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MODELING WAVE-DRIVEN CHANNEL ACCRETION IN THE LITTORAL ZONE

by

Clayton B. Kendrick-Holmes Jr.

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MODELING WAVE-DRIVEN CHANNEL ACCRETION IN THE LITTORAL ZONE

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ABSTRACT

Cross-shore channels dredged in the littoral zone may be helpful to naval amphibious landing operations. Research and experiments conducted in the U.S. Army Corps of Engineers' (USACE) large-scale sediment transport facility (LSTF) show that these channels fill in due to longshore sediment transport and cross-shore sediment transport. This thesis describes the process of modeling a 2019 experiment conducted in the LSTF with the Surface-water Modeling System (SMS). Waves were modeled with the Steady-State Spectral Wave (STWAVE) model, and sediment transport was modeled using the Adaptive Hydraulics (ADH) model. The main tuning parameter for STWAVE was the bottom friction value, quantified by Manning's roughness coefficient, n. The n values that caused STWAVE wave height outputs to match experimental values were 0.425 in the channel and 0.325 in the rest of the basin. Wave stresses from the STWAVE model were input to the ADH model, along with bathymetry extracted from LIDAR scans of the LSTF, to examine the change in the bathymetry of the LSTF due to sediment transport. The bathymetry output of the model after an initial 20-minute run of waves matched the experiment closely. Several courses of action for future development of the model will contribute to USACE's dredge development and research of channel accretion.

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LIST OF ACRONYMS AND ABBREVIATIONS

ADH	Adaptive Hydraulics
ADV	acoustic Doppler velocimeter
CHL	Coastal and Hydraulics Laboratory
CST	cross-shore sediment transport
ERDC	Engineering Research and Development Center
JLOTS	joint logistics over-the-shore
LST	longshore sediment transport
LSTF	large-scale sediment transport facility
SMS	Surface-water Modeling System
STWAVE	Steady State Spectral Wave
USACE	United States Army Corps of Engineers

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First, I would like to thank God for leading me through this thesis process and causing me to grow immensely this past year. Isaiah 40:31 says, “But those who hope in the Lord will renew their strength. They will soar on wings like eagles; they will run and not grow weary, they will walk and not be faint.” Writing a thesis is a long and often arduous task with many unexpected hurdles, but the Lord truly gave me the strength and wisdom I needed every day to produce the finished product.

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I. MOTIVATION

Joint logistics over-the-shore (JLOTS) operations are crucial to the mission of the United States Navy and Marine Corps team. They allow Marine amphibious landing groups and SEAL teams alike to operate from ship to shore and execute their missions swiftly and effectively. However, amphibious vessel draft limits the scope of JLOTS missions because it restricts the distance from shore at which unloading of vehicles and troops can take place. Simply building vessels with smaller drafts does not solve the problem because they cannot carry as much of a payload. Therefore, the United States Army Corps of Engineers (USACE) is building an offshore-deployable robotic dredge that will be used to cut channels in the littoral zone and allow current amphibious naval vessels to sail closer to shore for JLOTS operations. For this dredging to be effective, operational planners must know how fast these channels fill in based on wave conditions (height and period), channel parameters (width and depth), and bottom conditions (sediment size and bathymetry). This thesis contributes to that knowledge by calibrating a numerical model that can exhibit accretion for any combination of environmental and channel variations. This model sets the stage for researchers to develop an empirical formula or look-up table to indicate the amount of time these channels remain operational, once cut by the dredge in the nearshore region.

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II. INTRODUCTION

A. PREVIOUS RESEARCH

Presently, little is known about how dredged nearshore channels fill in under different wave and current conditions, a process referred to in this paper as "channel accretion." Research on waves and nearshore currents reveals some possibilities. As waves approach the shore, they shoal, meaning that their heights increase and wavelengths decrease. The increase in wave height leads to an increase in wave energy, which is released upon breaking. The water particles moving toward the shore as the waves shoal carry momentum that must be conserved as the waves break. This conservation happens through a momentum flux that occurs perpendicular to the direction of the wave propagation, or parallel to the shoreline for shore-normal waves. Longuet-Higgins and Stewart (1964) explained this phenomenon and defined the momentum flux as a "wave radiation stress." Thornton and Guza (1986) modeled their findings and confirmed them with a comparison to field data. The wave radiation stress creates alongshore currents of water that move sediment in the nearshore region. This movement of sediment by nearshore currents is the main cause of channel accretion.

Two main types of nearshore sediment transport processes contribute to channel accretion: longshore sediment transport (LST) and cross-shore sediment transport (CST). LST is the process of currents moving sediment parallel to the shoreline, while CST is the process of waves and rip currents moving sediment perpendicular to the shoreline. Experimental data collected by Smith et al. (2003) from USACE's large-scale sediment transport facility (LSTF) show that LST is a catalyst for channel accretion in the littoral zone. However, CST also plays a significant role, as shown by the experiments described in the appendix. Waves and wave-induced currents are primarily responsible for accretion of dredged areas-tides do not have much of an effect because they are more of a large-scale phenomenon (Fernández-Fernández et al. 2019).

LST is primarily driven by waves and important to estimating channel accretion rates. According to the 2003 study by Smith et al., two equations are commonly used to approximate LST rate. The first equation, also known as the "CERC formula," comes from USACE's Shore Protection Manual (1984):

$$Q = \frac{K}{16\sqrt{\gamma_b}} \rho g^{\frac{3}{2}} H_{sb}^{\frac{5}{2}} \sin 2\theta_b \qquad (1)$$

Where Q is the submerged total longshore transport rate, K is an empirical coefficient (fit to a local dataset or assumed to be 0.39), ρ is density of water, g is gravitational acceleration, H_{sb} is significant wave height at breaking, γ_b is the breaker index, and θ_b is wave angle at breaking.

The second equation, referred to in this paper as the Kamphuis equation, describes the change in sediment transport rate by taking breaker type (e.g., plunging versus spilling waves) into account (Kamphuis 1991):

$$Q = 2.27 H_{sb}^{2} T_p^{\frac{3}{2}} m_b^{\frac{3}{4}} d_{50}^{-\frac{1}{4}} \sin^{0.6} 2\theta_b \qquad (2)$$

where T_p is the peak wave period, m_b is the beach slope from the breaker line to the shoreline, and d_{50} is the median sediment grain size. Smith et al. simulated sediment movement along a long, straight beach in the LSTF and found that Equation 2 predicted LST well (<25% error), while Equation 1 was off by an order of magnitude in most cases. Another study of longshore transport rates at Galveston Island, Texas proved the inaccuracy of the CERC formula (Rogers and Ravens 2008). The CERC formula is ineffective at predicting LST rates because it does not consider the breaker type by including wave period (Smith et al. 2003). However, it performs much better when the coefficient, K, is calibrated to a local dataset. A 2014 study by Güner and Yumuk comparing LST rates calculated from a model to calculations made by the CERC and Kamphuis formulas proved this. In the study, they made calculations using the uncalibrated CERC formula (K = 0.39) and the CERC formula with a calibrated coefficient (K = 0.08). The uncalibrated formula yielded a 413.9 percent error, while the calibrated formula performed even better than the Kamphuis formula (15.3 percent error), with an error of 6.9 percent. Ultimately, they found that the CERC formula over-predicts LST for beaches with relatively mild slopes (Arı Güner and Yumuk 2014); therefore, the Kamphuis formula is better suited for use with the LSTF.

B. CONDUCTED EXPERIMENTS

Laboratory experiments were conducted at USACE's Engineering Research and Development Center (ERDC) in Vicksburg, Mississippi to better understand how channels cut in the nearshore region fill in. The LSTF, shown in Figures A-1 and A-2 and described in Hamilton et al. (2001), was used to replicate the accretion of two sandy channels of different widths, using two different wave breaker types from Smith et al.'s (2003) original experiments as a control condition. The LST rates were known for these two wave conditions; therefore, adding channels would allow channel accretion rates to be compared to LST rates. The experimental conditions are shown in Table 1.

Table 1. Wave conditions and channel widths for June 2019 LSTF experiments

Experiment	Channel Width (ft)	Scaled Wave Height (cm)	Wave Period (sec)
A	3	25	1.5
B	3	23	3
C	9	23	3

The waves in experiment A were spilling breakers and the waves in experiments B and C were plunging breakers. The scale of the experiments was 1:15.

The experimental set-up was the same as Smith et al. (2003), and is described in the appendix. Waves were run for 20 minutes at a time, the basin was emptied, and a survey was taken in the center of the channel at 31 cross-shore locations to quantify channel accretion. After this, the basin was filled again and the process was repeated. The original hypothesis was that LST would be the primary cause of channel accretion. This seemed to be the case after initial observations; the channel filled in and migrated slightly in the alongshore direction. A similar phenomenon occurred in another experiment conducted in the LSTF, where a mound of sediment placed in the nearshore region moved alongshore due to longshore currents transporting suspended sediment (Smith et al. 2017). In addition, a field experiment off the coast of central California showed channel migration in the presence of LST (Orzech et al. 2010). However, to confirm this, the data still had to be analyzed using MATLAB, a process also described in the appendix.

The experimental data showed that CST was actually the main cause of channel accretion. LIDAR scans of the basin after each run of waves revealed a large area of erosion on the part of the shore that the waves were hitting and disturbing sediment, as seen in Figure 1. Research on the impact of CST on beach profiles gives insight to this experimental result. Just as LST, CST takes two forms, suspended transport and bed load transport. Suspended transport is the movement by currents of sediment suspended in the water column, and is represented by Equation 3 (Kobayashi et al. 2005):

$$q_{off} = 0.9\overline{V}\overline{U_0} \tag{3}$$

where q_{off} is the offshore CST rate, $\overline{V}$ is the suspended sediment volume per unit area, and $\overline{U_0}$ is the depth-averaged offshore mean current velocity.

