

**LABORATORY EXPERIMENTS AND HYDRODYNAMIC MODELING OF A
BED LEVELER USED TO LEVEL THE BOTTOM OF SHIP CHANNELS
AFTER DREDGING**

A Thesis

by

EPHRAIM UDO PAUL

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 2010

Major Subject: Ocean Engineering

**LABORATORY EXPERIMENTS AND HYDRODYNAMIC MODELING OF A
BED LEVELER USED TO LEVEL THE BOTTOM OF SHIP CHANNELS
AFTER DREDGING**

A Thesis

by

EPHRAIM UDO PAUL

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

Approved by:

Co-Chairs of Committee,	Robert E. Randall
	Hamn-Ching Chen
Committee Members,	Richard S. Mercier
	David A. Brooks
Head of Department,	John Niedzwecki

December 2010

Major Subject: Ocean Engineering

ABSTRACT

Laboratory Experiments and Hydrodynamic Modeling of a Bed Leveler Used to Level
the Bottom of Ship Channels after Dredging.

(December 2010)

Ephraim Udo Paul, B.Eng., Federal University of Technology, Owerri, Nigeria

Co-Chairs of Advisory Committee: Dr. Robert E. Randall
Dr. Hamn-Ching Chen

This study was conducted to ascertain the impacts of bed leveling, following ship channel dredging operations, and to also investigate the hydrodynamic flow field around box bed levelers. Laboratory experiments were conducted with bed levelers operating in the laboratory using video cameras for flow visualization. Computer software and numerical codes, called FANS, were used to validate the laboratory experiments.

The study was split into two major parts: laboratory experiments and hydrodynamic modeling. The laboratory experiment was conducted to model how bed levelers interact with the ship channel bottom after hopper dredge dragheads (blades) made passes and created uneven trenches. These interactions were observed using both underwater and hand-held cameras. The hydrodynamic modeling was accomplished using GRIDGEN and PEGSUS commercial software for generating grid and input data files in the pre-processing phase, Finite-Analytic Navier-Stokes (FANS) software for simulation in the

processing phase, and two commercial software (Fieldview and Tecplot) for plotting the images and graphs in the post-processing phase.

An interesting phenomenon was observed in the laboratory experimental runs. The flow field showed reversed flow in front of the moving bed leveler and the trench parallel to the direction of the bed leveler. The flow in the parallel trench was observed to be in the same direction as the bed leveler movement, and it was expected that the flow would travel under the bed leveler. The bed leveler was towed at two specified constant speeds: 0.25 m/s (0.82 ft/s) and 0.5 m/s (1.64 ft/s) and at a water depth of 1.22 m (4.00 ft)

Similarly, the images and plots of the hydrodynamic modeling obtained from FieldView and Tecplot software showed flow reversal, depicted by the negative velocities, within the vicinity of the trench, as the model bed leveler moved past and interacted with the fluid. The negative velocity had a magnitude close to 0.5 m/s (1.64 ft/s), which was the velocity used in running the laboratory experiments.

The hydrodynamic simulation matched closely with the experimental observations, and thus, the laboratory observation was confirmed. The final results obtained from the numerical modeling helped to understand the hydrodynamic effects around the box bed leveler.

DEDICATION

To my parents, Obong Udo P. Ukpabio and Mrs. Charity U. Akpabio.

ACKNOWLEDGEMENTS

I would like to express my heart-felt appreciation to my committee co-chairs, Dr. Randall and Dr. Chen, and my committee members, Dr. Mercier and Dr. Brooks, for their guidance and support throughout the course of this research.

Thanks also to my friends and colleagues and the Zachry Department of Civil Engineering faculty and staff for making my time at Texas A&M University a worthwhile experience. I also want to extend my gratitude to Mr. Tim Welp of the United States Army Corps of Engineers, Engineering Research and Development Center, that provided funding for the laboratory experiments during the summer and fall of 2008. I want to thank John Henriksen, Dustin Young, and Arun Manikantan who were working on this project for their team work and cooperation that made this study a success. A special thank you to my employer, Akwa Ibom State University of Technology, Uyo, Nigeria, for funding my entire graduate program at Texas A&M University.

Finally, thanks to my parents and siblings for their encouragement, Mr. Edet A. Ekanem for providing me with unlimited internet access during my pre-admission processes, Mr. Daniel Ukpong for providing all the financial and moral assistance, Mr. Ime Udong for his accommodation and hospitality, Mr. Lawrence Isung for his advice and direction, Mr. Edet O. Udoh, and to my dear wife, Mfon, for her understanding, patience and love.

TABLE OF CONTENTS

	Page
ABSTRACT	iii
DEDICATION	v
ACKNOWLEDGEMENTS	vi
TABLE OF CONTENTS	vii
LIST OF FIGURES	viii
CHAPTER	
I INTRODUCTION	1
II LITERATURE REVIEW	6
III EXPERIMENTAL SET-UP	13
IV EXPERIMENTAL RESULTS	33
V HYDRODYNAMIC MODELING	39
VI SUMMARY, CONCLUSIONS AND RECOMMENDATIONS	63
REFERENCES	66
VITA	70

LIST OF FIGURES

FIGURE	Page
1. Box beam bed leveler attached to a dredge	2
2. Blade bed leveler (courtesy of Great Lakes dredge and Dock)	2
3. A sketch of a box beam bed leveler attached perpendicular to the trench ...	3
4. A sketch of a box beam bed leveler attached parallel to the trench	4
5. Production cycle of a bed leveler	12
6. Elevation and plan view of dredge/tow tank in the Haynes Coastal Engineering Laboratory at Texas A&M University	13
7. Haynes Coastal Engineering Laboratory crane	14
8. Fine sand packaged in white polyethylene bags	15
9. Sand bed smoothed and ready for trenching	16
10. Plan view of the sand bed used for the experimental runs	17
11. Elevation view of sand bed used for the experimental runs	18
12. Trenching tool used to excavate troughs (trenches) in sand bed	19
13. USACE underwater camera	19
14. Bed leveler and underwater camera attached to a dredge carriage after sand bed was leveled for experimental run	20
15. Towing set up for model bed leveler attachment	21
16. Computer laboratory in Haynes Coastal Engineering Laboratory	22
17. A picture of the Bobcat used to level the sand bed	24

FIGURE	Page
18. Net used to prevent fine sand from leaving the tank when water is drained to reform sand bed after bed leveling	25
19. Dredge carriage at sediment pit in Texas A&M dredge/tow tank	26
20. Control panel and knobs for driving dredge carriage electronically and remotely	27
21. Dredge/tow tank vertical calibration (in feet) and glass windows for close flow visualization	28
22. Carriage ladder attachment and laboratory model bed levelers (box beam attached to the carriage on left and on top of right picture), I-beam (middle of right picture), and curved plough (bottom of right picture))	32
23. Movie converted to a still picture showing flow around trench	35
24. Snap shot of flow reversal around the bed leveler when the reversed flow moved at speed closed to the forward flow	36
25. More laboratory movie snapshots showing flow reversals around bed levelers	38
26. 2-D plots of: (a) normalized pressure variation along a line in the x-axis of grid block 8 and (b) normalized (x-y) and (x-z) coordinates of block 8 ...	43
27. 2-D plots: (a) normalized w-velocity and (b) normalized v-velocity along a line in the x-axis of grid block 8	44
28. 2-D plots for grid block 5 (a) normalized pressure, (b) normalized coordinates, (c) normalized v-velocity, and (d) normalized w-velocity	45

FIGURE	Page
29. (a) Normalized pressure, (b) normalized coordinates, (c) normalized w-velocity, and (d) normalized v-velocity of grid block 1 vertical plane ...	46
30. Pressure contours from hydrodynamic modeling at time, $t=140T_0$ for a constant y-plane (i.e. x-z plane)	47
31. Pressure contours from at time $t=182T_0$ for constant y-plane	48
32. Pressure contours at time $t=104T_0$ seconds rotated about the z-axis	49
33. Pressure contours at time $t=166T_0$ seconds rotated about the z-axis	50
34. Velocity contours at time $t=288T_0$ for constant y-plane	51
35. Velocity vectors and contours at simulation time $t=50T_0$ seconds	52
36. Velocity vectors and contours at simulation time $t=90T_0$ seconds showing evolution of reversed velocity	53
37. Velocity vectors and contours at time $t=192T_0$ seconds showing wider wake and larger reversed flow	54
38. Vorticity in constant x-plane at time $t=84T_0$ seconds	55
39. Vorticity in constant x-plane downstream of the box-beam bed leveler at time $196T_0$ seconds	56
40. Vorticity in constant y-plane at time $t=96T_0$ seconds	57
41. Vorticity in constant y-plane at time $t=158T_0$ seconds	58
42. Vorticity in constant y-plane at time $t= 238T_0$ seconds	59

FIGURE	Page
43. A J-plane snapshot of longitudinal velocity vectors and contours from Tecplot with earth fixed coordinates	60
44. Longitudinal velocity contours and vectors with coordinate axis fixed at the model bed level	62

CHAPTER I

INTRODUCTION

Bed levelers are used to level the bottom of ship channels following dredging operations. Although bed leveling literature is scanty, the technology has been employed extensively in Europe and by some dredge contractors in the United States for many years. Hopper dredges and pipeline dredges leave an uneven channel bottom consisting of ridges and trenches that are parallel and perpendicular (depending on the direction and orientation of the dredge draghead) to the channel axis. The bed leveler is lowered, by winches, to the channel bottom and towed over the uneven bottom resulting in the sediment being moved from the ridges into the trenches. This operation provides a smoother channel bottom and also guarantees the desired final grade.

There are several types of bed levelers that are used in field operations. Examples of bed levelers include a box-beam, Figure 1, I-beam, curved plough, triangular beam, or large blade bed leveler shown in Figure 2.



Figure 1. Box beam bed leveler attached to a dredge (courtesy of Weeks Marine).



Figure 2. Blade bed leveler (courtesy of Great Lakes Dredge and Dock) (ANAMAR and CH2M HILL, 2005).

Dredging is defined as the process of excavating or moving sediments using a dredge. A dredge is a vessel that is equipped with some means to remove or excavate sediment underneath water. During the process of dredging, ridges and trenches are created as the hopper dredge draghead or a pipeline dredge cutterhead makes passes through the sediment. Figure 3 shows a box beam bed leveler attached to a barge that is moving in a direction perpendicular to the ridges and trenches. Figure 4 shows the same box beam bed leveler attached in a direction parallel to the ridges and trenches. Bed levelers are used to level off the ridges into the trenches so as to achieve the required final grade. Bed levelers are preferred to other dredging equipment because they are relatively less expensive and can access some areas other types of dredges cannot access.

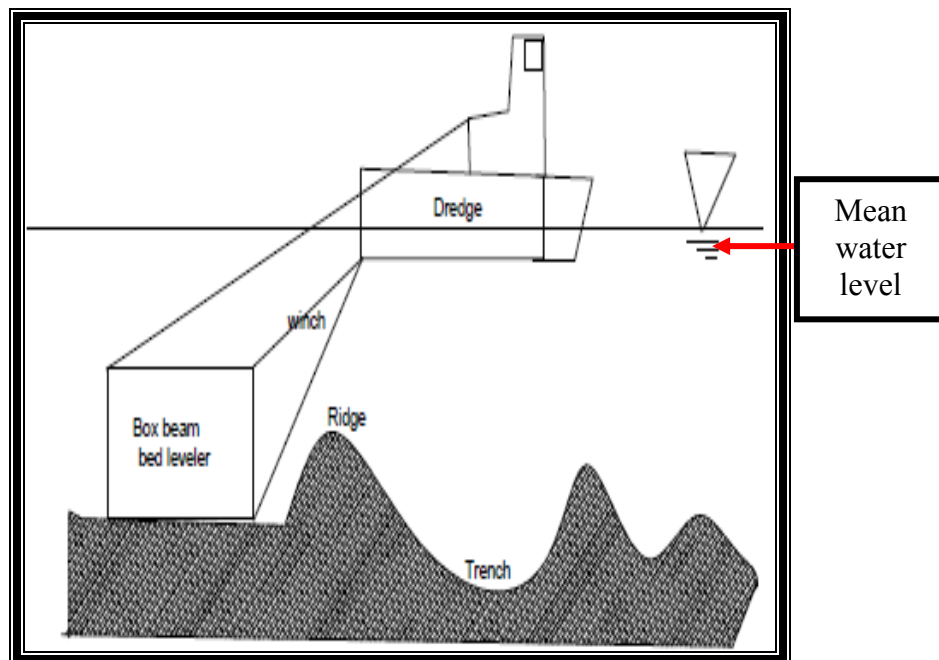


Figure 3. A sketch of box beam be leveler attached perpendicular to trench.

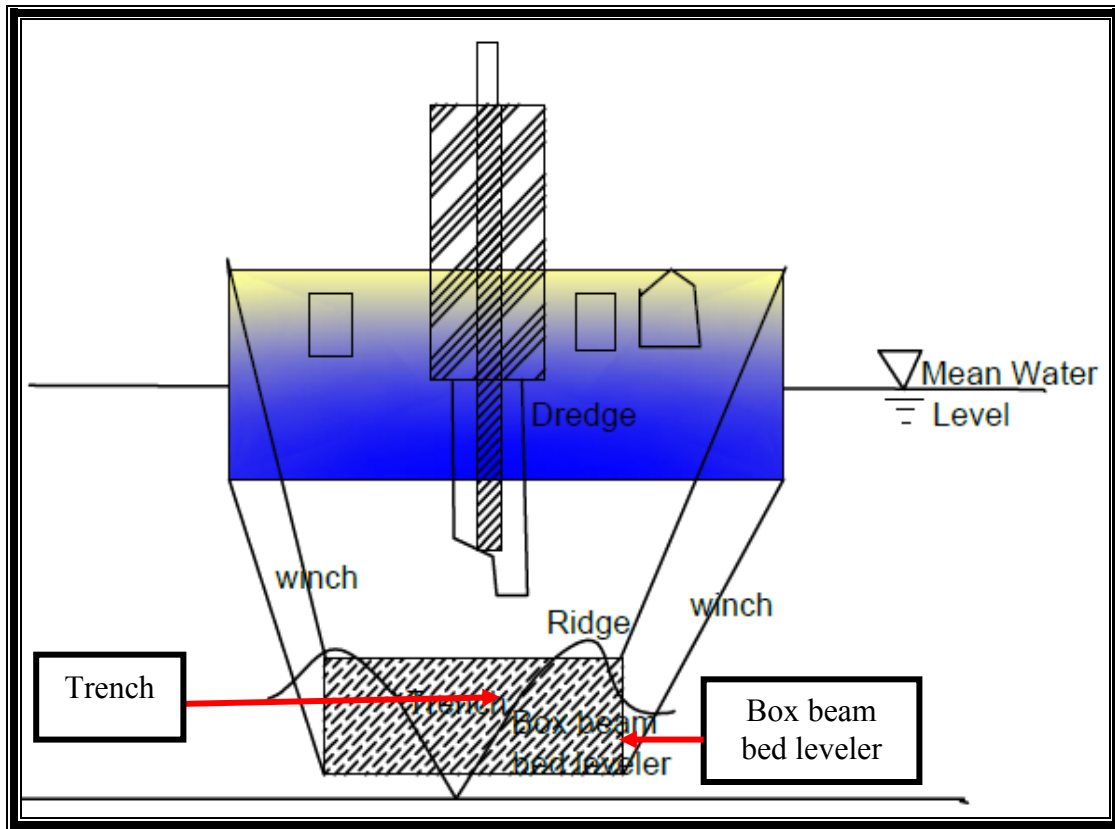


Figure 4. A sketch of box beam bed leveler attached parallel to trench.

The objective of this research on bed leveling is to investigate the hydrodynamic flow field around bed levelers within the vicinity of the trenches. Laboratory results were obtained on bed levelers operating in the laboratory using video cameras for flow visualization. Computer software and numerical codes, called Finite-Analytic Navier-Stokes (FANS) were used to validate the laboratory experimental observations. The results from the hydrodynamic model were compared to those observed in the laboratory. Trenches and ridges were created perpendicular and parallel to the longitudinal axis of the bed leveler for the initial experimental runs. It was observed that

parallel trenches produced some interesting results, and hence final laboratory experiments and hydrodynamic modeling were conducted for only the parallel trenches. The bed leveler was towed to smooth off the ridges into the trenches. The final results obtained from the numerical modeling helped in understanding the effects of bed levelers on aquatic organisms and provided a better understanding of the hydrodynamics around the bed leveler.

In the summer of 2008, model bed levelers were operated in the Haynes Coastal Engineering Laboratory in the dredge/tow tank and a jet of fluid was formed in front of the bed leveler and in the same direction as the bed leveler was towed. The bed leveler was 0.05 meters (0.17 ft) below the ridges on either side of the trench. Based on this observation, this study investigated the hydrodynamic flow fields in the vicinity of the moving bed leveler. The study was divided into two parts: the laboratory experiments and the computer hydrodynamic modeling.

The laboratory experiments were conducted, using box beam model bed leveler, in the Haynes Coastal Engineering Laboratory Dredge/Tow tank. The hydrodynamic modeling was accomplished using GRIDGEN, PEGSUS, Finite_Analytic Navier-Stokes (FANS), Tecplot, and FieldView software.

CHAPTER II

LITERATURE REVIEW

Van de Graaf (1987) indicates that sketches of bed levelers were seen as far back as 1565, and hence he wonders why people should consider bed leveling as a new development. He said that bed leveling during hopper dredging operation has an advantage since it is moving materials from ridge peaks to trench bottom, therefore the draghead will always be positioned at the bottom sediment, giving a higher efficiency (up to 30 percent) for trailer dredging. Van de Graaf also stated that the bed leveler can be used as a stand-alone dredging tool in less cohesive sediment.

According to Mohammed (1994), bed levelers have been employed for several years both to help hopper dredges in their operations and for direct leveling of less cohesive sediment in small areas. He pointed out that the use of bed levelers, as a stand-alone dredge, is limited to sand wave regions such as a ship turning basin. He stated that the bed leveling set up consists of a heavy beam attached to a barge which is pushed by a tug. Ballasting the barge assists a low-powered tug to gain enough momentum to push the bed leveler and move the densely packed sand to the required distance with relative ease.

Bray et al. (1997) stated that bed leveler may either be used to move materials by itself or used to enhance dredger efficiency. The power required for moving the bed leveler is

provided by a tug. The power requirement depends on both the thickness and shear strength of the material to be removed. The bed leveler can be used alone to move materials from shoal areas over relatively short distances to deeper water. Bed levelers also have the advantage of easily accessing work areas which the hopper dredge cannot access. A powered winch is used to lower the bed leveler blade until it reaches the required sea bed. As deeper water is approached, sediments captured in the scraper blade falls off and another cycle starts. If material suspension is needed, water jets can be attached to the blade of the bed leveler to aid in agitating the material.

Reine et al. (1998) indicates that allowable dredging windows (time periods when water temperatures are below 16 °C and sea turtles go into hibernation) should be strictly enforced so that the number of cases of sea turtle and other sea organism stranding (injury) and takes (killings) could be minimized during bed leveling following dredging operations.

Heaps (2001) observed that the bed leveler has brought more efficiency to the dredging operations since the dredge is supported by a modern and multi-purpose built plough vessel which allowed the trailing suction hopper dredge to accomplish enhanced production. The improved production is achieved either by bringing sediments into regions easily accessed by the trailing suction hopper dredge or by directly leveling areas worked by the dredger. High spots hunting (leveling) are removed by the plough bed

leveler, while the trailing suction hopper dredge continues to strive for maximum production and minimum cycle times.

