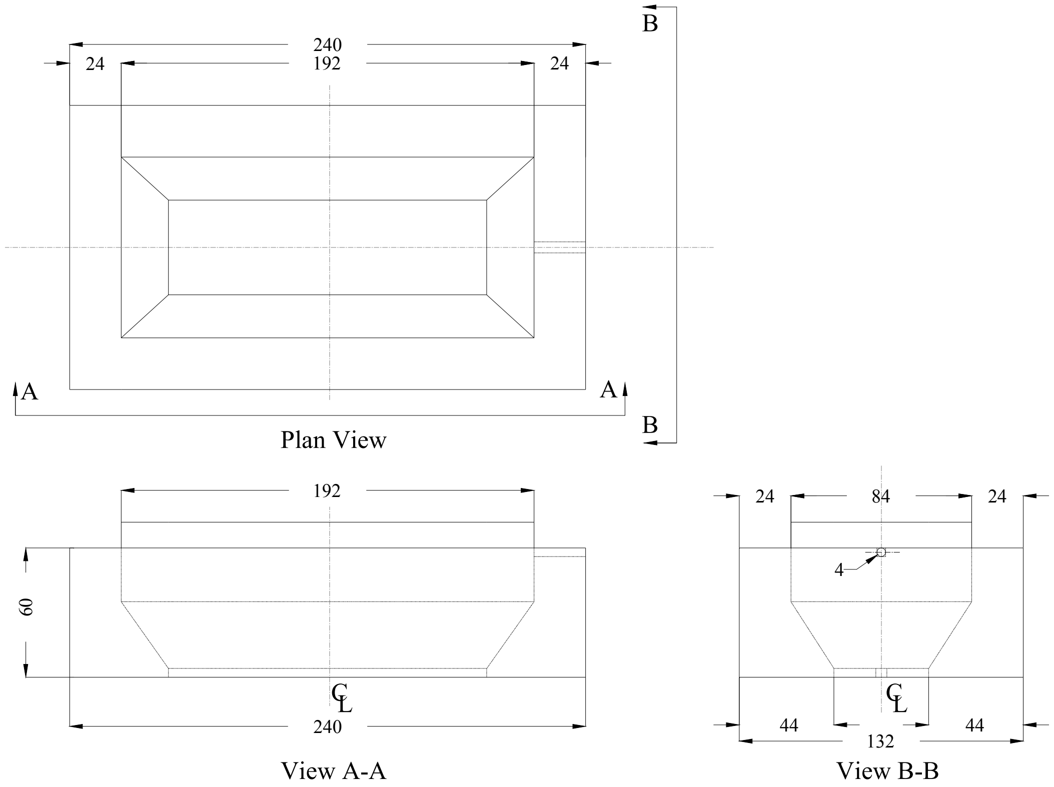
The model hopper barge is constructed with a 3/32in thick steel plate. The outer dimensions of the hopper are 73.15 x 40.23 x 18.28m (240 x 132 x 68in), while the internal volume is 562 ft$^3$ (20.8 yd$^3$). The complete weight of the hopper is 6416 lbs.

This is calculated using the draft measurements from the sensors attached to the four sides of the hopper.

The hopper rests on top of the tow tank on 3 I-beams when experiments are not being conducted. The hopper is maneuvered by the laboratory’s electric overhead crane, which has a capacity of 6000 lbs. The hopper doors, which weigh approximately 1000 lbs, are dissembled from the hopper before it is lifted by the crane in order to restrict the total weight to the 6000 lb crane capacity. The hopper rests on four jacks inside the tow tank when the tank is not filled with water. Once the hopper is in the tank, the doors are then fitted. The hopper has two winches mounted on the top of the barge with their cables and chains attached to the doors at the bow and stern; these winches are used for the opening and closing of the hopper doors. Rubber tires (Figure 5) are attached on all four sides of the hopper and act as fenders to prevent the hopper from hitting the walls of the tank. When the hopper floats in water, the doors do not open completely due to the buoyancy force of the water acting on the doors. Lead blocks are attached to the doors to overcome this problem.

**Figure 5:** *Hopper barge resting on jacks (left) rubber tires act as fenders (right).*

Pressure sensors are housed in water tight PVC pipes and are attached on all four sides of the hopper. The pressure sensors are used to measure the amount of slurry collected in the hopper during dredging. A data acquisition system (DAS) captures pressure variation every second and converts it into an electrical signal. Measuring tapes attached to the PVC pipes help in knowing the draft of the hopper when empty and full. The draft of the empty hopper is 17.8cm (7in), and thus the weight of the hopper is calculated to be 2910kg (6416lb). A linear scale is drawn in the internal volume so as to give a fair idea of the slurry height in the hopper. This scale is also used to calculate the volume of sand in the hopper. Before the dredge/tow tank is filled with water, the hopper doors are completely closed and caulked. The hopper is attached to the carriage by a 3.05m (10ft) long rod and moves in the same direction as the carriage, maintaining a constant gap between the carriage and the hopper. Once the dredging operation starts, the slurry is pumped into the hopper. A provision for overflow is provided to drain the excessive water. After dredging is completed, the carriage and the hopper are moved to the extreme end of the tow tank, away from the pit where the hopper doors are opened to release the sediment from the hopper. Throughout the dredging operation, the data from the pressure sensors are continuously recorded and analyzed to acquire the weight of the sediments in the hopper. The schematic of the hopper is as shown in Figure 6. The hopper is attached to the carriage by means of a 10ft long tie-rod, maintaining a constant gap as the carriage moves backward and forward (Figure 7). The attachments to the hopper are shown in Figure 8.



Plan View

View A-A

View B-B

All dimensions are in inches

**Figure 6:** *Dimensions of the hopper barge.*

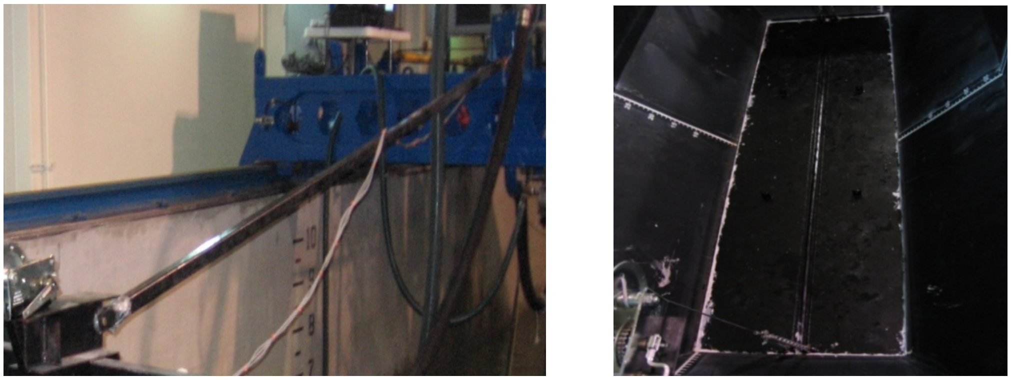


**Figure 7:** *Hopper attached to the carriage using a 10 feet long rod (left) and hopper doors closed and caulked before the dredging operation and a scale is shown that is used to measure the volume in the hopper (right).*

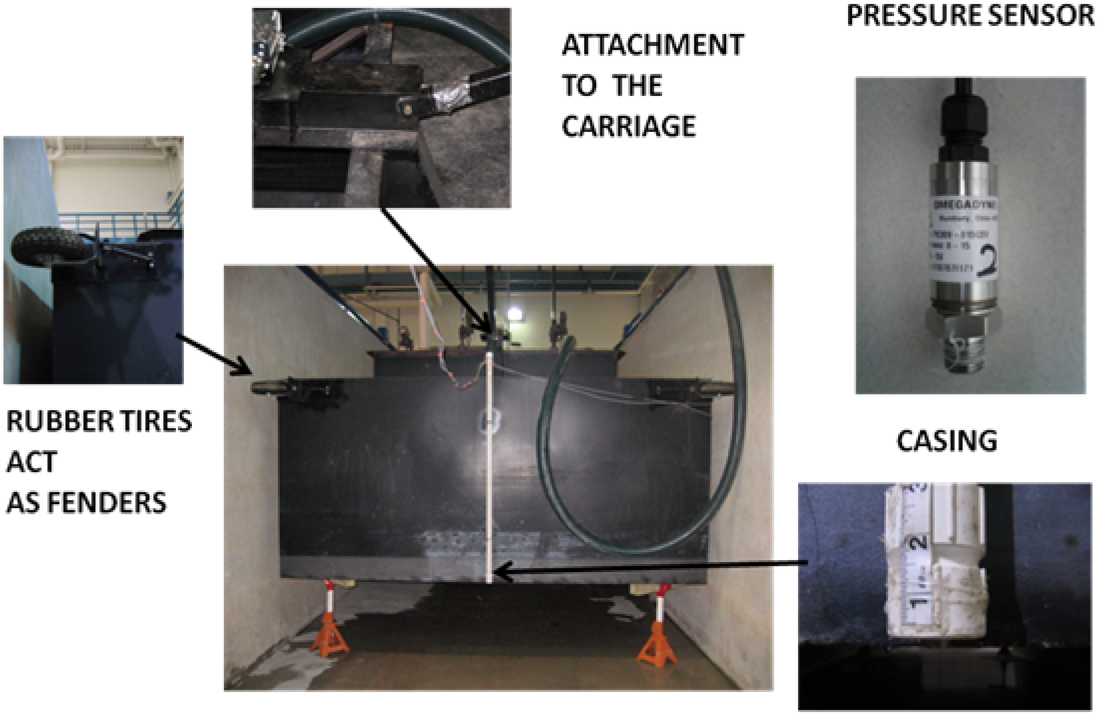


**Figure 8:** *General set up of the hopper.*

### 4.3 Pressure Sensors

Four pressure sensors (Figure 9) were used in the experiment, each sensor attached to a different side of the hopper. The pressure sensors used are the Omegadyne - PX309 015G5V, which are stainless steel high performance pressure transducers. Ruggedness, solid state design, high stability, and low drift are the characteristics of these pressure transducers. Figure 9 shows the pressure sensor. These sensors have a gauge pressure range of 1-15psi and have an electrical cable output. The other end of the cable is connected to a data logger, which is capable of recording continuous change in pressure. Table 3 shows the specifications of the Omegadyne - PX309 015G5V sensor.

