EFFECTS ON CUTTER SUCTION DREDGE PRODUCTION WHILE DREDGING SIMULATED DEBRIS IN THE LABORATORY

R. Randall[1], M. Warwick[2], J. Henriksen[3], D. Young[4], and A. Manikantan[5]

ABSTRACT

The cutter suction dredge is commonly used to excavate sediment in ship channels, rivers, bays and ports. It can work almost continuously while excavating and pumping the sediment (dredged material) through a pipeline to a placement area. Delays and loss of production are a consequence when the cutter encounters debris such as roots that can foul or clog the suction inlet. The objective of this report is to discuss the laboratory test results of a model cutter suction dredge excavating sand with and without simulated roots (rope). The effect of the roots on dredging is compared with that of dredging in sand only to demonstrate the reduced production resulting from fouling the suction inlet located directly behind the cutter back ring. Digital video and still pictures were recorded to show the laboratory dredging operation. The dredge/tow tank and dredge carriage in the Haynes Coastal Engineering Laboratory at Texas A&M University was used to conduct dredging in medium sand (d_{50} = 0.28 mm) without simulated roots and the same medium sand with simulated roots. The results and photographs of the laboratory test for a model cutter suction dredge working in simulated roots show that the simulated roots foul, or clog, the suction inlet very quickly. The results also show the fouling causes the suction pressure to increase, slurry velocity to decrease, and the instantaneous production to decrease. Dredging sand only shows the instantaneous production is approximately 50% more than the instantaneous production measured while dredging sand with implanted simulated roots.

Keywords: Dredging, debris, production, model dredge testing, reduced production, laboratory experiments.

INTRODUCTION

The cutter suction dredge (Figure 1) is commonly used to excavate sediment in ship channels, rivers, bays and ports. It can work almost continuously while excavating and pumping the sediment (dredged material) through a pipeline to a placement area. Delays and loss of production are a consequence when the cutter encounters debris such as trash, roots, or cables that can foul or clog the suction inlet. As an example, the Manson Construction Co. 0.457 m (18 in) suction and 0.407 m (16 in) discharge cutter suction dredge was excavating medium sand in the vicinity of mangrove roots. The cutter severed roots that clogged the suction inlet causing reduced production. The dredge had to be stopped frequently in order to remove the roots from the cutter and the suction intake as shown in Figure 2.

The objective of this paper is to discuss laboratory test results of a model cutter suction dredge excavating sand with and without simulated roots. The effect of the roots (debris) on dredging is compared with that of dredging in sand only to demonstrate the reduced production resulting from fouling the suction inlet located directly behind the cutter back ring. Digital video and still pictures were recorded to show the laboratory dredging operation.

[1] Professor and Director, Center for Dredging Studies, Ocean Engr. Prog., Zachry Dept. of Civil Engineering, Texas A&M University, College Station, Texas, 77843-3136, Tel 979-845-4568, Email r-randall@tamu.edu.
[2] Dredging Production and Estimating Manager, Manson Construction Co., Jacksonville, Florida.
[3] Production Engineer, Manson Construction Co., Jacksonville, Florida
[4] Research Assistant, Ocean Engineering Program, Zachary Department of Civil Engineering, Texas A&M University, College Station, Texas, 77843-3136, Tel 979-845-4515, and Email dyoung@tamu.edu.
[5] Research Assistant, Ocean Engineering Program, Zachry Department of Civil Engineering, Texas A&M University, College Station, Texas, 77843-3136, Tel 979-845-4515, Email arunkumar@tamu.edu.

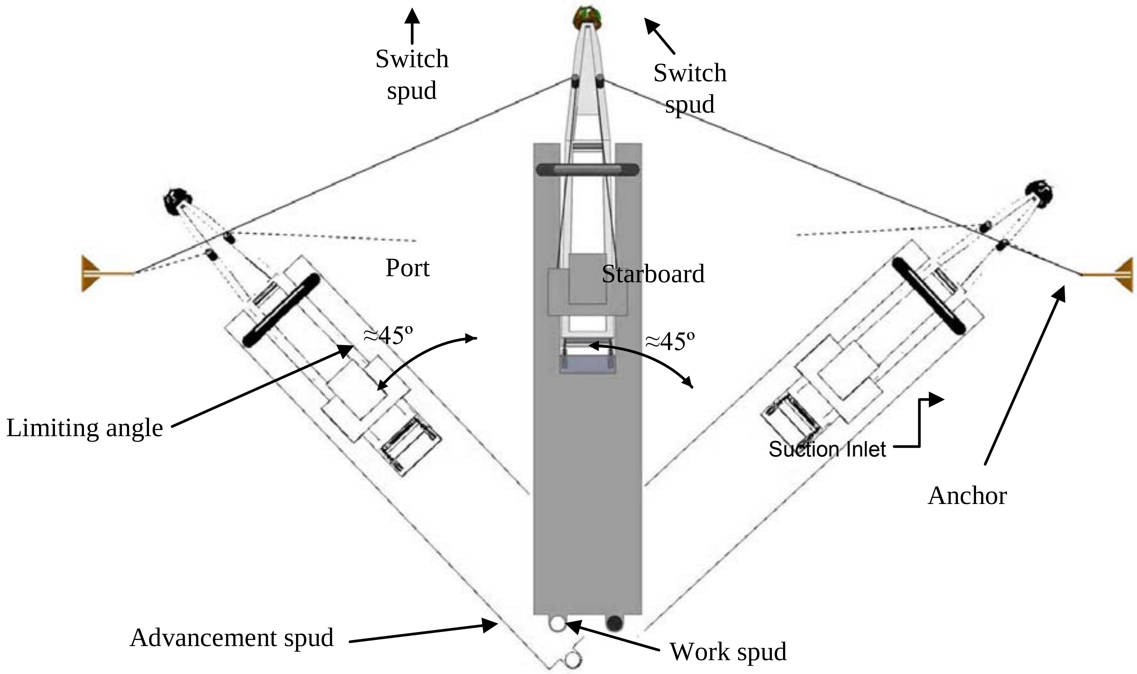

Figure 1. Top view of a cutter suction dredge (Young 2009).