Hales (2003) states that sediment re-suspension and turbidity, which is generated by bed leveling operations, is becoming a potential environmental concern in marine dredging operations. However, no studies that document the details of that aspect of bed-leveling had been published as of the date his paper was published in 2003. More information and data are required to substantiate this claim.

Dickerson and Clausner (2003) attributed the scanty literature in bed leveling to the fact that bed leveling is used periodically (not frequently) in the United States during channel dredging projects throughout the sea turtle's range. The effect of bed leveler on sea organisms is difficult to assess due to lack of documentation.

Bed levelers have mainly been used by US contractors to smooth channel bottom following dredging, or to bring down the height of dredged material disposal mounds to the desired elevation (DOTS, USACE, SAD, 2003). Although most contract statements contain clauses implying the application of bed levelers to achieve final desired grades of sea bottom, dragging the bottom (bed leveling) has not been included in plant and equipment lists of contractors' bids because it is not a pay item. Bed leveling is a relatively inexpensive method to achieve final desired grade, and hence the continued and growing employment.

Hales (2003) said that sea organisms may rest in trenches created by repetitive transit of the dragheads/cutterheads and then exposed to entrainment hazards when the dredge tries to level the ridges during the clean-up phase of the project. Thus, the use of a bed-leveler is preferred because it does not use suction and is operated at a slower speed (1.00 m/s). The bed leveler has better deflection capabilities and slower speed compared to the speed of hopper dredge dragheads (2.50 m/s) or pipeline dredge cutterheads (2.50 m/s). The use of bed leveler during hopper dredging projects to remove the trench formation effectively reduces sea turtles' chances of inhabiting trenches.

Prior to 2003, resource agencies were not able to ascertain the impacts of bed levelers on sea turtles and other organisms which may inhabit trenches left by dredges during operations (Premo, 2003). Discussions were still on-going in 2003 among stakeholders on whether bed leveling can be categorized as a dredging option so that it should be documented in the dredging logs during operations.

(Verna, 2003) stated that the act of dragging sediment is not removing the sediment. Verna argues that since channel dredging involves removal of sediment while bed leveling only involves dragging and redistributing the sediment, and therefore bed leveling should not be categorized as dredging.

The Maritime Craft Services, Largs, Ayrshire, United Kingdom (2003) describes the use of seabed leveler behind an appropriate tugboat as one of the most economical, flexible,

and quiet forms of dredging. It stated that application of bed leveling does not disturb the environment as other dredging techniques do because the dredged material is relocated by containment within the seabed leveler. Mobilization to site is quick and relatively inexpensive. In most cases dredging operators do not bother about obtaining dumping license since it is not required for seabed leveling.

An industry survey conducted by the United States Engineering Research and Development Council and reported by Hales (2003) revealed that wave climate played a vital role in the applicability of bed-leveling. Thus, bed levelers are mostly used in soft sediments (silts, clays, etc.) but less often used in sandy sediment. Hence, bed levelers are not typically used to level bar entrance channels. At the bar entrance channel, the high waves will level the sandy sediments brought into the channel.

ANAMAR and CH2M HILL (2005) describes the bed leveler as any dragged device used to smooth sediment bottom irregularities or undulations that had been left by a dredge. The bed levelers are suspended from work barges by winches on A-frames and towed at speeds ranging from 0.52 meter per second (1.71 ft/s) to 1.03 meters per second (3.42 ft/s). Tug boats with about 746 to 2,238 KW (1,000 to 3,000 hp) of power are required to perform the towing functions. A typical bed leveler varies from 9.14 meters (30 ft) to 15.24 meters (50 ft) in width and weighs from 25,000 kilograms (55,116 lb) to 50,000 kilograms (110,231 lb). Some bed levelers are used to redistribute sediments to maintain navigational depths.

The cost-effectiveness and efficiency of bed-levelers over other dredge alternatives has been emphasized in the ANAMAR and CH2M HILL (2005) report. Bed-levelers, in combination with multi-beam precision bathymetry survey systems, can locate critical working areas better than other dredging equipment. Bed levelers also minimize sea turtle take. This is due to the fact that bed levelers neither have cutting nor sucking parts. This accounts for the growing demand of bed levelers in the dredging industry.

Munson, Young, and Okiishi (2007) provide equations used for the hand calculations and inputs variables to computer modeling. The equations were used to obtain the variations of velocity and pressure with area of flow. Some assumptions (potential flow, uniform bottom and trench, etc.) were made in the calculations. The equations are shown in equations 2 and 3 in the experimental result chapter, and equation 4 in the hydrodynamic modeling chapter.

In a personal discussion with Dickerson (2008) she stated that some on-going research point to the fact that certain designs of bed levelers are friendlier to sea organisms than others. Some designs and towing speeds also have higher efficiencies.

Randall et al. (2009) conducted a laboratory experiment and found that some designs of bed leveler can minimize the rate at which sea organisms can be destroyed during bed leveling operations. Randall et al. (2009) experiments used some apparatus set-up and equipment designed and used by Henriksen et al. (2007).

Figure 5 shows a flow diagram of a typical production cycle of a bed leveler. The cycle starts by properly positioning the tug in the region that requires bed leveling. The bed leveler (blade) is lowered beneath the ridge (depth beneath the ridge depends on the towing power of the tug). The blade is towed to level off the ridges into the trenches. When it reaches the end of the channel, the bed leveler is raised. The cycle is repeated the desired bottom grade is achieved.

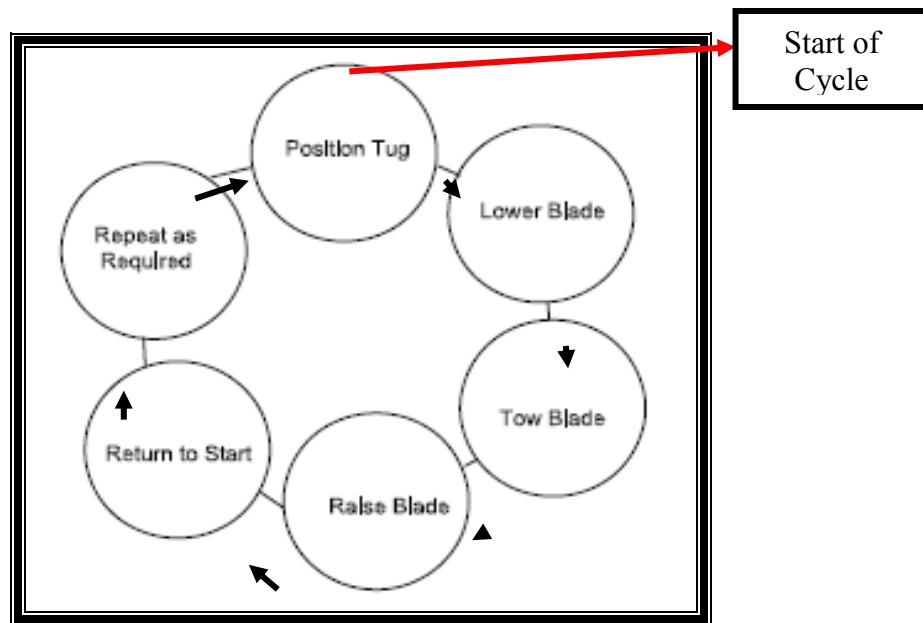


Figure 5. Production cycle of a bed leveler.

CHAPTER III

EXPERIMENTAL SET-UP

The laboratory experiments were conducted in the Texas A&M University dredge/ tow tank in the Haynes Coastal Engineering Laboratory during the summer and winter of 2008. A schematic of the dredge/tow tank is shown in Figure 6.

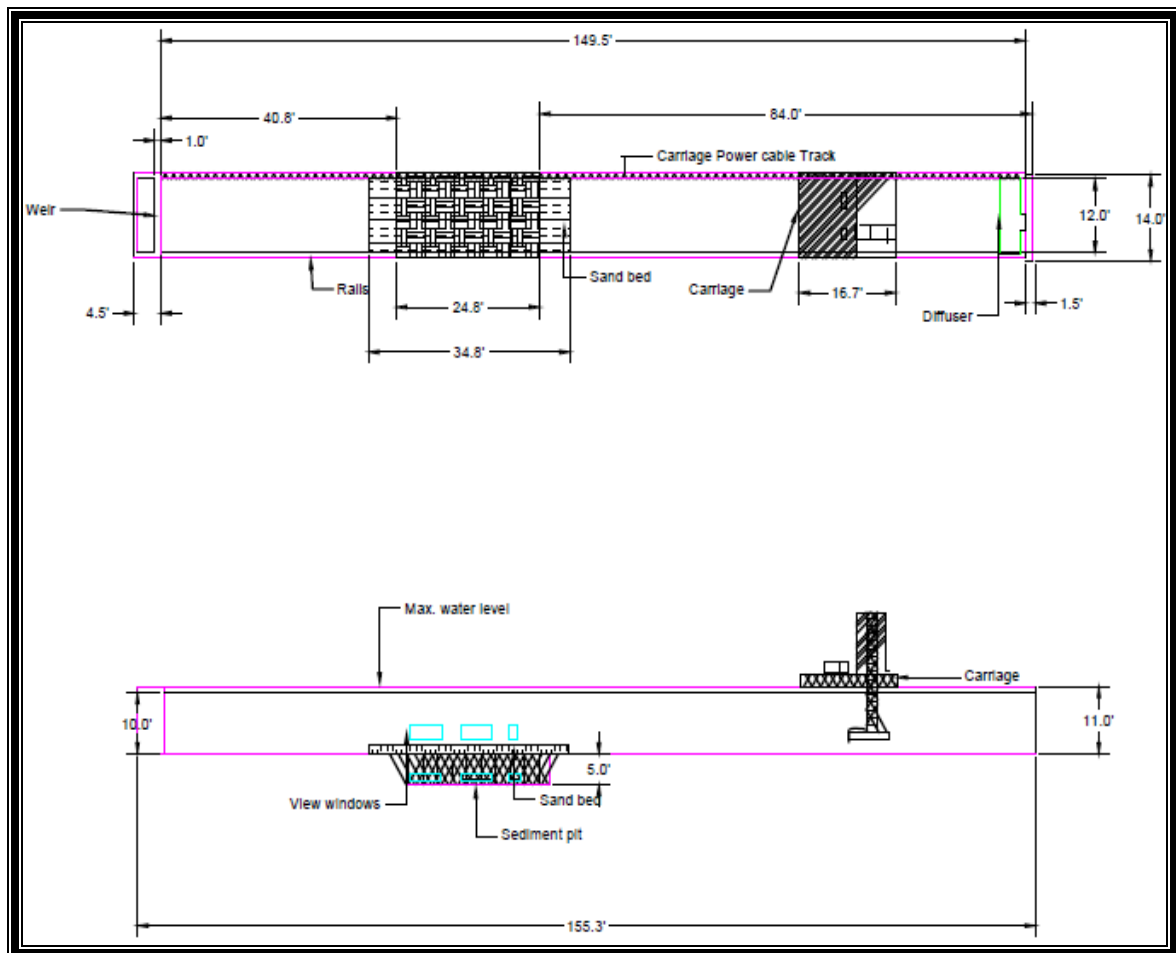


Figure 6. Elevation and plan view of dredge/tow tank in the Haynes Coastal Engineering Laboratory at Texas A&M University.

A television monitor, DVD player, VHS player, and some connecting cables were mounted on the dredge carriage to facilitate real time viewing of the experiments using the two underwater cameras. This set-up and configuration for the experiment required about eight hours of the first experiment day. The following day, fine sand ($d_{50}=0.27\text{mm}$) was brought into the dredge tank using the Haynes Coastal Engineering Laboratory crane shown in Figure 7.

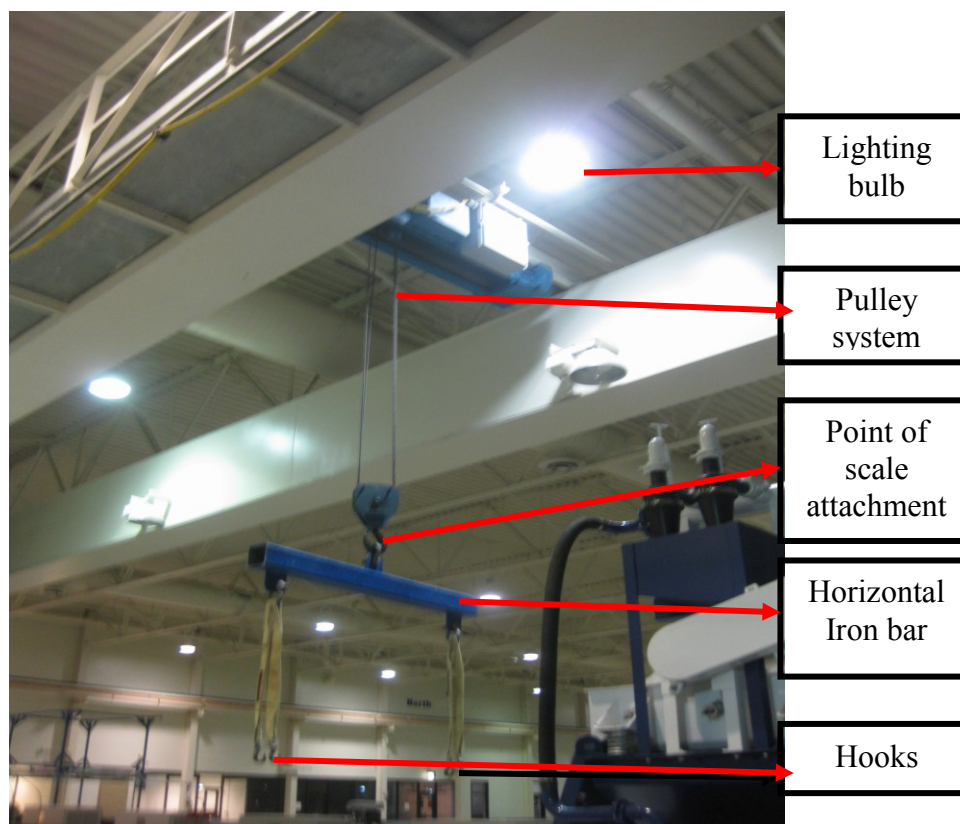


Figure 7. Haynes Coastal Engineering Laboratory crane.

The fine sand was contained in twenty-five white polyethylene bags as shown in Figure 8, each weighing approximately 953 Kg (2100 lb). The weight of the sand inside the

polyethylene bag was measured by attaching a weight measuring scale on the crane before lifting the sand bag. The point of attachment of the weight measuring scale to the crane is shown in previous Figure 7.



Figure 8. Fine sand packaged in white polyethylene bags.

The clean fine sand was spread over the sediment pit location of the dredge/tow tank. The smoothed sand bed ready for trenching is shown in Figure 9.

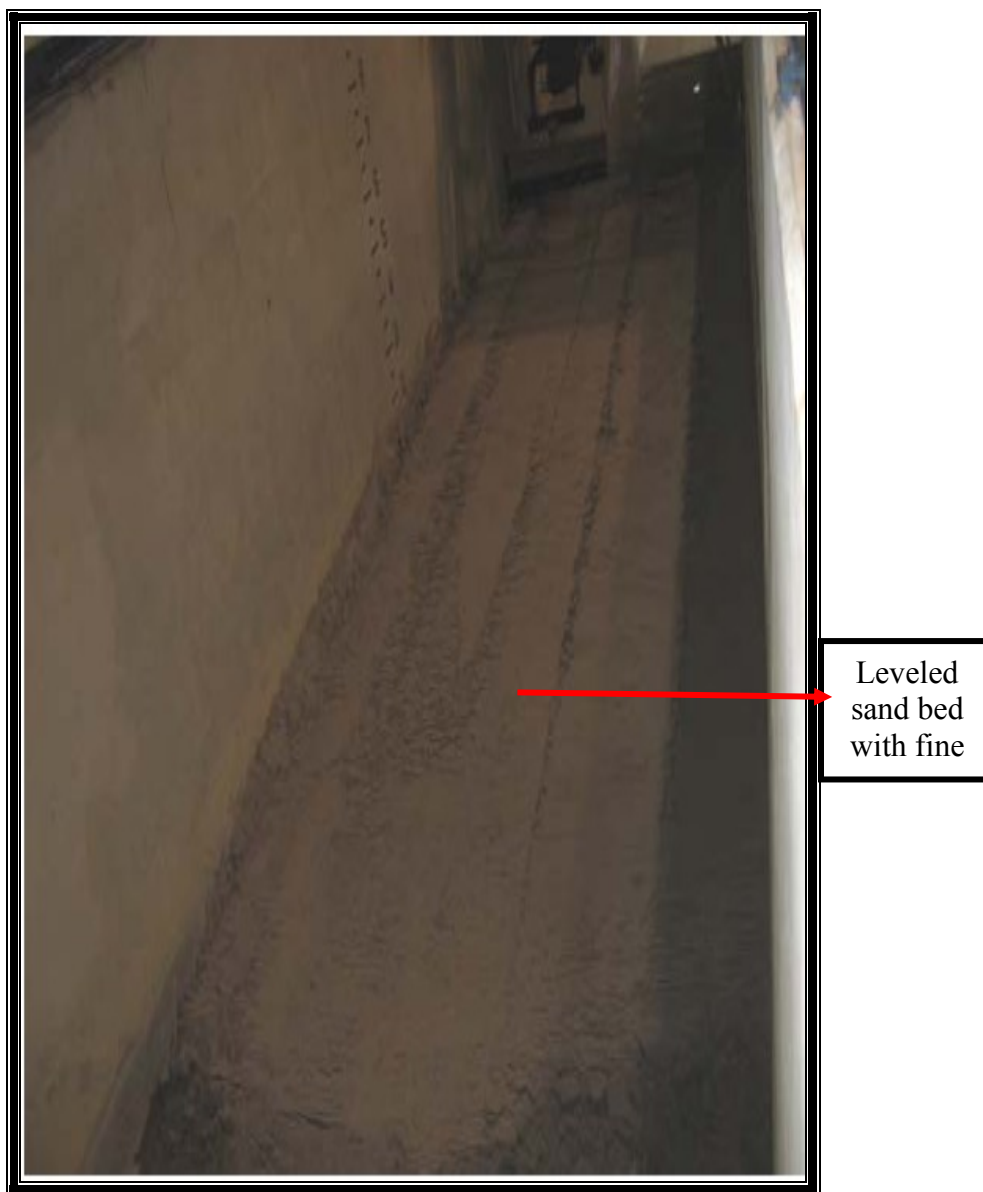


Figure 9. Sand bed smoothed and ready for trenching.

The fine sand spread over a longitudinal axis of the tank a distance of 10.61 meters (34.8 ft) as sketched in Figures 10 and 11.