A 2002 study by Wang et al. (2002), conducted in the LSTF, showed that suspended sediment concentration decreases from the seafloor to the surface throughout the surf zone. Furthermore, they also noted that wave-induced, cross-shore currents flowed onshore in the upper water column and offshore in the lower water column, a process called undertow. This undertow probably deposited wave-suspended sediment into the channel through suspended load transport.

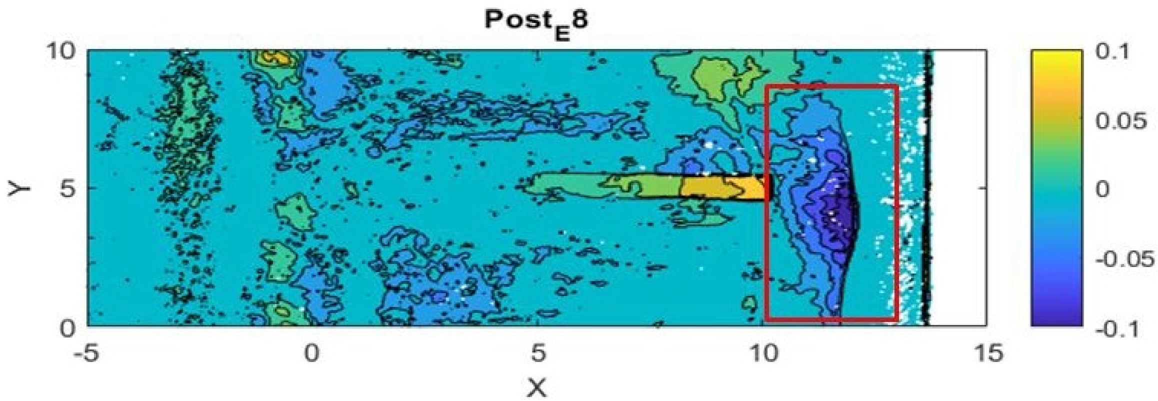

Figure 1. Source of the cross-shore contribution to channel accretion

Bed load transport is the movement of sand along the sea floor. It is quantified by Equation 4, which describes bed load transport rate, q_b, in the direction of wave propagation (Kobayashi et al. 2008):

$$q_b = bP_b\sigma_U{}^3 / [g(s-1)] \tag{4}$$

where P_b is the probability of sediment movement, σ_U is the standard deviation of the horizontal current velocity, g is the gravitational acceleration constant, s is the sediment specific gravity, and b is the bed load parameter, which includes the small-scale sediment dynamics that the formula rejects and is equal to 0.002.

The initial shape of the channel most likely contributed to infilling by bed load transport. The edges of the initial cut for the experiments were sharp and steep, as seen in Figure 2, which increases probability of sediment movement in Equation 4 (Kobayashi et al. 2008). According to a study by Moulton et al. (2014), downslope, gravity-driven sediment transport was a direct cause of the accretion of excavated holes. It likely contributed to channel accretion in the LSTF experiments as well, through bed load transport.

Figure 2. Initial cut of the 9-ft. wide channel for experiment C

Another contributing factor to channel accretion was likely a rip current induced by the manmade channel. Rip currents are jets of water that flow rapidly offshore from the surf zone, and are normally induced by wave refraction over irregular bathymetry (Dalrymple et al. 2011). This description fits the set-up of the LSTF experiments: waves originated at the wave maker at a 10-degree angle, and refracted once they reached the surf zone, where they encountered an irregularity in the beach bathymetry. The channel in the nearshore created a gradient that drove alongshore currents to converge in the channel and form an offshore rip current (Moulton et al. 2017). The rip current then likely transported wave-suspended sediment offshore, into the channel (Aagaard et al. 1997), contributing to accretion alongside the process of undertow.

Ultimately, the 2019 LSTF experiments, described in the appendix, augmented understanding of channel accretion in the littoral zone, giving insight into the processes that contribute to channel accretion. However, the goal of this thesis work is not to add to the body of research on sediment transport, but to accurately model channel accretion.

Research on sediment transport can give more insight into tweaking the model later in the process, but the groundwork must first be laid to numerically model the channel accretion experiments from the LSTF. This is because the process of cutting the channel by hand and emptying the basin after each run of waves to collect survey data took too long, about a week on average. USACE needs a tool (look-up table/plot with accretion rate for different wave conditions and channel widths or correction factor to Equation 2) that can be used operationally with the dredge to predict channel accretion. A vast number of operational environments and wave parameters are encountered when planning JLOTS operations, so many more experiments must be conducted to predict channel accretion under these conditions. Executing these experiments in the lab would set the dredge project back years, which is why a numerical model of the LSTF must be developed.

C. PROPOSED WORK

While experiments are excellent in that they depict the real world under specific conditions, numerical modeling can augment these observations by extending the wave parameter space. By numerically modeling the LSTF, research engineers with USACE can experiment with many more wave conditions and channel sizes to develop a better understanding of channel accretion. A basic model of the LSTF bathymetry has already been developed in the Surface-water Modeling System (SMS), which provides data visualization for a wide variety of coastal and riverine applications. However, the model does not currently include a channel, which this thesis adds by modifying the bathymetry data. In addition, this thesis inserts the other aspects of the 2019 LSTF experiments to the model, namely wave forcing and bathymetric evolution. This is accomplished by coupling the Adaptive Hydraulics (ADH) circulation and sediment transport model (Savant et al. 2020) with the Steady State Spectral Wave (STWAVE) model in SMS.

The main concern with using a numerical model is that an inaccurate model produces inaccurate or misleading results. Therefore, the goal of this thesis is to validate the improved LSTF model by comparing the output data to the results of the 2019 experiments, and adjusting the model parameters accordingly until the results closely align. A similar process was completed in a study of the LSTF, in which the EBED numerical model was modified using experimental data from the LSTF (Nam et al. 2009). This thesis adds to that body of work by validating the channel-containing SMS LSTF model. Once the model is properly validated by results from the physical experiments, it will show that sediment movement is caused by gradients in wave radiation stress and wave-induced longshore currents, just like in the physical ocean. A reliable model will help USACE make much quicker progress in developing their offshore-deployable dredge for operational use by providing the ability to test many more experimental conditions.

III. METHODOLOGY

A. EDIT MODEL BATHYMETRY (LIDAR DATA)

The first step in modifying the numerical model to properly reflect the physical experiments was to modify the ideal bathymetry by integrating observed LIDAR scans of the LSTF. These LIDAR scans consist of x, y, and z coordinates of (portions of) the basin with a channel cut into it, and show how the bathymetry of the basin developed over the course of the experiments. However, the data was messy when initially loaded into SMS. The LIDAR scans included superfluous data points from the structure around the basin that were not relevant to the experimental area in question. MATLAB was used to select the data points that were located inside the basin bathymetry and eliminate the ones that were not. However, when the data was loaded into SMS again, it was not properly aligned with the Cartesian grid. Different MATLAB code was used to find the rotation angle needed to align the LIDAR data with the SMS grid. Once the angle was found, the LIDAR data was once again loaded into SMS, rotated, and translated to proper alignment.

Another issue arose when it became clear that the dataset was not large enough to encompass the whole SMS grid; therefore, it needed to be expanded before it could be interpolated onto the initial model bathymetry. A new scatter set was created to reflect the bathymetry of the LIDAR dataset on the edges of the Cartesian grid, and the LIDAR data was manually expanded to encompass the entire grid. This merged dataset was then interpolated to the grid.

The final change necessary was to convert the LIDAR scan from an elevation to a depth in order for the STWAVE simulation to work properly. However, when calibrating the wave model, it was discovered that the offshore bathymetry of the LIDAR dataset did not extend as far offshore as the actual basin. The offshore portion of the bathymetry was not deep enough to accurately reflect experimental wave climate. Therefore, the experimental area needed to be expanded in the MATLAB code and the whole process was repeated again to edit the model bathymetry. Once the depth at the wave maker was fixed, the SMS model reflected the actual bathymetry of the LSTF when experiments were conducted!

B. SET UP WAVE SIMULATION WITH STWAVE

The next step in modeling channel accretion was to set up a wave simulation in STWAVE that could accurately represent the wave conditions of the physical experiments. Only spilling breakers, representing the wave spectra of experiment A, were modeled for initial calibration. This spectrum was chosen because it was the first experimental condition from the 2019 experiments. The spectrum was developed in SMS by specifying a range of frequencies from one-half of the desired peak frequency to double the peak frequency. For experiment A, the desired peak frequency was 0.66 Hz, or a 1.5-second period. Therefore, the spectra ranged from 0.33 to 1.33 Hz. STWAVE places wave energy from the spectrum into frequency bins, so the range serves to place limits on where STWAVE can distribute the energy of the wave spectrum.

Next, monitoring stations were established at the same locations in the channel where wave gauges were set up during physical experiments. These monitoring stations output significant wave height and peak period for the STWAVE spectrum at those locations. Experimental wave data was processed in MATLAB to compare to the STWAVE outputs. Average wave heights and periods for each twenty-minute run were output at the same locations in the channel where the monitoring stations were placed in STWAVE. These data were compared with the outputs of the STWAVE run to show if the model was accurate or not. As the STWAVE data was processed, it was discovered that more monitoring stations needed to be placed in SMS to examine the wave climate outside the channel as well as inside the channel. The wave height values were not similar enough at first, so model parameters needed to be adjusted.

