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Low Sill Control Structure

Physical Modeling Investigation of Riprap Stability Downstream of End Sill

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Final Report

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Under WIC C24687; "Low Sill Control Structure Physical Model Riprap Stability Study"

Abstract

The model investigation reported herein describes the process to model and analyze the stability of scaled riprap in the existing 1:55 Froude-scaled Low Sill Control Structure physical model. The existing model is a fixed-bed model, so modifications were made to create a testing section for the scaled stone. Three separate gradations of scaled riprap were tested at varying boundary conditions (discharge, head and tailwater elevations, and gate openings). Each test was surveyed using lidar for pre to posttest comparisons. It was found that Gradation B remained stable throughout the tests in the physical model.

Contents

Figures and Tables

Figures

Tables

Preface

This study was conducted for the US Army Corps of Engineers (USACE), New Orleans District, under WIC C24687, "Low Sill Control Structure Physical Model Riprap Stability Study." The technical monitor was Mr. David Ramirez, Hydraulics and Hydrology branch chief.

The work was performed by the River and Estuarine Engineering Branch of the Flood and Storm Protection Division, US Army Engineer Research and Development Center–Coastal and Hydraulics Laboratory (ERDC-CHL). At the time of publication, Mr. Casey M. Mayne was acting branch chief; and Mr. David P. May was division chief. The deputy director of ERDC-CHL was Mr. Keith Flowers, and the director was Dr. Ty V. Wamsley.

COL Christian Patterson was commander of ERDC, and Dr. David W. Pittman was the director.

1 Introduction

This US Army Corps of Engineers (USACE), Engineer Research and Development Center–Coastal and Hydraulics Laboratory (ERDC-CHL), effort describes the process to evaluate the stability of the scaled riprap downstream of the end sill of the Old River Low Sill Control Structure (LSCS).

1.1 Background

The LSCS is one structure in the much larger Old River Control Complex (ORCC). The structure is used by USACE to regulate the amount of flow from the Mississippi River that is allowed to pass down the Atchafalaya River. USACE currently uses the structure to help maintain a 70/30 latitude flow split of the Atchafalaya and Mississippi river as mandated by congress. Any issues with the LSCS that prevent MVN (New Orleans District) from normal operations can potentially cause concern for the rest of the ORCC. An overview of the ORCC as well as a view looking downstream of the LSCS physical model can be seen in Figure 1.

In 2019–2020, scour holes were found developing downstream of the end sill of the structure. The scour downstream of Gate Bay 10 was especially severe and it was feared that this scour could potentially lead to undermining of the structure (Gate Bays are numbered 1–11 going from northwest to southeast). Repairs to the scoured areas were made by MVN in March of 2021 in which they deployed R-5000 (W50 of 2,200 lb) stone downstream of the structure with an approximate blanket thickness of 9 ft.* The survey conducted in April of 2022 indicated that the riprap placed in March 2021 had been removed and deposited just downstream of the scoured areas. The resulting scour looked very similar to the scour that had been seen in 2019–2020. The scour progression and rock placement and movement can all be seen in Figure 2 (areas in orange or red are southwest of scour holes). For reference, gate numbering can be seen in the 2018 May survey.

* For a full list of the spelled-out forms of the units of measure used in this document and their conversions, please refer to *US Government Publishing Office Style Manual*, 31st ed. (Washington, DC: US Government Publishing Office, 2016), 248–52 and 345–47, https://www.govinfo.gov/content/pkg/GPO-STYLEMANUAL-2016/pdf/GPO-STYLEMANUAL-2016.pdf.

Figure 1. Physical model Gate Bays (looking downstream) on the *left* and Old River Control Complex (ORCC) overview on the *right*.