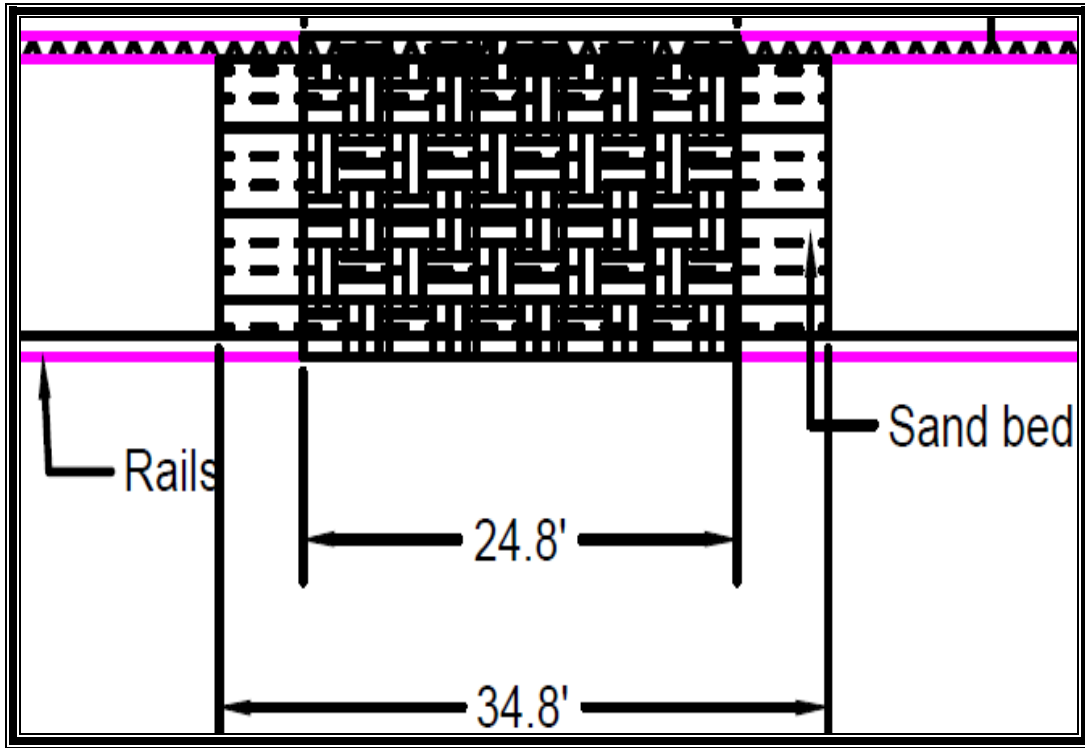


Figure 10. Plan view of the sand bed used for the experimental runs.

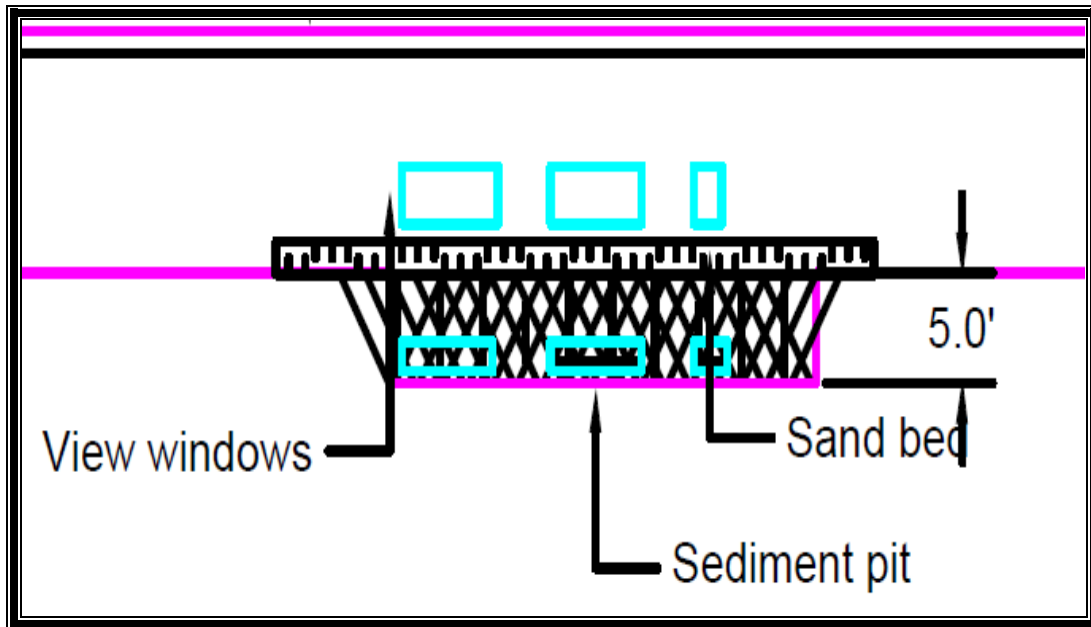


Figure 11. Elevation view of the sand bed used for the experimental runs.

The laboratory experiments were conducted in the Haynes Coastal Engineering Laboratory Dredge/Tow tank during the summer and winter of 2008. Trenches and ridges were artificially created, perpendicular and parallel to the longitudinal axis of the tow tank, using a trenching tool shown in Figure 12. As shown in the meter rule of Figure 12, the triangular trenching tool has a dimension of 0.61 meter (2 ft) long. The height from the midpoint of the base to the vertex is 0.20 meter (0.67 ft).

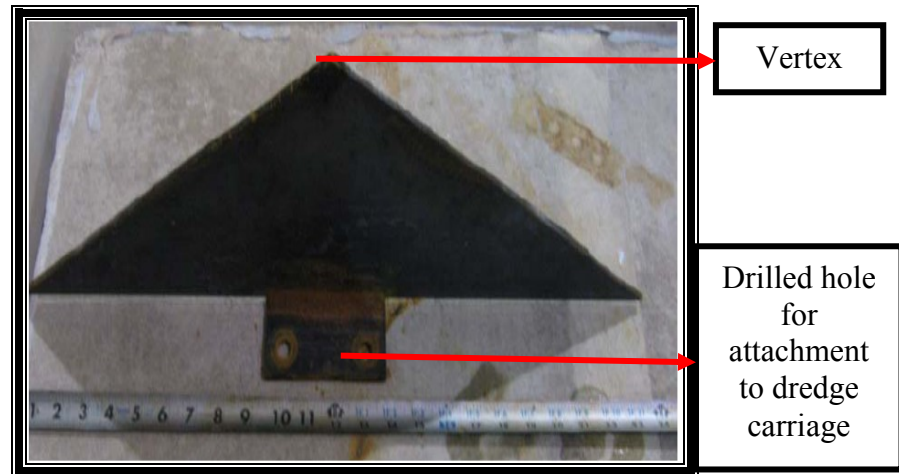


Figure 12. Trenching tool used to excavate troughs (trenches) in sand bed.

Underwater cameras (named USACE and OTRC) were attached to the dredge ladder to facilitate flow visualization within the vicinity of the trenches as the model bed leveler was towed along the tank sand bed. The United States Army Corps of Engineers (USACE) camera, with its attachment device to the dredge carriage is shown in Figure 13.

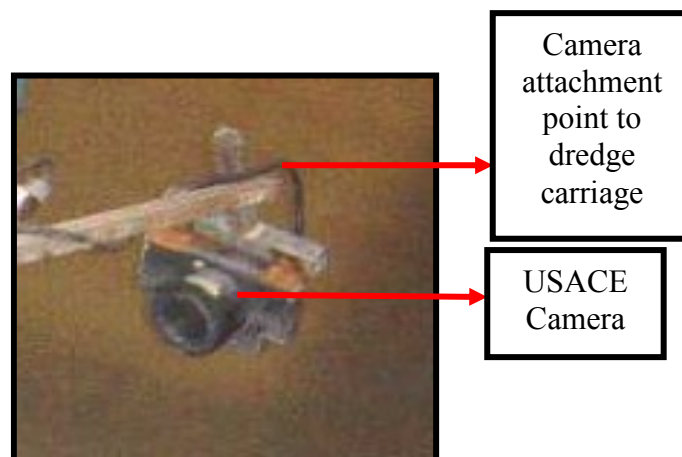


Figure 13. USACE underwater camera.

Figure 14 shows a picture of the model bed leveler and underwater cameras attached to the dredge carriage lower ladder. Figure 14 also shows the sediment pit after it was leveled for the test run.

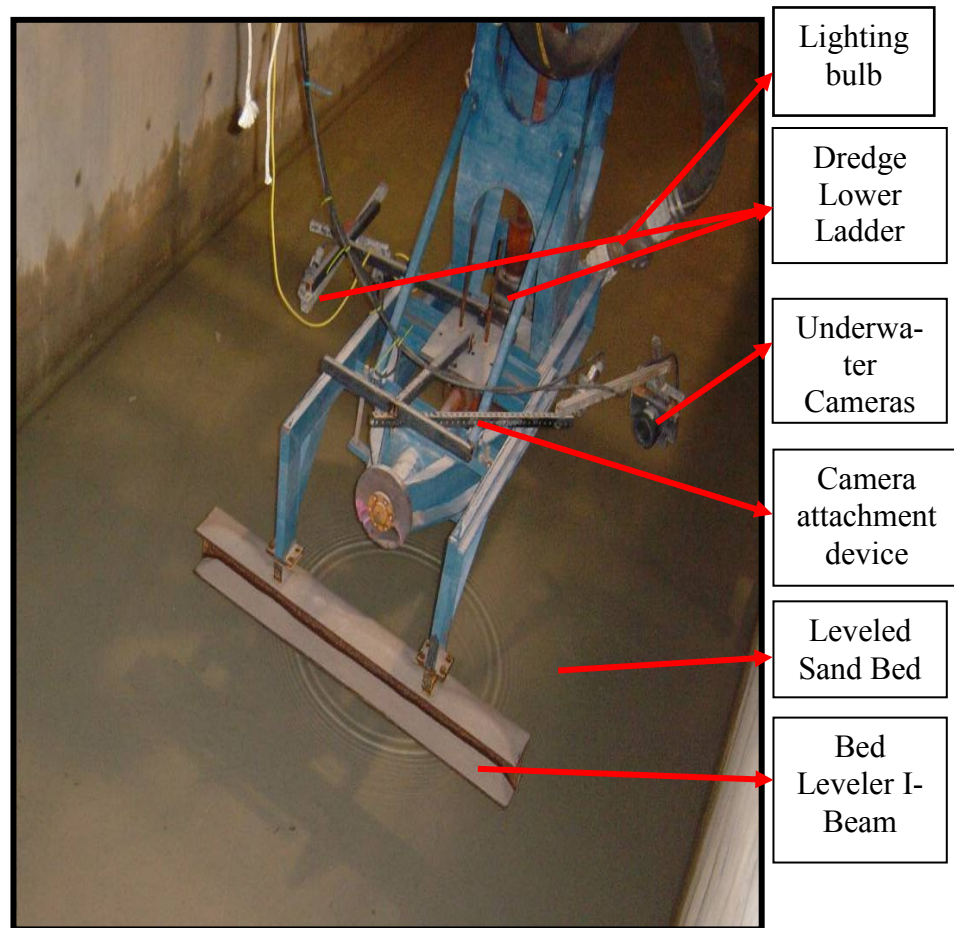


Figure 14. Bed leveler and underwater camera attached to dredge carriage after sand bed was leveled for experimental run.

Figure 15 shows the apparatus for attaching the underwater cameras, lights, and bed leveler to the lower ladder of the carriage.

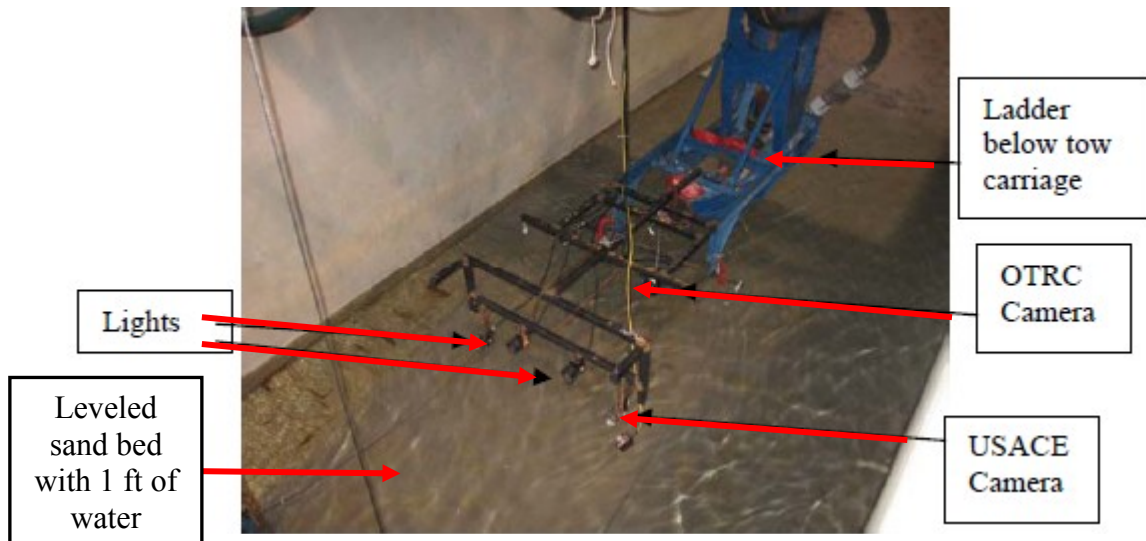


Figure 15. Towing set up for model bed leveler attachment.

To ensure that all interesting flow regimes around the bed leveler were thoroughly visualized, hand held cameras were strategically located to visualize the flow fields generated at different points along the trench. Windows Media Video (WMV) software was installed in one of the computer systems in the Haynes Coastal Engineering Laboratory computer room. Figure 16 shows the Computer Laboratory at the Haynes Coastal Engineering Laboratory.



Figure 16. Computer laboratory in Haynes Coastal Engineering Laboratory.

The WMV software was used to convert the Audio Video Interleave (AVI) movies obtained from the USACE and OTRC cameras to wmv file formats that could be viewed and played on the computer and other media. The WMV software also converted the handheld camera images from the Moving Picture Experts Group (MPEG) format to WMV file format.

Different types of bed levelers were manufactured for the experiment. The flow reversals around the bed levelers and the trenches showed that some designs of bed levelers are friendlier to sea organisms that may inhabit trenches than other types of bed levelers. However, this thesis focused entirely on the box beam.

A Bobcat (mini-bulldozer) shown in Figures 17 was used to pile up and level the sand bed to get a flatter surface for the test runs. The Bobcat was lowered into the dredge tank by the overhead crane. Other laboratory tools, such as hand rakes, and a box beam were used to give the surface a final desired grade. A fine net with openings with a diameter of 0.25mm (0.01 inch) (opening diameter smaller than fine sand $d_{50}=0.27$ mm) was fabricated with cross sectional dimensions of the transverse cross section of the dredge/tow tank, 3.66 m by 3.05 m (12.00 ft by 10.00 ft). The net was positioned at the end of the sand bed (towards the weir side of the dredge/tow tank) when the turbid water was drained out of the tank. The net prevented the unsettled fine sand from leaving the tank along with the water.

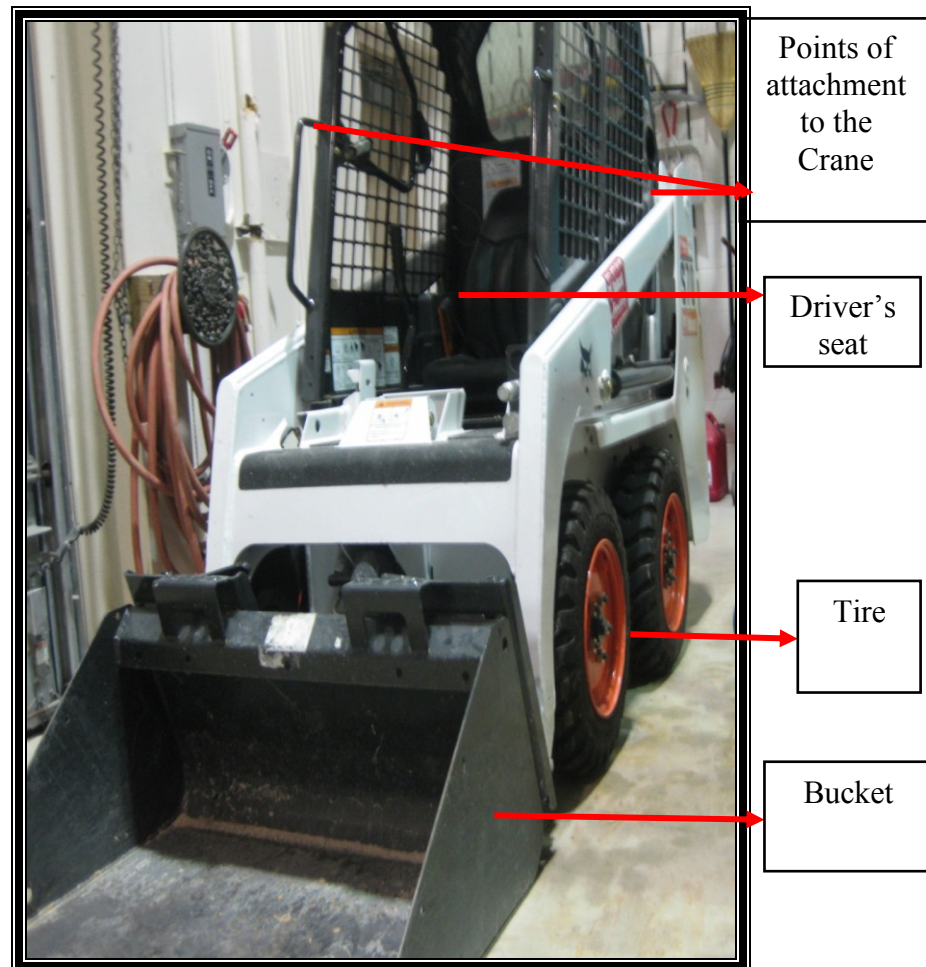


Figure 17. A picture of the Bobcat used to level the sand bed.

Figure 18 shows the picture of the net used to prevent unsettled fine sand from leaving the tank when water is drained to reform sand bed after bed leveling.



Figure 18. Net used to prevent fine sand from leaving the tank when water is drained to reform sand bed after bed leveling.

When the water level reduced to about 0.31 m (1.00 ft), the net was removed and the weir was lowered successively in 0.03 m (1 inch) steps to slowly drain the water. To ensure that the fine sand bed was not scoured by water coming from the extreme end of the tank, two PVC pipes of diameters 0.10 meter (0.33 ft) each were positioned on the side walls of the dredge/tow tank to drain the water completely out of the dredge tank and to allow the water to flow by the sand bed when refilling the tank for the next tests.

Customized bed levelers were attached to a model dredge carriage ladder that moved on the top of the rails mounted to the dredge/tow tank. The tank has a sediment pit (Figure 19) which was filled with fine sand. An additional 0.46 m (1.50 ft) of fine sand ($d_{50} = 0.27$ mm) was placed on top of the sediment pit sand and extended 1.53 m (5.00 ft) on the weir side of the tank and 3.05 m (10.00 ft) on the other side of the pit. Parallel and perpendicular trenches and ridges were artificially created, using the trenching tool shown in Figure 12. The trenches parallel to the tank longitudinal axis were investigated for the purpose of this thesis.