Figure 2. Roots in suction mouth (left), cutter (middle) and being cleaned from cutter (right) (Courtesy of Manson Construction Co.).

LABORATORY APPROACH

The dredge/tow tank and dredge carriage in the Haynes Coastal Engineering Laboratory at Texas A&M University was used to conduct dredging in medium sand (d_{50} = 0.28 mm) without simulated roots and the same medium sand with simulated roots. A schematic of the dredge/tow tank is shown in Figure 3, and a picture of the dredge carriage is illustrated in Figure 4. The cutter shown in Figure 4 has a 26.5 cm (10.5 in) diameter back ring, and the largest diameter is 34.0 cm (13.5 in). The dredge pump is mounted on the carriage and is powered by a 14.9 kW (20 HP) variable frequency drive motor, and the maximum flow rate in liters per minute (LPM) or gallons per minute (GPM) is 2271 LPM (600 GPM).

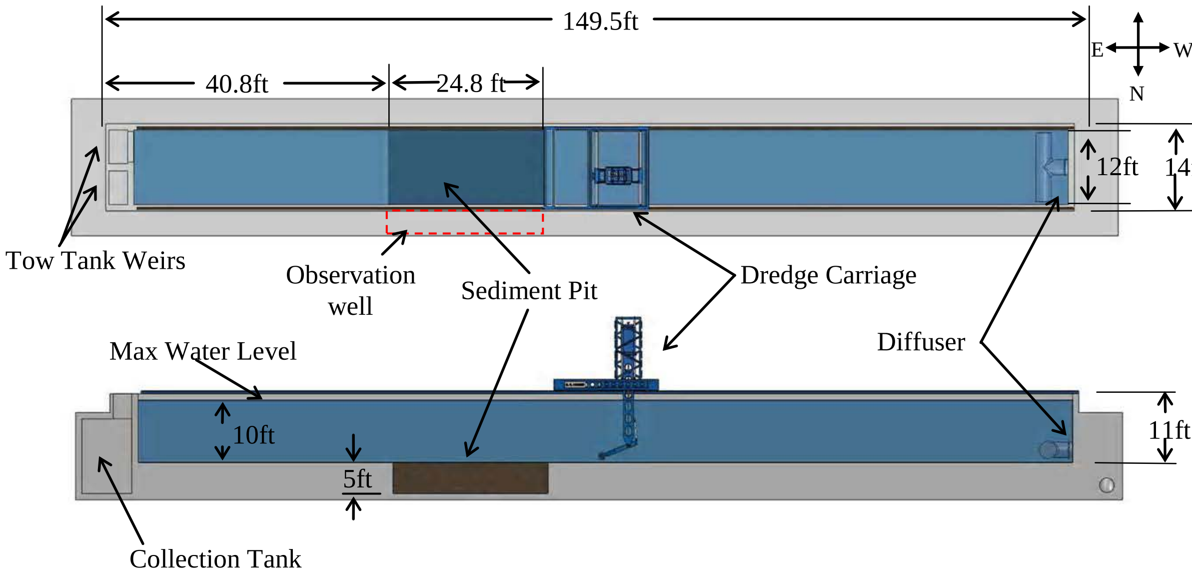

Figure 3. Elevation and plan view of dredge/tow tank in the Haynes Coastal Engineering Laboratory at Texas A&M University (Multiply dimensions by 3.28 to obtain values in meters).

Figure 4. Dredge carriage (left), screened suction inlet (center), and cutter (right).

The prototype dredge has a 0.457 m (18 in) suction and 0.407 m (16 in) with a cutter having a 1.26 m (49.5 in) back ring. The sediment pit in the dredge/tow tank was filled with 1.52 m (5 ft) of medium sand (d_{50} = 0.28 mm). The laboratory dredge has a 10.1 cm (4 in) suction and 7.56 cm (3 in) discharge with a cutter having a 26.5 cm (10.5 in) back ring and maximum cutter diameter of 34.0 cm (13.5 in). The approximate scale ratio (model/prototype) is 1/5. The roots shown in the previous Figure 2 appear to range in size (diameter) from approximately 5.0 cm (2 in) to 0.63 cm (0.25 in). The roots are modeled with 1.1 cm (7/16 in) nylon-polyester fiber ropes that are 30.2 cm (12 in) in length (Figure 5). The model suction inlet was fitted with a screen with 0.473 cm (3/16 in) openings (Figure 5). The flow rate of the laboratory dredge pump is 757 or 1136 LPM (200 or 300 GPM) based upon the critical velocity in the discharge pipeline. The model roots were pushed into the sand to a depth of 0.305 m (1 ft) over a 1.22 m by 1.83 m (4 ft by 6 ft) area according to the template shown in Figure 6, and the model roots were painted with high visibility red paint to make the simulated roots clearly visible. This set-up allowed three dredging cuts for each set-up. The cutter was set to dredge a 15.1 or 20.2 cm (6 or 8 in) deep cut, and the dredge ladder swing rate was 2.52 cm/s (1 in/s). A total of 15 tests were conducted with 11 tests run with sand and simulated roots. Four additional tests were made in only sand so that a standard was obtained to compare dredging in simulated roots to standard dredging in sand without simulated roots. A summary of the dredging tests are tabulated in Table 1.

Figure 5. Rope used to simulate roots (left) and suction inlet screen (right). The scales are in inches which may be converted to centimeters by multiplying by 2.52.