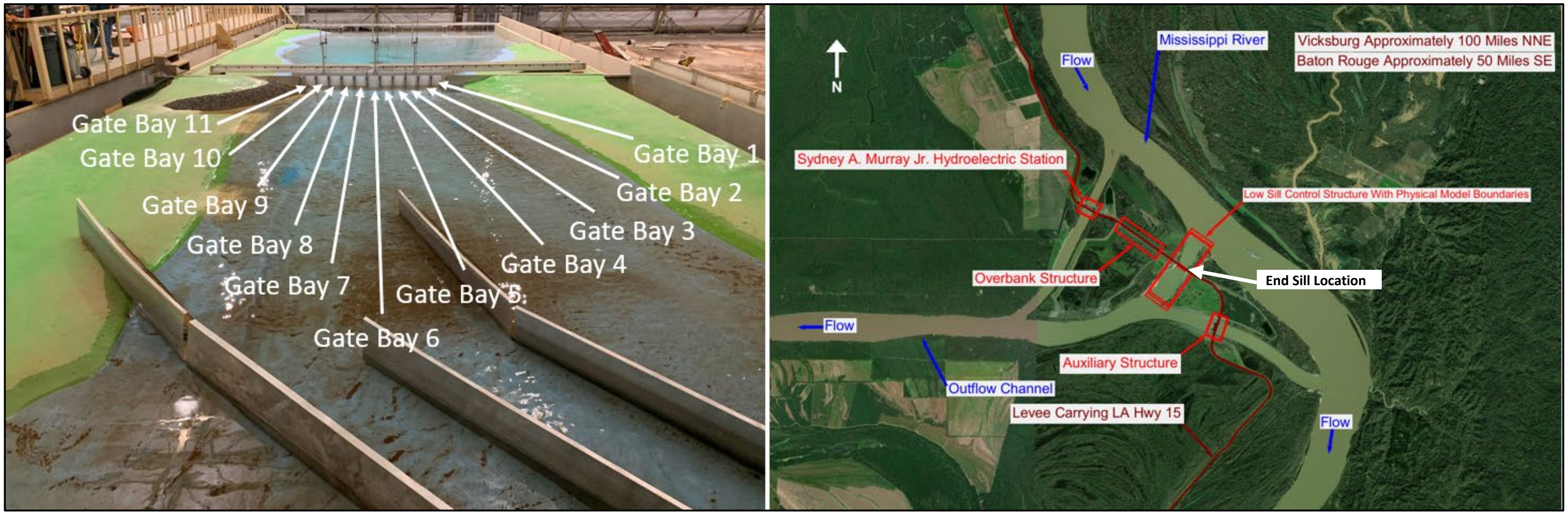
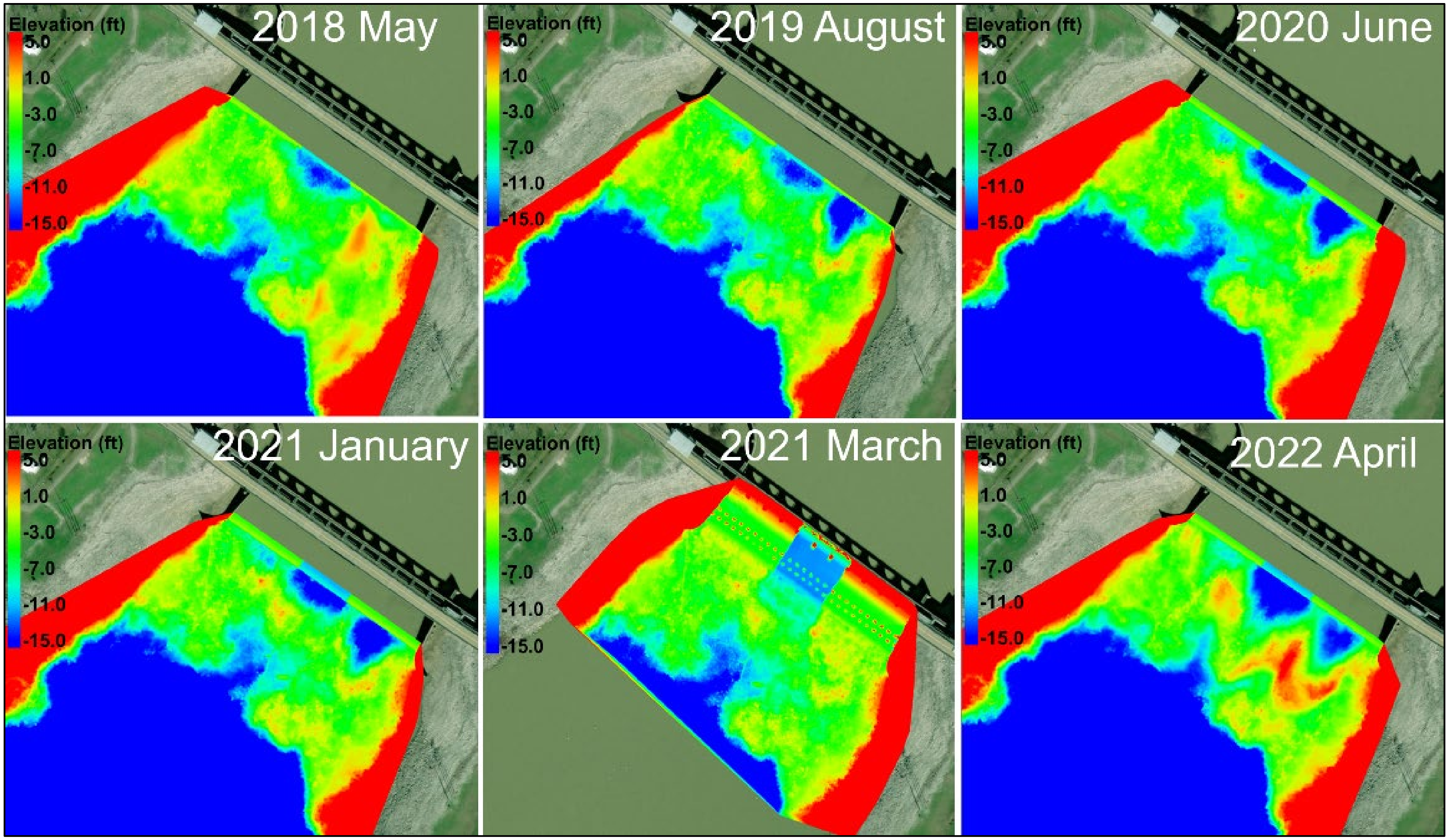


Figure 2. Bathymetric surveys downstream of the end sill of the Old River Low Sill Control Structure (LSCS) from May of 2018 to April of 2022.



In 1976, Waterways Experiment Station (WES) performed tests on scaled riprap using a 1:36 section model but experiments were halted due to pressing concerns to use the model for ongoing repair operations for the stilling basin (USACE 1976). They were able to test one gradation with a W50 of 2,286 lb applied in a blanket 8.5 ft thick. This was less than their goal of a W50 of 2,900 lb based on projected average velocities of 19 ft/s at the LSCS stilling basin end sill when the structure is operated in orifice control or 22 ft/s when the structure is operated with all gates fully open. Table 1 from USACE 1976 details early scour and repair incidents downstream of the structure.

Table 1. History of the Low Sill Control Structure (LSCS) repairs during early operation.

Date	Problem	Location	Repair	Cost
January 1962	Scour hole	North outflow channel	10,700 ton riprap	$57,000
February–August 1962	Scouring	Outflow channel	58,000 ton riprap	$362,000
April–December 1964	Bank erosion and scour hole	Outflow channel and bank	276,000 ton riprap	$1,880,000
March 1966	Scour hole	Outflow channel	6,300 ton derrick stone	$70,000
March–May 1966	Scour hole	Outflow channel	30,500 ton derrick stone and 3,700 ton riprap	$291,000
December 1968	Scour	Outflow channel	3,840 squares of concrete mattress	$190,000
April–June 1974	Scour hole and bank erosion	Outflow channel	210,000 ton riprap	— [1]

[1] Cost of repair was ongoing at time of report.

Rothwell and Grace (1977) measured velocities downstream from the LSCS stilling basin using a 1:36-scale section model. These data were recorded using a pitot tube and by timing dye. The downstream velocities for these tests were measured 100 ft downstream of the end sill 10 ft above the bed of the model.

Bell et al. (2024) also measured velocities downstream of the LSCS around the recent 2022 scour (see Figure 3) but used an Acoustic Doppler velocimeter (ADV). The measurements were taken approximately 72 ft downstream of the end sill. Velocity measurements were taken at depths of 4.6 ft and 10 ft above the bed as well as at 60% of the height of the water column. These measurements were delivered to MVN to provide preliminary suggestions of stone sizes to repair the scour holes.

Figure 3. Velocity measurement locations.