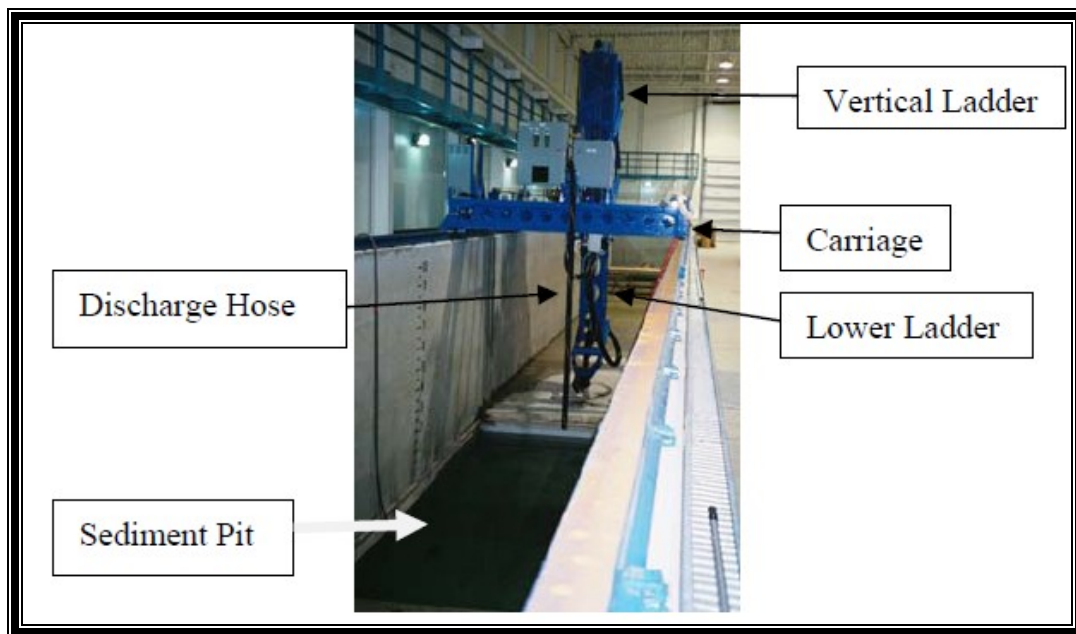


Figure 19. Dredge carriage at sediment pit in Texas A&M dredge/tow tank.

Water was filled to a depth of 1.22 meters (4.00 ft) for each test run. The dredge carriage with the attached box beam bed leveler was pulled parallel to the tank

longitudinal axis. The model dredge carriage was electronically driven, using the control knobs shown in Figure 20, and the flow regime around the bed leveler was observed using underwater cameras as well as hand held cameras.



Figure 20. Control panel and knobs for driving the dredge carriage electronically and remotely.

The experiment was conducted in a 45.72 meters (150.00 ft) long, 3.05 meters (10.00 ft) deep and 3.66 meters (12.00 ft) wide towing tank. The sand bed is on the bottom of the tank and is 0.46 meters (1.50 ft) thick and 9.14 meters (30.00 ft) long shown in the previous Figures 10 and 11.

In the laboratory, different types of bed levelers were designed, fabricated and attached to the carriage on the dredge/tow tank. Trenches were dug to required dimensions using 0.20 meters (8.00 inches) by 0.61 meters (2.00 ft) triangular device (Figure 11) after clean fine sand ($d_{50} = 0.27\text{mm}$) was filled to a height of 0.46 meters (1.50 ft) above the tank floor at the location of the sediment pit. The length of the sand bed was 10.61 meters (34.80 ft.).

The tank was filled with water to a depth of 1.22 meters (4.00ft) after the bed levelers were attached to the dredge carriage. Figure 21 shows the calibration of the tank height in feet.

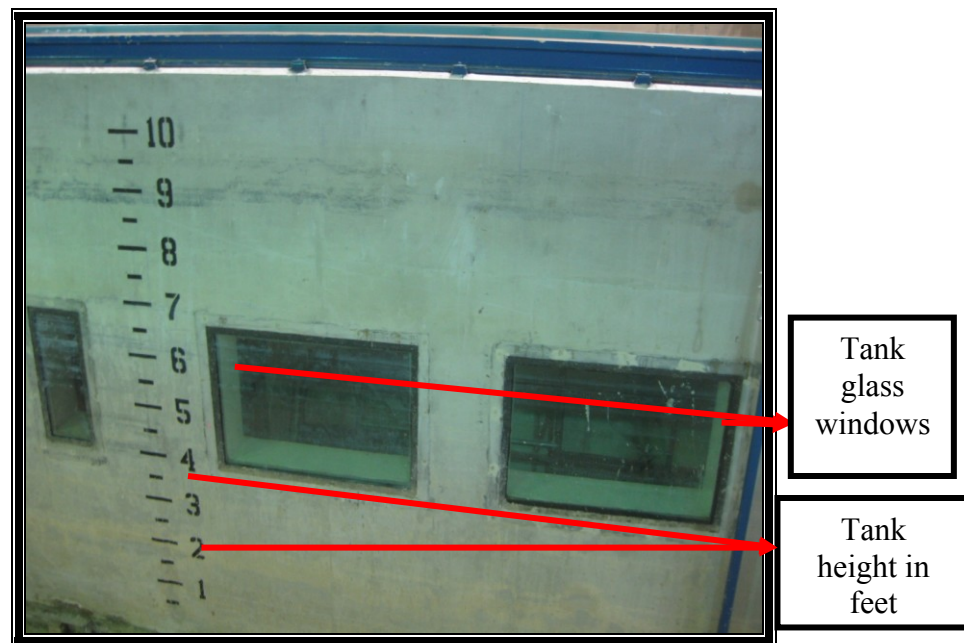


Figure 21. Dredge/Tow tank vertical calibration (in feet) and glass windows for close flow visualization.

The bed leveler was set to a height of 0.05 meters (0.17 ft) below the top of the ridges and towed at two specific constant speeds of 0.25 m/s (0.82 ft/s) and 0.50m/s (1.64 ft/s). These speeds were obtained using a model length scale of 1/4. The Froude scale modeling was used since the experiments involved a free surface flow. The Froude number (F) is

$$F = \sqrt{\frac{V^2}{gL}} \dots\dots\dots (1)$$

where V is the towing speed, g is the acceleration of gravity, and L is the characteristic length scale. Available dredging data indicated that the prototype bed levelers are commonly towed at speeds of 0.50 m/s (1.64 ft/s) and 1.00 m/s (3.28 ft/s).

Underwater and hand held cameras were used to view the flow field around the bed leveler and the trench at different locations. Two underwater cameras (named OTRC and USACE) were attached to a locally fabricated attachment mechanism that was attached to the carriage as shown in Figure 18. Three project team members took videos of the fluid-structure interactions within the vicinity of the bed leveler using hand held cameras. One of the hand held cameras was positioned on top of the carriage so that it can view the plan view of the flow. The other two hand held cameras were used to video side views. One hand held camera used for the side view was mounted at the glass window of the observation well (Figure 20). The USACE camera was viewed and recorded using a television and a VHS recorder that were mounted on the dredge

carriage. The OTRC underwater camera video was recorded with a DVD player mounted on top of the dredge carriage. Sometimes, the OTRC camera recordings were viewed on the television set.

To ensure that the model bed levelers had the required weight as the prototypes, a weight of 97.80 Kg (220 lbs) was added to the designed bed levelers in some test runs. This additional weight ensured that the dynamics of the flow did not raise the model bed levelers above the measured lowered depth into the sediment for each of the test runs.

Four underwater lights were attached to dredge carriage to provide light so that the underwater cameras were able to capture the flow fields. The underwater lights were positioned close to the underwater cameras. The underwater lights were also attached to the same apparatus as the underwater cameras. However, the lights were located at a distance of 0.46 m (1.50 ft) in front and at the back of each underwater camera.

Since cameras were the only means of visualizing the flow phenomena around the bed levelers, the water in the tank was drained out after three test runs because the water became turbid after three runs. Turbidity hinders flow visualization. Also, after three test runs, the bed leveler moved sand from the ridges and filled the trenches in a non-uniform manner. The water was drained out to level the sand bed in order to remake the trenches. The processes of leveling the sand bed, changing the bed leveler, digging the trenches,

positioning the model sea organisms in the trenches, etc. were repeated before the tank was refilled to a water depth of 1.22 meters (4 ft) for the next set of test runs.

It took six hours to drain and refill the tank. This limited the maximum set of test runs with different types of model bed levelers to two per day. As the experiment progressed, it was realized that different types of bed levelers produced different flow field within the vicinity of the trench, hence, we chose to keep other experimental parameters constant and change the bed levelers during successive experimental runs. To accomplish this while saving time, only 0.46 m (1.50 ft) of water was drained out of the tank after each test run (provided the water was still clean enough to visualize the flow), then two project team members put on waders, entered the tank, and changed the bed leveler. They also measured the depth of the trench. If the trench is shallower than the required depth, then the trenching tool was used to excavate it to 0.20 m (0.67 ft) set for the experiment before mounting the model bed leveler for the next test run.

Different types of bed levelers were designed and constructed for the study, and Figure 22 shows the bed levelers and the attachment to the carriage. The attachment device or panel was constructed in the laboratory and bolted to the lower ladder of the dredge carriage. Wires and chain were also used to connect the box-beam bed leveler to the upper part of the dredge carriage to ensure that the box beam was held in a fixed position during each experimental run. The slacking of the wires was used to measure the

displacement length of the box-beam bed leveler, from its initial position below the top of the ridges, as the experimental run progressed.

Each set of experiments was conducted at least three times to ensure that the details of the flow around the bed leveler in the vicinity of the trench were well captured for visualization. Minimum of three sets of data is also required for statistical analysis.

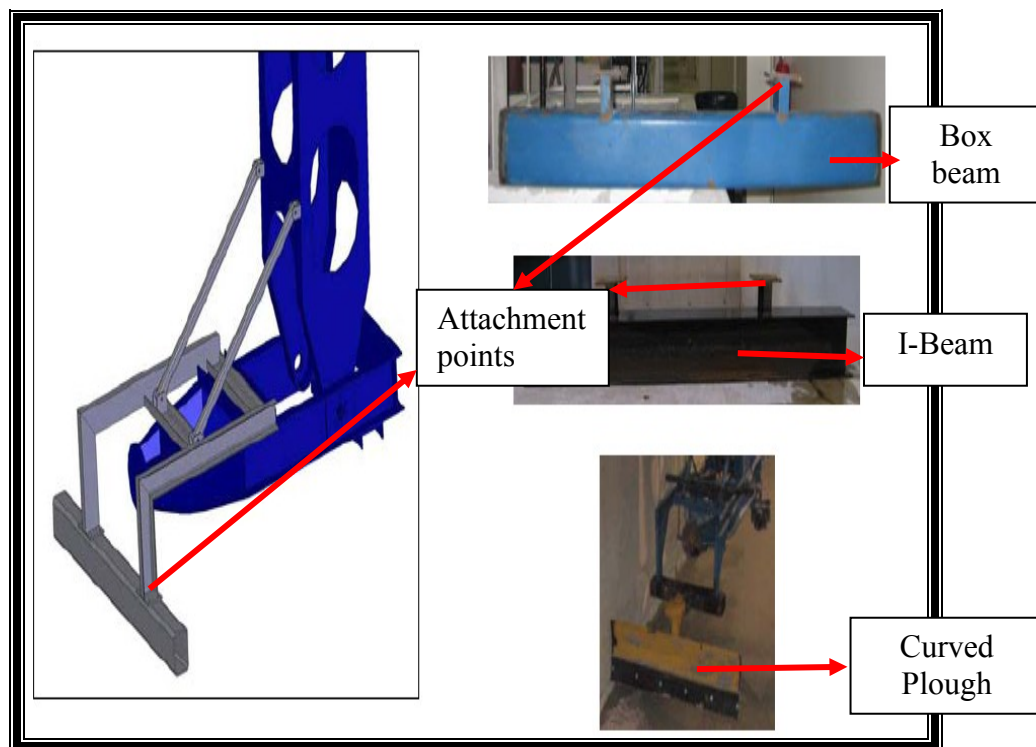


Figure 22. Carriage ladder attachment and laboratory model bed levelers (box beam (attached to the carriage on left and on top of right picture), I-beam (middle of right picture), and curved plough (bottom of right picture)).

CHAPTER IV

EXPERIMENTAL RESULTS

The fundamental objective of the experiment was to investigate the flow field around the model bed levelers in the laboratory. The cameras were the only medium to visualize the hydrodynamics since the experiments were conducted under water in the presence of fine sand. The camera movies were recorded on DVDs and properly labeled immediately after each experiment. A 90 GHz external hard drive was also used for backing up the movie file data. The DVDs were ejected from the DVD player set on top of the dredge carriage and taken to the Haynes Coastal Engineering Laboratory computer room for processing. A Windows media video (wmv) converter was downloaded and installed in the particular workstation used for the movie conversion. The videos from the two underwater cameras were processed into a format (with .wmv extension) that could be played and viewed in the computers available in the Haynes Coastal Engineering Laboratory using the wmv video converter files. Each of the underwater cameras (OTRC and USACE) took approximately 20 minutes to convert a single test-run to the .wmv file format. During the evening hours of each experiment day, the input files were processed and fed to the wmv converter, then the system was allowed to stay on and convert all the test runs throughout the night hours. The conversion to .wmv format was completed the next morning. After the OTRC and USACE underwater movie conversions were completed, all the five videos (from the different five cameras – the movies from the three handheld cameras were downloaded directly and viewed on the computers) were

played, one after the other, for each test run. The cameras were started just before the dredge carriage was moved from the start end of the sand bed and the cameras stayed on until the end of the sand bed. By simple calculations, the sand bed had a length dimension of 10.61 m (34.80 ft) and the carriage speeds were set at 0.25 m/s and 0.50 m/s, and this translated to movie duration of 42.45 seconds and 21.22 seconds respectively assuming the set speed was maintained throughout the experiment and the cameras were started and stopped instantly. However, the dredge carriage motion slowed down when the bed leveler gathered more sand around it as it traverses towards the other end of the sand bed. On the average, each unedited movie took one minute to play. The movies were then edited to capture the most interesting flow visualization around the bed leveler and the model sea organisms inhabiting the trenches. Each edited movie had a maximum play time of twenty seconds.

The edited movies were saved on external storage devices and downloaded to hard drives on office computers. They were played on office computers and converted to still pictures with the aid of the print screen key on the key board. The office computers have windows media players installed on them. When the movie played to a point of interest needed to be captured in a snapshot, the movie was paused and the print screen key was pressed, this process copied the whole screen to the clipboard. The still image was then pasted on a Microsoft word page. Since print screen captured the whole page, the pasted picture was edited to get rid of the unwanted parts. To edit the still pictures, two techniques were used. The first technique used the crop in the picture tool sub-menu of

the Microsoft word and edited out the unwanted parts of the movie. The second technique involved the conversion of the Microsoft word image to a PDF image format and saved. Tools sub-menu on the PDF page was clicked and “select and zoom” was selected from the drop down menu. Finally, the snapshot tool was picked to edit the images. Figure 23 shows a movie converted to a still picture using the second technique described above.

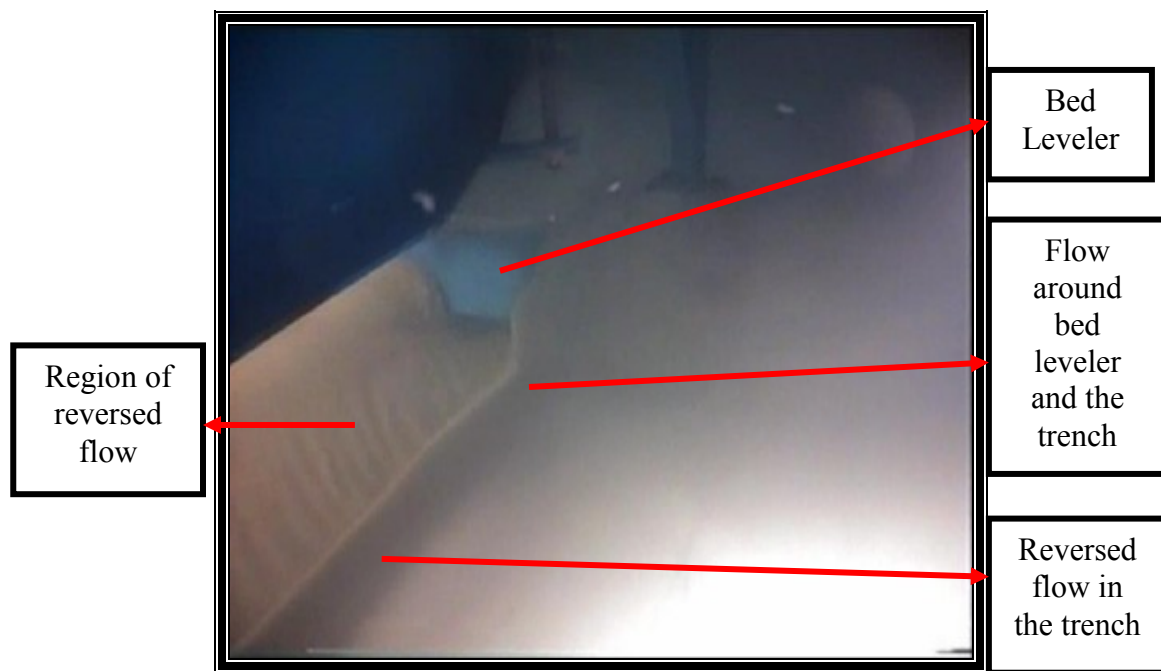


Figure 23. Movie converted to still picture showing flow around the trench.

The movie shown in Figure 23 shows that at some points of the experiment, the fluid flow did not follow the normal Bernoulli and mass conservation principle.

$$\rho Q = \text{Constant} \quad \dots\dots\dots (2)$$

$$p + (V^2/g) + z = \text{Constant} \quad \dots\dots\dots (3)$$

where ρ is fluid density, Q is volumetric flow rate, p is pressure, V is velocity, and z is water depth.

The viscous flow did not meet the assumptions of Bernoulli principle. The flow did force itself through the trenches with increased speed as could be calculated using mass conservation and Bernoulli equations with appropriate assumptions. The flow direction within the vicinity of the bed leveler and the trench was reversed as shown in Figure 24.

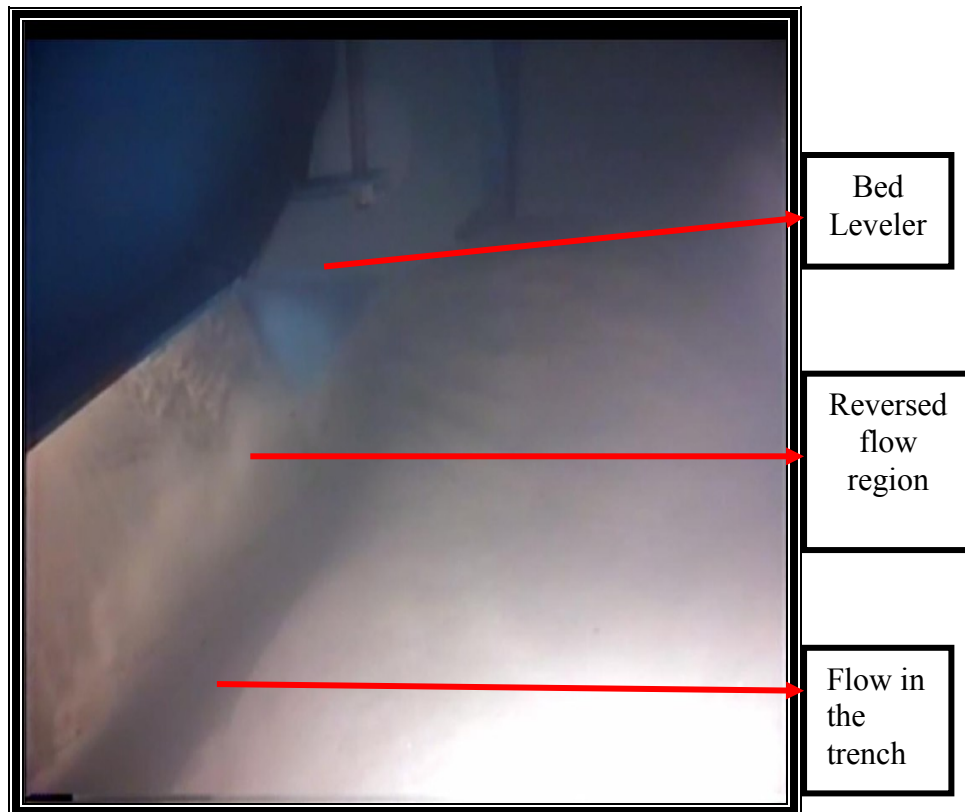


Figure 24. Snap shot of flow reversal around the bed leveler when the reversed flow moved at speed closed to the forward flow.