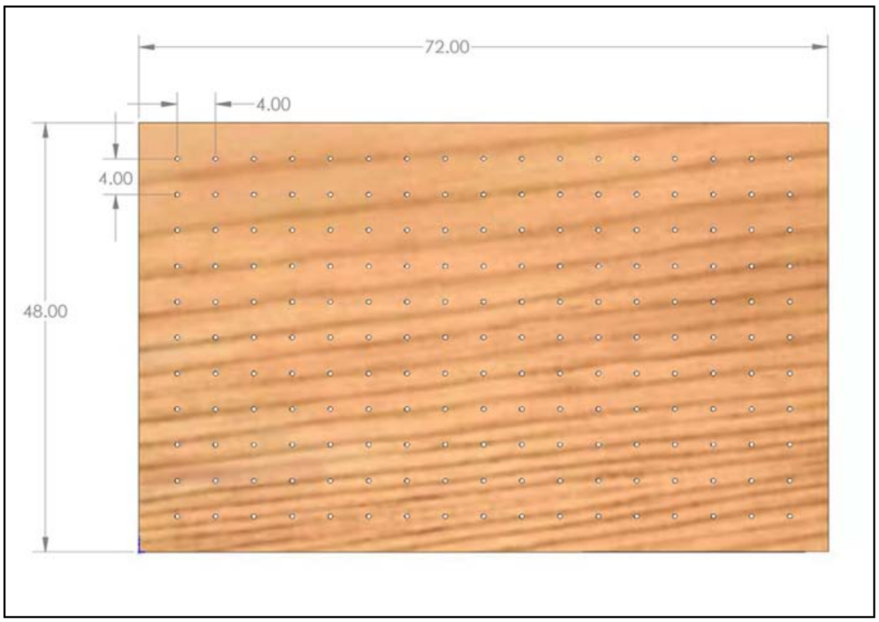

Figure 6. Plywood template used for placing rope in sediment pit. Dimensions are in inches (Multiply by 2.52 to convert to centimeters).

PRODUCTION CALCULATION

The instantaneous production (IP) in cubic yards per hour (cy/hr) is calculated using

$$IP = D^2 V (SG_s - 1) 0.661 \tag{1}$$

where D is the pipe inside diameter (inches), V is the average velocity (ft/s), and SG_s is the specific gravity of the slurry (Turner 1996). The in-situ specific gravity of the sand in the sediment pit is assumed to be 2.1 and the constant (0.661) is a conversion factor that results in the instantaneous production being cubic yards per hour (cy/hr). The instantaneous production is converted to cubic meters per hour by multiplying by 0.765.

Table 1. Summary of dredging cuts.

Cut Number	Date	Flow Rate LPM (GPM)	Cutter Rotation RPM	Depth of Cut cm (in)	Type of Cut	Material
1	7/23/08	757 (200)	30	20.2 (8)	undercutting	Sand and Rope
2	7/23/08	757 (200)	30	15.1 (6)	overcutting	Sand and Rope
3	7/23/08	757 (200)	30	15.1 (6)	undercutting,	Sand and Rope
3A	7/23/08	757 (200)	30	20.2 (8)	overcutting	Sand
4	7/25/08	757 (200)	30	20.2 (8)	undercutting,	Sand and Rope
5	7/25/08	757 (200)	30	20.2 (8)	overcutting,	Sand and Rope
6	7/25/08	757 (200)	60	20.2 (8)	undercutting,	Sand and Rope
6A	7/25/08	757 (200)	30	20.2 (8)	undercutting,	Sand
7	7/25/08	757 (200)	30	20.2 (8)	undercutting,	Sand and Rope
8	7/25/08	606 (160)	30	20.2 (8)	overcutting	Sand and Rope
9A	7/25/08	757 (200)	60	20.2 (8)	undercutting	Sand
10	7/26/08	757 (200)	30	20.2 (8)	undercutting	Sand and Rope
11	7/26/08	1136 (300)	30	20.2 (8)	overcutting	Sand and Rope
12	7/26/08	1136 (300)	30	20.2 (8)	undercutting	Sand and Rope
12A	7/26/08	1136 (300)	30	20.2 (8)	overcutting	Sand

CRITICAL VELOCITY

The critical velocity is the slurry velocity that must be maintained to keep the sand from settling in the discharge pipeline and eventually plugging the pipeline. For the laboratory model dredge, the critical velocity is 1.8 3m/s (6 ft/s) for the 7.6 cm (3 in) discharge pipe (Wilson et al 2006) when pumping sand with a d_{50} of 0.28 mm. The flowrate in the laboratory tests was 757 and 1136 LPM (200 and 300 GPM). The 757 LPM (200 GPM) flowrate corresponds to an average slurry velocity of 2.8 m/s (9.1 ft/s) and is 50% above the critical velocity. The prototype dredge pump has a 45.7 cm (18 in) suction and 40.6 cm (16 in) discharge and the sand being pumped had a d_{50} of 0.4 mm. The critical velocity is 4.27 m/s (14 ft/s) and the velocity for 50% above critical velocity is 6.4 m/s (21 ft/s). The flowrate corresponding to this average velocity is 49,835 LPM (13,165 GPM).

DISCUSSION OF RESULTS

A comparison of discharge pressure, suction pressure, slurry specific gravity, slurry velocity, and instantaneous production are plotted versus time. The effects of the simulated roots are discussed for dredging cut number 3 and 3A that are for a 15.1 cm (6 in) depth of cut at a flowrate of 200 GPM, dredging cut number 4 and 6A that are for an 20.2 cm (8 in) cut and 757 LPM (200 GPM), and cut number 12 and 12A that are for an 20.2 cm (8 in) cut at 1136 LPM (300 GPM).

Dredging Cut Number 3

Cut number 3 is for a 15.2 cm (6 in) cut, pump operating at 757 LPM (200 GPM), cutter rotating at 30 RPM, and working in the undercutting mode (cutter blades cutting up on the sediment in the direction of swing). The material is sand and rope. The dredging swing begins at 6 s, and the swing stops at 25 s due to the breaker tripping. The breaker reset at 120 s, and the swing begins a second time at 125 s. The swing ends at 175 s, and ladder raising begins at 177 s and ends at 237 s. A swimmer observes rope clogging the suction inlet and rope wrapped around cutter hub. The swimmer removes rope from the cutter. The maximum instantaneous production in the first swing is 4.5 m^3/hr (5.9 cy/hr) that occurs at 24 s, and in the second swing, the production is 3.9 m^3/hr (5.1 cy/hr) at 140 s as illustrated in Figure 7.