Data from the physical experiments showed that the spectrum developed by the wave maker in the LSTF output an average wave height of 20 cm instead of the desired 25 cm wave height, so the STWAVE spectra was adjusted accordingly by changing the H_s. Furthermore, research shows that bottom friction reduces the breaking wave height 30 to 50 percent (Maa and Kim 1992), so this parameter was also adjusted because the wave height outputs from STWAVE greatly exceeded the wave heights from the experiments. The bottom friction value needed to be changed to minimize error. The correct bottom friction value was discovered through an iterative process of increasing the bottom friction constant in the STWAVE simulation to decrease model wave height outputs until they differed from experimental wave heights by 10 percent or less. The iteration is shown in Figures 3 and 4 in the results section, and was performed first outside the channel and then inside the channel. It was discovered that wave heights in the channel needed to be lower than those outside the channel at the same cross-shore location because of the larger depth of the channel, so bottom friction in the channel was set to a slightly higher value. Once the wave outputs from STWAVE and the experiments matched both in the channel and outside the channel, the ADH simulation could be set up.

C. ADH MODEL SET UP FOR SEDIMENT TRANSPORT

ADH was used to model the transformation of channel bathymetry by sediment transport. Three types of files comprised the ADH simulation: a mesh file (*.3dm), boundary conditions file (*.bc), and an initial conditions hot start file (*.hot). The first step in constructing an ADH simulation in SMS was to pull in the mesh file, assembled by Gaurav Savant, a Research and Hydraulic Engineer at ERDC and co-advisor on the project. The mesh projection was set to the local coordinate system of the LSTF. Material properties were set to represent the sediment in the LSTF basin from the Smith et al. (2003) experiments, which was fine quartz sand with an average grain diameter of 0.15 mm. Two sediment bed layers of 0.125 meters were established to represent the total sediment beach thickness of 0.25 meters from Smith et al. (2003). The time step was fixed to 2 seconds to capture the wave physics at play in the model. Next, boundary conditions were set at the wave maker and at the two sides of the basin. The boundary condition at the wave maker was a constant water surface elevation of 0 meters, so that the STWAVE portion of the model would control the wave spectrum. The boundary conditions at the sides of the basin were total discharge boundary conditions set to the LST rate of experiment A's conditions from Smith et al. (2003). These boundary conditions modeled the longshore currents pumped through the LSTF during physical experiments. Finally, the initial conditions were set to the initial LIDAR bathymetry scan of the LSTF and the wave stresses from STWAVE and the simulation was run! This purpose of this process was to compare bathymetry outputs of the model to subsequent LIDAR scans of the LSTF from the physical experiments, thereby evaluating the model's effectiveness in reproducing experiments. The next two chapters display and discuss the results for wave and sediment modeling, respectively.

IV. WAVE MODELING RESULTS AND DISCUSSION

As described in Chapter III, bottom friction had to be adjusted so that the STWAVE wave heights would match up with experimental wave heights. This was done through an iterative process; the bottom friction value was set to a common Manning's roughness coefficient for channels, 0.025 (Chow 1959), and increased by 0.1 until STWAVE wave heights at each wave gauge matched experimental wave heights by less than ten percent error. As seen in Figure 3, the Manning's roughness coefficient that caused STWAVE wave heights to be closest to the experimental wave heights inside the channel was 0.425. The error values for the channel calibration are displayed in Table 2. Figure 4 shows the bottom roughness to be 0.325 for the rest of the basin.

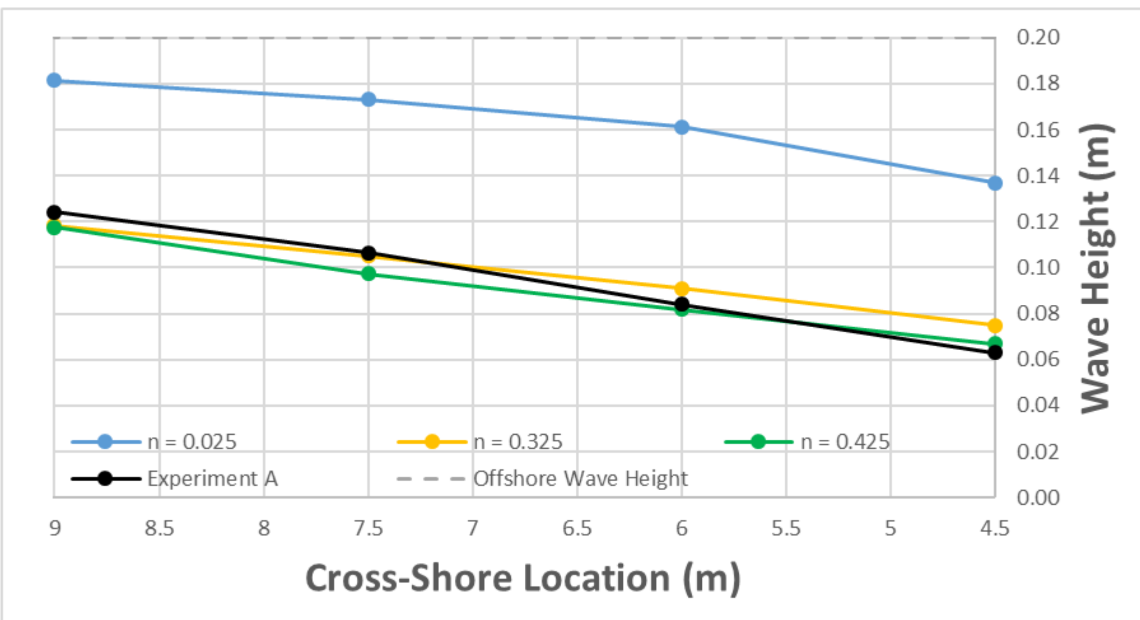

Figure 3. STWAVE wave height calibration for waves inside the channel (x = 0 is the beach)

Table 2. Percent error values for bottom friction calibration in the channel

Cross-Shore Location (m)	n = 0.025 Error (%)	n = 0.325 Error (%)	n = 0.425 Error (%)
4.5	116.7	18.8	5.9
6	92.0	8.5	2.4
7.5	62.4	1.5	8.6
9	46.2	4.6	5.4

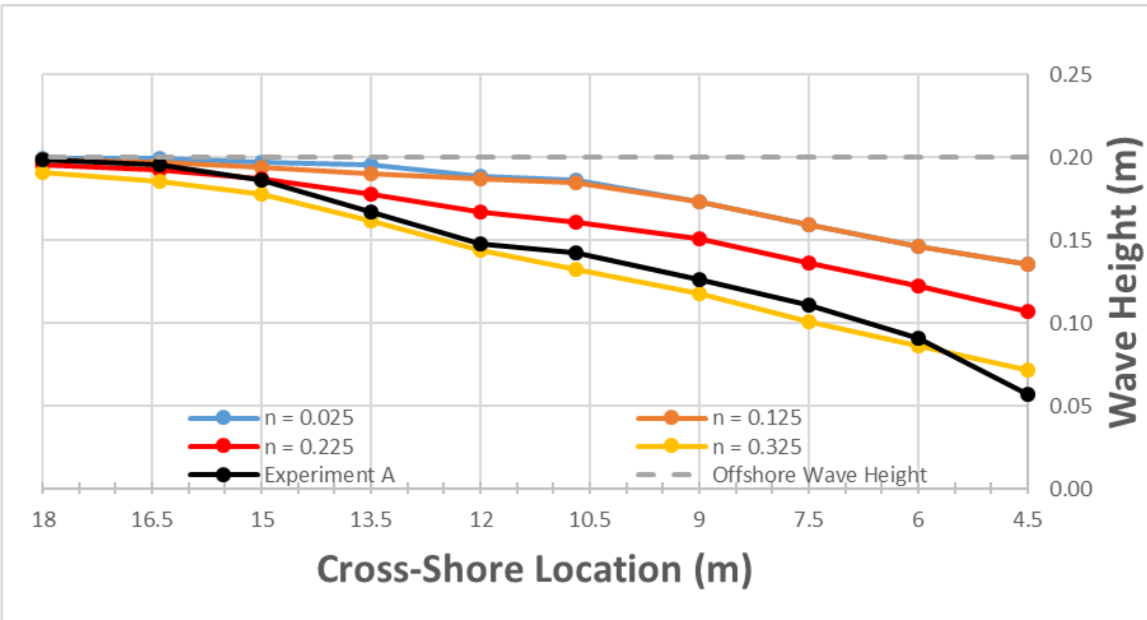

Figure 4. STWAVE wave height calibration for waves outside the channel

At first glance, these Manning's roughness coefficients seem extremely high, as normal values for sandy channels sit well below 0.1 (Chow 1959). However, this large difference can be explained by considering the intended use and limitations of the STWAVE model. STWAVE was designed to model nearshore wave growth, propagation and transformation for large-scale, coastal applications (Massey et al. 2011). It is not normally used to model a laboratory environment, which was its purpose in this thesis. Thus, the model does not incorporate small-scale nearshore source terms such as nonlinearities and dissipation of spilling waves across the surf zone (Massey et al. 2011) that are significant in the laboratory environment. These losses were likely accounted for in the Manning's roughness coefficient because bottom friction is the only nearshore source term incorporated into STWAVE. This is why the Manning's roughness coefficients used in the model were so high.

STWAVE correctly modeled the wave pattern of the experiment with these Manning's roughness coefficients for the channel and basin, as shown in Figure 5.