This observation was an unexpected but interesting phenomenon. Initially, it was thought that the bed leveler might push some sand from the ridges into the trenches such that the trench will completely be filled with sand, but a closer look at the movies showed that there was still some gap in the trench. It was also thought that as the flow forced itself through the trench, the velocity of the jet would have increased and scoured the trench linings to create a wider cross sectional area for free flow in the trench in the direction opposite to the direction of motion of the model bed leveler. The fact that part of the flow reversed suggested that if sea organisms inhabit trenches created by uneven passes of a draghead during dredging operations, such organisms could have ample time to move away from the trenches or be pushed towards the sides of the bed levelers.

The different designs of the bed levelers also gave some interesting observations: The model sea organisms placed in the trenches were pushed over and towards the sides of some bed levelers. These model bed levelers were called friendly bed levelers. Figure 25 shows the hydrodynamics around some of the bed levelers constructed for the study. Although the exact speed of the reverse flow was not measured, the movie indicated that it moved slightly slower than the carriage speed.

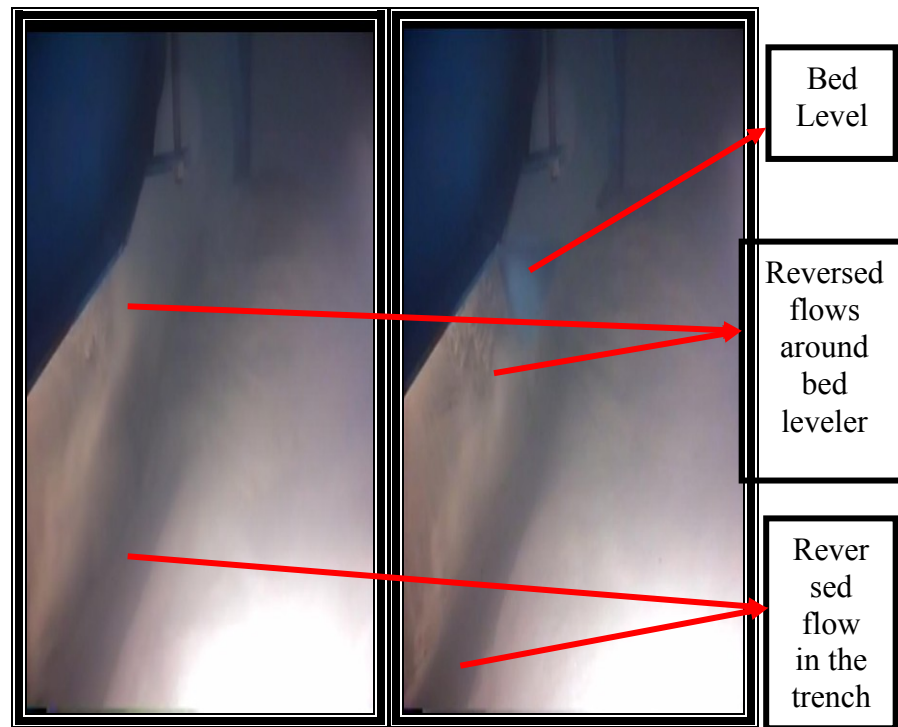


Figure 25. More laboratory movie snapshots showing flow reversals around bed levelers. The speed of reversed flow matches the forward speed.

CHAPTER V

HYDRODYNAMIC MODELING

The hydrodynamic modeling was accomplished in three phases namely: pre-processing (grid generation and input data files), processing (numerical simulation), and post-processing. In the pre-processing phase, GRIDGEN commercial software was used to generate ten (10) grid blocks. PEGSUS was used for grid interpolation and to obtain blanking information, interpolation stencils, interpolation coefficients, hole-fringe points and outer boundary points. The input data files were also generated.

The processing or numerical simulation was accomplished using a FORTRAN code called Finite Analytic Navier Stokes (FANS) (Chen, 1982) software. FANS solved the Navier Stokes equations.

FieldView and Tecplot commercial softwares were used for the post-processing. Both grid and solution data files were loaded into the post-processing software as plot3d data format.

Table 1 shows the number of nodes in each grid block.

Table 1. Number of nodes in each grid box.

S/No.	X	Y	Z
1	121	101	75
2	41	39	123
3	41	34	91
4	41	34	91
5	31	5	10
6	11	5	5
7	11	5	5
8	31	5	10
9	11	5	5
10	11	5	5

Commercial software called Fieldview (Intelligent Light, 2010) was procured and installed in the office computer. The installed FieldView was launched on the desktop and the grid and solution movie data files were imported and loaded into the commercial software. Since the data were simulated in plot3d format, the same plot3d format was chosen for loading the data files into FieldView environment. Only the first solution movie file at time step of $20T_0 = 1.02$ seconds (T_0 is the characteristic time given by: $T_0 = L / U_0 = (0.0254 \text{ m}) / (0.5 \text{ m/s}) = 0.0508 \text{ Sec}$, where $L = 0.0254 \text{ m}$ (0.083 ft) is the length scale and $U_0 = 0.5 \text{ m/s}$ (1.64 ft/s) is the velocity scale) was selected but Fieldview software questioned if one intends to load the 150 movie files since all the 150 files are linked solutions. When yes is chosen, all the solution movie files were loaded.

Fieldview has the capability to generate the pressure, velocity, density, momentum vorticity, and many other vectors and contours plots. The objective of the hydrodynamic modeling was to generate pressure and velocity contours and vectors and compare them

with what was observed in the laboratory. The vorticity contour and vectors (in the y-z plane) was also plotted to show the effect of the wake.

Another commercial post-processing modeling plotting tool, Tecplot (Tecplot Inc. 2005) was also procured and installed in the office computer system, and then used to generate some plots. The processes of launching and loading the data files in Tecplot were similar to that of Fieldview. Tecplot also had the capability to load either an individual solution movie files or a group of movie files and plot the results. The plots obtained from Tecplot and FieldView showed similar contours and vectors for the particular function (example pressure, velocity, etc.). Most of the plots shown in this thesis were generated using FieldView.

The FieldView 2D plotting tool shows curves of the flow fields at different planes and slices of the bed leveler. The different axes (normalized with L) are shown in the horizontal axis while the properties (pressure, velocity, vorticity, etc.) examined are plotted in the vertical axis.

The pressure curves show negative pressures behind the bed leveler in the vicinity of the trenches. The corresponding horizontal (v) and vertical (w) velocity plots show the flow reversal depicted by negative velocity.

The pressures were normalized with respect to the dynamic pressures, ρU_0^2 . In the laboratory, fresh water of density $\rho = 1000 \text{ Kg/m}^3$ was used to run the experiments. The model bed leveler was towed at a constant speed (U_0) of 0.5 m/s. Thus the normalized pressure, P^* , is:

$$P^* = p/\rho U_0^2 \dots\dots\dots (4)$$

where p denotes pressure, ρ is the fresh water density; U_0 is the speed of the bed leveler. The dynamic pressure was ($\rho = 1000 \text{ Kg/m}^3 \times 0.5 \text{ m/s}^2$) = 250.00 Pascals (0.04 psi). Thus the non-dimensional pressure value of -1 implies -250.00 Pascals (-0.04 psi). Similarly, the velocity was also normalized to the Haynes Coastal Engineering Laboratory dredge carriage operating velocity of 0.5 m/s. Hence, a normalized velocity of 0.5 indicates a simulated flow velocity of 0.25 m/s.

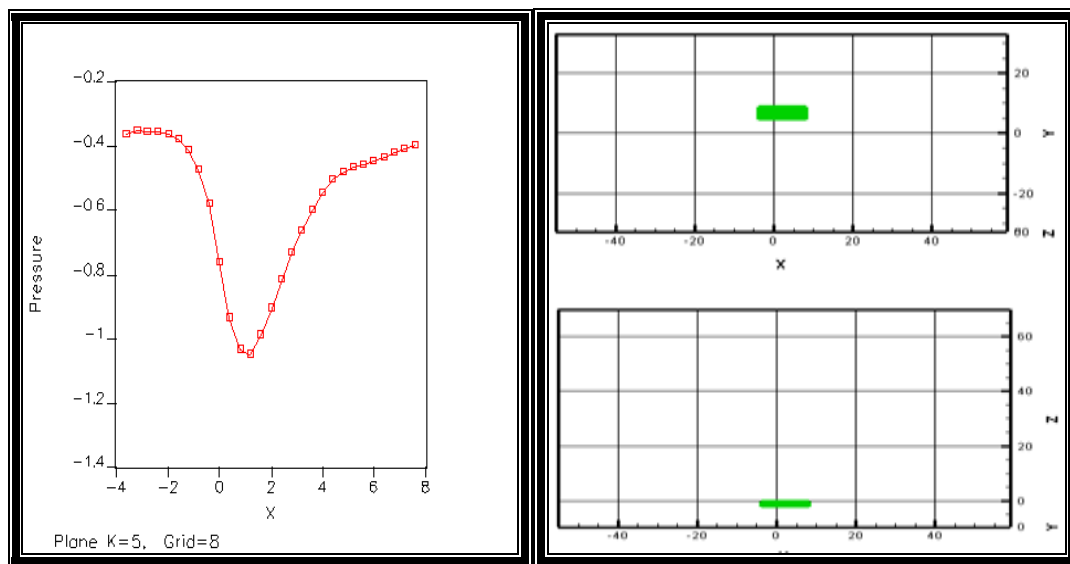
The length scale (L) used was 0.0254 m (0.083 ft). All the coordinate axes (X, Y, Z) were normalized to this length scale. The time scale is, $T_0 = L/ U_0 = (0.0254 \text{ m}) / (0.5 \text{ m/s}) = 0.0508 \text{ Sec}$.

The reversed flow occurred behind the bed leveler. There was an external forcing mechanism (a dredge carriage moved at a constant speed of 0.5 m/s) that was driving the forward flow, but the reverse flow was caused by boundary layer separation.

The numerical grid XYZ axes orientations with respect to the direction of motion of the bed leveler are: X is the longitudinal axis, Y is the lateral axis, and Z is the vertical axis.

The domain dimensions for X, Y, and Z-axes are 2.46 m (8.67ft), 1.52 m (5.00 ft), and 5.50 m (1.68 ft) respectively. The trench is created along the X-axis and has its center line at $Y = 0$. The trench is 0.15 m (0.50 ft) deep below the sand bed. The Z-axis origin is on the sand bed, so the deepest part of the trench is at $Z = -0.15$ m (-0.50 ft).

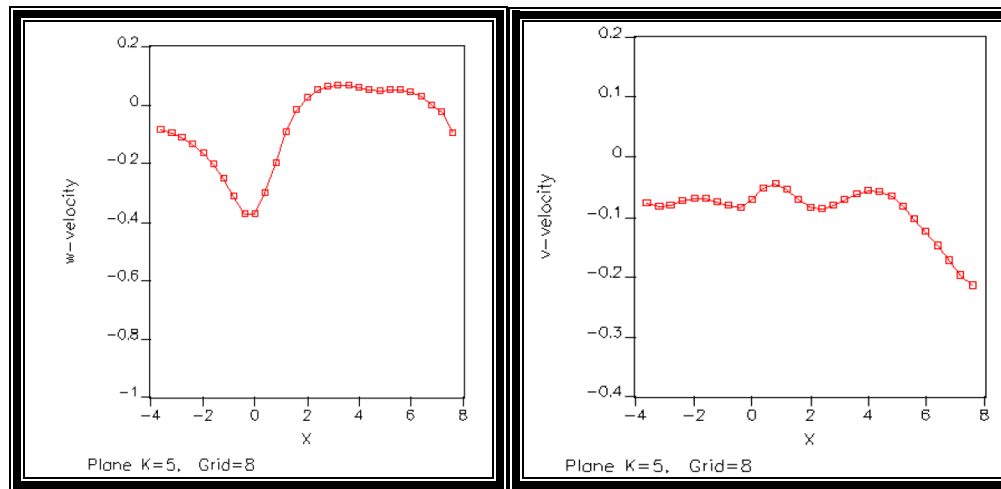
Figures 26 to 29 show the normalized horizontal movement of bed leveler velocity and pressure at some points in the simulation (2-D plots). Figures 26 and 27 show a FieldView 2-D plots of the dynamic pressure variations and the vertical (w) and horizontal (v) components of the velocity along a line in the x-axis of the simulation domain. Grid block 8 coordinates at $k=5$ are $(Y, Z) = (-5.5, -1)$ and X is from -4 to 8.



(a)

(b)

Figure 26. 2-D plots of: (a) nomalized pressure variation along a line in the x-axis of grid block 8 and (b) normalized (x,y) and (x,z) coordinates of block 8.



(a)

(b)

Figure 27. 2-D plots: (a) normalized w-velocity and (b) normalized v-velocity along a line in the x-axis of grid block 8.

The negative pressure variation indicates a normalized value of about -1 at some points near the trench (plane K = 5 is near the trench bottom). Negative pressures behind the bed leveler indicate form drag that causes wake. Negative velocities represent flow reversal.

Figure 28 is a FieldView 2-D plot of grid block number 5 sliced at k=5 along a line in the x-axis. It shows a similar result as the one for grid block number 8. The coordinates of grid block 5 at slice K = 5 are (Y, Z) = (-5.5, -1) and X is from -4 to 8.

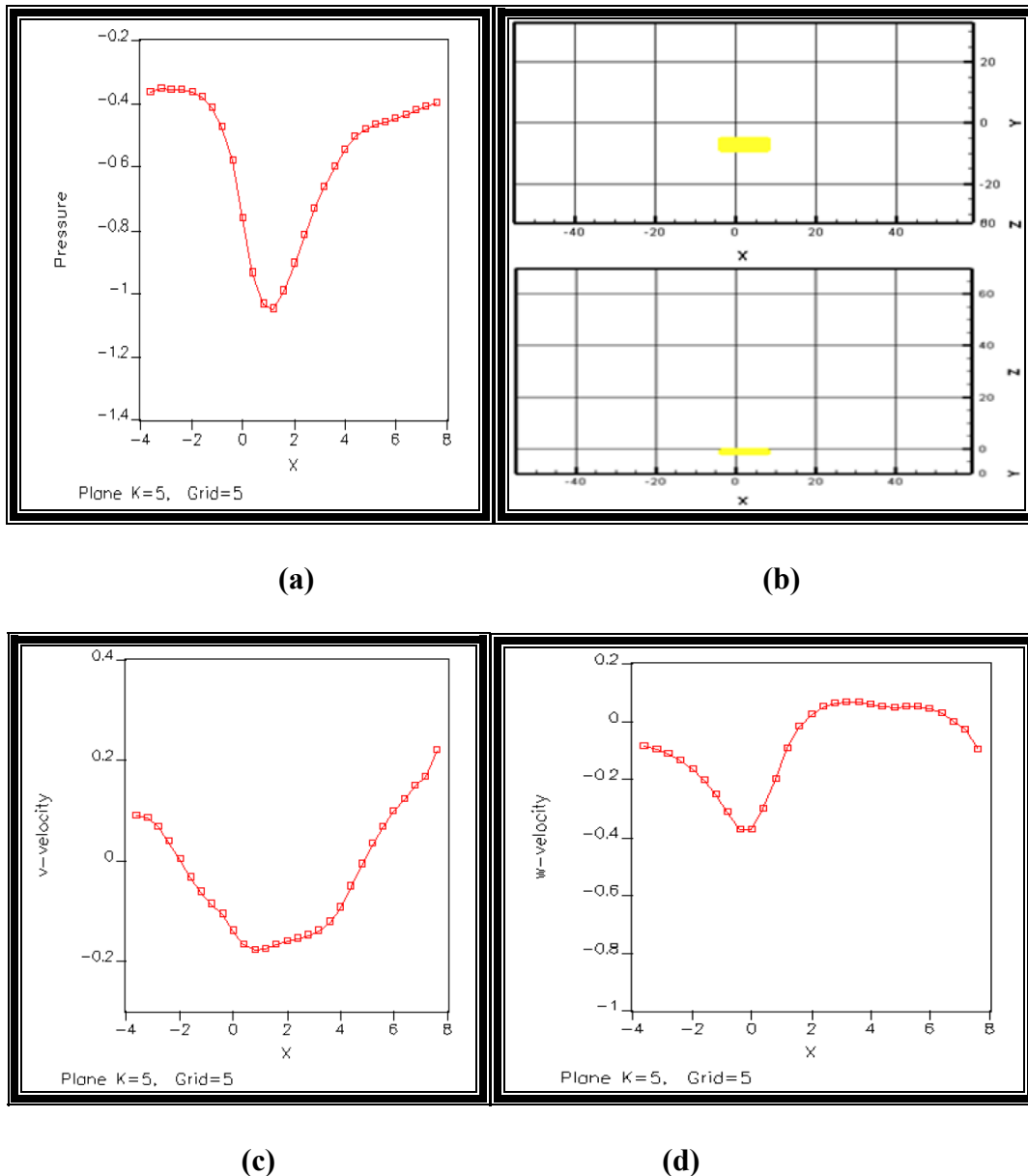


Figure 28. 2-D plots for grid block 5 (a) normalized pressure, (b) normalized coordinates, (c) normalized v-velocity, and (d) normalized w-velocity.

Figure 29 shows a FieldView 2-D plot of the largest grid block number 1. The plots show a sharp gradient on both the pressure and velocity curves near the front of the bed

leveler ($X = 0$). The curves have mild gradients at locations further from the origin. Plane $K = 26$ is at the top of the trench. The coordinates shown are $(Y, Z) = (5.5, 1)$ and X ranges from -60 to 60 .