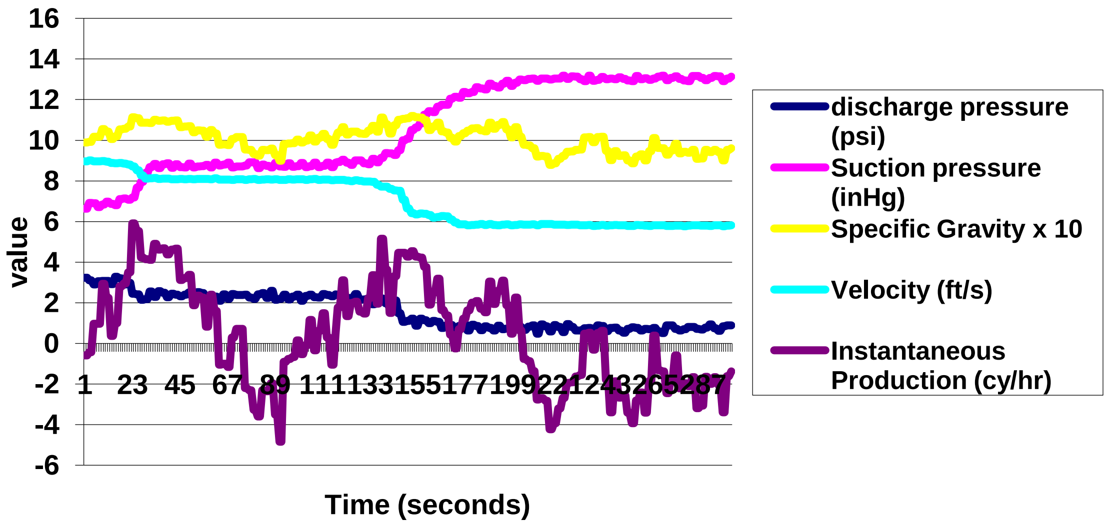

Figure 7. Results from dredging cut number 3.

Dredging Cut Number 3A

For cut number 3A, the pump operates at 200 GPM and the cutter is rotating at 30 RPM. The depth of cut is 20.3 cm (8 in) and the cutter is overcutting. The material being dredged is sand without the simulated roots (rope). The dredging swing begins at 54 s and ends at 106 s when the breaker trips. The breaker is reset at 120 s, and the ladder begins to swing again at 126 s and ends at 170 s. The ladder is raised at 180 s and stopped at 237 s. The maximum instantaneous production is 9.1 m^3/hr (11.9 cy/hr) at a time of 94 s and 9.7 m^3/hr (12.7 cy/hr) at 160 s as shown in Figure 8. The suction pressure remained at approximately 17.8 cm of Hg (7 in of Hg) and the discharge pressure is nearly constant at 20.7 kPa (3 psi). The slurry velocity is also nearly constant at 2.74 m/s (9 ft/s). The production of 9.7 m^3/hr (12.7 cy/hr) is significantly greater than the 4.5 m^3/hr (5.9 cy/hr) value for cut number 3, and thus, it illustrates the reduced production due to simulated roots clogging the suction inlet.

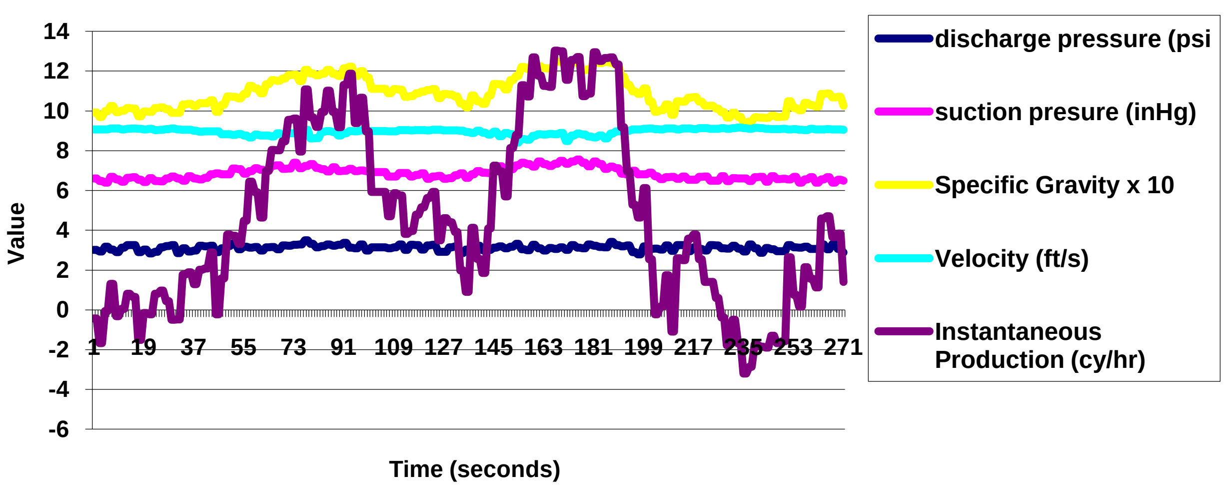

Figure 8. Results from dredging cut number 3A.