In analysis of previous model testing and prototype responses to repairs downstream of the LSCS end sill, it became obvious that the stone sizes being used to make repairs were inadequate and that the design velocity for selection of the stone was also inadequate. For the final gradations, it was recommended for stone which "can reasonably be produced and handled." (USACE 1976). At that time the recommended stone had a maximum weight of 14,000 lb and a minimum weight of 2,000 lb with a W_{50} of about 7,500 lb (or 4.5 ft stone size). It is unclear exactly what stone gradation was installed at the time.

In reviewing Figure 2, it is obvious that in May 2018 the only potential scoured area was downstream of Gate Bays 5 to 7. By August 2019 the channel downstream of Gate Bays 8 to 10 had scoured significantly and the channel bed scour downstream of Gate Bays 5 to 7 had enlarged slightly. By June 2020 these two scour areas deepened and enlarged but after that remained relatively unchanged until January 2021. The stone used to produce the bed configuration in March 2021 was designed based on a velocity of 17.5 ft/s and classified as R-5000 (W_{50} of 2,200 lb) by

MVN. The stone used in the 2021 repair was based on a lower velocity than the recommended stone size in 1976. Therefore, the scour that occurred between March 2021 and April 2022 was similar to the past performances of various sized stone used over the years downstream of the end sill.

This scour is what caused MVN to request the CHL to determine the magnitude of velocities downstream of the end sill (Bell et al. 2024). To determine what flows should be used for model testing, a review of the flow conditions that occurred through the LSCS was performed. The intent was to evaluate the problematic conditions that potentially caused the scour areas downstream of the end sill from 2018 to 2019 and from 2021 to 2022. This was necessary since during the 2018 to 2019 period the discharge through the LSCS was relatively low. However, there were several instances where the tailwater elevations were low and could have potentially created high velocities even though the flow was relatively low. During the 2021 to 2022 period the LSCS discharges were higher as were the tailwater elevations, but there were numerous situations where the exit channel velocities were high.

In Bell et al. (2024) the flow condition review resulted in six specific flow conditions that potentially created high downstream velocities from the LSCS. Those conditions are the first three and last three flow conditions shown in Figure 4. The fourth condition is a hypothetical flow condition proposed by MVN for testing. There were several parameters considered in the testing. As mentioned above in Bell et al. (2024), the bottom velocities were considered. Therefore, based on the velocity data collected by the ADV measurements in Bell et al. (2024), the maximum bottom velocities and the sixth-tenths depth velocities (when available) were used to evaluate the seven flows tested in the model and provide guidance to MVN.

Since the bottom velocities measured in the 1:55-scale model exceeded the assumed design velocities from 1976 (19 ft/s) and in 2021 (17.5 ft/s), it was determined at this point that the existing physical model would be modified and used to perform riprap stability testing on scaled stone downstream of the stilling basin. This approach would provide the most defendable stone size for the LSCS outflow channel repair and potentially provide a long-term solution to the downstream channel scour that has occurred over the years.

Figure 4. Boundary conditions.

FLOW 1	FLOW 2	FLOW 3	FLOW 4	FLOW 5	FLOW 6	FLOW 7
96,000 cfs	126,000 cfs	199,000 cfs	243,000 cfs	169,000 cfs	96,000 cfs	86,000 cfs
HW=50.40', LW=30.20'	HW=50.40', LW=30.40'	HW=60.7', LW=43.6'	MVN Hypothetical	HW=53.40', LW=33.40'	HW=43.00', LW=25.70'	HW=28.2', LW=17.8'
HEAD=20.20'	HEAD=20.00'	HEAD=17.1'	HW=57.00', LW=37.00'	HEAD=20.00'	HEAD=17.30'	HEAD=10.4'
7 Hours (model)	7 Hours (model)	7 Hours (model)	HEAD=20.00'	7 Hours (model)	7 Hours (model)	7 Hours (model)
Gates 1, 3, 9, & 11	Gates 1, 4, 5, 7, 8, & 11	Gates 1, 2, 10, & 11	7 Hours (model)	Gates 1, 4, 8, &11	Gates 1, 4, 5, 7, 8, &11	Gates 1, 4, 8, & 11
7.36 ft	CLOSED	19.28 ft	Gates 1, 2, 3, 9, 10,&11	CLOSED	CLOSED	CLOSED
Gates 2 & 10	Gates 2, 3, 9, & 10	Gates 3 & 9	19.28 ft	Gates 2 & 10	Gate 2, 3, 9, & 10	Gates 2, 3, 5, 6, 7, 9, & 10
11.36 ft	19.28 ft	28.96 ft	Gates 4 & 8	11.36 ft	14.65 ft	14.65 ft
Gates 4, 5, 7, & 8	Gate 6	Gates 4 & 8	CLOSED	Gates 3 & 9	Gates 6	August 11, 2018
CLOSED	24.86 ft	CLOSED	Gates 5, 6, & 7	11.36 ft	24.86 ft	NOTE: Lowest Tailwater tested
Gate 6	March 7, 2022	Gates 5 & 7	24.86 ft	Gates 5, 6, & 7	January 13, 2022	
24.86 ft	NOTE: Bed Velocity highest on Gates 2 & 10	7.36 ft	NOTE: Highest Discharge and F_R high on Gates 2, 6, & 10	24.86 ft	NOTE: F_R high on Gate 2	
May 12, 2021		Gate 6		March 15, 2022		
NOTE: F_R high on Gate 6		14.65 ft		NOTE: Bed Velocity highest on Gate 6		
		March 1, 2019				
		NOTE: F_R high on Gates 2 & 10				

1.2 Objectives

The objective of this effort is to provide the New Orleans District model data and analysis for the selection of appropriately sized riprap downstream of the LSCS stilling basin. This was accomplished by adjusting the existing fixed-bed model to accommodate the scaled stone for model testing.

1.3 Approach

Modifications were made to the existing bathymetry that resulted in a recessed area of the model for placement of scaled riprap. Three separate gradations were tested in the modified model with the seven flow boundary conditions presented in Figure 4. Livestream sessions were performed for collaborators' participation. All physical model results presented here are in units of feet at the prototype scale.