**Figure 9:** *The pressure sensor.*

**Table 3**: *Specifications of the pressure sensor*

| **Category** | **Characteristic** |
|---|---|
| Excitation: | 9 to 30 Vdc (<10 mA) (reverse polarity and overvoltage protected) |
| Output: | 0 to 5 Vdc |
| Accuracy: | ±0.25% includes linearity, hysteresis and repeatability |
| Operating Temperature: | -40 to 85ºC (-40 to 185ºF) |
| Weight: | 155 g (5.4 oz) max |

Prior to testing, each of these pressure sensors is housed in water tight PVC pipes and is calibrated at different depths of water. The PVC pipes were held together and lowered until the probes just touched the water surface, and the data for the depth of zero inches was recorded for a period of 30 s. Similar readings were recorded at depths of 5.1 cm, 10.2 cm and so on up to 96.5 cm (i.e. 2 in, 4 in and so on up to 38 in). The pressure sensor records one signal every second, and thus approximately 30 readings for each depth were obtained. The calibration curves show the sensors are linear as demonstrated in Figure 10. These calibrated sensors housed within the PVC pipes are attached to all four sides of the hopper as shown in Figure 11.

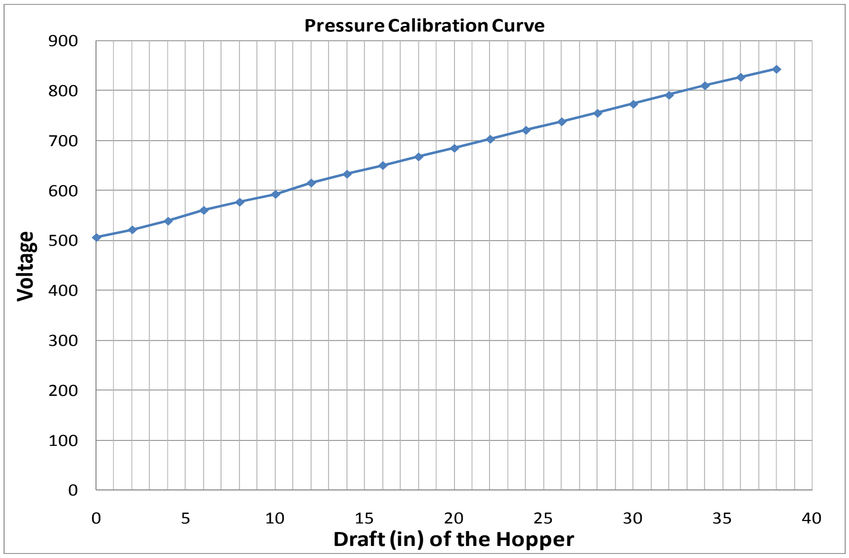


**Figure 10:** *Example pressure calibration, depth vs. voltage (Sensor1).*

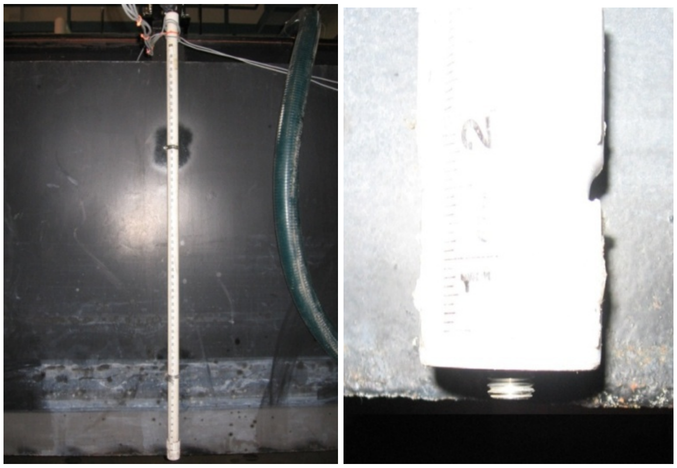


**Figure 11**: *Example pressure sensor PVC tube (left) and pressure sensor at bottom of tube (right).*

The four sensors are attached using clamps at the center of all four sides of the hopper. As the hopper is filled during the dredging operation, the water pressure on the sensors increases or decreases as the weight on the floating hopper increases or decreases respectively. Data from each pressure sensor are identified, and the readings are continuously recorded, using the data logger every second as the hopper is filled. These data are compared to the calibrated data to determine the draft of the hopper and the weight of the slurry in the hopper.

## 4.4 Data Acquisition System

An interactive graphical interface on a personal computer (PC) is used to access a manual operating station and essential drives to operate Dredge/Tow Carriage. The operational data from the gauges is recorded in the PC. The last feature includes programmable dredging simulations replicated through the Graphical User Interface (GUI). Figure 12, below, illustrates a manual operating station and a dredge automated PC.

Figure 13 shows diagrammatic presentation of data acquisition system and dredge carriage operating components, while Figure 14 illustrates the schematic of the DAS and control setup for the dredge/tow carriage. The carriage movements can be controlled through GUI or manual controls from the operation station. In both cases, the data is exchanged between hubs and servo/vector programmable logic computers (PLC). A servo PLC is used for controlling tower, cradle, and ladder movements, and a vector PLC is used to control carriage, cutter and pump movements. A laser accompanied with vector PLC determines the horizontal position of the carriage along the tank as shown in Figure 15.

**Figure 12**: *Manual control system (left) next to PC automation system (right).*

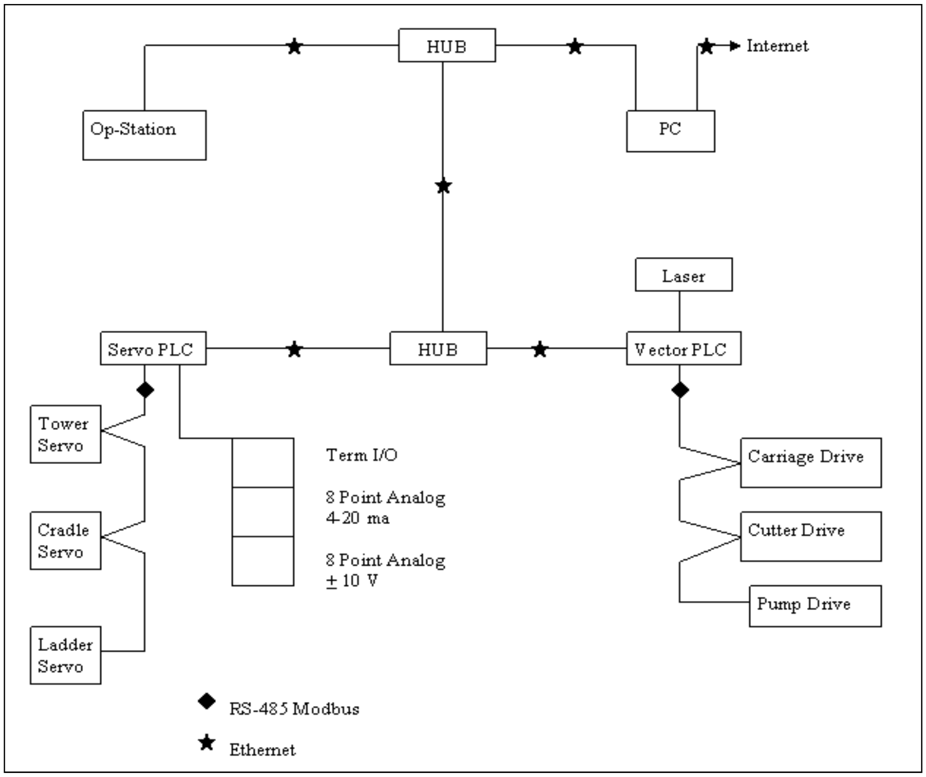
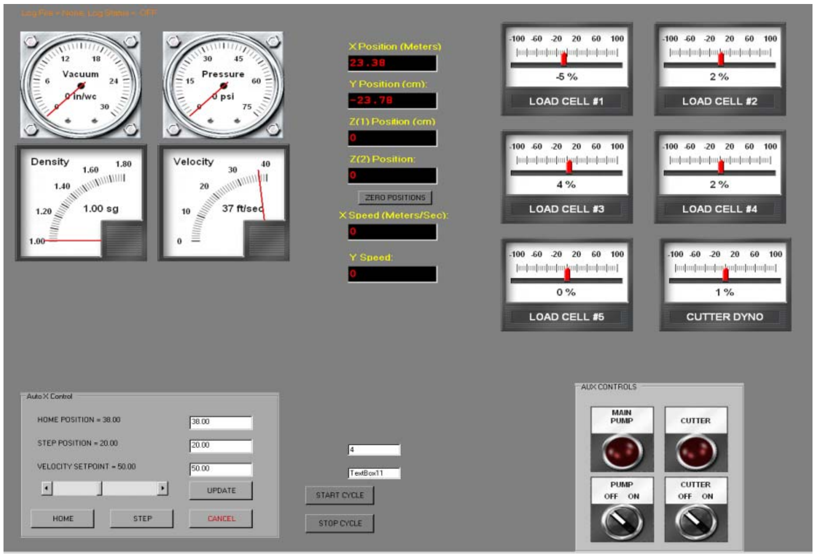