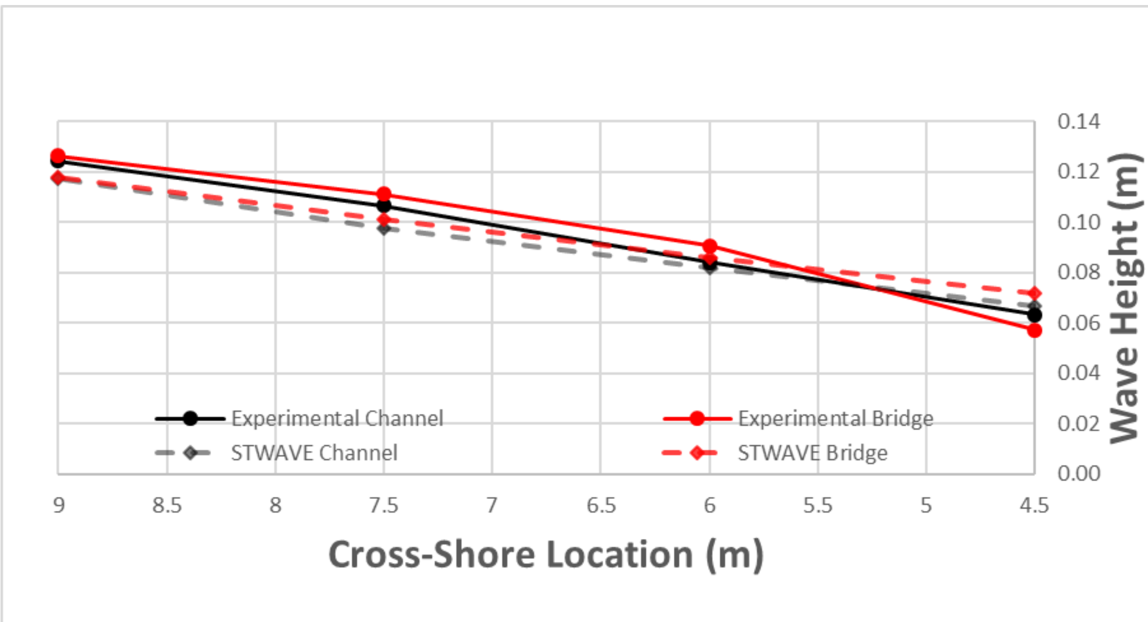

Figure 5. Wave height comparison of channel to instrumentation bridge wave gauges between experiment and STWAVE model

In the experiment, wave heights outside the channel, which were measured by wave gauges fixed on the instrumentation bridge, were greater than wave heights inside the channel, which were recorded by wave gauges positioned in the channel. Research showed that this result should be expected because the depth of the channel would prevent waves in the channel from experiencing the same bottom-induced shoaling as waves outside the channel, which felt shallower bathymetry (Rijn 1986).

The fact that STWAVE matched the wave heights of waves from the experiment is an encouraging result. The seemingly unrealistic Manning's roughness coefficient can be explained by the assumptions and limitations of the STWAVE model. It can be concluded that the STWAVE simulation accurately models the wave conditions of the 2019 experiment in the LSTF.

V. SEDIMENT MODELING RESULTS AND DISCUSSION

The difference in bathymetry between the initial LIDAR scan of the basin before any waves were run and the final LIDAR scan of the basin after eight wave runs were completed is shown in Figure 6. These datasets were compared by subtracting the final LIDAR scan from the initial LIDAR scan and displaying the result on the LSTF grid. The depth of the channel was greater in the initial scan than in the final scan, which is why initial bathymetry minus final bathymetry yielded a positive number. This result mirrors the physical process of channel accretion. The height of the beach decreased over the course of the experiments, which mirrors the physical process of beach erosion due to waves beating against the shoreline, disturbing the sand, and moving it through the phenomenon of undertow discussed in Chapter II. The survey data analysis in the appendix and LIDAR data analysis using SMS yielded the same result, demonstrated by the similarities of Figures 1 and 6. The erosion of the beach and simultaneous channel infilling proves that there is a significant cross-shore contribution to channel accretion. An accretion area slightly offset from the channel in the alongshore direction, also shown in Figures 1 and 6, hints at a longshore current contribution to channel accretion as well.

In the physical experiments, there were artificial longshore currents set to reflect the longshore transport induced by the waves, and to account for the finite size of the tank (discouraging recirculation). These currents likely moved sediment across the basin in the alongshore direction, creating this area of accretion downstream of the channel. ADH results also show these longshore currents. In the experiment, the pumps were located at the top boundary of the basin, as oriented in Figure 7, and pumped water in the alongshore direction toward the bottom boundary. However, the circular flow pattern in Figure 7 presents a more complicated picture. The flow near the beach and channel follows the experimental pattern, but not the flows in the rest of the model area. It is likely that flow going across the model was not allowed to leave the basin, as in the lab; therefore, it was recirculated through the model. This could be fixed in future model runs by creating an integrated boundary condition that splits the flow rate across the model depth, allowing the model cells to handle the flows more accurately. It is worth noting that this flow condition did not have a major impact on the model's accuracy, as its output was closely aligned with the bathymetry change of the physical experiments.

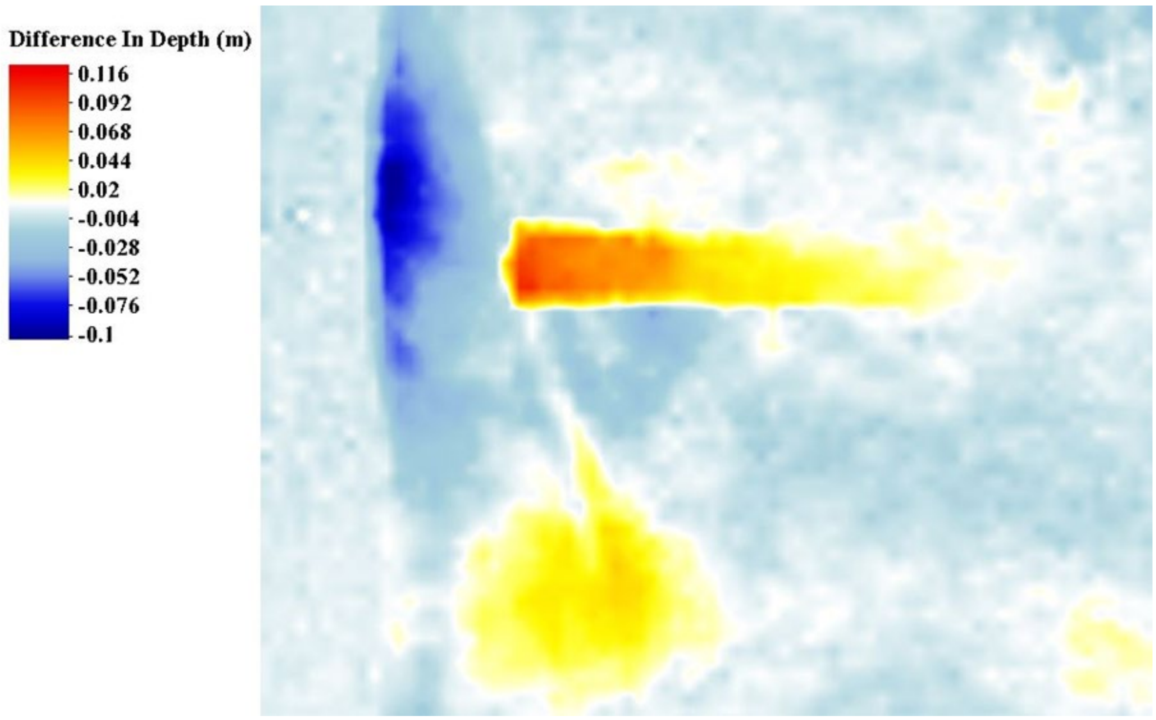

Figure 6. Difference between initial and final LIDAR scans from the physical experiments