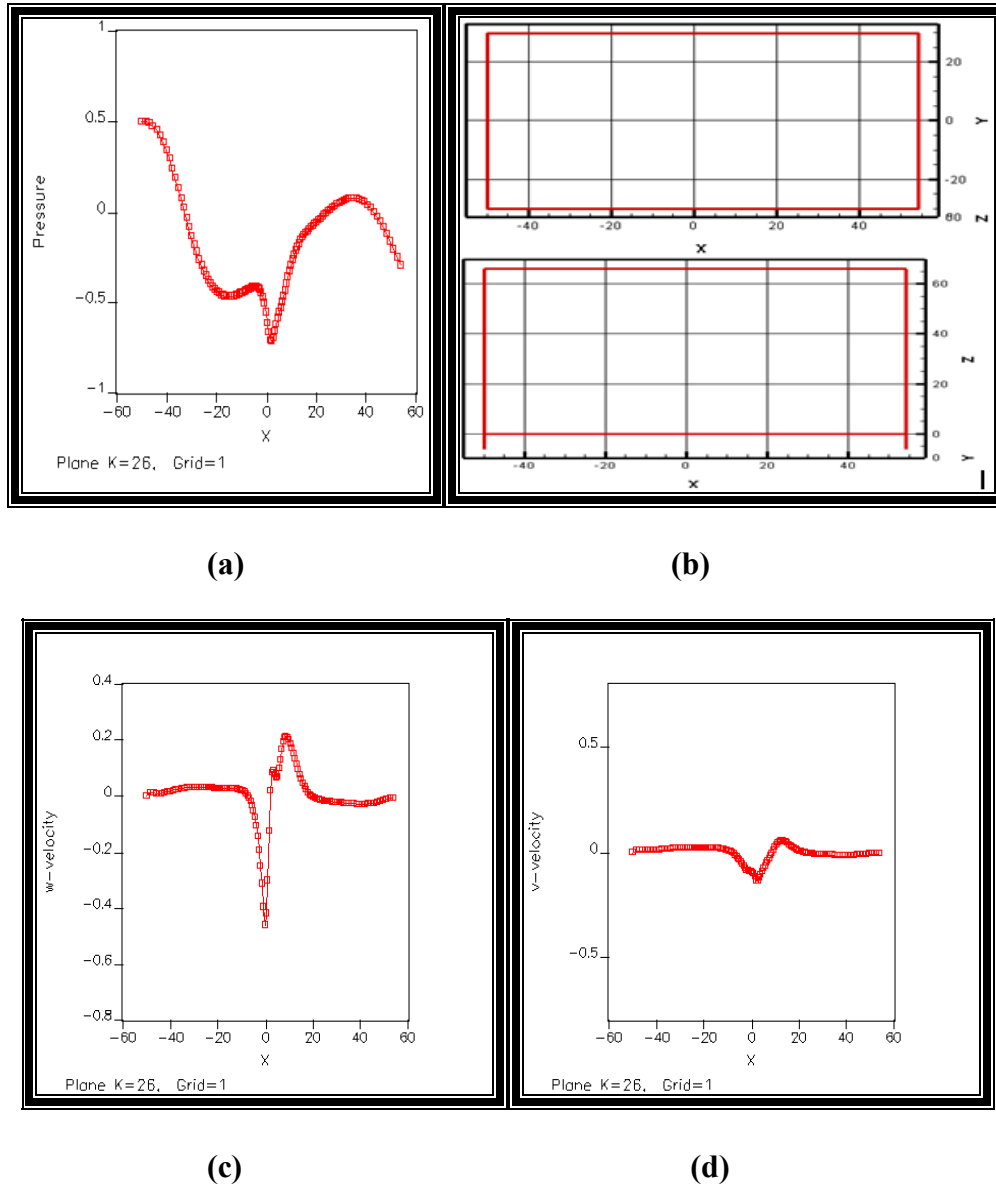


Figure 29. (a) Normalized pressure, (b) normalized coordinates (c) normalized w-velocity, and (d) normalized v-velocity of grid block 1 vertical plane.

The snapshots of the FieldView images used in generating the 2-D plots are shown in Figures 30 to 42 below. The results show flow reversals behind the model bed leveler. The flow accelerates through the trench and on top of the bed leveler. The maximum acceleration occurred in the trench. The movies were played and paused at regular intervals, and then snapshots of the images were taken using the methods described in the experimental results section. More images are required to visualize the evolution of the flow reversal, in space and time, at the vicinity of the trench and the box beam bed leveler along the length of the sand bed.

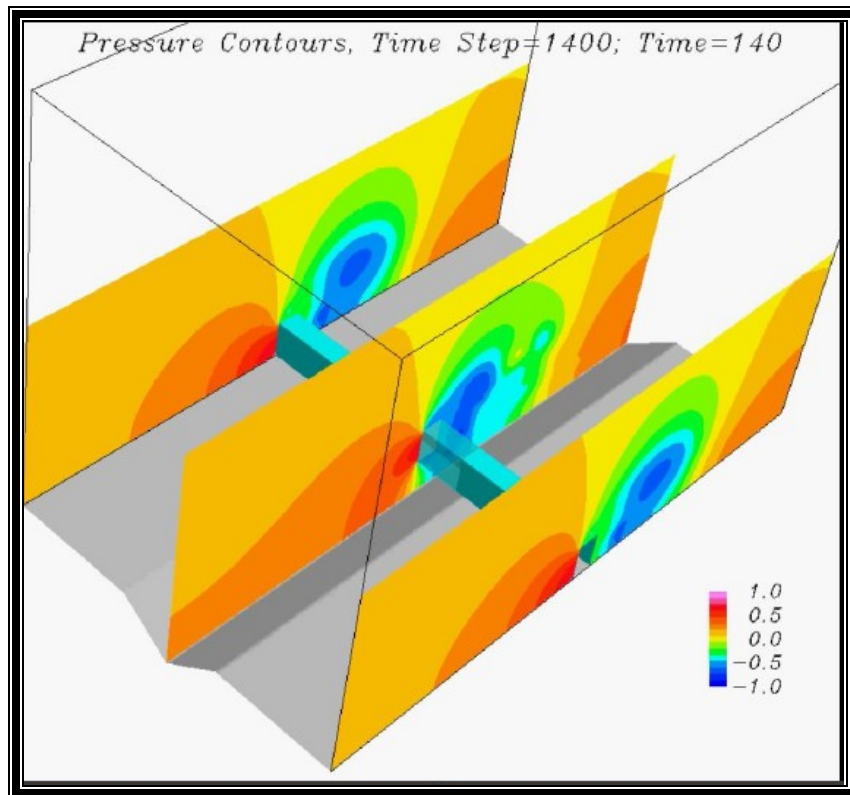


Figure 30. Pressure contours from hydrodynamic modeling at time, $t = 140T_0$ for a constant y-plane (i.e. x-z plane).

Figure 30 shows a 3-D pressure contour at time, $t = 140T_0$ while Figure 31 shows the pressure variations of the same grid blocks at a time, $t = 182T_0$. The figures are drawn for constant y-planes ($y = -0.76$ m, 0 m, and 0.76 m).

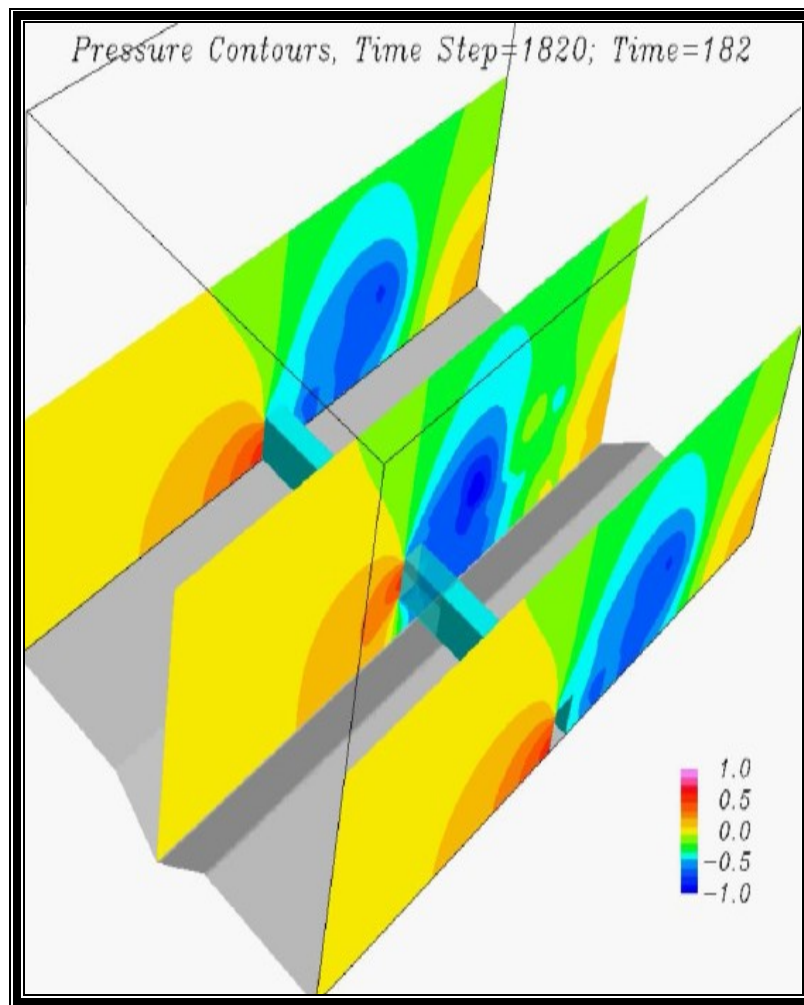


Figure 31. Pressure contours at time, $t = 182T_0$ for constant y-plane.

In Figures 32 and 33 below, pressure contours are shown at time, $t = 104T_0$ and $t = 166T_0$ respectively.

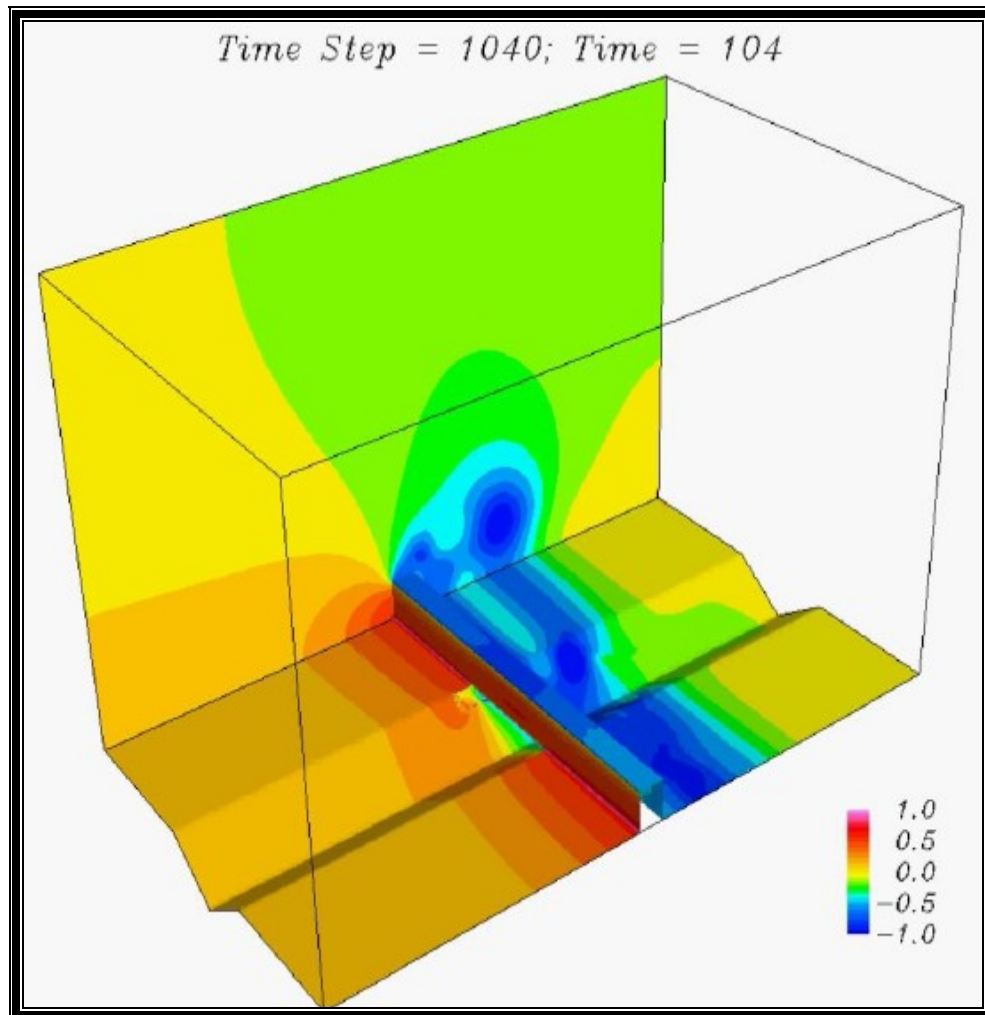


Figure 32. Pressure contours at time, $t = 104T_0$ seconds rotated about the z-axis.

Going from time $t = 104T_0$ to $t = 166T_0$, the negative pressure decreases but extends the wake downstream further away from the bed leveler. This implies an enlarged space behind the bed leveler where negative velocity can be generated

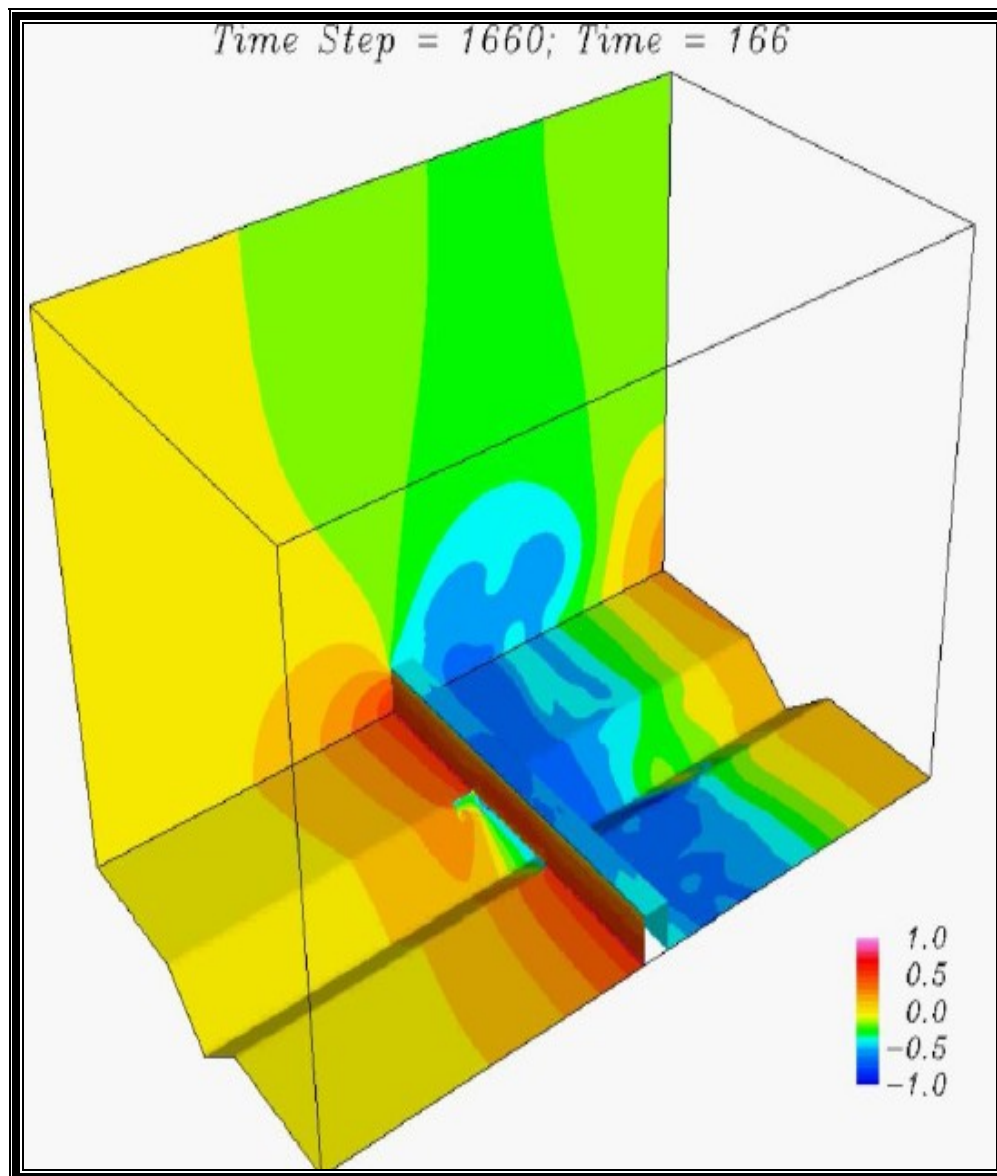


Figure 33. Pressure contours at time $t = 166T_0$ seconds rotated about the z-axis.

Figure 34 is a FieldView image of velocity contours using grid blocks 1 and 2 sliced in three constant y (x - z) planes ($y = -0.76$ m, 0 m, and 0.76 m). The blue- and green-colored segments show the flow reversal or negative velocity, while the magenta, brown and red colors show positive velocity.

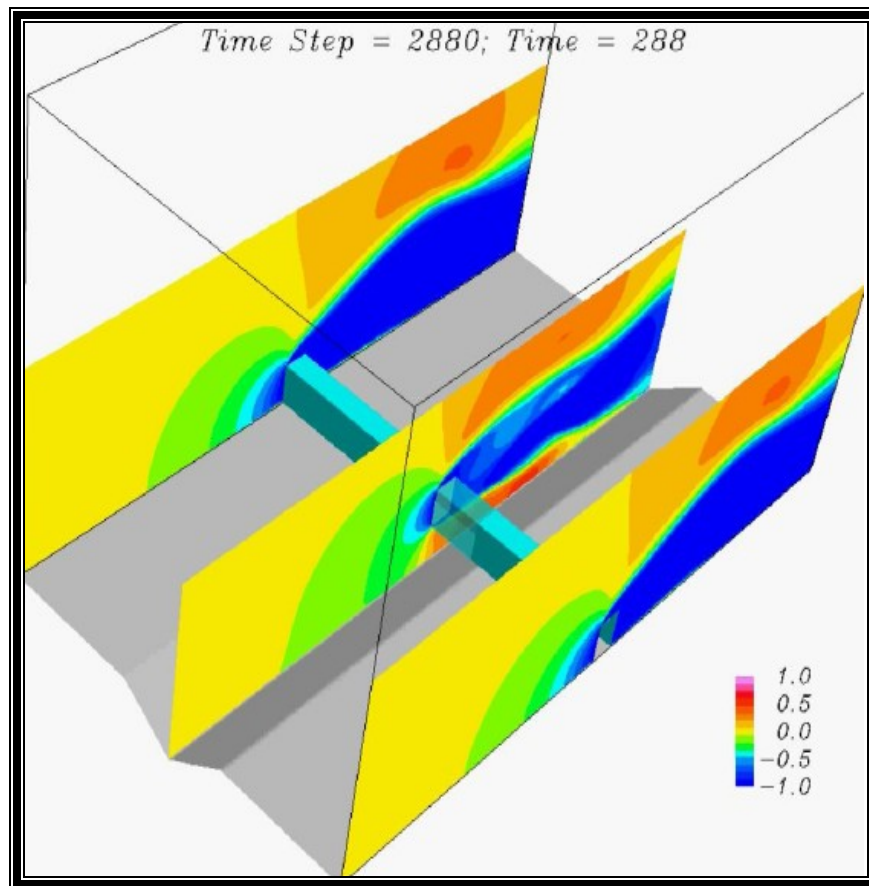


Figure 34. Velocity contours at time, $t = 288T_0$. The image is for constant y -plane.

Figures 35, 36, and 37 are FieldView images of velocity vectors and showing time evolution of the reversed flow. The lengths of the arrows correspond to the normalized velocity magnitude. The Figures (35, 36, and 37) are snapshots at time, $t = 50T_0$, $90T_0$, and $192T_0$ respectively. As the simulation time increases, the wake region is widened, and more negative velocity is generated. The magnitude of flow reversal increases as the model bed leveler moves towards the other end of the sand bed. This is similar to what was observed in the laboratory experiments.