**Figure 13:** *The dredge carriage graphical user interface.*



Log File = None, Log Status = OFF

X Position (Meters) 23.38
Y Position (cm): -23.78
Z(1) Position (cm) 0
Z(2) Position: 0
X Speed (Meters/Sec): 0
Y Speed: 0

LOAD CELL #1 -5 %
LOAD CELL #2 2 %
LOAD CELL #3 4 %
LOAD CELL #4 2 %
LOAD CELL #5 0 %
CUTTER DYNO 1 %

HOME POSITION = 38.00 38.00
STEP POSITION = 20.00 20.00
VELOCITY SETPOINT = 50.00 50.00

**Figure 14:** *Schematic of the data acquisition and control setup for the dredge/tow carriage.*

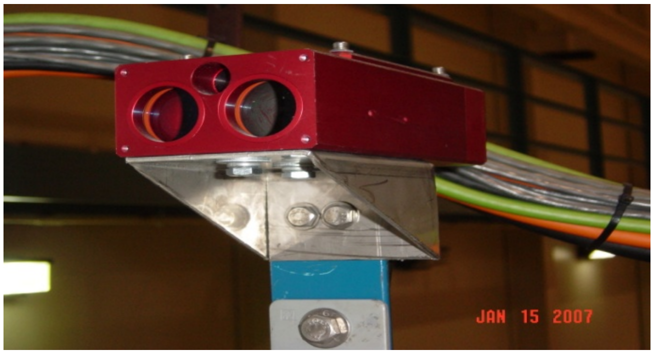


**Figure 15:** *Picture of the horizontal position laser mounted on the dredge/tow carriage.*

## 4.5 Data Logger

The data logger used is a Campbell Scientific make CR10X-series. It is compact and has a modular line of data loggers with a measurement and control module, external power supply, and keyboard display. Figure 16 shows a picture of the data logger.

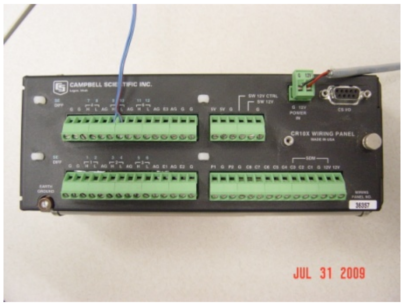


**Figure 16:** *Picture of the data logger.*

## 4.6 Magnetic Flowmeter and Nuclear Density Gauge

The flowmeter is a Krohne IFC 090 K magnetic flowmeter that is calibrated in both stagnant and moving water and is mounted inline in a vertical section of the 7.6 cm (3 in) discharge line. Output for the flowmeter is a 4-20 mA signal. In order to monitor the slurry or water flow, the output data from the flowmeter is sent to the data acquisition system.

The nuclear density gauge is located below the flowmeter, and it is clamped onto the 7.6 cm (3 in) vertical discharge pipe. The nuclear density gauge installed on the Dredge/ Tow Carriage is an Ohmart Vega DSG radiation-based density measurement system that renders outputs in the range of 4 to 20 mA signal. The gamma-based density

**Figure 17:** *Two way valve, with the nuclear density gage and flowmeter attached to it.*

gauge has a sealed Cesium 137 source in a source holder with a scintillation detector. The density gauge was calibrated using water in pipe and a sand filled tube. The flowmeter and density gauges constantly measure the flow and specific gravity of the fluid being pumped. Thus, this is also a way to determine the volume of sand dredged into the hopper. Figure 17 shows a nuclear density gauge and a flowmeter situated behind the two way valve.

# CHAPTER V

# EXPERIMENTAL PROCEDURES

## 5.1 Procedures for Experimental Measurements

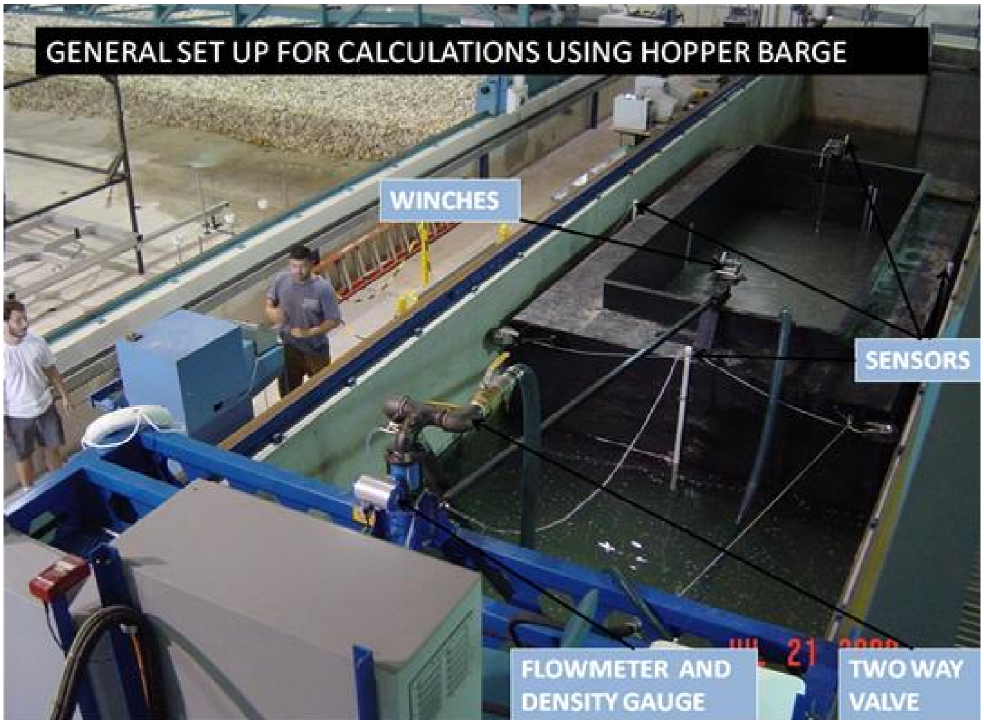


**Figure 18:** *General set up of the experiment.*

The sediment is uniformly spread before every test, and a laser profiler is run over the sediment pit. The laser profiler records the z-distance from the head (from where the LASER beam is emitted) to the sediment pit. This data is stored as a text file. The tank is then filled up to six feet of water. The hopper is kept empty. This is ensured by using sump pumps to keep the water out of the hopper. The dredge pump on the carriage is then primed, which may take 15 to 20 minutes. After priming, the pump is kept running until the test is complete. Next, the flow rate is set and the specific gravity is measured. Once the pumping starts, care is taken such that the suction of the pump is not above the sediment bed to avoid the suction of sediments before the actual dredging operation begins. The water from the pump is discharged back to the tow tank initially. Once the cutter starts dredging, the dredged sediments are directed to the hopper barge. Table 4 shows the test parameters while Figure 18 shows the experimental set up at the Haynes Laboratory.

**Table 4:** *The test matrix for the 7 day testing period*

| DAYS<br>Test Parameters | DAY 1<br>Jul 12 | DAY 2<br>Jul 16 | DAY 3<br>Jul 17 | DAY 4<br>Jul 18 | DAY 5<br>Aug 25 | DAY 6<br>Aug 27 |
|---|---|---|---|---|---|---|
| Flow rate (GPM) | 200 | 200 | 150 | 150 | 200 | 200 |
| Cutter rpm | 86 | 86 | 86 | 86 | 86 | 86 |
| Depth of Cut(inches) | 8,10,12 | 8,10,12 | 8,10,12 | 8,10,12 | 8 | 8 |
| | Filled till overflow | | | | | |
| Ladder angle (deg) | 26 | 26 | 26 | 26 | 32 | 32 |

Once the flow rate and the cutter speed are set, the carriage moves in a predefined path along the sediment pit. The depth is defined by the operator at the start of every cut. At the beginning of the dredging process, the slurry is directed into the hopper by using a Y valve, which switches the flow. The dredge carriage was automated for the last two tests and eight cuts were made along the sediment pit. The motion of the dredge carriage and the geometry of the cutter are as shown in Figure 19.