Dredging Cut Number 4 (8 inch cut and 200 GPM)

In this test, the model dredge is dredging in sand with 7/16 inch diameter rope imbedded in the sand. The cutter is making a 20.3 cm (8 in) cut, rotating at 30 RPM, and the dredge pump flowrate is 757 LPM (200 GPM). The rope is 30.5 cm (12 in) long and pushed vertically into the sand at 10.2 cm (4 in) intervals using the previously described plywood template. The 10.2 cm (4 in) suction by 7.6 cm (3 in) discharge centrifugal pump was set to operate at a flowrate of 757 LPM (200 GPM) that corresponds to a velocity on 2/74 m/s (9 ft/s) in the discharge pipeline.

During the dredging, the rope simulated root debris in the dredging area. The discharge and suction pressure, average velocity, slurry specific gravity, and instantaneous production data are plotted on Figure 9. The model dredge cutter is lowered to a depth of cut equal to 20.3 cm (8 in) into the sand and rope area and begins its swing at 61 s and stops swinging at 80 s. The swing was stopped due to a breaker tripping on the swing motor. The breaker was reset at 103 s, and the swing begins at 106 s and stops again at 122 s. The dredge began its swing again at 140 s and stopped at 179 s when the dredge reached the edge of the sand and rope area. The ladder is raised beginning at 181 s and stopped at 230 s. A swimmer entered the water to inspect the cutter and take underwater pictures of the simulated roots fouling the cutter and the suction inlet. The photographs showed the rope wrapped around cutter hub and clogging suction inlet.

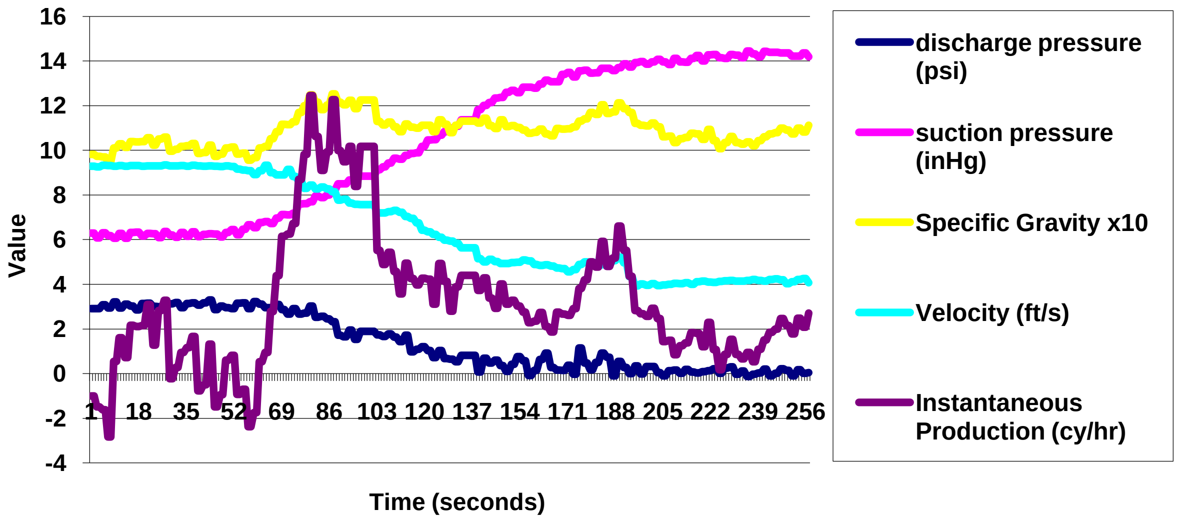

Figure 9. Variation of pressure, specific gravity, average velocity, and instantaneous production during dredging of sand and rope (dredging cut number 4).

The discharge pressure started at 20.7 kPa (3 psi) and began dropping at 70 s to near 0 kPa (0 psi). The suction pressure began at 15.2 cm of Hg (6 in of Hg) and began rising at 70 s to a maximum value of 35.6 cm of Hg (14 in of Hg). The increase in suction pressure is due to the increase in specific gravity of the slurry and the fouling of the suction inlet. The slurry velocity decreased from 2.74 m/s to 1.22 m/s (9 ft/s to 4 ft/s) with the decrease starting at 70 s. The instantaneous production for the model dredge is 9.6 m^3/hr (12.5 cy/hr) at 80 s, 4.1 m^3/hr (5.4 cy/hr) at 109 s, and 3.3 m^3/hr (4.3 cy/hr) at 143 s. The reduction in production from 9.6 to 4.1 m^3/hr (12.5 to 5.4 cy/hr) is attributed to the reduction in average velocity resulting from the fouling of the suction inlet with the simulated roots that is caused by the large pressure drop. The instantaneous production is reduced by ½ once the suction inlet is fouled. The pump was running at a constant RPM and the fouling of the suction inlet resulted in a large energy loss, and thus the average flowrate of the pump output had to decrease as shown in Figure 10.

Dredging Cut Number 6A

In test number 6A, the model dredge was used to dredge sand only in the dredge/tow tank. The dredge pump was set to operate similarly at a flowrate of 757 LPM (200 GPM) that corresponds to a velocity of 2.74 m/s (9 ft/s) in the discharge pipeline. The cutter was rotating at 30 RPM and the depth of cut was set at 20.3 cm (8 in).

The swing began at 90 s and stopped at 115 s when the breaker on the swing motor tripped. The breaker was reset at 126 s and swing began at 128 s and stopped again at 160 s. The breaker was reset again at 169 s. The swing began again at 196 s and stopped at 262 when the cutter reached the edge of the sand area, and the ladder is raised out of the sand. Figure 10 shows the velocity, suction pressure and discharge pressure remained relatively constant during the sand dredging at values of 2.74 m/s (9 ft/s), 17.8 cm Hg (7 in Hg), and 27.6 kPa (4 psi), respectively. The maximum instantaneous production for the sand dredging was 14.8 m^3/hr (19.3 cy/hr) at 126 s and 16.7 m^3/hr (21.9 cy/hr) at 176 s. This production is 1.5 and 1.8 times the maximum production measured when similar dredging occurred with the simulated roots in the dredging area for cut number 4. After total fouling occurred, the instantaneous production is 4.1 and 3.3 m^3/hr (5.4 and 4.3 cy/hr) which is 25% of the sand only dredging instantaneous production as shown in Figure 10.