2 Testing Process and Setup

2.1 Existing Model Modifications

The existing model is a Froude-scaled 1:55 undistorted fixed-bed model. Therefore, modifications had to be made to the model that would allow for the proper testing of riprap stability downstream of the end sill. The model scale conversions are listed in Table 2. Modification of the model was accomplished by removing approximately three of the existing foam blocks that made up the model bathymetry just downstream of the structure. New foam blocks were cut to grade such that the top elevation of the blocks were at an elevation of –27.5 ft. The tip of the sheet piling at the end of the end sill is at elevation –25 ft. Figure 5 displays these modifications (looking upstream from the descending right bank).

Table 2. Model scale conversions.

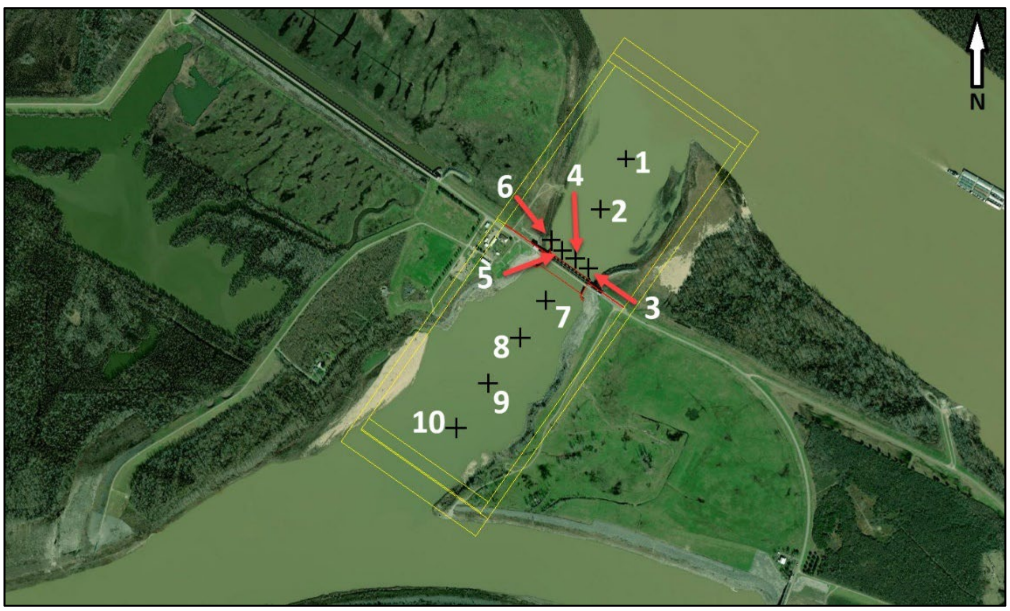
Variable	Froude Similitude Scale
Length	$L_r = 55$
Velocity	$V_r = L_r^{0.5} = 55^{0.5} = 7.416$
Time	$T_r = L_r^{0.5} = 55^{0.5} = 7.416$
Discharge	$Q_r = L_r^{2.5} = 55^{2.5} = 22{,}434$

Figure 5. Model modifications: initial removal of existing blocks (*left*), new lowered blocks placed and sealed (*middle*), and final area painted with polyurea (*right*).

2.2 Data Collection and Instrumentation

To monitor and set the discharge rates into the physical model, the flow was measured using a BIF (Builder's Iron Foundry) Venturi meter 20 in. Model 0181 (serial number 97548-1) with manometer using M3 (specific gravity or S.G. = 2.95). Water-surface elevation (WSE) measurements were conducted at 10 gage locations using a Lory Type-A point gage (error ± 0.001 ft) in a 5 in. × 5 in. stilling bucket. Tailwater control was monitored by the average of gages 7 and 8. Headwater elevation was controlled by gage 2 which is approximately in the same location as staff gages that are used to monitor the headwater in the prototype. Figure 6 displays the gages within the physical model boundary outlined in *yellow*.

Figure 6. Model water-surface elevation (WSE) gage locations.

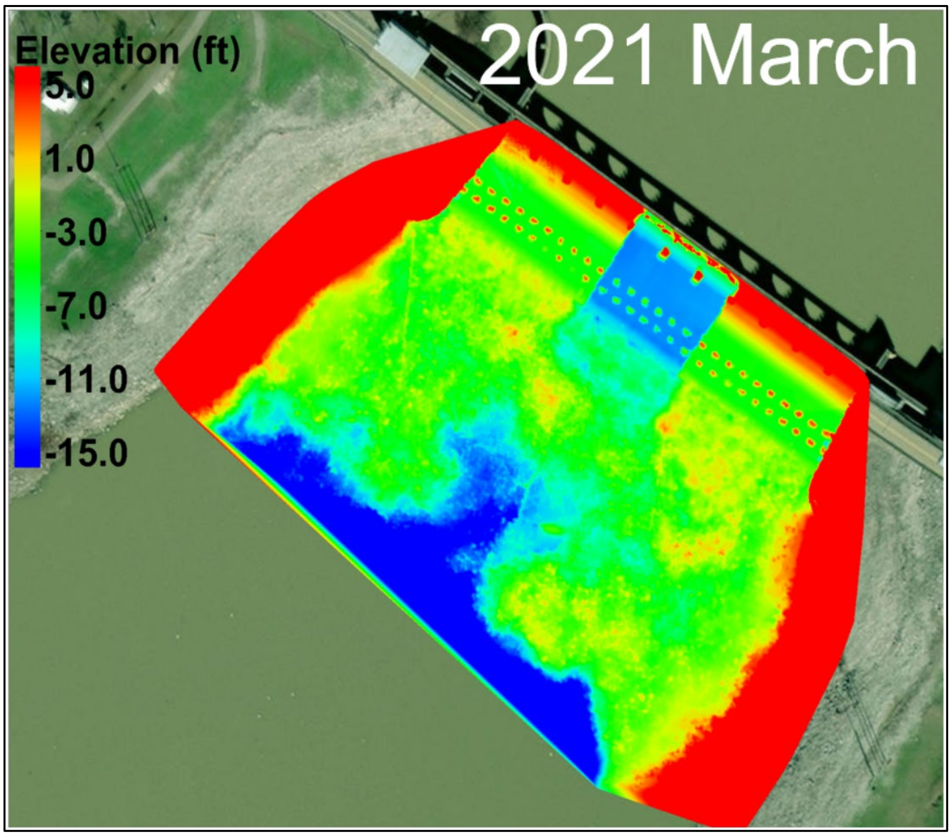


2.3 Boundary Conditions and Model Operation

As discussed in Section 2.1, the model was modified to provide an area for testing the three stone gradations for the study. The first stone gradation represented the R-5000 stone previously used in the prototype as a verification test that the model was adequately reproducing the scour trends that had occurred in the prototype and depicted in Figure 2. Gradation A was initially selected based on the velocity results from bell et al. (2024), discussions with MVN, and the desire to test a stone larger than R-5000 in the model. The Gradation B stone was selected based on the results of the Verification and Gradation A tests, again in discussions with MVN.