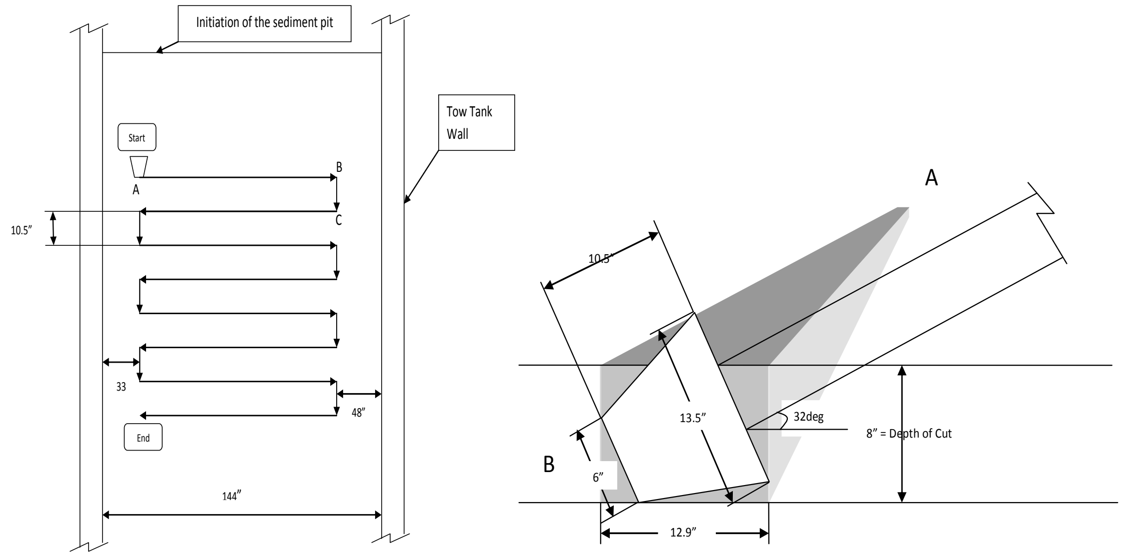


**Figure 19:** *Schematic of the volume of sand removed when moving from A to B (left) Motion of the cutter suction dredge (right).*

When the hopper is filled to overflow, the ladder is raised and once the Specific Gravity (SG) goes back to 1.0, the pumping is stopped. The data from the pressure gauges are measured and the SG is recorded. The hopper is disconnected from the carriage and moved to the extreme end of the tank. A screen is kept between the sediment pit and the hopper so as to avoid mixing. The bottom doors of the hopper are then opened to discharge the sand on the bottom of the tank. The water is then drained and the hopper is rested on the bottom of the tow tank. The sediment pit is dewatered using sump pumps, so as to run the laser profiler effectively. The laser profiler is run on the sediment pit as well as the sand dropped from the hopper. The data (text files) from the laser profiler are inputs to a MATLAB code that determines the volume of sand removed by the cutter as well as material in the hopper respectively. The hopper is cleaned, the released sand is shoveled back to the pit, and the tank is ready for the next test run.

The motion of the dredge as described in Figure 19 gives an idea as to what the production is even before the tests are conducted. This may not be the actual value of the production, but is a theoretical estimate based on the geometry of the cut. The distance that the dredge traverses, depth of cut, the cutter dimensions, and the angle of the articulating ladder on which the cutter is mounted are the inputs to this calculation.

The tests conducted on August 25 (Day6) and on August 27(Day 7) were tests for repeatability. The carriage movement was automated. The ladder, as it reached the position where dredging was initiated, was lowered to a set depth of 8in. The predetermined path in which the carriage, hence the cutter moved is as shown in Figure 19.

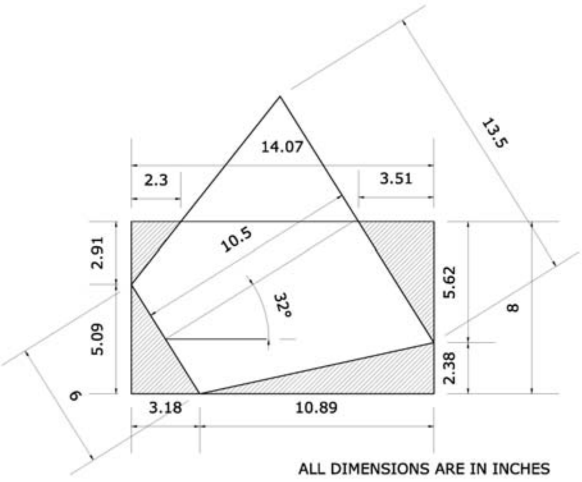


**Figure 20:** *Blown up view of cutter in the sediment pit*

The shaded area in Figure 20 indicates the amount of sand removed in one pass of the cutter, before it advances to take the next pass.

The length from point A to point B (Figure 19) is 144 – 33 – 48 = 63in.

The volume of material in the rectangular block in 8 such to and fro passes = 8 x (63 x 8 x 14.07) = 56730.24 cu in.

The volume of material when all the triangles bordering the cutter are added, in one length of the cutter run = {(0.5 x 10.89 x 2.38) + (0.5 x 5.62 x 3.51) + (0.5 x 2.3 x 2.91) + (0.5 x 5.09 x 3.18)} x 10.5 = 359.74cu in.

Volume of material in 8 such passes = 359.74 x 8 = 2878 cu in = 0.06168cu yd. This can be assumed as the amount of material that is not captured by the cutter. Hence, the total volume of sand removed = 56730 - 2878 = 53852 cu in. = **1.154 cu yd.**

The volume of sand removed calculated is the amount of material “supposed” to be removed by the dredging process. There are losses due to turbidity and resuspension, residuals, spillage, etc which results in lesser volume of material being actually removed. This value may vary largely based on the cutter speed and the direction of the cut.

## 5.2 Calculation of Time Required

Before the test, the expected time required to run the test is calculated. If the slurry is pumped at a rate of 300gpm (i.e. 0.024cu yd/sec), then, the time experiment was calculated. This calculation was in line with the actual run time for the experiment. The capacity of the hopper is 20.81cubic yards. If the slurry is pumped at a rate of 20gpm (i.e. 0.0161cu yd/s), then, the time required for the hopper to fill up is 22 minutes required for the hopper to fill up is 15 minutes. The additional standard set up times that are added to the time required to fill the hopper up are listed in Table 5 below.

**Table 5:** *The expected time required for testing*

| **Activity** | **Time (min)** |
|---|---|
| Time required for priming the pump | 30 |
| Time elapsed by the dredging operation till the time we get slurry in the discharge | 30 |
| Time required for removing the water from the sediment pit after dredging | 120 |
| Time required for setting and record the quantity of sediments dredged using the laser profile system | 60 |
| Time require d for pumping the sediment back to the pit and leveling the sediments | 60 |
| Time required for filling the channel back with water | 120 |

Total time required for the test is approximately eight to nine hours, including the time for data Acquisition.

## 5.3 Problems During Set Up and Testing

When attempting to release the sediments from the bottom of the hopper by opening the doors, the buoyancy of the doors did not allow them to open. This problem was overcome by clamping lead blocks to the doors of the hopper. These lead blocks increased the weight of the doors leading them to open wide when the winches were lowered during the release of the sediments. The area where the dredged sediments are dropped from the hopper barge is not too far from the sediment pit. For that reason, during the first experiment, it was very difficult to determine the boundary between the sediment pit and the sediments dropped from the hopper. Hence, determining the area that the laser needs to cover became difficult. This difficulty was overcome by placing a screen between the sediment pit and the area where the sediments from the hopper were dropped. The screen thus defined the two areas as shown in Figure 21.

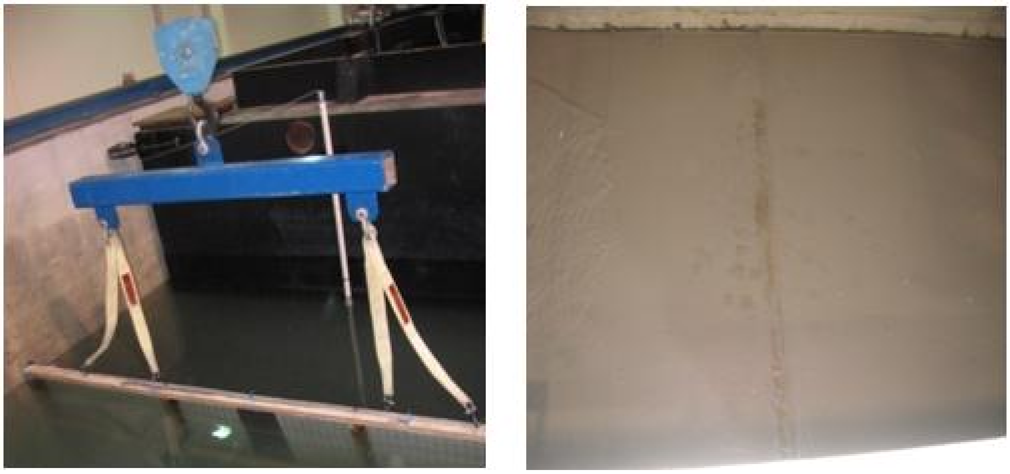


**Figure 21:** *The filter being placed between the hopper and sediment pit (left) The bottom of the tow tank after the filter is removed (right).*

Previous experiments by Henriksen and Randall (2007), for calculating resuspension, suggested the use of a frame for holding the laser profiler so as to avoid the possibility of the laser profiler sinking into the sediments as the readings are being taken. Such a frame was fabricated in the laboratory and is shown in Figure 22. As the sediments were pumped into the hopper the hose had a tendency to sway dangerously. This problem was solved by attaching the hose rigidly to the hopper by means of clamps as shown in Figure 22.