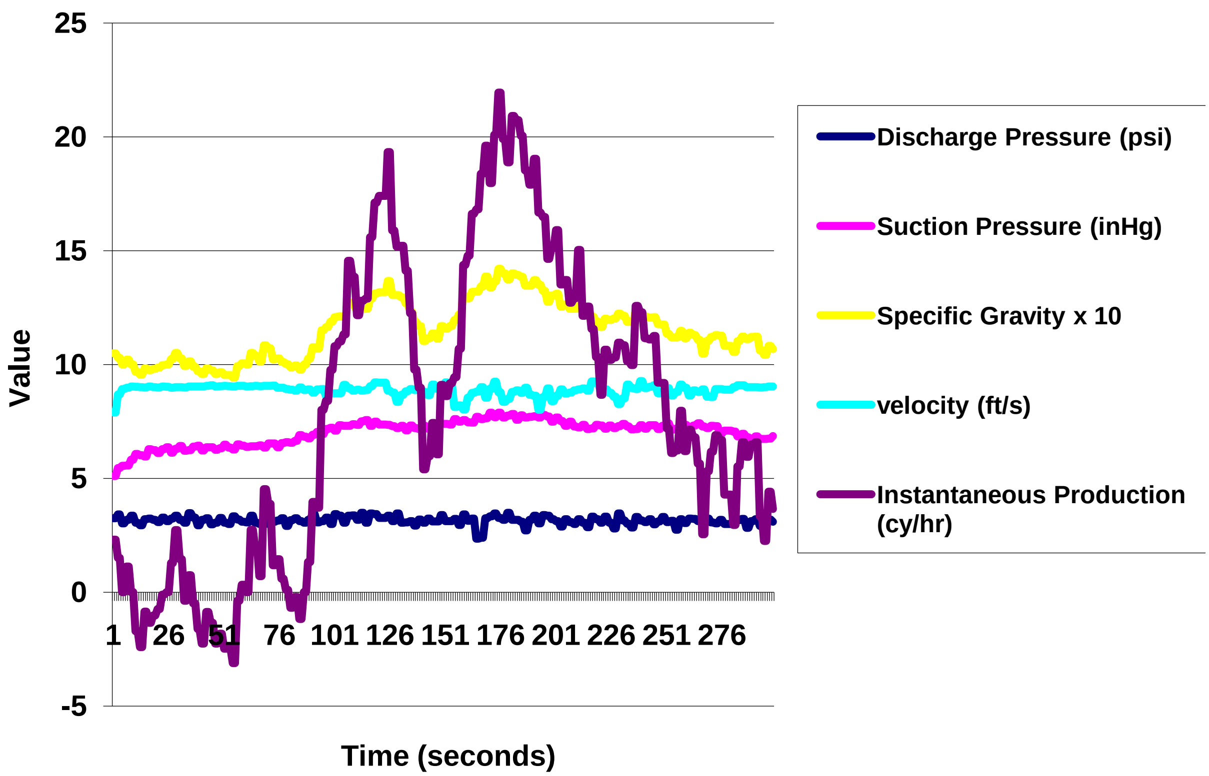

Figure 10. Variation of pressure, specific gravity, average velocity, and instantaneous production during dredging of sand only (dredging cut number 6A).

Dredging Cut Number 12

For cut number 12, the pump was operating at 1136 LPM (300 GPM) and the cutter was rotating at 30 RPM. The depth of cut was 20.3 cm (8 in) and the cutter was undercutting. The material in the dredging area was sand and rope. The ladder swing begins at 119 s and stops at 132 s. The breaker is reset at 144 s. The ladder swing begins again at 146 s and stops at 158 s. The breaker is again reset at 171 s. Swinging begins again at 196 and stops at 230 s, and the ladder is raised. A swimmer inspects the cutter and finds rope jammed in the suction inlet and around the cutter hub. The suction pressure increased from 22.9 cm Hg to 66.0 cm Hg (9 in Hg to 26 in Hg), but the pump remained running this time. The velocity dropped from 4.3 m/s to 1.5 m/s (14 ft/s to 5 ft/s), and the discharge pressure dropped from 55.2 kPa to 6.9 kPa (8 psi to 1 psi). Figure 11 shows the maximum instantaneous production is 5.7 m^3/hr (7.5 cy/hr) at 145 s and 2.4 m^3/hr (3.2 cy/hr) at 230 s. The reduced instantaneous production is caused by the simulated roots clogging the suction inlet and not allowing the sand to enter the suction pipe.