Once the stone was installed in the model, it was molded to represent the bed configuration that existed in the prototype in March 2021 (see Figure 7). The rock was placed on a layer of sand with filter cloth on top. Prior to initiation of testing a lidar survey was obtained to document the initial bed configuration. Testing then proceeded using the discharge, stage, and gate openings presented in Figure 4. Also, the gates in the LSCS were adjusted to produce the exact settings that had existed in the prototype for the stages and discharges being tested.

Figure 7. Topography used to mold the stone for testing.



Once the hydrograph was completed, the model was drained and another lidar survey was taken of the model bed. This allowed a comparison to be made between the pre- and posttest bed configuration to determine whether any scour of the stone had occurred and if so, how much scour. Then the stone gradation under investigation was removed, the next gradation installed, and the testing process was repeated. It should be noted that the duration for each flow on the model was 7 hr which corresponds to about 52 hr or slightly over 2 days prototype. Therefore, the model total testing time was 49 hr or slightly over 15 days prototype.

3 Physical Model Results

3.1 Model Verification Test Gradation (R-5000)

To adequately evaluate the ability to model various stone protection gradations, it is necessary to ensure that the model being used can address such issues. Over the years CHL (and previously the Hydraulics Laboratory [HL]) has used models of various scales to study riprap stability downstream of hydraulic structures. Such models have varied in scale from 1:36, 1:40, 1:150, etc. and provided reasonable results. Therefore, using the existing 1:55-scale fixed bed model was considered to be adequate to address riprap stability downstream of the LSCS.

Based on the analysis above, it was imperative that an adequate R-5000 model stone be processed to use in the model. It was determined that the model R-5000 stone should be sized such that it fit between the lower and upper limits of the prototype R-5000 gradation which was provided by MVN. The final R-5000 gradation used in the model is shown in Figure 8. A gradation analysis was performed on a sample of the Verification Gradation stone at the CHL Sediment Laboratory (SEDLAB). The maximum size of the Verification Gradation stone was about 3.5 ft, the medium size was about 2.3 ft, and the minimum size was about 2 ft. As shown in Figure 8, the model gradation developed fits within the lower and upper limits of the R-5000 stone used in the prototype.

The Verification Gradation stone was installed in the recess constructed downstream of the LSCS (see Figure 5) and molded to conform to the March 2021 prototype survey and shown in Figure 7. Comparing the model lidar survey (Figure 9) and the March 2021 prototype survey indicates that the model bed presented a reasonable replication of the prototype with some minor scour downstream of the end sill located downstream of Gate Bays 5 to 7. The model bed also replicated some slight deposition downstream of Gate Bays 1 to 4 with somewhat greater deposition downstream of Gate Bays 8 to 11. The cut out on the left, downstream corner on all of lidar figures is used as a nontest, sump area to remove water from the test area. This allows obtaining the lidar surveys to effectively scan the area of interest. The pretest mold can be seen in Figure 10.

Figure 8. Verification gradation curve.

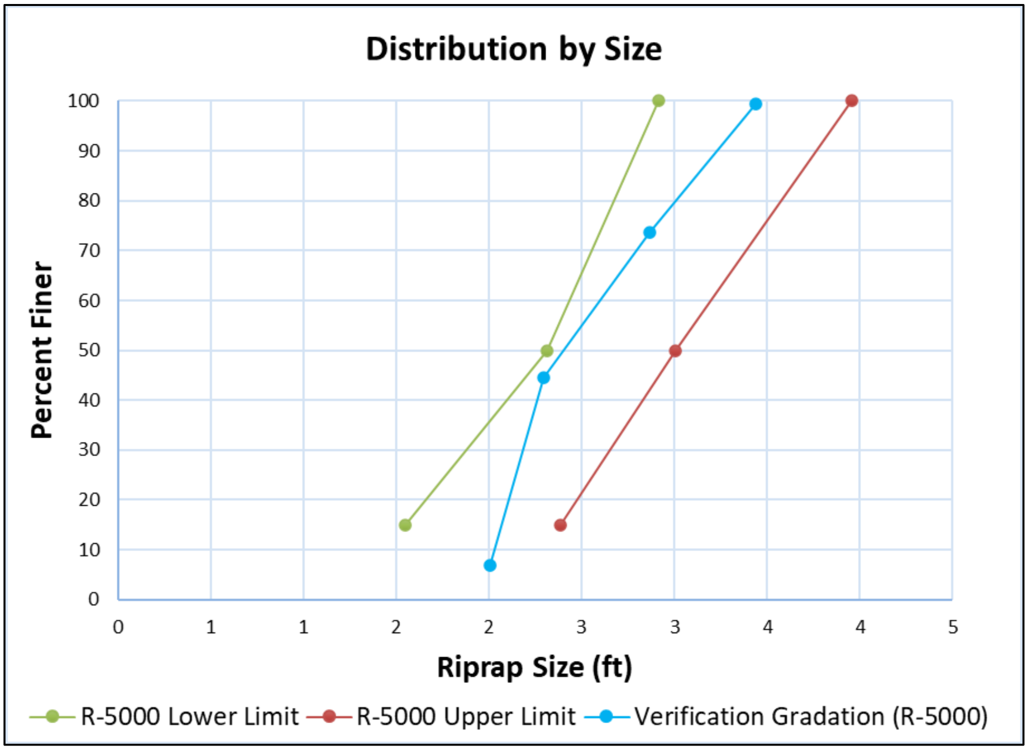


Figure 9. Pretest lidar from the verification gradation stone test.