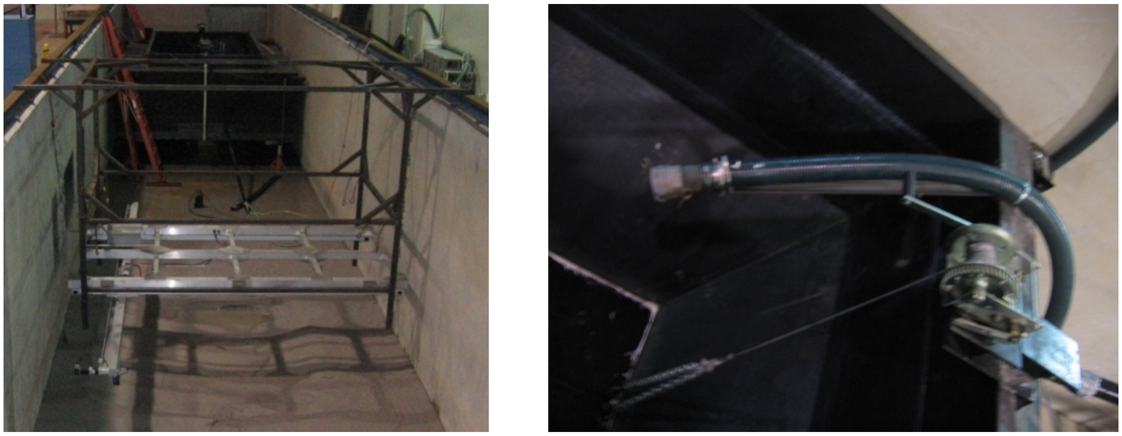


**Figure 22:** *Laser Profiler on the frame, hanging from the top of the tow tank (left) Hose attached to the hopper barge (right).*

## 5.4 Experimental Methods

Four different approaches were used to find the amount of sediments dredged. The approaches are the following:

1. Using the Laser profiler over the before (flat) and after (dredged) bathymetry of the sediment pit.
2. Using the Laser profiler over the sediments placed on the surface of the tow tank from the hopper.
3. Using pressure gauges attached to the model hopper barge.
4. Using the flow meter and the density gauge on the carriage.

Each of the methods is explained separately in the next section.

# CHAPTER VI

# DATA ANALYSIS

## 6.1 Method A: Using the Laser Profiler over the Sediment Pit

The sediment pit is smoothened every time prior to the test, and is made flat before the next test begins. The laser is mounted on the sediment pit such that the laser can cover the area of the sediment pit that would be dredged. Necessary connections to the computer are made. Inputs to the laser such as the laser area and the x and y increments at which the data are recorded are given using computer software. The laser takes the depth readings at each 5mm and 20 mm x and y increments, respectively. The software generates a text file and a notepad file for every run of the laser.

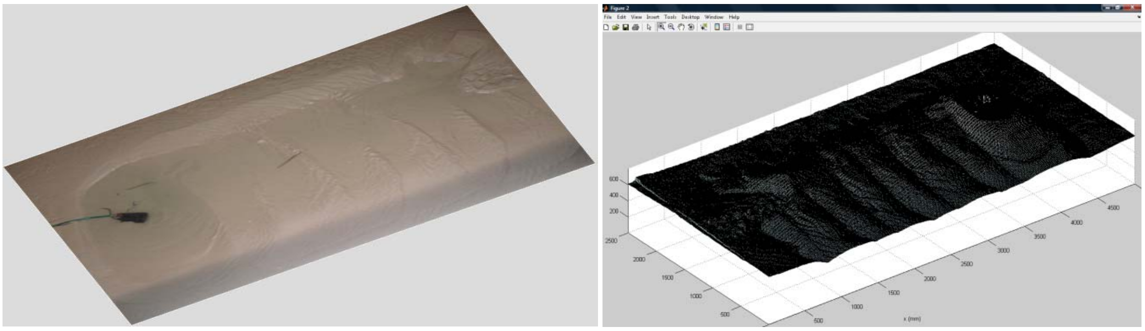


**Figure 23:** *A profile of the sediment pit (left), generated by MATLAB; the eight cuts can be distinctly seen (Test 7).*

These data are input to the MATLAB code which returns the user with the volume of sediments dredged. The MATLAB code generates a flat profile of the sediment pit. Similarly, the laser is run to know the new depths of the sediment after the dredging operation is completed. The depth data before and after the dredging operation are an input to the MATLAB program, which generates the transect of the sediment pit and the profiles of the sediment bed before and after the dredging process. The MATLAB also calculates the volume of the sediments removed. Figure 23 shows the actual picture of the pit as well as the profile generated by MATLAB after dredging. The results obtained from this method are shown in Table 6.

**Table 6:** *Volume of sand removed using the laser profiler over the pit*

| Test Date | July 12 | July 16 | July 17 | July 18 | August 25 | August 27 |
|---|---|---|---|---|---|---|
| *Volume of sand removed in* $yd^3$ | 0.4432 | 0.4444 | 0.8572 | 0.9894 | 0.4433 | 0.4334 |
| *Volume of sand removed in* $m^3$ | 0.3388 | 0.3397 | 0.6553 | 0.7564 | 0.3389 | 03313 |

With the parameters changed there is a marked difference in the tests on July 17, July 18 and the tests on July 12, July 16, August 25 and August 27. In the test experiments on July 12 and July 16 the hopper was filled to overflow. But most of the sediments fell back to the pit, due to leakage or spillage.

### 6.2 Method B: Using the Laser Profiler over the Sediments Placed on the Surface of the Tow Tank from the Hopper

The dredged sediments are continuously pumped into the hopper as the dredging process is conducted. After the dredging operation is completed, the hopper is moved to the extreme end of the tow tank, and the hopper doors are opened to release the sediments on the bed of the tank. The hopper is then disengaged from the carriage and moved to a position over the jacks, where it sets after the water is drained. The water is then drained and the sand released from the hopper is piled up so that it is contained in the laser area. The laser area is set and the depth readings are taken using the laser. A laser run of the flat surface of the tow tank is also taken. This data serves as an input to the MATLAB code that gives us an output in terms of the volume. The MATLAB generated image and the actual image are juxtaposed in Figure 24. The results from this method are shown in Table 7.

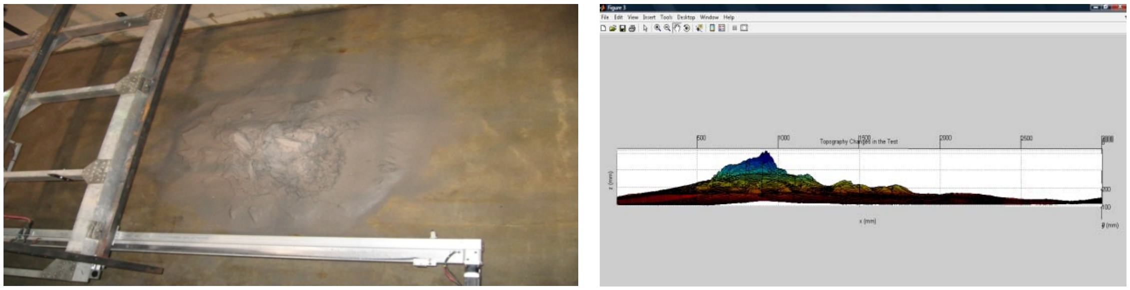


**Figure 24:** *A profile of the dropped sediments generated by MATLAB; the eight cuts can be distinctly seen.*

**Table 7**: *Volume of sand removed using the laser profiler over the pile*

| Test Date | July 12 | July 16 | July 17 | July 18 | August 25 | August 27 |
|---|---|---|---|---|---|---|
| *Volume of sand removed in $yd^3$* | 0.2903 | 0.4197 | 0.3263 | 0.2135 | 0.2903 | 0.3927 |
| *Volume of sand removed in $m^3$* | 0.2219 | 0.3208 | 0.2494 | 0.1632 | 0.2219 | 0.3002 |

Similar to the previous method, the differences in volume are seen. There is a consistent difference seen here too. The reason as why a difference is seen is explained in the next chapter.