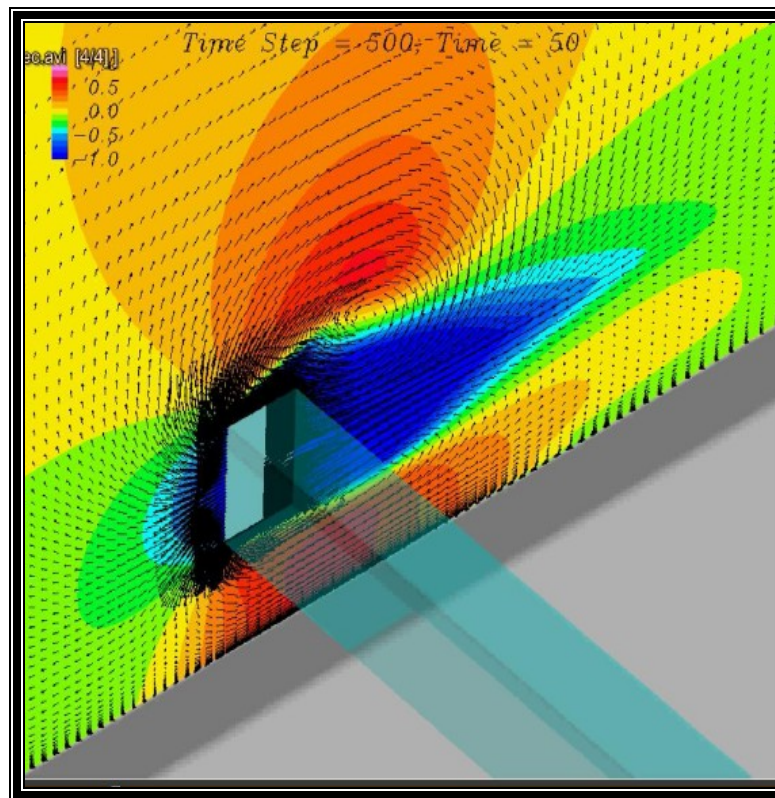


Figure 35. Velocity vectors and contours at simulation time $t = 50T_0$ seconds. The flow separation just created the wake region.

As the simulation progresses from time, $t = 50T_0$ to time $t = 90T_0$, the magnitude of the negative velocity increases. This indicates that the flow in the wake region is experiencing more turbulence as the bed leveler advances towards the other end of the trench.

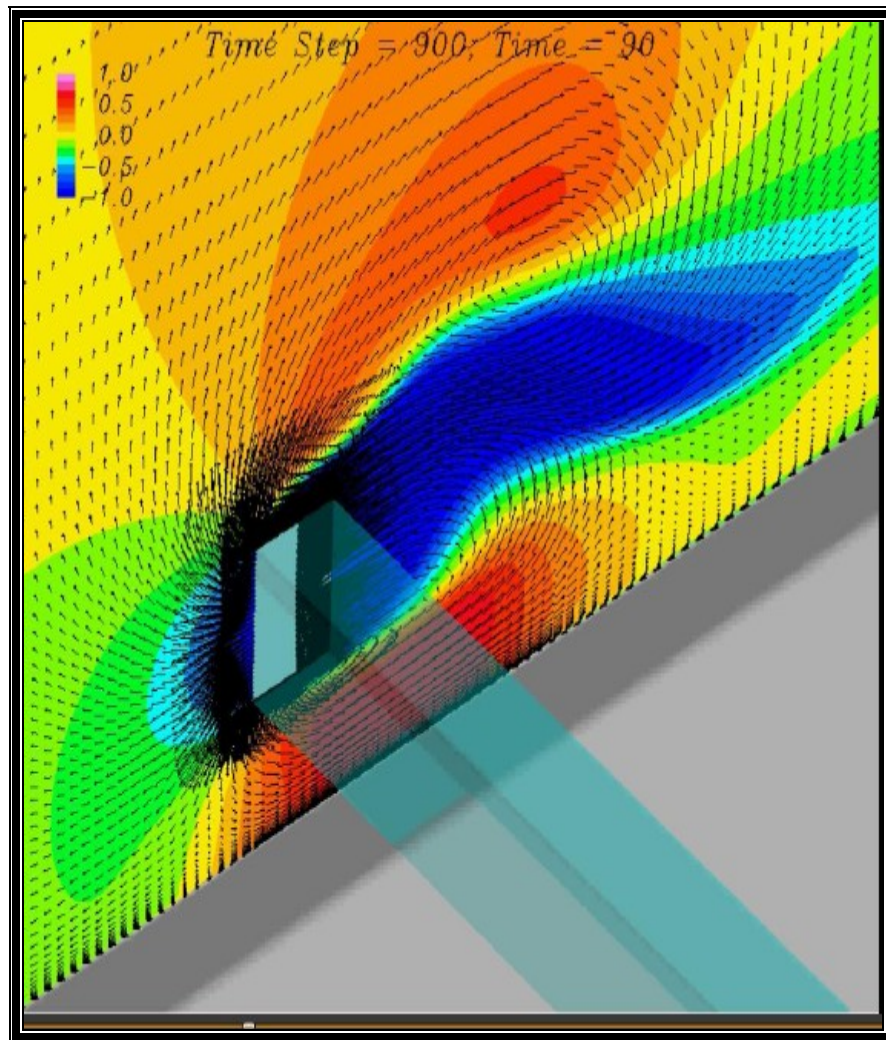


Figure 36. Velocity vectors and contours at simulation time, $t = 90T_0$ seconds showing evolution of reversed velocity.

As simulation time further increases to $192T_0$ seconds, the wake region becomes wider. This aids better visualization of the reversed flow. Vortex shedding starts to occur.

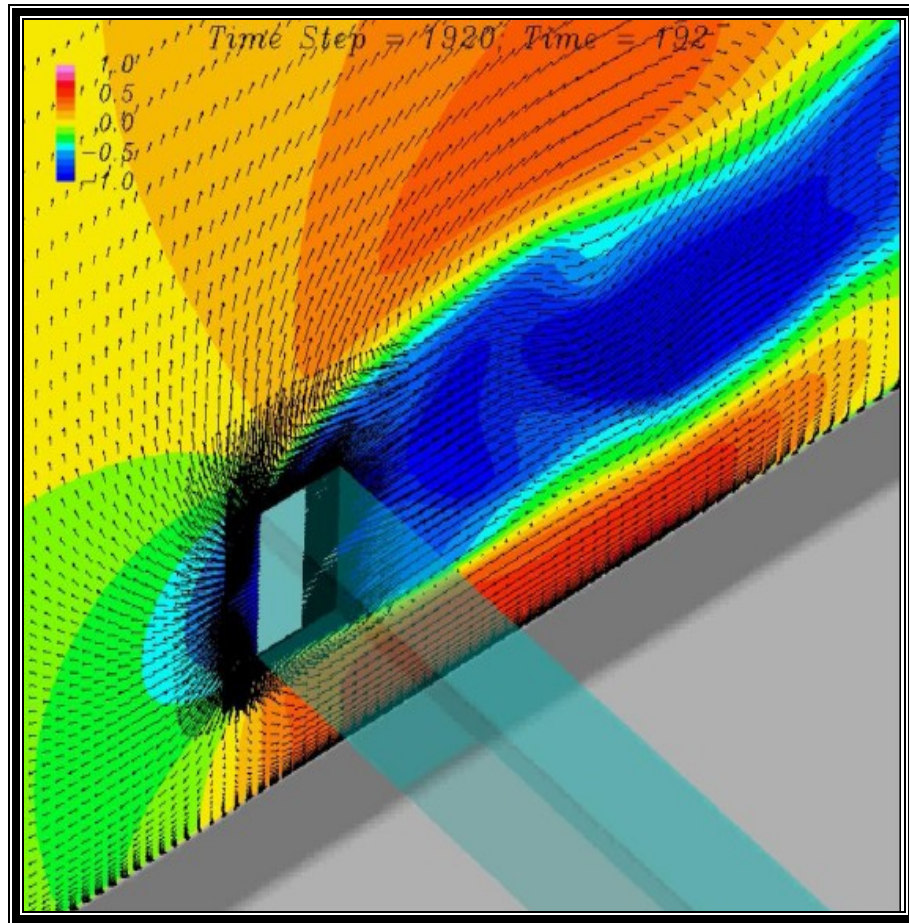


Figure 37. Velocity vectors and contours at time $t= 192T_0$ seconds showing wider wake and larger reversed flow.

Figures 38 and 39 are Fieldview image plots of the vorticity in the y-z plane (i.e. constant x-plane). The snapshots are captured at time, $t = 84T_0$ and $196T_0$ respectively. The plot in Figure 38 shows two counter-rotating vortices.

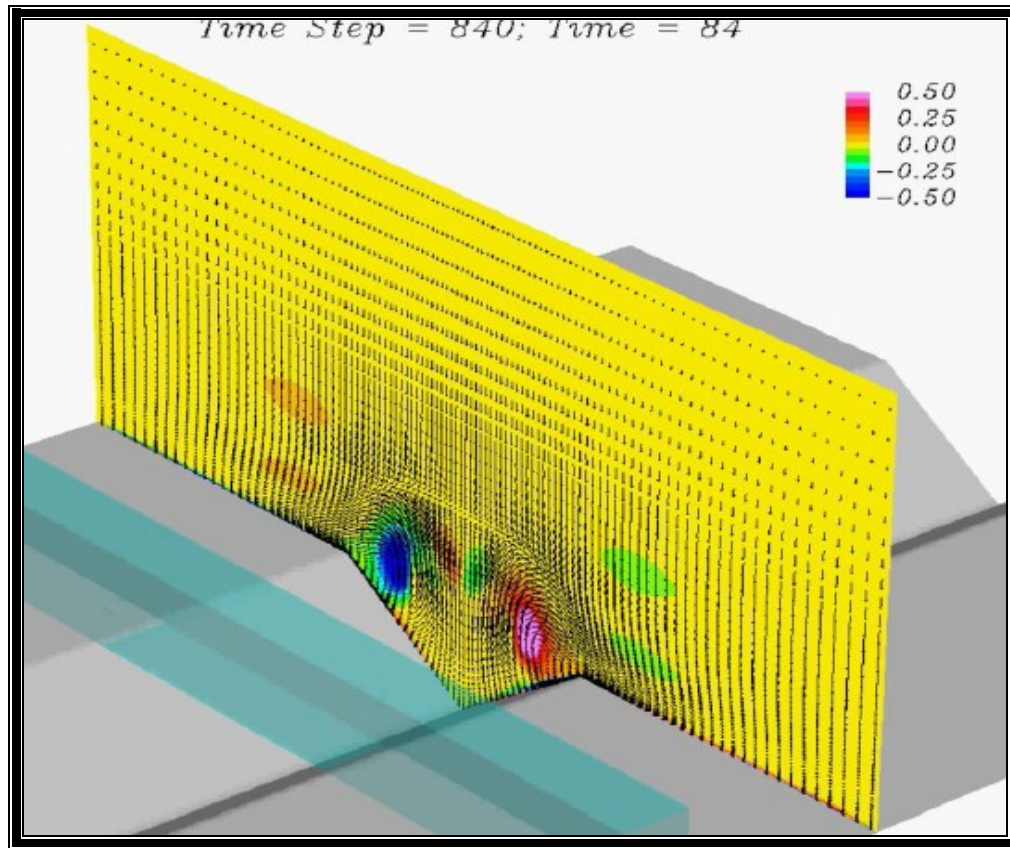


Figure 38. Vorticity in constant x-plane at time, $t = 84T_0$ seconds. The flow just starts to separate.

The two counter-rotating vortices in Figure 38 are likely due to boundary layer effects because the flow just starts to separate. Both the clockwise and anti-clockwise vorticities are confined to the boundary layers. The force gradient was gentle at this time step since the water was stationary at the beginning of the modeling.

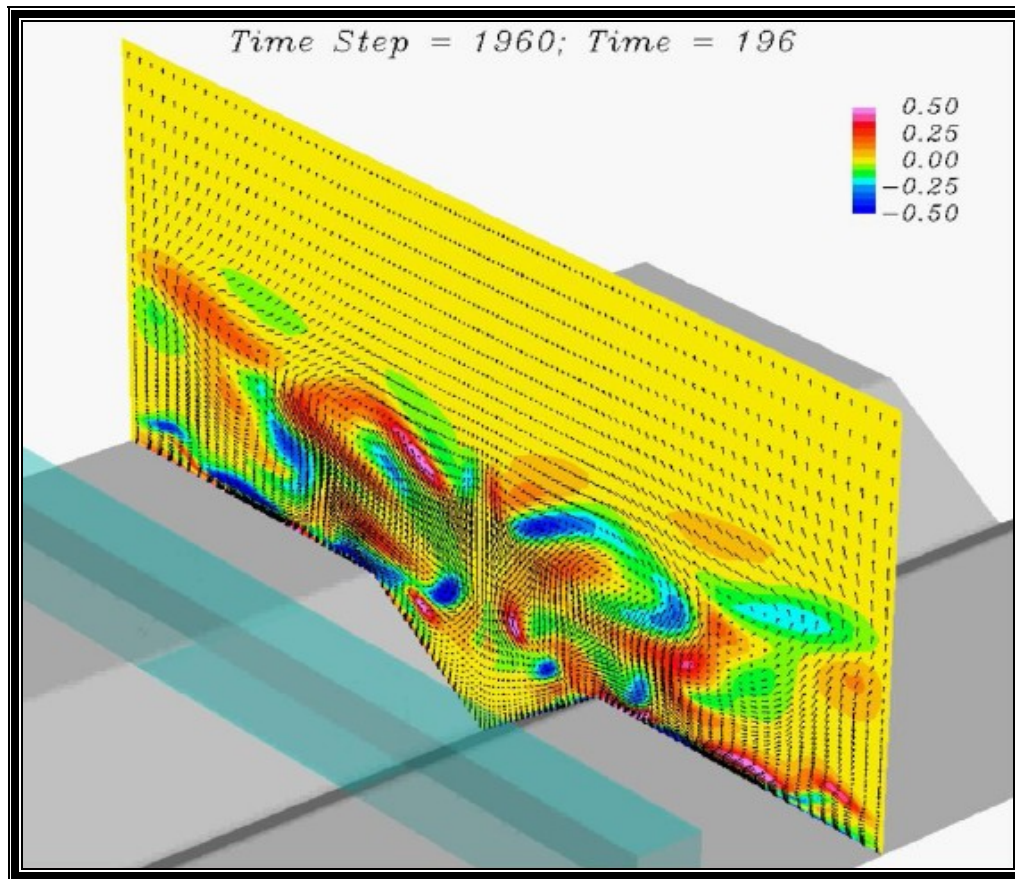


Figure 39. Vorticity in constant x-plane downstream of the box-beam bed leveler at time $t=196T_0$ seconds. The larger force differential created wake region.

As the simulation progresses from time, $t = 84T_0$ to $196T_0$, the magnitude of the vorticity is larger and evenly distributed across the channel as shown in Figure 39. The larger force differential resulted in a steeper gradient between the front and back of the box-beam bed leveler. Eventually, a wake region is created due to adverse pressure gradient or velocity deficit at the back of the moving model bed leveler. The vorticities gained more momentum and the eddies that developed shed.

Figures 40, 41, and 42 show snapshots of evolution of vorticity along constant y (x - z) plane. As the run is advanced as indicated by increase in simulation time, vorticity spreads further away from the bed leveler. This is due to a larger force differential between the front and back side of the bed leveler. The pressure force cannot recover fully after the wake. There is a velocity deficit in the wake region. The reversed flow in the wake region gained more momentum as the model bed leveler continues to traverse the water in the X -direction.

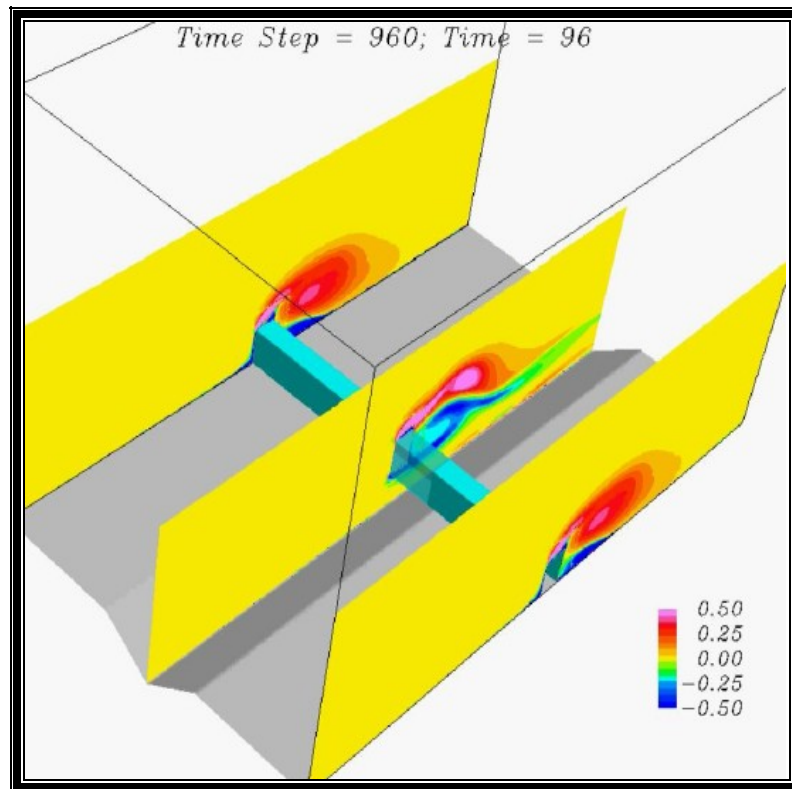


Figure 40. Vorticity in constant y -plane at time, $t = 96T_0$. The vorticity is confined to the boundary layer.

As the modeling run time increases from $96T_0$ seconds to $158T_0$ seconds, the pressure force differentials increase, and vorticity is generated outside the boundary layer as shown in Figure 41. The magnitude of the vorticity in the wake region increased.

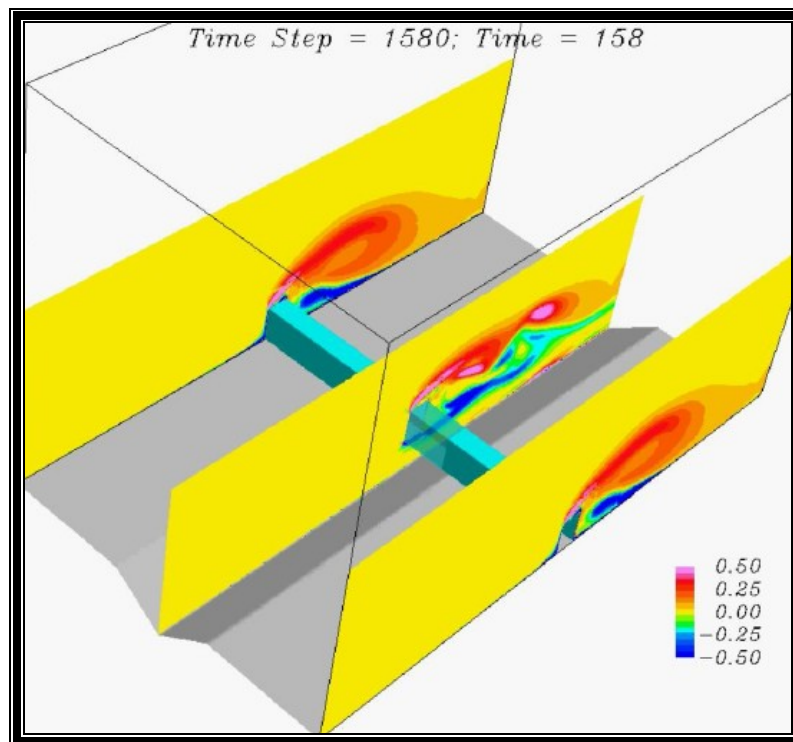


Figure 41. Vorticity in constant y-plane at time, $t = 158T_0$ seconds. The vorticity starts to develop outside the boundary layers.