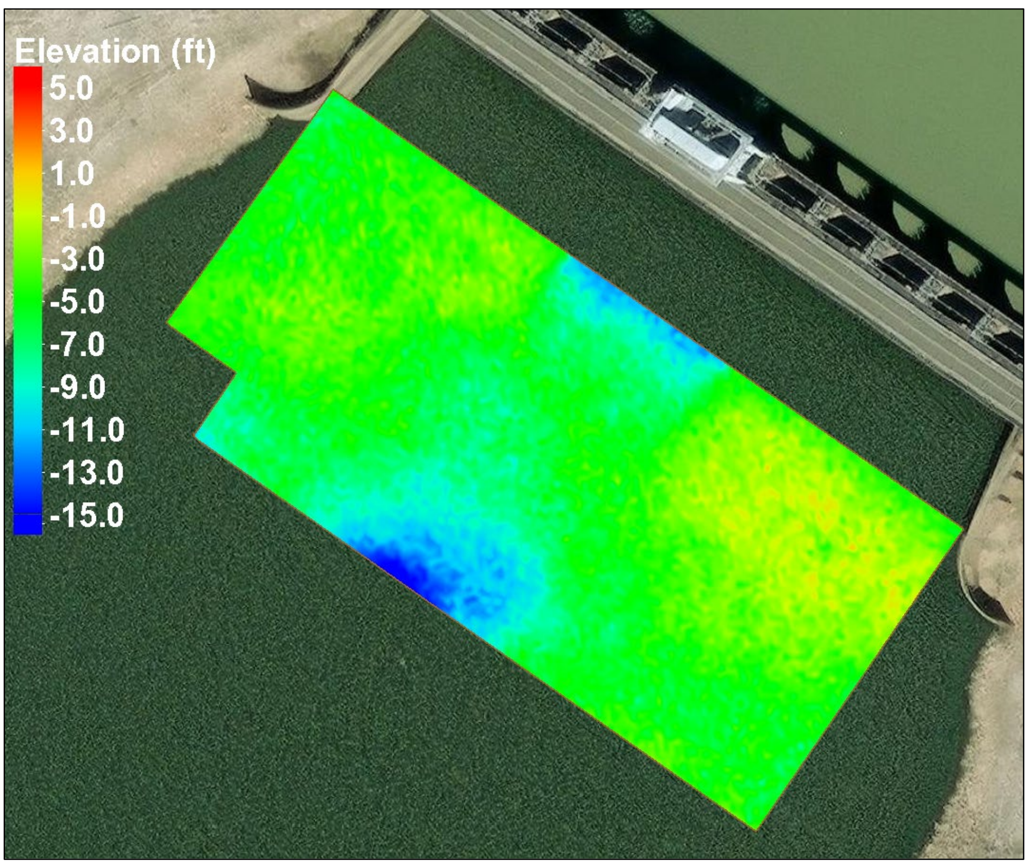
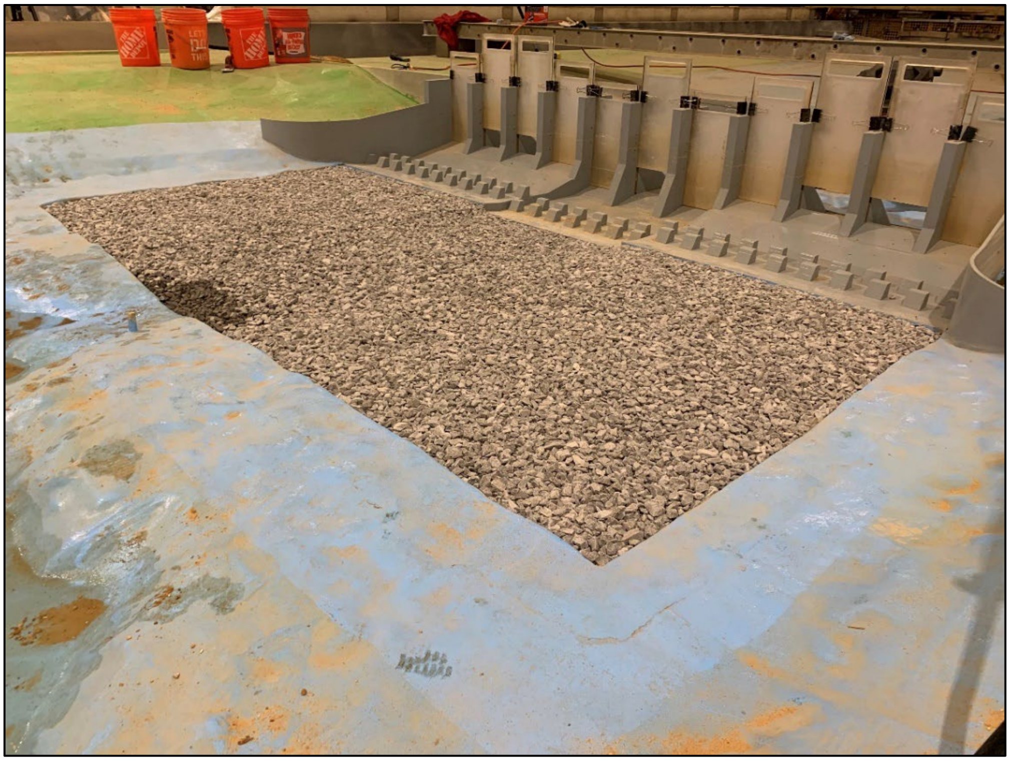


Figure 10. Pretest molded verification gradation stone test.