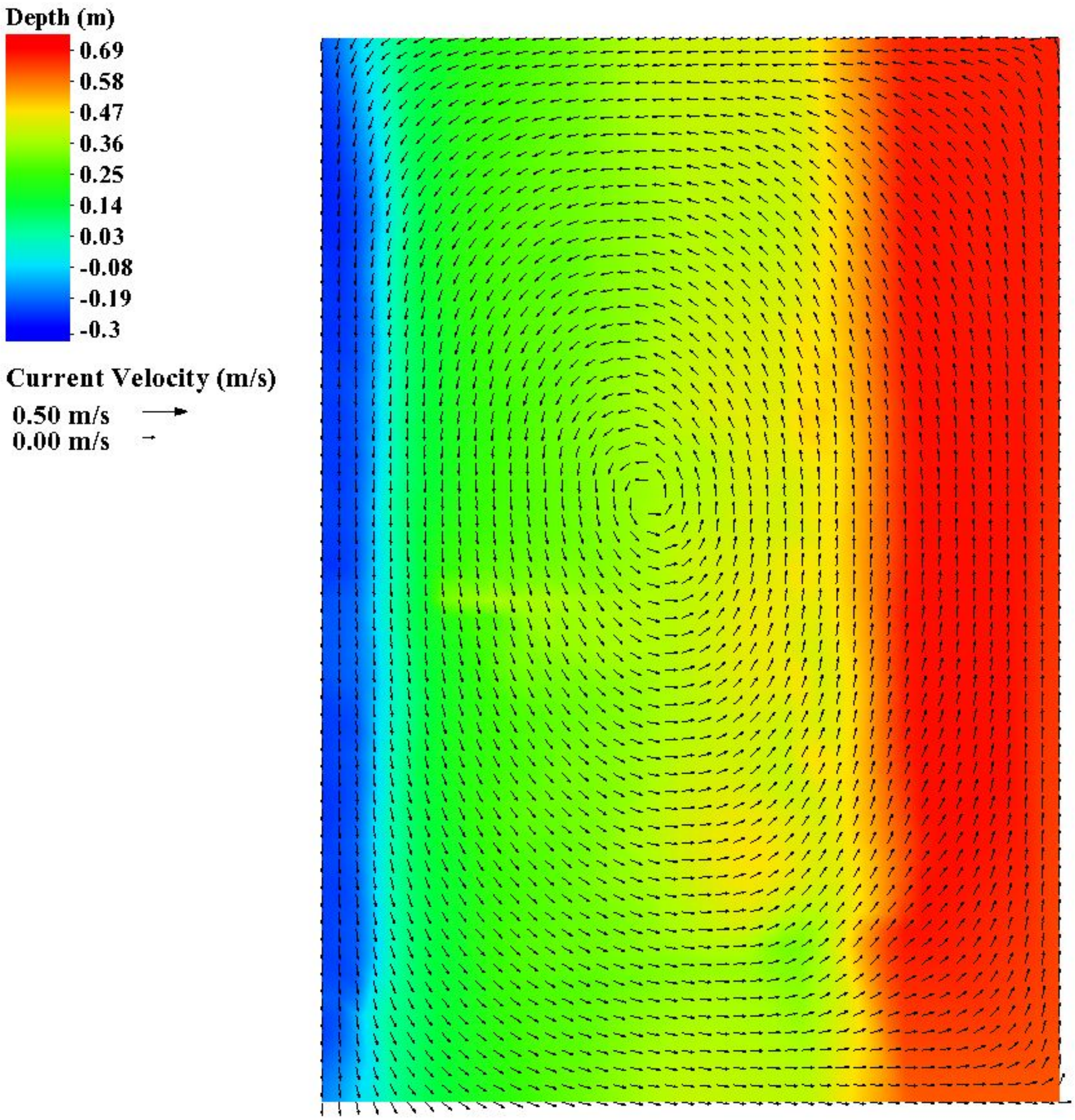

Figure 7. Current velocity circulation pattern resulting from successful ADH model run

Channel accretion can be further examined by investigating the wave radiation stress outputs of the STWAVE model, as seen in Figure 8. As discussed in Chapter II, change in wave height leads to a gradient in wave radiation stress. Sediment then moves in the direction of this gradient. Waves that propagate at an angle to the shore combine the effects of wave radiation stress and wave-induced longshore currents on sediment transport. Figure 8 shows that this phenomenon occurred in the simulation as well. Near the shallowest part of the channel, radiation stress gradients are the strongest on the side experiencing direct wave action. Conversely, there is a minima of radiation stress gradient on the side shadowed by direct wave action (Figure 8). Radiation stress gradients are most substantial at the edges of the channel, where there is a sharp change in depth. Therefore, the effects of sediment movement due to wave radiation stress gradients and downslope gravity-driven sediment transport combined to produce channel infilling from the sides of the channel, in the longshore direction.

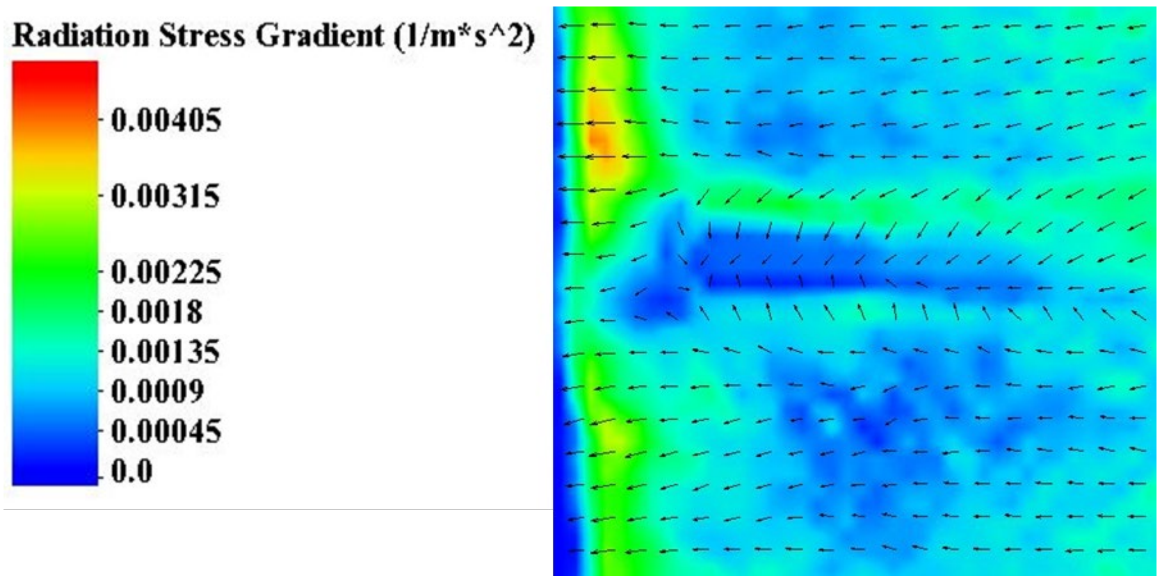

Figure 8. Wave radiation stress gradients output from STWAVE and input into ADH (Color contours indicate magnitude and arrows indicate direction)

The ADH model performed extremely well in modeling the sediment transport of the physical experiments for one cycle of waves, producing a similar bathymetry to the experimental LIDAR scan, shown in Figure 9. A comparison of the channel bathymetries is shown in Figure 10. Figure 11 shows the initial model bathymetry subtracted from the model bathymetry after one 20-minute cycle of waves. The result of this first model run yielded similar sediment movement patterns to the physical experiment, with slight accretion of the channel and initial development of an offshore bar.

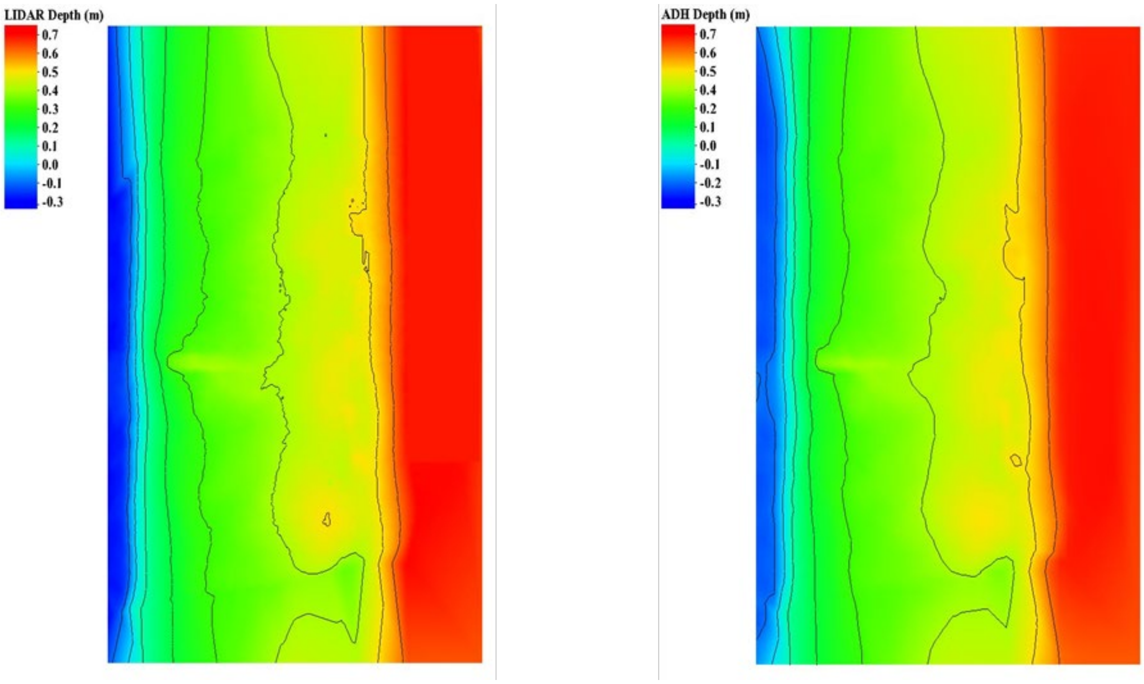

Figure 9. Side-by-side comparison of physical LIDAR bathymetry data (L) and ADH bathymetry data (R) after a single 20-minute run of waves