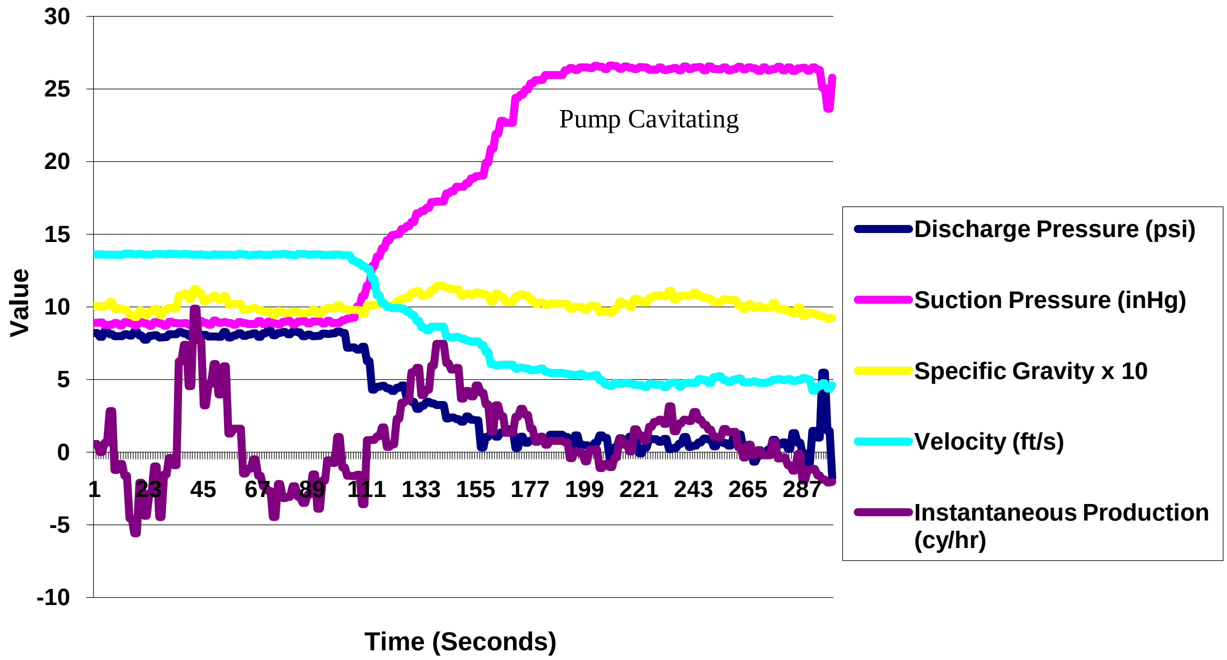

Figure 11. Results from dredging cut number 12.

Dredging Cut Number 12 A

The pump is operating at 1136 LPM (300 GPM), and the cutter is rotating at 30 RPM. The depth of cut is 20.3 cm (8 in) and the cutter is undercutting. The material being dredged is sand only. The ladder swing begins at 118 s and stops at 169 s. The carriage is then advanced. Swinging begins again at 307 s and stops at 433 s. The maximum production occurs at 353 s with a value of 20.0 m^3/hr (26.1 cy/hr). The slurry velocity remains constant. The suction pressure increases slightly with time and the discharge pressure remains constant. Pumping sand without the simulated roots results in a production of 20.0 m^3/hr (26.1 cy/hr) that is much higher than the production under similar pumping conditions that resulted in a maximum production of 5.7 m3/hr (7.5 cy/hr). At the high flowrate of 1136 LPM (300 GPM), the clogging of the suction inlet with roots has a much greater effect on production and causes cavitation

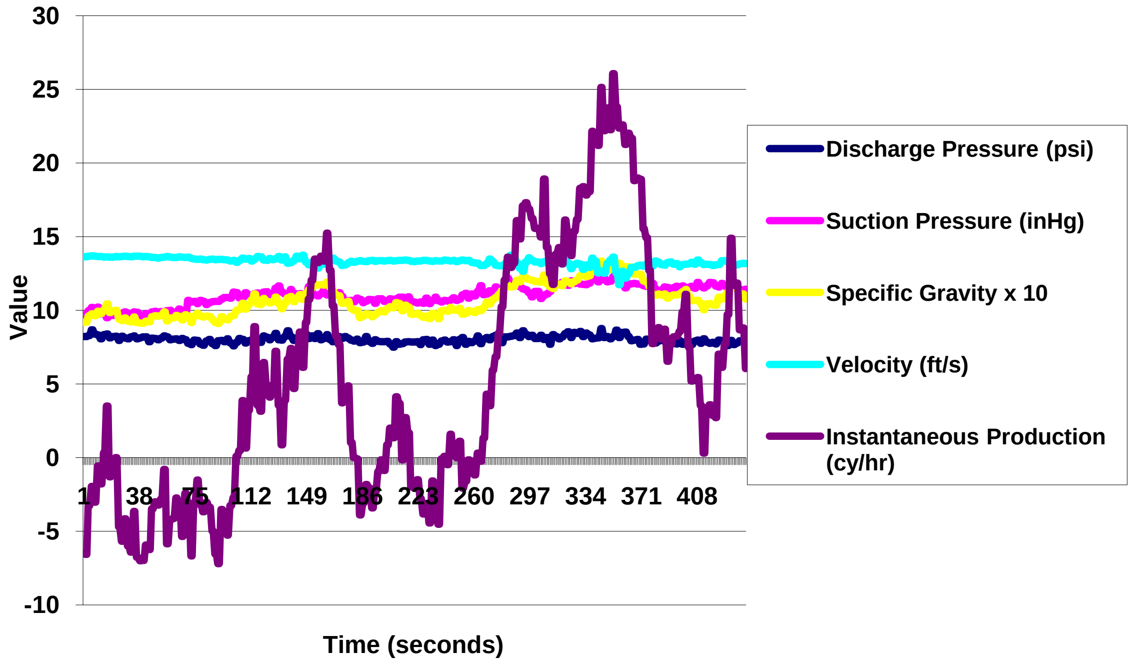

Figure 12. Results from dredging cut number 12A.

Summary

The instantaneous production for all the tests is shown in Figure 13 to illustrate the reduction in production resulting from dredging in a simulated roots and sand area compared to the dredging of sand only. The first three tests are for a 757 LPM (200 GPM) flowrate, and the average instantaneous production for test 2 S&R and 3 S&R is 5.4 m^3/hr (7 cy/hr) while the sand only test (3A S) is 9.6 m^3/hr (12.5 cy/hr). A reduced production of approximately 44% is shown due to the fouling of the suction inlet with the simulated roots (rope). A 20.3 cm (8 in) depth of cut is used for tests 4, 5, 6, 6A, 7, and 8, and test 6A and 9A are for sand only dredging at a flowrate of 757 LPM (200 GPM). The average of the instantaneous production in tests 4, 5, 6, 7, 8, and 10 is 7.4 m^3/hr (9.7 cy/hr) while the average of the sand only dredging (6A and 9A) is 15.4 m^3/hr (20.1 cy/hr). These results show the instantaneous production of sand only is reduced by an average of 52%, and this reduced production is attributed to the fouling of the suction inlet by the simulated roots (rope).