### 6.3 Method C: Using Pressure Gauges Attached to the Model Hopper Barge

A valve, on the carriage, that was used to pump the dredged sediments was replaced by the two way valve (Figure 25). Hoses are attached to the two-way valve, and one hose is directed back to the tow tank (valve 1), while the other is directed to the hopper (valve 2). The pump is primed with the valve 2 closed and valve 1 open. When the dredging operation begins, valve 2 is opened and valve 1 is shut simultaneously. This is done when the density of the dredged sediments increases as the cutter starts to cut into the sediments. The amount of sand removed during dredging is determined using draft measurements outside the hopper barge. The amount of sand and water inside the hopper is determined from the internal height ($I_m$) measured vertically as illustrated in

Figure 25. The calibrated pressure gauges provide measurements corresponding to the variations in the load. The hopper draft (h) is calculated by averaging the values from the four pressure gauges.

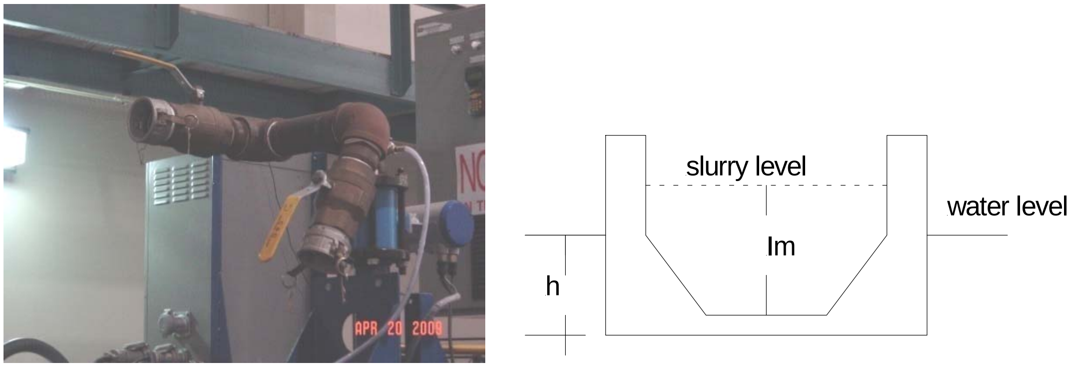


**Figure 25:** *The two way valve on the carriage (left) Schematic of model hopper (right).*

The total weight of the hopper ($W_t$) is

$$W_t = W_e + W_i \tag{9}$$

where $W_e$ is the weight calculated from the pressure gauge reading when the hopper is empty and $W_i$ is the weight of the slurry in the hopper. The total weight of the hopper is also the displaced volume of the hopper multiplied by the specific weight of the water in the dredge/tow tank

$$W_t = \gamma_w V_d \tag{10}$$

where $V_d$ is the displaced volume of the hopper and $\gamma_w$ is the specific weight of water. The draft of the hopper (h) and the weight per unit draft ($m_l$) of the hopper displacement are defined by

$$\frac{h}{m_l} = \gamma_w V_d \tag{11}$$

The relationship between the draft (h) and the hopper total weight is illustrated in Figure 26, where $m_l$ is the slope of the line.

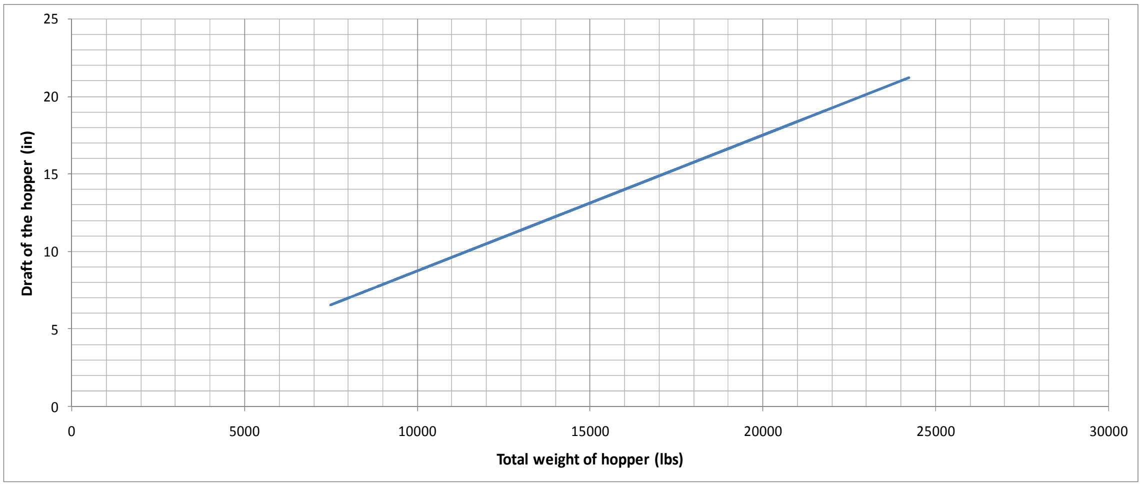


**Figure 26:** *Graph showing the increase in weight of the hopper as draft (h) changes.*

The total weight of the hopper and dredged slurry is

$$W_t = W_e + W_i = \frac{h}{m_l} \tag{12}$$

The volume of the slurry inside the hopper is the sum of the volume of sand ($V_s$) and water ($V_W$), and it is determined by the height of the slurry in the hopper. Based on the geometry of the hopper, the volume of the hopper can be divided into two parts, a cuboid ($V_c$) and a frustum of a pyramid ($V_p$). $I_{mp}$ is the height of the frustum of a pyramid, while $I_{mc}$ is the height of the slurry in the cuboid.

$$V_s + V_w = V_c + V_p = I_{mp} m_p + I_{mc} m_c \tag{13}$$

The volume $V_p$ and $V_c$ are plotted against the respective heights, $I_{mp}$ and $I_{mc}$ and the slopes $m_p$ and $m_c$ are determined (Figure 27).

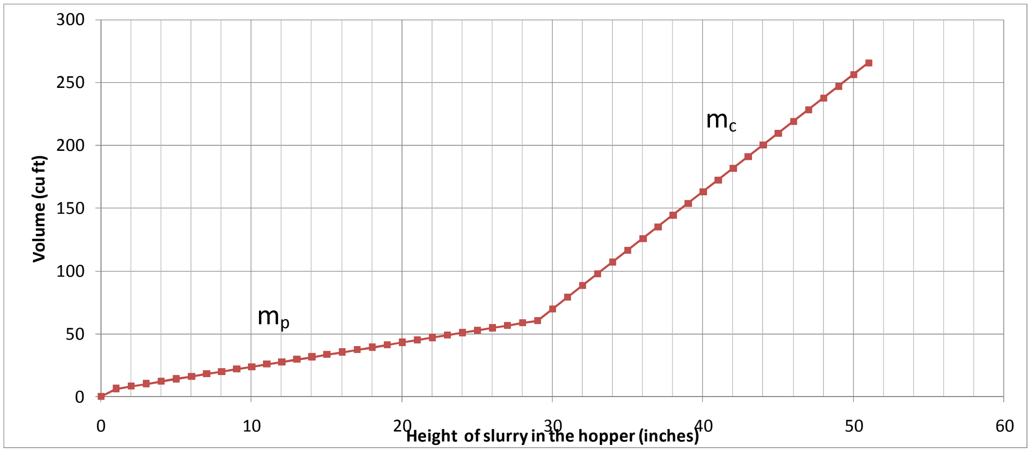


**Figure 27:** *Graph showing the change in volume of the hopper as $I_m$ changes.*

The volume of sand ($V_s$) in the hopper is determined using

$$V_s = \frac{\dfrac{h}{\gamma_w m_1} - \dfrac{W_e}{\gamma_w} - m_p I_{mp} - m_c I_{mc}}{SG - 1} \tag{14}$$

where SG is the specific gravity of the sand. An example calculation of the sand volume using one of the pressure sensors (sensor #1) is shown in Table 8. Similarly, the volume of sand for sensor #4 was found to be 0.191m$^3$ (0.250yd$^3$). There were four pressure sensors mounted on the hopper barge with # 1 and #2 at the bow and stern respectively and #2 and #3 centered at the port and starboard. Pressure sensor #3 malfunctioned during the tests so only the sensors #1 and #4 (bow and stern) were used, and the average of the two volumes results in average volume of 0.261m$^3$ (0.342 yd$^3$).