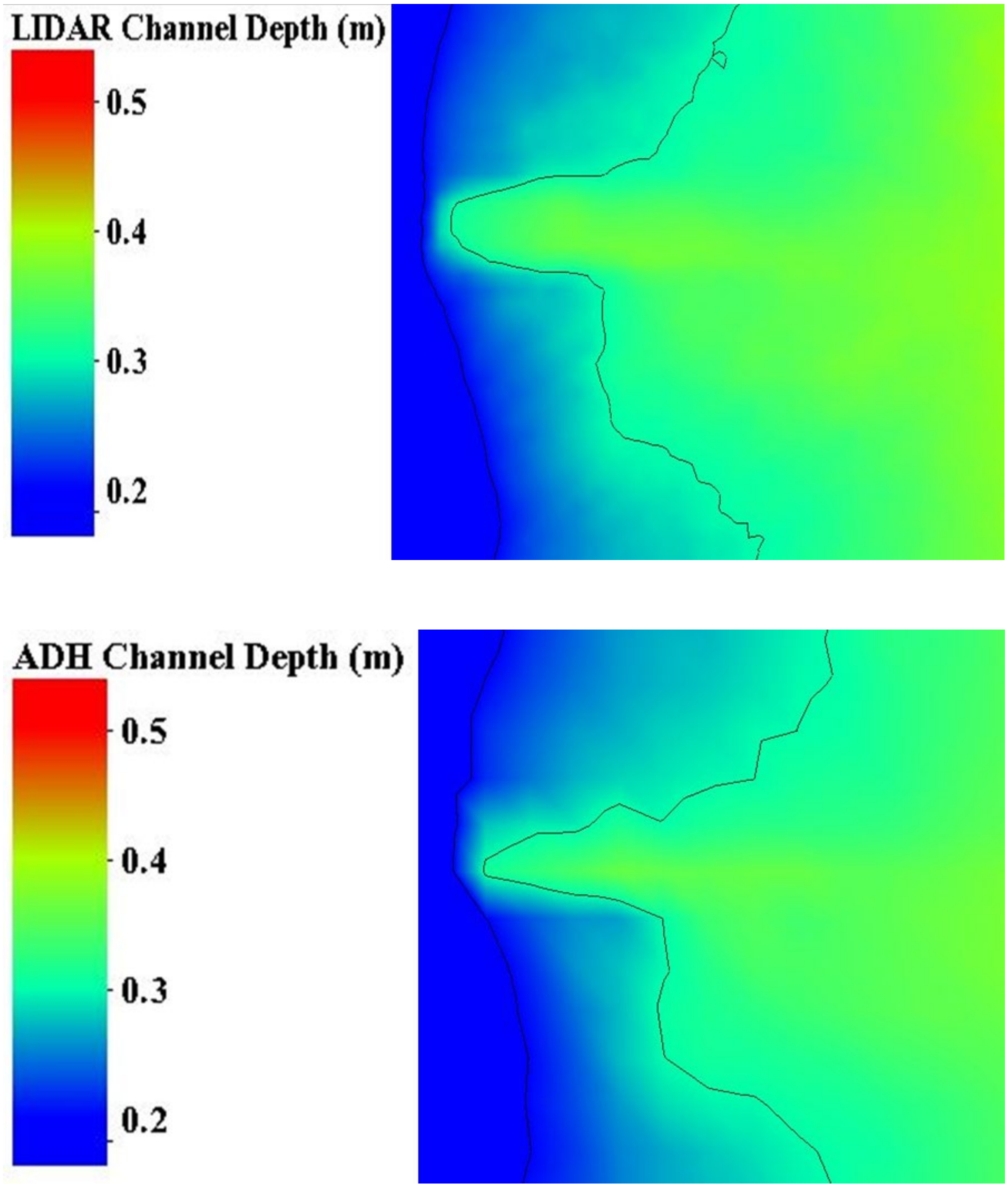

Figure 10. Comparison of LIDAR channel bathymetry data (L) and ADH channel bathymetry data (R) after a single 20-minute run of waves

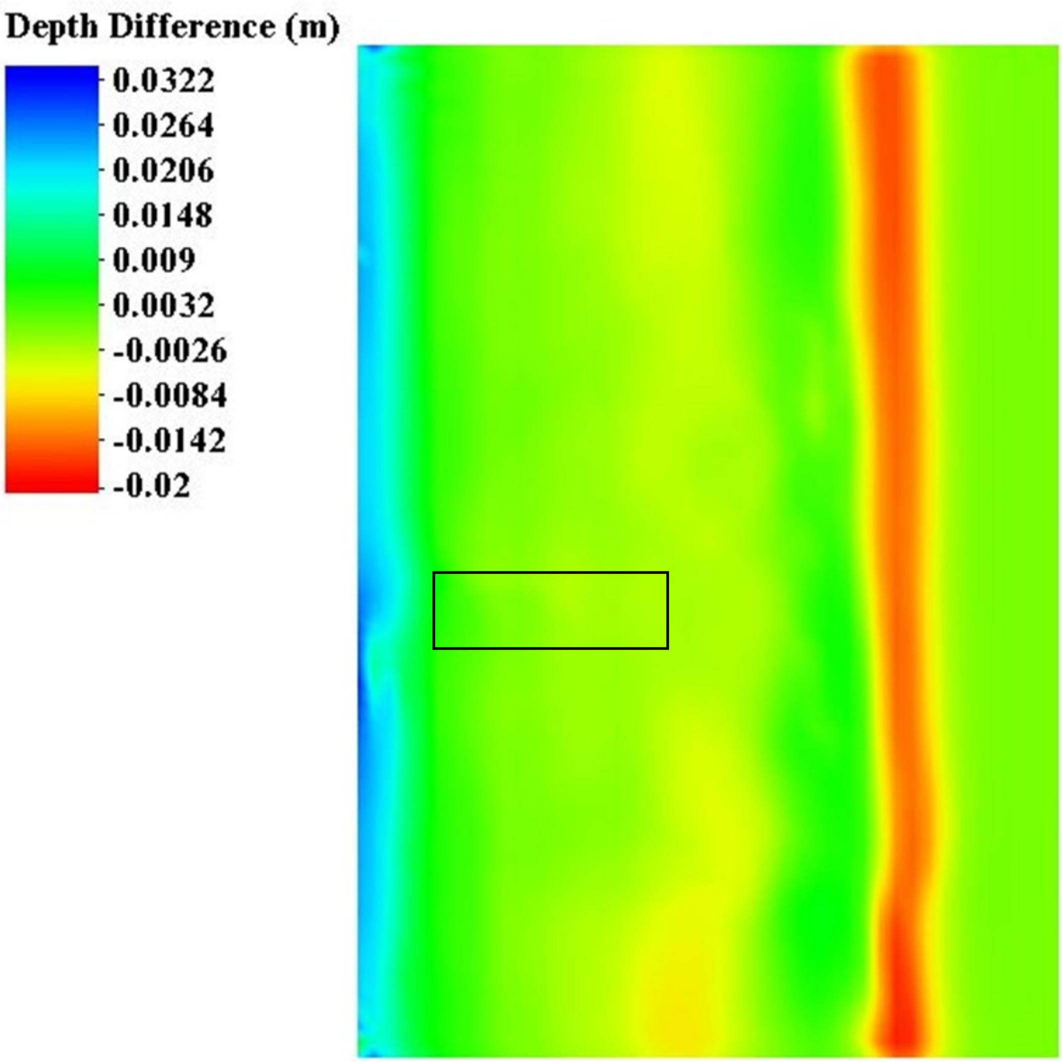

Figure 11. Bathymetry change after a single 20-minute run of waves in the ADH model with a box indicating the channel (Final – Initial)

Although the LIDAR data has finer resolution in its contours, both depth datasets show similar values and contour patterns. A closer examination of the data on the same grid confirms the similarity. The only considerable depth difference on the entire grid is located in the area of the channel, as shown in Figure 12. This difference was calculated by subtracting the ADH bathymetry after one run of waves from the LIDAR scan taken after the first run of waves in the physical experiment. The positive difference of one to five centimeters on the beach and the negative difference in the channel indicates that the model slightly under-predicts beach erosion and channel accretion. This small error can potentially be minimized by increasing the resolution of the ADH mesh.

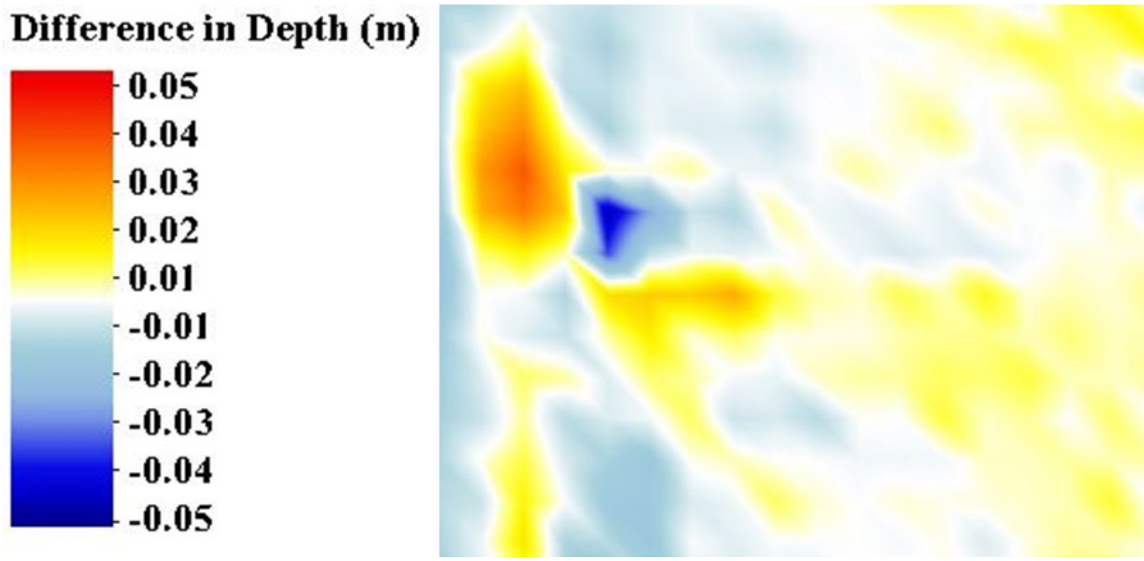

Figure 12. Comparison of physical LIDAR bathymetry data and ADH bathymetry on the same grid after a single 20-minute run of waves (LIDAR-ADH)

With a baseline STWAVE and ADH model of the LSTF now constructed, there are many opportunities for future work and research. First, the remainder of the 2019 physical experiments should be modeled and the results analyzed to further confirm the accuracy of the model. The results of this thesis are surely promising, but more work needs to be done for a stronger confirmation of model reliability. After data from the 2019 experiments is completely processed, the wave spectra, channel bathymetry, ADH boundary conditions, and other input parameters can be varied within the model for additional insights into channel accretion under different environmental conditions. Another area of future research could be a more thorough examination of wave radiation stresses to determine their impact on channel accretion. Modelers could make controlled changes to the LSTF STWAVE model inputs and examine the resulting radiation stress gradient outputs. Exploring the parameter space would give more insight to channel accretion's contributing factors, a major research goal of the LSTF experiments.