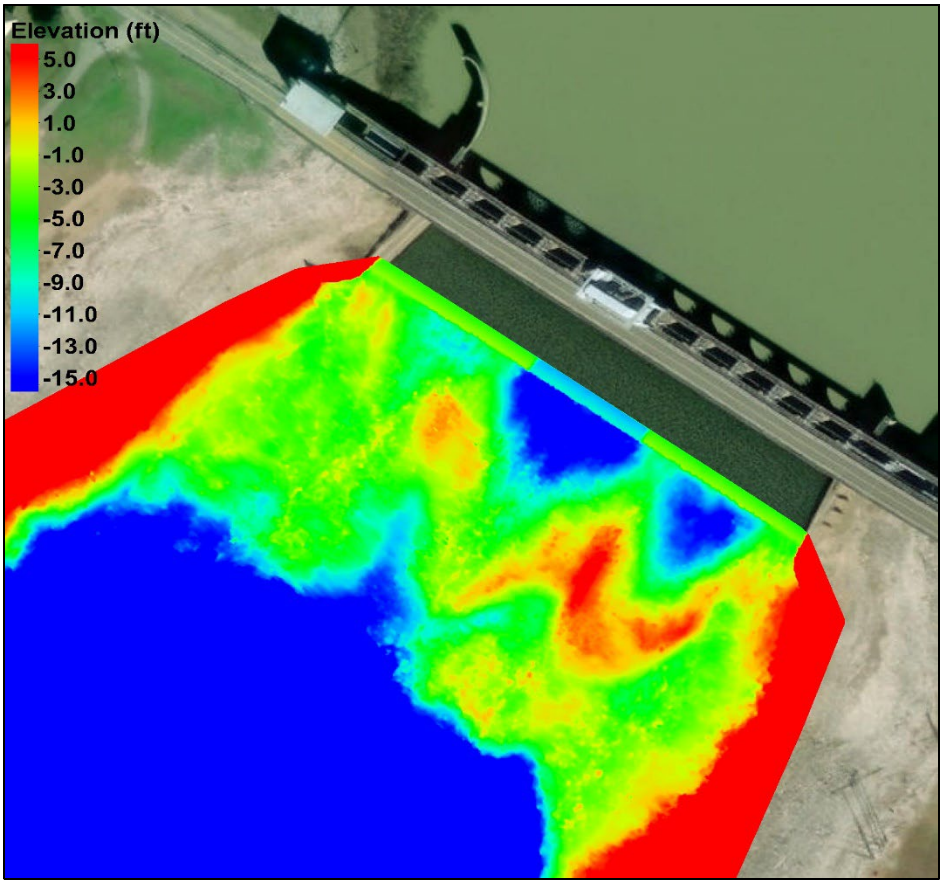
The testing was conducted using the stepped hydrograph shown in Figure 4. These flows were a compilation of 6 days that occurred in the prototype in 2018, 2019, 2021, and 2022 plus a hypothetical flow added by MVN. The hydrograph was created using tailwater elevations, discharge, and gate operations from the test results in Bell et al. (2024).

The goal of the model verification test is to ensure that the model is capable of reproducing movement of the modelled R-5000 stone in a similar manner as had occurred in the prototype. Since the amount of time the prototype was exposed to potentially scouring flow conditions was not modelled, the desired results would be to reproduce trends and not necessarily reproduce the exact amounts of scour or deposition as the prototype. The April 2022 prototype survey is shown in Figure 11.

The bed configuration at the end of the test is shown in Figure 12. Comparing the model ending survey to the Pretest conditions (Figure 9) indicated that the areas downstream of Gate Bays 1 to 4, 5 to 7, and 8 to 11 scoured during the testing. Downstream of Gate Bays 1 to 4 approximately 6 ft to 7 ft of scour occurred. Downstream of Gate Bays 5 to 7 the existing scour area increased in size and deepened approximately 3 ft to 4 ft.

Downstream of Gate Bays 8 to 11 about 10 ft of stone was scoured and some of that material was deposited directly downstream.

Figure 11. April 2022 prototype lidar survey.



Comparing the model ending survey to the April 2022 survey (Figure 11) indicates that the scour downstream of Gate Bays 1 to 4 is very similar to what occurred in the prototype. The scour downstream of Gate Bays 5 to 7 was like the prototype, although the scoured area was not as large or as deep as in the prototype; however, as in the prototype, of the three scoured areas this was the largest. The scour and stone deposition downstream of Gate Bays 8 to 11 was a reasonable representation of the prototype tendencies. The pre minus posttest lidar comparison is in Figure 13 and the post test bed can be seen in Figure 14.

Based on these model results, it was concluded that the model was adequately capable of reproducing scour potential for the modeled R-5000 stone and would be useful in investigating other potential stone sizes to eliminate the scour that has occurred downstream of the end sill over the years.

Figure 12. Posttest lidar from the verification gradation stone test.

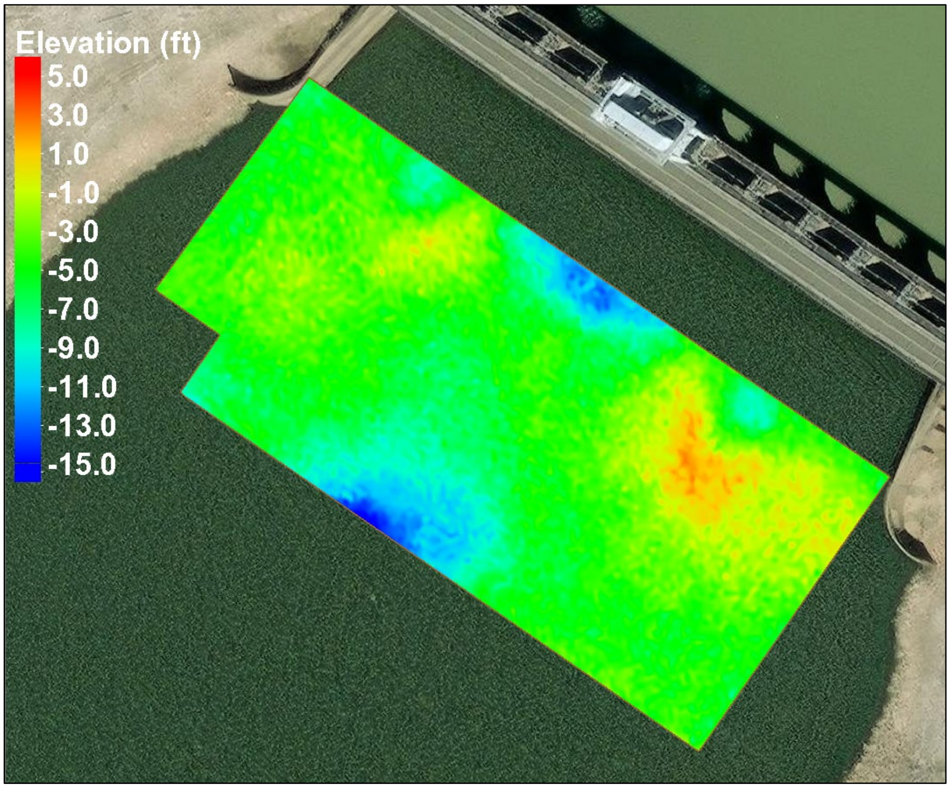


Figure 13. Difference lidar plot of pretest minus posttest bathymetry from the verification gradation test.