**Table 8:** *Example calculation of dredged sand volume for pressure sensor #1*

| $W_t$ kg (lb) | h m (in) | $m_1$ m/kg (ft/lb) | $I_{mc}$ m (in) | $I_{mp}$ m (in) | $V_p$ m$^3$ (ft$^3$) | $V_c$ m$^3$ (ft$^3$) | $m_c$ m$^3$/m (ft$^3$/ft) | $m_p$ m$^3$/m (ft$^3$/ft) | $V_s$ m$^3$ (yd$^3$) |
|---|---|---|---|---|---|---|---|---|---|
| 21510.1 | 18.8 | 7.29E-05 | 29 | 15 | 60.47 | 140 | 23.24 | 112 | 0.435 |
| 9756.83 | 0.478 | 4.89E-5 | 0.737 | 0.381 | 1.712 | 3.96 | 2.159 | 10.41 | 0.332 |

### 6.4 Method D: Using the Flow Meter and the Density Gauge on the Carriage

The flowmeter on the carriage is also used to determine the volume of sediments pumped into the hopper. The flowmeter records the flow in GPM of the sediments while the density gauge measures the specific gravity of the slurry every second as it is pumped into the hopper. The production (cubic meters/hr or cubic yards/hr) is calculated using the following equation,

$$P = C_v Q \tag{15}$$

where $C_v$ is the concentration by volume and Q is the flowrate. The concentration by volume is

$$C_v = \frac{SG_s - 1}{SG_{solids} - 1} \tag{16}$$

where $SG_s$ is the measured slurry specific gravity being pumped by the model dredge and $SG_{solids}$ is the specific gravity of the insitu sand. This is used to calculate the instantaneous production of sand and the instantaneous production is integrated over time to give the total production of insitu sand. This process is illustrated in Figure 28 where the flowrate (red line) and specific gravity (blue line) are used in equations 15 and 16 to calculate the instantaneous production for the slurry (green line) and sand (purple line). The instantaneous production shown in the graph was integrated using MatLab to get total production of sand using a specific gravity of 1.65 that resulted in a total insitu production of $0.196m^3$ ($0.256yd^3$).

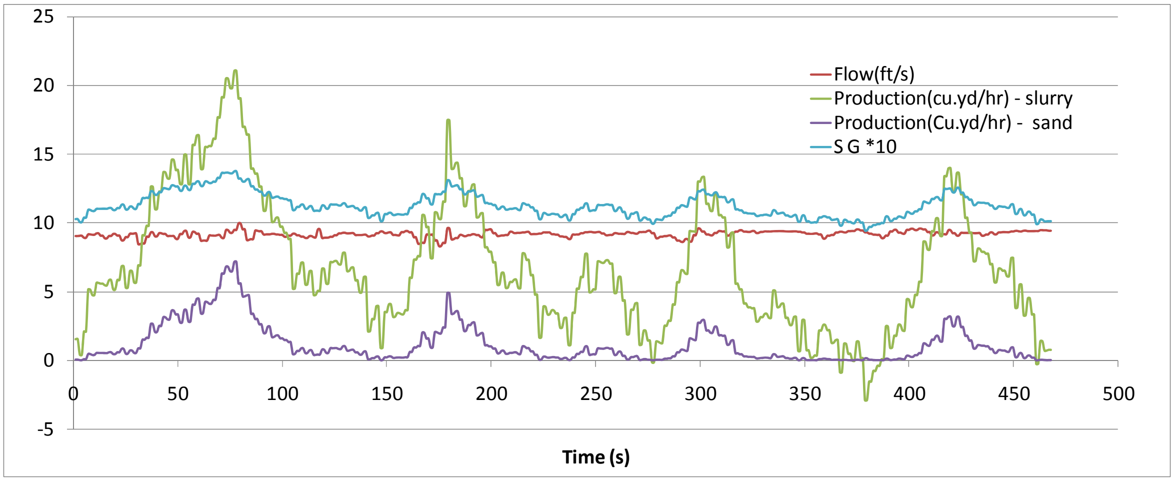


**Figure 28:** *An example of the production plot while discharging slurry into hopper barge during dredging with model cutter suction dredge.*

The production values of sand computed using different values of SG in the expression for calculating the concentration factor ($C_v$), are listed in Table 9.

**Table 9:** *Values of production in Cu Yd for different values of SG*

| Values of SG used in expression for $C_v$ | Test 1<br>12 July | Test 2<br>16 July | Test 3<br>17 July | Test 4<br>18 July | Test 5<br>25 August | Test 6<br>27 August |
|---|---|---|---|---|---|---|
| 2.1 | 1.083 | 1.293 | 0.354 | 0.315 | 0.150 | 0.209 |
| 2 | 1.192 | 1.422 | 0.390 | 0.347 | 0.165 | 0.230 |
| 1.9 | 1.324 | 1.5801 | 0.433 | 0.385 | 0.183 | 0.256 |
| 1.8 | 1.489 | 1.778 | 0.487 | 0.433 | 0.194 | 0.288 |
| 1.7 | 1.702 | 2.031 | 0.557 | 0.495 | 0.206 | 0.329 |
| 1.6 | 1.986 | 2.370 | 0.649 | 0.578 | 0.275 | 0.384 |

# CHAPTER VII

# SUMMARY AND DISCUSSION OF RESULTS

## 7.1 Summary and Discussions of Results from All the Tests

The Table 10 summarizes all the values from the various methods used in the study (Method A, Method B, Method C and Method D). A direct comparison can be made between various methods by looking at the table.

**Table 10:** *Summary of results from all the methods*

| **Test Date** | **July 12** | **July 16** | **July 17** | **July 18** | **August 25** | **August 27** |
|---|---|---|---|---|---|---|
| **THE VOLUME OF SAND REMOVED IN CUBIC YARDS** | | | | | | |
| **Laser over pit (A)** | 0.443 | 0.444 | 0.857 | 0.989 | 0.443 | 0.433 |
| **Laser over pile (B)** | 0.290 | 0.420 | 0.326 | 0.213 | 0.290 | 0.392 |
| **Hopper draft (C)** | 4.27 | 1.117 | 5.84 | 5.635 | 0.343 | 0.335 |
| **Flowmeter and Density Gauge (D)** | | | | | | |
| **SG** | **July 12** | **July 16** | **July 17** | **July 18** | **August 25** | **August 27** |
| **2.1** | 1.083 | 1.293 | 0.354 | 0.315 | 0.150 | 0.209 |
| **2.0** | 1.192 | 1.422 | 0.390 | 0.347 | 0.165 | 0.230 |
| **1.9** | 1.324 | 1.5801 | 0.433 | 0.385 | 0.183 | 0.256 |
| **1.8** | 1.489 | 1.778 | 0.487 | 0.433 | 0.194 | 0.288 |
| **1.7** | 1.702 | 2.031 | 0.557 | 0.495 | 0.206 | 0.329 |
| **1.6** | 1.986 | 2.370 | 0.649 | 0.578 | 0.275 | 0.384 |

The first set of raw data was processed from tests conducted on July 12, 16, 17 and 18 of 2008. There were some problems and errors found during the tests and, after data processing, a few others were revealed. These first four tests paved the way for the two final, successfully completed tests. The tests on the 12 and 16 of July were similar tests in that their flowrates were set at 200 gpm, and the tests on the 17 and 18 had flowrates of 150gpm. Amongst all the results obtained from various methods, Method D (using flow meter and density gauge) shows a fairly accurate value of the sediments dredged, for the value of SG used in the equation of $C_{v.}$

The results from Method C (using the pressure gauges) are not in agreement with the Method D (using flow meter and density gauge). One of the reasons being, at the beginning of the dredging process, the recording of data from the pressure gauges was not simultaneous with the switching of the valves. The first readings from the pressure gauges were recorded when the team thought that the slurry pumped had enough sediment or, in other words, the cutter started cutting through sediments. Thus, when the first reading was taken, the hopper already contained water and sediments and the exact weight of the empty hopper ($W_e$) at the beginning of the experiment was not known.

The leakage of the hopper was evident during the second experiment when the slurry level inside the hopper kept dropping significantly as the dredging experiment continued and the hopper was continuously filled. Attempts to prevent leakage by tightening the winches in the third and fourth tests did not help to reduce the leakage significantly. Most of the material leaked and was deposited on the bottom of the tank before the sediments were dropped into the sediment pit. This problem was eliminated in the last two tests by sealing the hopper doors with a simple window sealant. Thus, even though the hopper was filled up to overflow in the first four tests, the values of the volume of sediments dredged from method B is too low when compared to the value from the flow meter and density gauge (method D). While method A shows a lesser value, it is speculated that some sediments must have deposited back on to the sediment pit due to leakage.

This experiment experienced problems identifying the sediments that were originally in the sediment pit after dredging versus sediments from other sources. In the first four tests, leakage and resuspension were present, creating anomalies. In the final two tests, the issue of the leaked sediments from the hopper was resolved, but spillage was still a matter of concern.

The last two tests were completed with all the known problems corrected. In addition to the changes made, the carriage movement was automated and a uniform cut depth of 8in was used. The angle of the articulating ladder was also increased from 26 deg to 32 deg. The results obtained from the methods B and C are in close agreement with each other. They are also in line with the method D, when the $C_v$ is calculated with an SG in the range of 1.6 to 1.7. However, there is a difference seen in A and the difference is consistent in both methods. During the dredging operation, spillage occurs and sand is deposited (piles up) on both the sides of the sediment pit. This increases the dredged area, which in turn increases the values of sediments dredged from the sediment pit (Method A), when compared to other methods.

# CHAPTER VIII

# CONCLUSIONS AND RECOMMENDATIONS

It is seen in the last two tests that the hopper and its instrumentation functioned well. The results from the pressure gauges attached to the model hopper barge were more accurate in the last two tests than the first four tests. However, it is recommended to thoroughly check the pressure gauges for operation and the hopper doors for caulking, and to take few pressure readings before the water is pumped in the hopper.