VI. CONCLUSIONS

The U.S. Army Corps of Engineers is doing important work for the Navy and Marine Corps by developing a dredge able to cut cross-shore channels that expedite amphibious landing operations. Understanding channel accretion for different wave conditions, bottom bathymetries, and channel sizes is crucial to operate the dredge in different operational environments. Many different factors contribute to channel accretion, including CST and LST. This study establishes a numerical model for an experimental process that examines channel infilling over time at experiment scale. The model is aligned to wave and sediment transport results from a 2019 physical experiment in the LSTF.

The bottom bathymetry of the model was matched to the bottom bathymetry of the LSTF with a channel cut into it by interpolating LIDAR data from the physical experiments into SMS. Next, waves were run in the model using STWAVE. Wave height outputs from the model were compared to data from wave gauges used in the physical experiments. This was accomplished by aligning monitoring cells in STWAVE with the physical locations of the wave gauges during the experiment. Bottom friction was used as the primary tuning parameter to adjust STWAVE wave heights until they matched experimental values. A Manning's roughness coefficient of 0.425 worked best in the channel, while a value of 0.325 worked best in the rest of the basin. These values were much higher than normal bottom friction coefficients for sand because bottom friction is the only loss term that STWAVE incorporates, and it is expected that processes at laboratory scales are not optimized within the model. Two-dimensional plots of wave radiation stress gradients showed that the primary source of channel accretion was in the alongshore direction, confirming the hypothesis developed after observing physical experiments and researching channel accretion.

ADH, the sediment transport portion of the model, accurately modeled bathymetry change after one 20-minute run of waves. This result was confirmed by comparing to the LIDAR data from the physical experiments, which yielded miniscule differences. The model should continue to be developed by completing the modeling of all three 2019 experiments, which will validate the accuracy of the model. Environmental parameters such as channel bathymetry, longshore current, and wave spectra could then be adjusted in the model after the experiments are completed. Another option would be to examine outputs from the STWAVE portion of the model, varying the wave spectra to see how wave radiation stress gradients impact channel accretion. As the numerical model of the LSTF established in this thesis is developed further, USACE will be able to determine which factor dominates channel accretion, streamline experiments accordingly, and create a predictive tool for channel accretion that dredge operators can use in the field.

APPENDIX. JUNE 2019 EXPERIMENTS AND DATA ANALYSIS

A. METHODOLOGY

The experiments took place in the LSTF at USACE's Coastal and Hydraulics Laboratory (CHL), seen in Figure A-1. These facilities are located in Vicksburg, Mississippi.

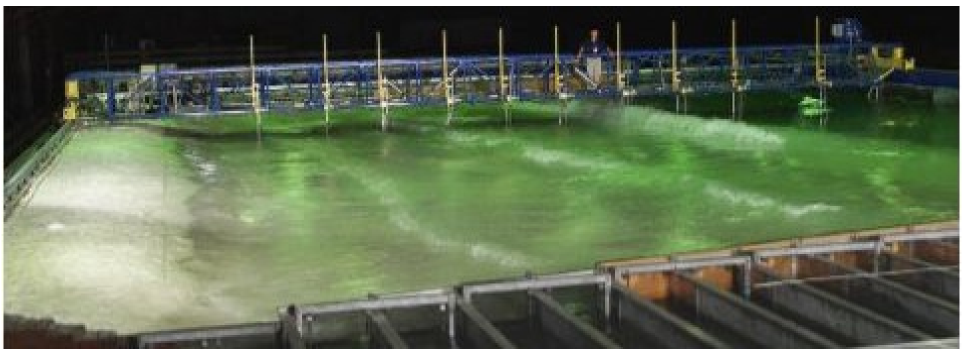

Figure A-1. The Large-Scale Sediment Transport Facility at USACE's Coastal and Hydraulics Laboratory

The LSTF is designed to model hydrodynamics and sediment transport along a long, straight beach (or infinite beach), while operating in a confined space. The basin is 30 meters cross-shore by 50 meters longshore by 1.4 meters deep, as shown in Figure A-2. The basin consists of a sandy beach, a moveable concrete beach, and four wave generators that can generate shore-normal or weakly oblique waves. Pumps move water across the basin, parallel to the shore, in order to simulate longshore currents, pushing sediment into weighing bins at the edge of the basin. After each wave condition in the Smith experiment was finished, the amount of sediment moved into the bins was weighed and the result divided by experiment run time and recorded as the experimental sediment transport rate. This experimental rate can be compared with predicted rates of sediment transport to improve empirical formulae.

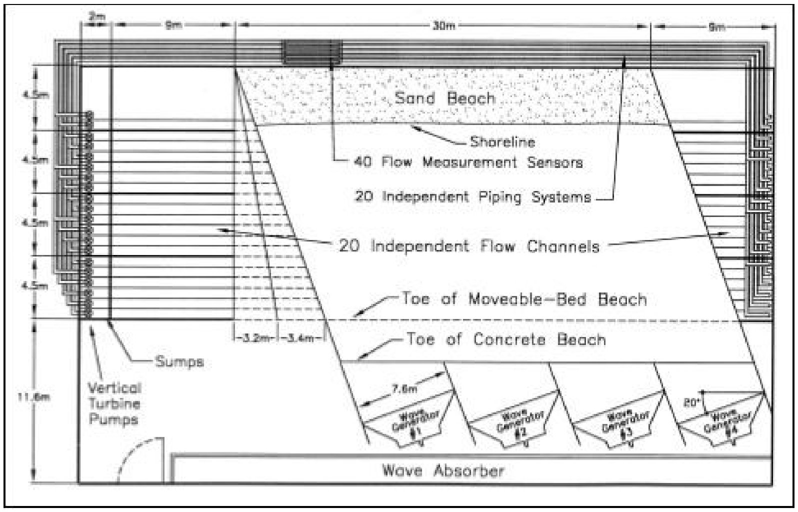

Figure A-2. Plan view of the LSTF

Extensive set-up was performed in order to prepare for the experiments. First, capacitance wave gauges were calibrated. Four gauges were set up in the channel and nine wave gauges were set up on the instrumentation bridge, spaced 1.5 meters apart, as shown in Figure A-3.

Figure A-3. Wave gauges set up in the channel and on the instrumentation bridge

These wave gauges were used to take data for wave height. Seven acoustic Doppler velocimeters (ADV) were also situated on the instrumentation bridge above the channel, as shown in Figure A-4. These were used to take data of the longshore current speed through sensors, the pronged objects on the end of the instruments, in the water. The ADV sends an acoustic signal into the surf, which then bounces off particles in the water and back to the receivers. The receivers use the principle of Doppler shift to produce a velocity.

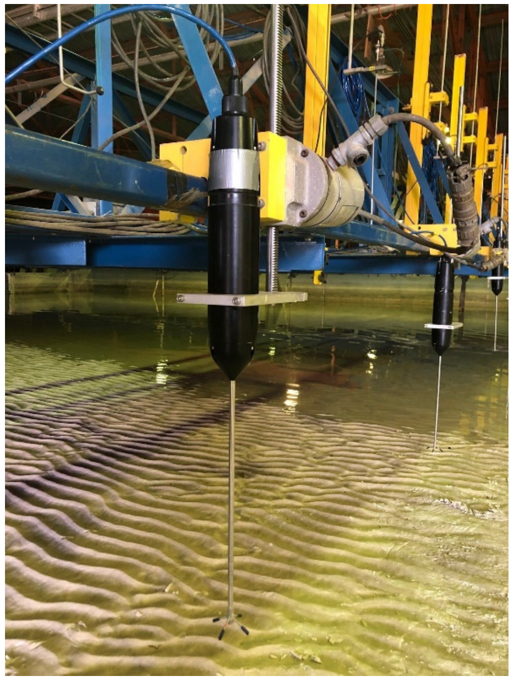

Figure A-4. ADV situated on the instrumentation bridge

The first step in the experimental process after setting everything up was to cut the channel into the beach by hand, using shovels. For the experiments, the cross-shore direction was considered the x-axis, while the longshore direction was considered the y-axis. The channel was always cut centered on the coordinate (0, 75) ft. Sand cut out of the beach was redistributed elsewhere in the basin to conserve the amount of sediment present, and the channel was leveled using surveying equipment. After the channel was completed, a LIDAR scan was taken of the entire facility in order to collect spatial data in the form of 3-D coordinates. Then, the basin was filled and an initial survey was taken using the Trimble DiNi digital level and rod, shown in Figure A-5. Survey points were taken every 0.25 meters in the channel. The beginning of the channel was at the x-coordinate of 2.5 meters and the end of the channel was at 10 meters. The rod was placed in the center of the channel for each measurement.