The vorticity, outside the boundary layer, is more pronounced as the simulation time increases as shown in Figure 42. The flow separated and the wake region developed further downstream of the flow domain. The eddy developed starts to shed.

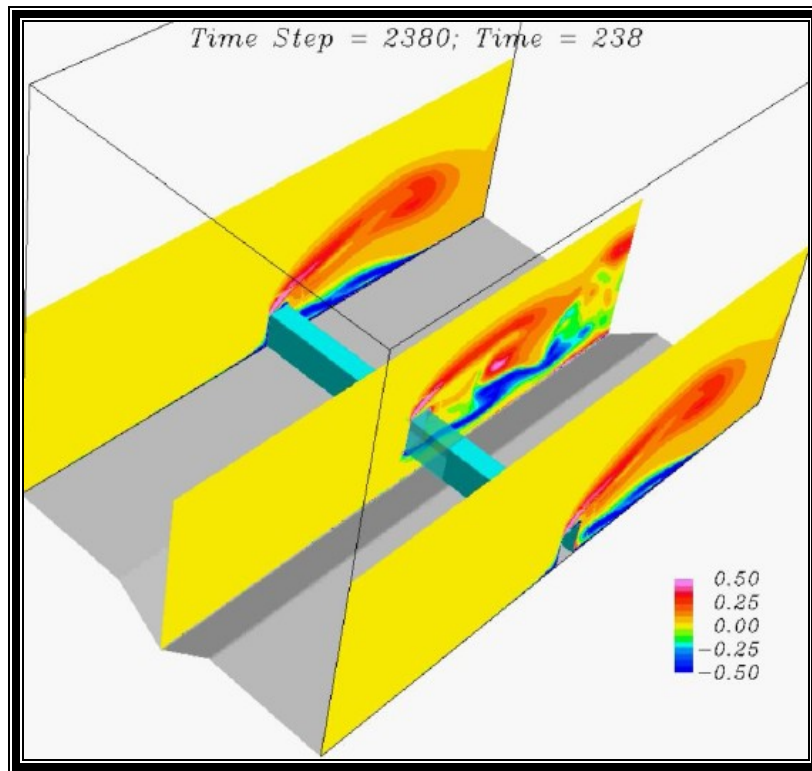


Figure 42. Vorticity in constant y-plane at time, $t = 238T_0$ seconds. More vorticity is generated outside the boundary layer as the wake region increases further downstream. Eddies start to shed.

Figure 43 shows a Tecplot image of a snapshot of the longitudinal velocity vectors and contours. Solutions at the model bed leveler are blanked. The function plotted is the longitudinal velocity, u (named RHO-U in the plot). The constant Y-section is at the deepest part of the trench ($Y = 0$). One solution time step is used for the plot. The navy blue contour color shows where the maximum negative velocity occurred in the simulation. At the front of the bed leveler the velocity is zero (green color). The highest velocity occurred in the constriction (trench). These results are in line with the physics of

fluid mechanics. The coordinate axes in Figure 43 are earth fixed coordinates as done in the physical (laboratory) modeling. Zones 1 and 2 are selected for this plot. The zones represent the individual grid blocks.

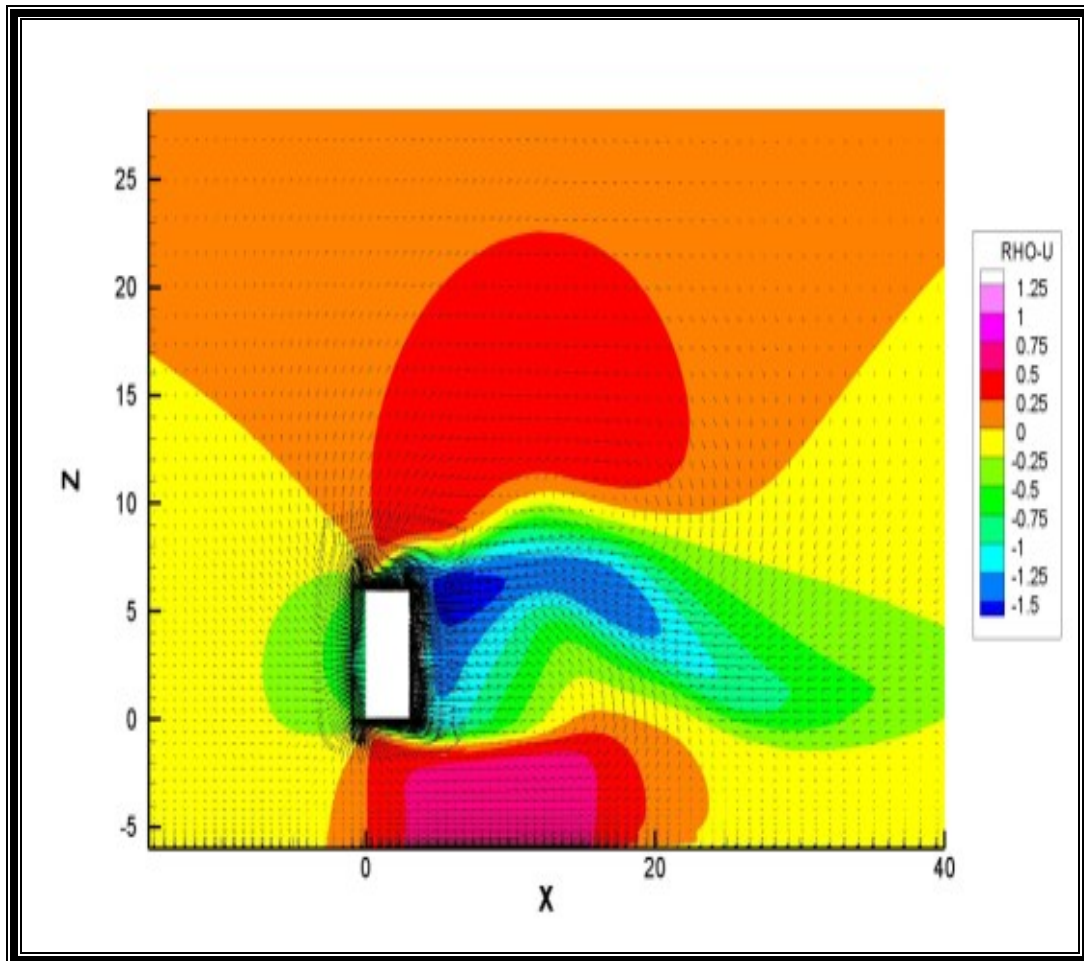


Figure 43. A J-Plane snapshot of longitudinal velocity vectors and contours from Tecplot with earth fixed coordinates.

In order to explain and show clearly how the flow reversed, the model equation for the longitudinal velocity component was modified using the alter equation tool in Tecplot.

The horizontal velocity variable (RHO-U) was modified by adding 1 using Tecplot syntax as shown in equation 5. The new variable is called UU.

$$\{UU\} = \{\{RHO-U\} + 1\} \dots\dots\dots (5)$$

The frame of reference is now a body-fixed coordinate whose origin is at the model bed leveler. The modified equation subtracts the constant speed of the bed leveler from the total flow, and this gives better visualization of the reversed flow in the simulation domain. Figure 43 shows a plot of UU contours and vectors. The time step and spatial coordinates of Figures 43 and 44 are exactly the same.

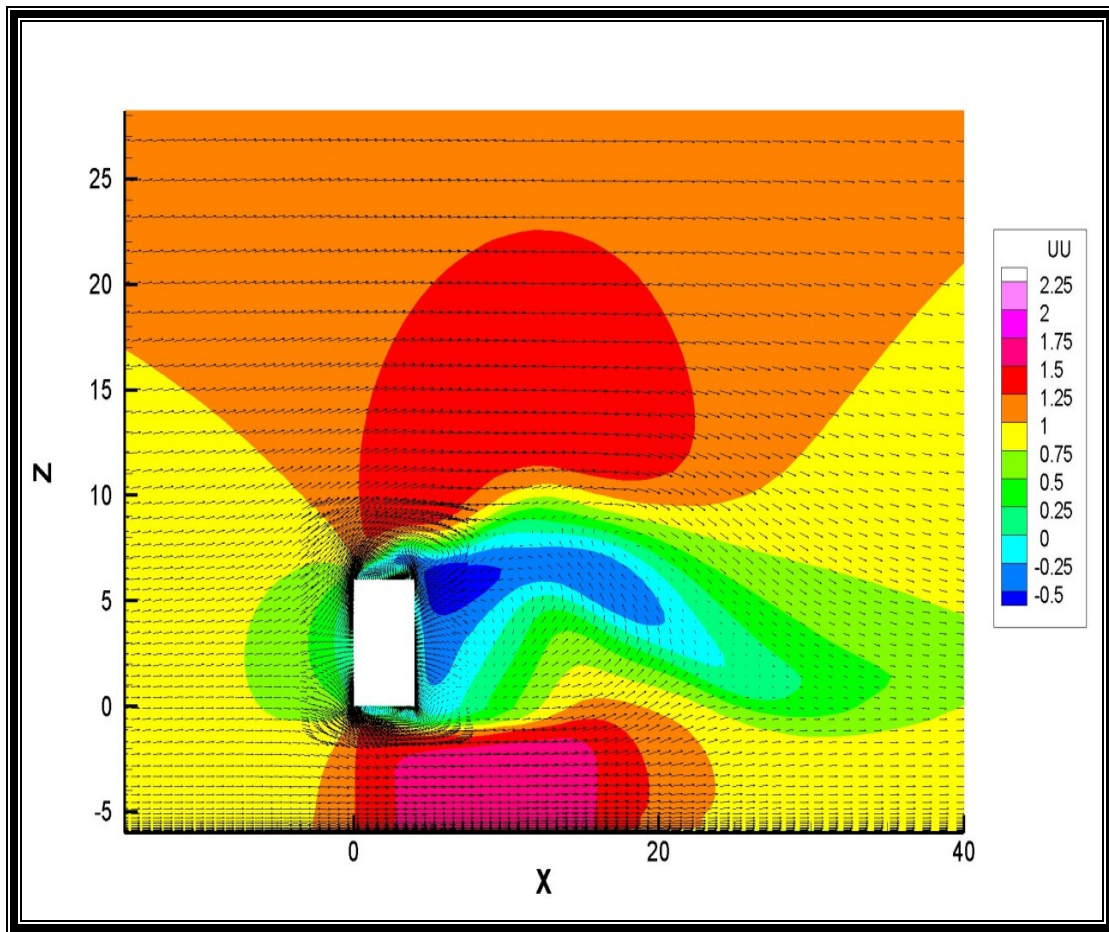


Figure 44. Longitudinal velocity contours and vectors with coordinate axis fixed at the model bed level.

The evolution of the flow in space and time along the longitudinal axis is shown in the different snapshots of the movies from FieldView (Figures 30 to 42). The complete evolution can also be demonstrated in Tecplot by loading solutions at different time steps and cutting sections of the J-plane at different locations.

CHAPTER VI

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Laboratory experiments and numerical model evaluations were used to study the hydrodynamics in the vicinity of a box-beam bed leveler following dredging operations.

In the laboratory experiment, a one-quarter scale model bed leveler was designed and constructed in the Haynes Coastal Engineering Laboratory at Texas A&M University. Other tools and equipment, such as the bed leveler attachment device and the underwater cameras attachment panel, were also fabricated. A trench was created parallel to the longitudinal (X) axis of the dredge tank using the trenching tool. The trench was 0.15 m (0.5 ft) deep and 0.46 m (1.5 ft) wide at the top. The model box beam bed leveler was attached to the lower ladder of the dredge carriage. Two underwater cameras and four lighting bulbs, for flow visualization, were attached to the lower ladder of the dredge carriage. Wires and chain were used to connect the box-beam bed leveler to the upper part of the dredge carriage. The slacking of the wires was used to measure the displacement length of the box-beam bed leveler, from its initial position below the top of the ridges, as the experimental run progressed.

Using Froude number scaling to obtain the desired towing speeds, the dredge carriage, with the box beam bed leveler attached, was moved at two distinct and constant speeds of 0.25 m/s (0.82 ft/s) and 0.5 m/s (1.64 ft/s). Most of the water in the tank moved in a

direction opposite to the direction of motion of the bed leveler while the water in the trench moved in the same direction as the model bed leveler. It was further observed that a wake was created behind the bed leveler. Vortices or eddies developed in the wake region. At the start of each experimental run, the vorticity was confined to the boundary layer because the pressure difference between the front and back of the bed leveler was small. Some sediment in the water column in front of the moving bed leveler were suspended as the model bed leveler advances to the other end of the sand bed.

The hydrodynamic modeling was accomplished in three phases: pre-processing, processing, and post-processing. GRIDGEN and PEGSUS were used to generate a ten-block grid and input data files in the pre-processing phase. Finite Analytic Navier Stokes (FANS) software was used in the numerical simulation or the processing phase. Two commercial softwares, FieldView and Tecplot, were used in the post-processing phase. FieldView and Tecplot were capable of generating the velocity, pressure, and vorticity images as well as some two dimensional plots of the velocity and pressure fields around the model bed levelers.

The FieldView and Tecplot images and plots showed some negative pressure and velocity contours as well as their vectors at different times and locations in the flow domain. Some counter-rotating vorticities were also shown. The vorticity initially developed within the boundary layers and later spread to other regions of the flow

domain. The longitudinal speed of the model bed leveler was subtracted from the total flow (Equation 5) to further describe the reversed flow (Figure 44).

The numerical modeling results compared favorably with the laboratory experimental observations. All the laboratory experimental observations and the hydrodynamic modeling results followed theoretical principles and physical laws governing fluid flows.

Some Acoustic Doppler Velocimeters (ADV) should be installed to measure the velocity in the three dimensions, for the desired range of depth of the box beam bed leveler beneath the height of the ridge, as the bed leveler moves through the sand bed. Three ADVs should be mounted in the trench and the two sides of the ridges. The ADVs could give us precise information about the variations of the velocities at every point of the experiment. It will help us to get better and detailed understanding of the processes and forcing mechanisms of the reverse flow.

More laboratory and field data should be acquired to validate and verify the model results. This will increase our level of confidence in the model results. High resolution underwater cameras and sophisticated visualization instruments should be bought for better visualization of the flow field evolution in laboratory experiments.

REFERENCES

ANAMAR and CH2M HILL, (2005). Draft Biological Assessment for Research and Compilation of Baseline Data for the Use of Bed-Leveling Devices at Port Canaveral Brevard County, Florida. ANAMAR Environmental Consulting, Inc., Report submitted to US Army Corps of Engineers, Jacksonville District, Jacksonville, Florida.

Bray, R.N., Bates, A.D., and Land, J.M., (1997). *Dredging – A Handbook for Engineers*, 2nd ed., New York, Arnold and John Wiley & Sons, Inc., pp. 175 – 177.

Chen, H.C. (1982). *Development of Finite Analytic Method for Unsteady Three-dimensional Navier-Stokes equations*. Iowa City, Iowa: University of Iowa, PhD Thesis.

Dickerson, D.D. (2008). Personal Discussions at Texas A&M University Haynes Coastal Engineering Laboratory, College Station.

Dickerson, D.D. and Clausner, J.E., (2003). Summary of Sea Turtle/Dredging Issues and Recommended Action Tasks. *Improved Draghead Design Meeting, 4 September 2003*, Atlanta, Georgia.

Hales, L.Z. (2003). Bed-Leveling Following Dredging Operations. *Report submitted to Dredging Operations Technical Support (DOTS) Program*, US Army Corps of Engineers, South Atlantic Division, Vicksburg, Mississippi.

Heaps, W. (2001). Dredging and Survey Support in Southampton. *Report of the 7th Workshop on Dredging and Surveying*, Scheveningen, The Netherlands.

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, May 27 – June 1, 2007, Lake Buena Vista, Florida.

Intelligent Light, (2010). FieldView Parallel. *Commercial Post-processing Software*, Rutherford, New Jersey.

Maritime Craft Services (2003). Use of Seabed Leveler behind a Tugboat. *Dredging Supports*, Largs, Ayrshire, United Kingdom. <http://www.maritimecraft.co.uk>.

Mohammed A.R. (1994). A Low Cost Dredging Device: A Laboratory and Field Study. *Terra et Aqua* 54, pp. 22-28.

Munson B.R., Young D.F., and Okiishi T.H. (2007). *Fundamentals of Fluid Mechanics*, 5th ed, Hoboken, New Jersey: John Wiley & Sons.

Premo, A.Y. (2003). South Atlantic Division: Email Communications to Thomas M. Verna, Barry W. Holliday, and Donald L. Pommer, United States Army Corps of Engineers, Vicksburg, Mississippi.

Randall R. E., Henriksen J., Young D., Manikantan A., and Paul E., (2009). Effects of Bed Levelers on Model Sea Turtles in a Laboratory Dredge/Tow Tank, Texas A&M University, College Station. *Final Report*, Submitted to Trap Puckette, Evans Hamilton Inc., Charleston, South Carolina.

Reine, K.J., Dickerson D.D., and Clarke D.G. (1998). Environmental Windows Associated with Dredge Operations. *DOER Technical Notes Collection (TN DOER-E2)*. U.S. Army Engineer Research and Development Center, Vicksburg, Mississippi. www.wes.army.mil/el/dots/doer.

Tecplot Inc. (2005). Tecplot. *Commercial Post-processing Software*, Bellevue, Washington, 98006.

Van de Graaf, C.J. (1987). The Use of Ploughs or Bed Levelers in Maintenance Dredging, *Maintenance Dredging*. Thomas Telford, London, England. Chapter 11, pp.177-195.

Verna T.M. (2003). South Atlantic Division: Email Communications to Angela Y. Premo, Barry W. Holliday, and Donald L. Pommer, United States Army Corps of Engineers.

VITA

Ephraim Udo Paul obtained his Bachelor of Engineering (B.Eng.) degree in Communications Engineering from the Department of Electrical and Electronic Engineering at the Federal University of Technology, Owerri, Nigeria, in April 2004. He did his compulsory National Youth Service Corpse (NYSC) with the Nigerian Army in 2005. He was posted to Yobe Broadcasting Corporation, Damaturu, for his primary assignment. He served as a News Editor for Yobe Koppa Magazine.

In January 2007, he joined Akwa Ibom State University of Technology (AKUTECH), Uyo, Nigeria, as a Graduate Assistant. He won AKUTECH staff development scholarship in August 2007, to pursue a Master of Science and a Ph.D. in Ocean Engineering at Texas A&M University, located at College Station, Texas. His research interests include Marine Dredging and Coastal and Environmental Sediment Processes. He is also working on a program to inform, educate, and entertain Aggies on African diversity. He likes swimming, adventuring and community development services. He is married to Mfon Paul.

Ephraim Paul can either be reached at Ocean Engineering Department, Texas A&M University, College Station, TX 77843-3136, or Akwa Ibom State University, Uyo, 520231, Nigeria. His email address is eupaullo@yahoo.com.