The results (volume of sediments dredged) from method D in the tests conducted on July 12 and 16 is much greater compared to those from July 17 and 18; the reason being the hopper was filled till overflow in the first two tests. The increase in the angle in the last two tests, from 26 deg to 32 deg, and the reduction of the depth to 8 inches also reduced the bulldozing of the cutter in the tests conducted on the 25 & 27 of August.

As explained in the previous chapter, some sediments fall outside the laser profiler's area in the sediment pit once the dredging is done, due to the cutter action. This increased the amount of sediment dredged from the sediment pit (method A), when compared to the values obtained from running the laser profiler on the sediments dropped from the hopper barge (method B). The difference is the spillage that occurs during dredging. Thus, the laser profiler is a good device in determining the spillage, but the value of spillage computed by this method need not be completely accurate. The inaccuracy in the spillage values could be due to the following reasons:

1. The specific gravity of the sand in the sediment pit is different from that of the sediments dropped from the hopper. The sediments dropped from the hopper are shoveled and moved into the laser profiler area and, in this process, the sand loses a lot of water content.
2. The laser profiler is subjected to reflection from the water present in the pit, as all the water could not be pumped out (excessive pumping leads to loss of sediments). The use of an acoustic profiler should be investigated. Such a system would not require the water to be removed. This would save water and speed up the testing procedure.

It is also recommended to reduce the area of the cutter movement (sideways) and wait until the water in the pit dries up before running the laser profiler. This would eliminate the issue of sediments settling outside the laser area and avoid the reflection of the laser from the water. This method is costly in time as well as money; hence, a better alternative needs to be thought of.

These experiments clarify various aspects of dredging. Many issues in laboratory testing are pointed out and solutions are provided. The instrumentation on the hopper was successful. This method also serves as a comparison with various methods of dredging. The laser profiler also serves instrumental in calculating the spillage of sand. More experiments with corrected procedures and varying input parameters need to be conducted. This would clarify the effects of parameter variation on the dredging process. Due to time constraints and other commitments, the effects of changing input parameters could not be studied.

# REFERENCES

Armstrong, P.L. and Grant, M.E. (1977) “Dredging Spoil Measurement Device”, *Dock and Harbor Authority*, June 1997.

Brahme, S.B. (1983). “Environmental Aspects of Suction Cutterheads.” *Dissertation*, Ocean Engineering Program, Civil Engineering Department, Texas A&M University, College Station, Texas.

Burger, M. den, Vlasblom, W.J., Talmon, A.M.(2005) “Design Aspects for Cutterheads Related to the Mixture Forming Process When Cutting Coarse Materials” Terra et Aqua, number 98, mart 2005, blz 12-18 ISSN 0376-6411.

Fortino, E.P. (1966) “Flow Measurement Techniques for Hydraulic Dredges”, *Journal of the Waterways and Harbors Division, Proceedings of the ASCE,* Vol.92, pp 109-125.

Glover, G.J., (2002) “Laboratory Modeling of Hydraulic Dredges and Design of Dredge Carriage for Laboratory Facility”, *Master of Science Thesis*, Texas A&M University, Ocean Engineering Program, Department of Civil Engineering, College Station , TX, December 2002.

Glover, G.J. and Randall, R.E., (2004). “Scaling of Model Hydraulic Dredges with Application to Design of a Dredge Modeling Facility”, *Journal of Dredging Engineering, Western Dredging Association (WEDA)*, vol. 6, no. 2, pp. 15-36, September.

Henriksen, J., Randall, R.E., deJong, P, and Sonye, S., (2007) “Initial Experiments and Data Acquisition for the Model Dredge Carriage”. *Proceedings of the World Dredging Congress XVIII*, Paper 6C-6, Lake Buena Vista, FL, USA, May 27-June1.

Herbich, J.B., (2000) “Handbook of Dredging Engineering”, Second Edition, McGraw-Hill, New York, NY.

Herbich, J.B & Brahme, S.B (1983) - “Literature Review and Technical Evaluation of Sediment Resuspension on During Dredging”, *Report No. COE-266*, Center for Dredging Studies, Texas A&M University, College Station, Texas.

Huston, J.W., and Huston, W.C. (1976) “Techniques for Reducing Turbidity with Present Dredging Procedures and Operation.” *Technical Report D-76-4*, U.S Army Engineering Waterways Station. Vicksburg, MS.

Joanknecht, L.W.F. (1976) “A Review of Dredge Cutterhead Modeling and Performance”, *Proceedings of the Seventh World Dredging Congress, WODCON VII*, San Fransisco, CA.

Meyer, G.M, Meynard, Granboulan and Babylon, (1986) “A Study of Decantation of Fine Sediments in a Trailing Suction Dredging Hopper with the Aid of a Photon Emitting Probe.” *Proceedings of the XIth World Dredging Congress,* Brighton, United Kingdom.

Miller, J., Palmero, M., and Groff, T. (2001), “Hopper Overflow Characteristics of the Delaware River”, *Journal of Dredging Engineering, Western Dredging Association (WEDA),*. vol.3, no.1, pp.1-20, March.

Palermo, M.R. and Randall R.E., (1989) “Economic Loading and Overflow for Dredge Scows and Hoppers”, *Proceedings of World Dredging Congress, WODCON XII*, Orlando, FL, May 1-5.

Rokosch, W.D, Van Vechgel, R.H.L and van der Veen, R. (1986), “Analysis of Mixed Hopper Loads in Dredging.” *Proceedings of the XIth World Dredging Congress, Brighton*, United Kingdom.

Slotta, L.S. (1968) “Flow Visualization Techniques Used in Dredge Cutterhead Evaluation.” *Proceedings of the 1968 World Dredging Congress, WODCON XV*, Las Vegas, NV.

Schroeder, P.R., (2009) “USACE Technical Guidelines for Practicing the 3R’s of Environmental Dredging”, *Proceedings of the Western Dredging Association Twenty-ninth Technical Conference and 40th Annual Texas A&M Dredging Seminar*, Tempe, AZ, June 2009.

# APPENDIX

## 1. The MATLAB Program for the laser profiler data

```
clc;clear;
%
xyz1 = load('predredgefinal.dat'); %Topography of pre-run
xyz2 = load('postdredgemonone.dat'); %Topography of post-run
%Input
x_min = 5; x_max = 5000; x_resolution = 5; %1st, end points and Resolution
y_min = 0; y_max = 2500; y_resolution = 20; %1st, end points and Resolution
dh = 20; %Threshold in Despiking
%End of Input
%--------------------------------------------------------------
%MATLAB data structure
flag_x = (x_max-x_min)/x_resolution+1;
flag_y = (y_max-y_min)/y_resolution+1;
for i = 1:flag_x
   x(i) = x_resolution*i;
end
for i = 1:flag_y
   y(i) = y_resolution*(i-1);
end
% Building the actuall z array for plotting
for j = 1:flag_y
  for i = 1:flag_x
```

```
   k = (j-1)*flag_x + i;
   z1(j,i) = xyz1(k,3);
   z2(j,i) = xyz2(k,3);
  end
end
z3 = z2 -z1;
%End of Task
%Despike
nz1 = despike(z1,dh); nz2 = despike(z2,dh); nz3 = despike(z3,dh);
%End of Task
%Output Figures
figure(1)
surf(x,y,nz1)
title('Topography before the Test');
xlabel('x (mm)'); ylabel('y (mm)'); zlabel('z (mm)');
xlim([x_min x_max]); xlim([y_min y_max]);
axis equal
figure(2)
surf(x,y,nz2)
title('Topography after the Test');
xlabel('x (mm)'); ylabel('y (mm)'); zlabel('z (mm)');
xlim([x_min x_max]); xlim([y_min y_max]);
axis equal
figure(3)
surf(x,y,nz3)
title('Topography Changes in the Test');
xlabel('x (mm)'); ylabel('y (mm)'); zlabel('z (mm)');
```

```
xlim([x_min x_max]); xlim([y_min y_max]);
axis equal
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Now going to calculate the amount of material using an integral
%Lets first create the right matrixs for x and y for the program and
%plotting
for k=1:flag_y
    for j=1:flag_x
        xmatrix(k,j)=x(j);
    end
end
for k=1:flag_x
    for j=1:flag_y
        ymatrix(j,k)=y(j);
    end
end
volume= int_2D_tabulated(xmatrix,ymatrix, nz3 )
%Lets look at a transect of these profiles
for i=1:flag_x
    transect1(i)=nz1(75,i);
    transect2(i)=nz2(75,i);
end
for i=1:flag_x
    xtransect(i)=i*5;
end
figure(4)
```

```
 plot(xtransect,transect1)
 title('Transect Profile');
 xlabel('x (mm)');ylabel('z (mm)');
%Output File-------If you think it's too slow, you can delete this part.
% for i = 1:flag_y
%  for j = 1:flag_x
%    k = (i-1)*flag_x + j;
%     Outxyz(k,1) = x(j);
%     Outxyz(k,2) = y(i);
%     Outxyz(k,3) = nz1(i,j);
%     Outxyz(k,4) = nz2(i,j);
%     Outxyz(k,5) = nz3(i,j);
%  end
% end
% save -ascii Outxyz_2.dat Outxyz
```

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