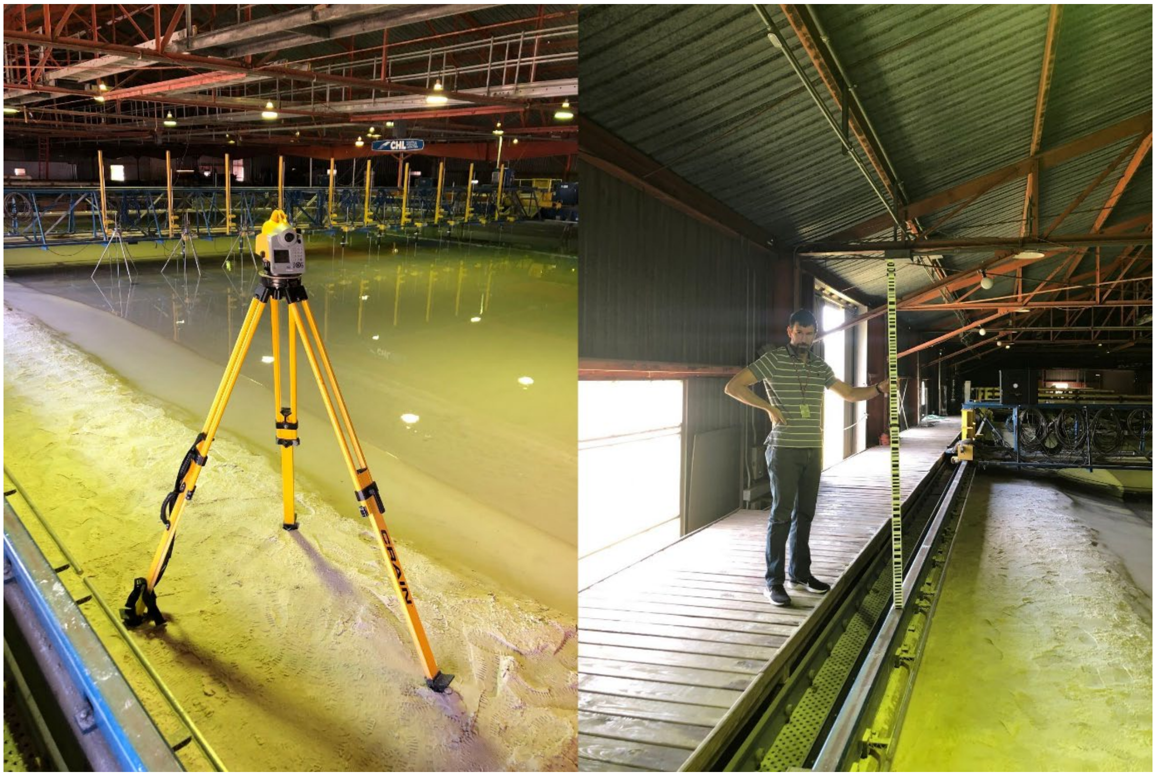

Figure A-5. Trimble DiNi digital surveying equipment

Following the initial survey, the longshore current pumps were set to the same values used in the original Smith experiment to mimic the longshore transport rate of the control experiment. Once the pumps were set, waves were run for an extended period. Two different wave conditions were used in the experiments, and three different experiments were performed. They all had the same methodology, as explained in this section, but had different conditions, which can be seen in Table 1.After waves had been run for 20 minutes (experiments A and B) or 40 minutes (experiment C), a new survey was taken to see how much the channel had filled. The steps of running waves and surveying were repeated until the channel had infilled to a relative equilibrium, which usually took seven or eight runs. The scale of the experiment was 1:15 in order for the waves to mimic a sea state 2. After the final survey was taken, the basin was drained and a final LIDAR scan was taken before cutting the channel for the next experiment. Survey data was analyzed in excel, and plots of channel elevation vs. cross shore location were produced to show channel infilling over time.

The first set of experiments produced unexpected physical results in the wave tank. The second wave condition run developed an offshore sandbar, and the channel itself actually shifted off of its original center in the longshore direction. In order to examine these physical processes more thoroughly, a new experiment was designed. Experiments A and B were run again with the same experimental set-up and conditions; however, after waves had been run for 20 minutes, the tank was drained and a LIDAR scan was taken of the basin to measure the x, y, and z coordinate locations of the exposed bathymetry. The equipment used to obtain the scan data is shown in Figure A-6. After the scan was finished, the tank was filled up and another set of waves was run. This process was repeated the same number of times that surveys had been taken in the original experiments to maintain the original observed equilibrium of the channel. Once this equilibrium point was reached, a final LIDAR scan was taken and the next experiment was set up. Taking a LIDAR scan after each run of waves allowed basin and channel bathymetry to be more accurately captured.

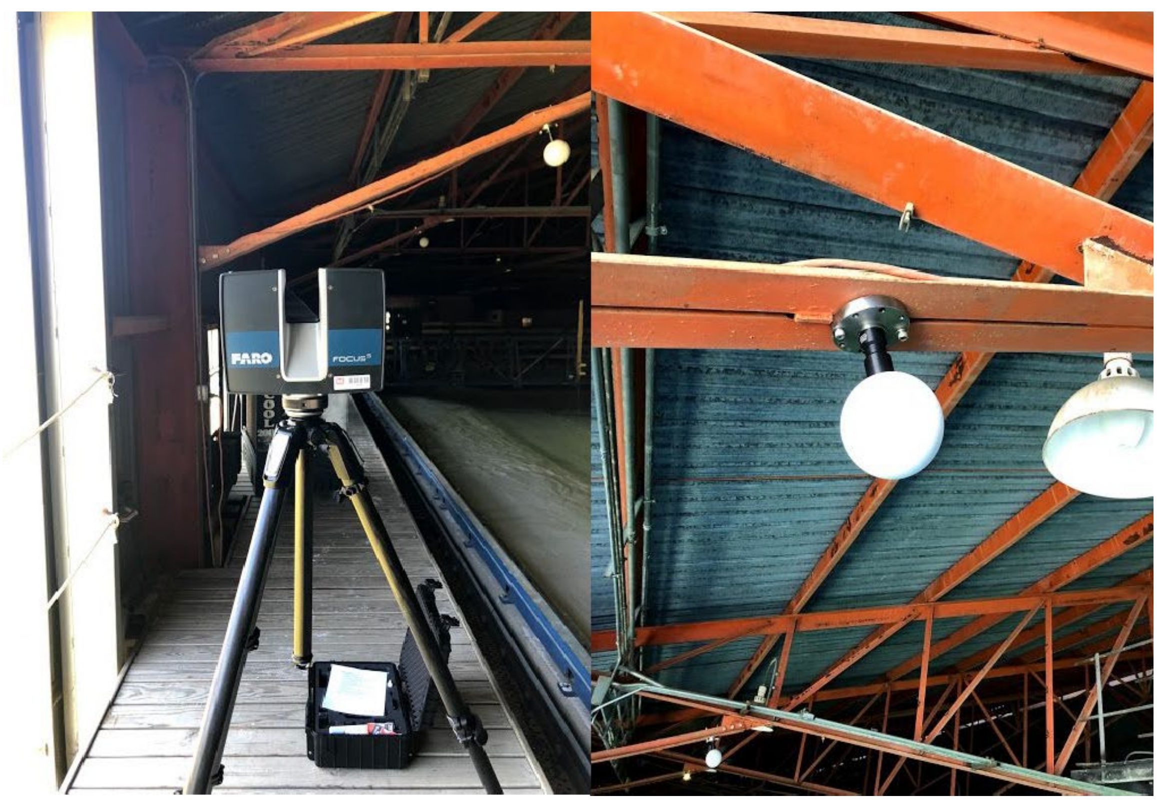

Figure A-6. FARO LIDAR machine and target

B. DATA ANALYSIS

1. 2-D Infilling Estimation Method:

The survey data was loaded into MATLAB for analysis. The data was examined for experiment A and then the code was copied and modified for experiments B and C. First, the excel spreadsheets were cleaned up of empty spaces and sorted into matrices. Each cross-shore location (x-coordinate) was paired with an elevation (z-coordinate) for the initial beach profile, and they were compiled into vectors. The volume of the beach was found using trapezoidal integration of the two vectors. The same process was done for each individual survey in the experiment. The volume of each survey subtracted from the volume of the beach gave a total volume of the channel after each run of waves. Finding the volume of the channel for each survey allowed infilling to be examined over time and experiments to be compared. The next step in data analysis was to plot channel volume over time. A line was fit to this plot, and the slope of this line gave the experimental infilling rate of the channel. An additional analysis was done by splitting the channel into inshore and offshore sections at the five-meter mark, but no appreciable difference in infilling rate was found. Therefore, it can be assumed that infilling is relatively constant in the cross-shore direction of the channel.

2. 3-D Infilling Estimation Method:

The LIDAR data from the second set of experiments was also analyzed in MATLAB. However, this data was much more difficult to clean up and process, so only the scans from experiment A were examined. The raw LIDAR data was interpolated to a 0.05-meter by 0.05-meter (x, y) grid and measurements at different LIDAR frequencies were averaged together to smooth out the results. Erroneous spikes in the gridded data were removed by checking for points more than three standard deviations from the local mean and gaps were interpolated over using linear interpolation. After loading the gridded data into MATLAB, the first step was to plot each scan of the channel, starting with the initial scan before any waves were run. Next, a boundary was established encompassing the entire area of the channel. This was done in order to determine the change in bathymetry of strictly the channel. The data inside the box was then integrated and multiplied by the grid spacing, or distance between data points, giving the areas of different slices of the channel. These areas were then summed together, yielding a volume of the channel for each scan. Two arrays were created: one containing the volume values from each scan, and one containing the times that waves were run between each scan. The volume array was divided by the time array to create a vector with the infilling rate for the duration of each run of waves. Finally, the mean of this vector was found, and identified as the overall infilling rate of the channel for experiment A.

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