The flowrate of the model dredge pump is increased to 1136 LPM (300 GPM) for tests 11, 12, and 12A. The higher flowrate causes the rope to pack tighter against the suction inlet screen and resulted in a very high suction pressure that likely caused the pump to cavitate. The average instantaneous production is 5.4 m^3/hr (7.1 cy/hr) for tests 11 and 12. For the sand only dredging (test 12A), the instantaneous production is 20.0 m3/hr (26.1 cy/hr). At the higher flowrate, the instantaneous production in the simulated roots is a 73% reduction of the sand only instantaneous production.

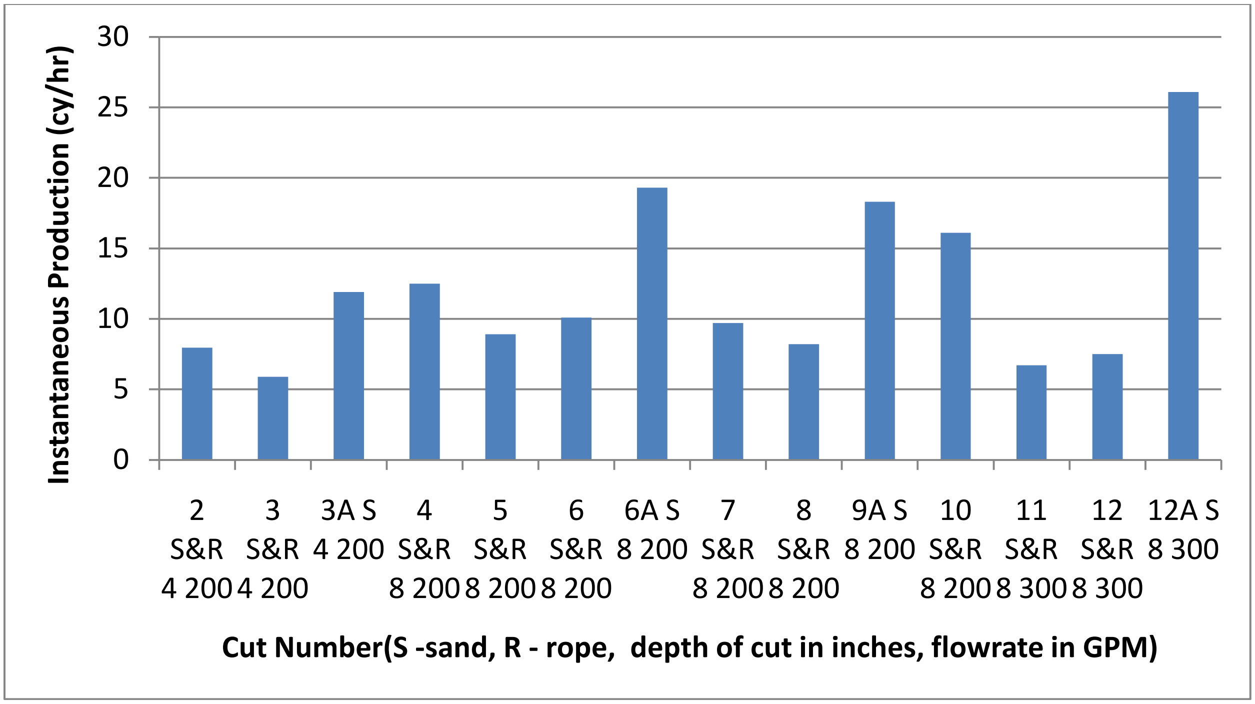

Figure 13. Model dredge instantaneous production of sand with and without rope debris. Multiply instantaneous production by 0.7646 to convert to cubic meters/hr.

Fouling of Suction Inlet Photographs

Underwater photographs were taken by a swimmer at the conclusion of each test to show the fouling of the suction inlet and wrapping of simulated roots around the cutter. Figure 14 shows the screened suction inlet between the cutter blades. When the cutter dredged through the simulated roots (1.11 cm or 7/16 inch ropes), the ropes were sucked onto the screen as shown in Figure 15. The fouling caused the production to drop to approximately 50% of the value when only sand was being dredged. The fouling also caused the suction pressure to increase sharply and the slurry velocity to decrease. If the fouling was severe enough, then the suction pressure could reach a value that would cause the dredge pump to cavitate as shown in dredging cut number 12.

Figure 14. View of screened suction entrance between cutter blades.

Figure 15. Three views of suction entrance clogged with rope.

CONCLUSIONS

The results and photographs of the laboratory test for a model cutter suction dredge working in simulated roots shows that the simulated roots (rope) foul, or clog, the suction inlet very quickly. The results also show the fouling causes the suction pressure to increase, slurry velocity to decrease, and the instantaneous production to decrease. Dredging sand only shows the instantaneous production is approximately 50% more than the instantaneous production measured while dredging sand with implanted simulated roots. Severe blockage of the suction inlet can cause the dredge pump to cavitate and that also further reduces production.

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REFERENCES

Henriksen, J., Randall, R. E., deJong, P., and Sonye, S. "Initial Experiments and Data Acquisition for the Model Dredge Carriage," Proceedings of the World Dredging Congress XVIII, Paper 6C-6, Lake Buena Vista, Florida, USA, May 27 – June 1, 2007.

Turner, T. M., *Fundamentals of Hydraulic Dredging*, Second Edition, ASCE Press: New York, 1996.

Wilson, K., Addie, G., Sellgren, and Clift, R., *Slurry Transport Using Centrifugal Pumps*, 3rd Edition, Chapman & Hall: London, 2006.

Young, D. "Forces on Laboratory Model Dredge Cutterhead," Master of Science Thesis, Ocean Engineering Program, Zachry Department of Civil Engineering, Texas A&M University, College Station, Texas, 77843-3136, December, 2009.