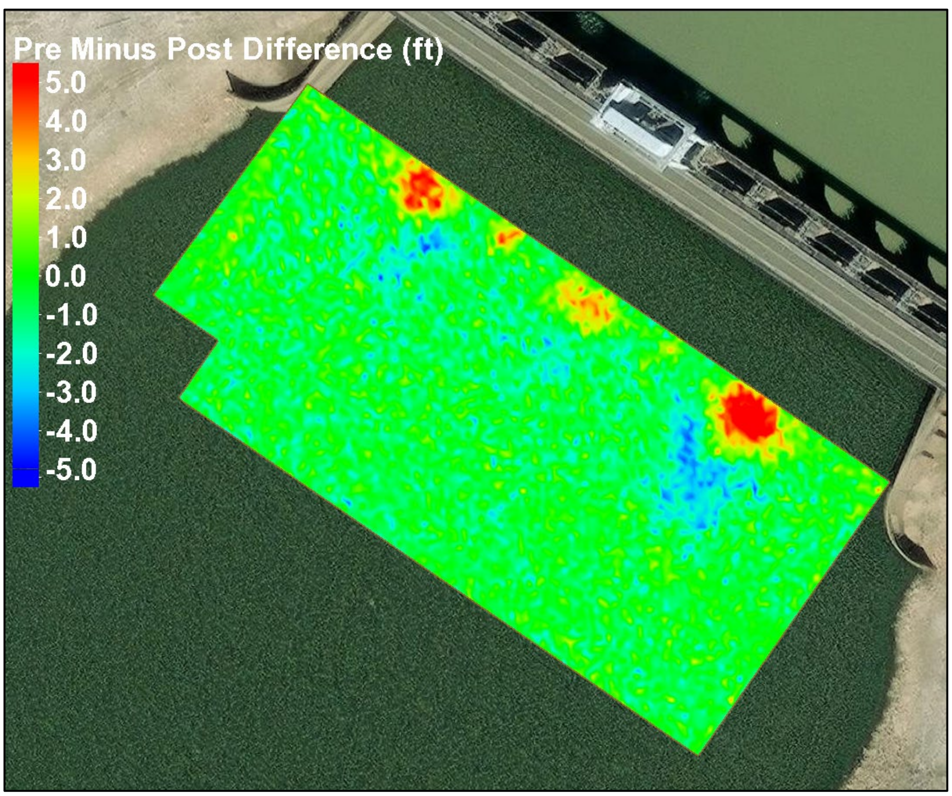


Figure 14. Posttest picture from verification gradation stone test.

3.2 Gradation A Tests

The Gradation A was selected based on USACE guidance for stone protection and the velocities measured by Bell et al. (2024). This resulted in a stone size significantly larger (and heavier) than the R-5000 gradation previously used in the prototype and in the verification test above. The maximum size of the Gradation A stone was about 9 ft (prototype), the median size was about 6 ft (prototype), and the minimum size was about 3.5 ft (prototype). The gradation curve of the for Gradation A stone is shown in Figure 15 along with the R-5000 gradation. From the gradation curves it is obvious that virtually all Gradation A stone is larger than the R-5000 stone. A gradation analysis was also performed on a sample of Gradation A stone using the CHL SEDLAB. The Gradation A stone was installed in the recess constructed downstream of the LSCS (see Figure 16) and molded to conform to the March 2021 prototype survey and shown in Figure 7.

All tests were conducted using the stepped hydrograph shown in Figure 4. During the testing there was no major movement in the areas of concern as seen in Figure 17 indicating that Gradation A was stable for the flow conditions tested. The pretest lidar results are shown in Figure 18.

Figure 15. Gradation A curve.

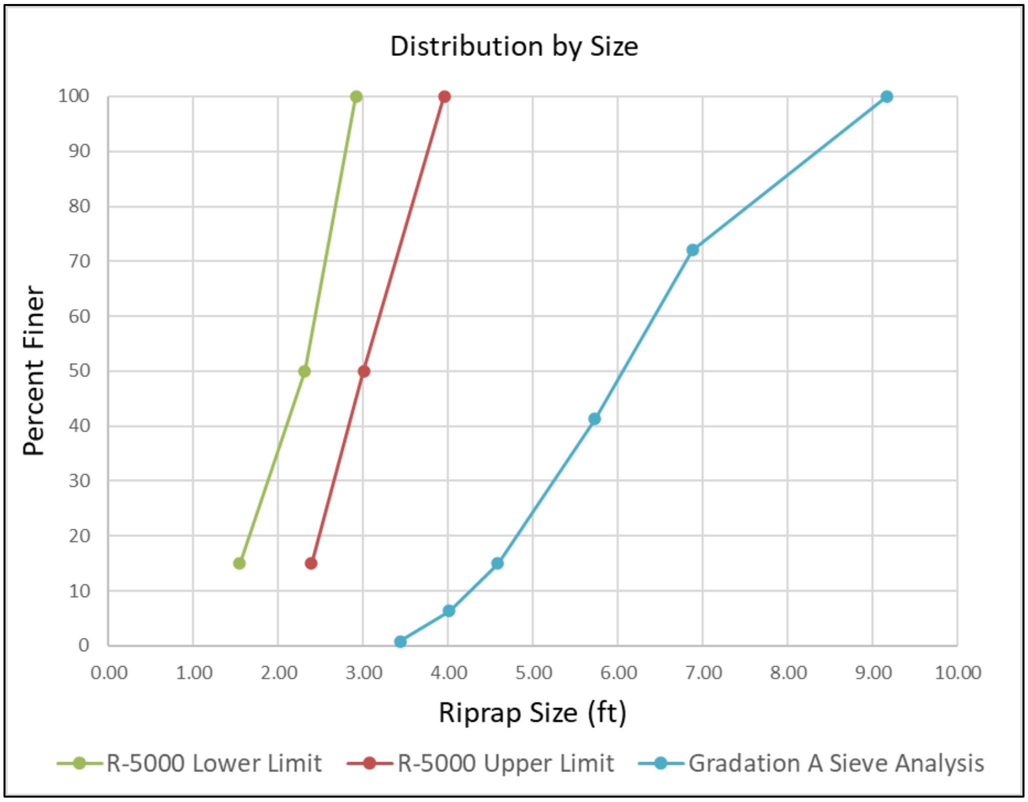


Figure 16. Photograph of Gradation A stone molded prior to testing.

Figure 17. Photograph of Gradation A test area before and after testing.

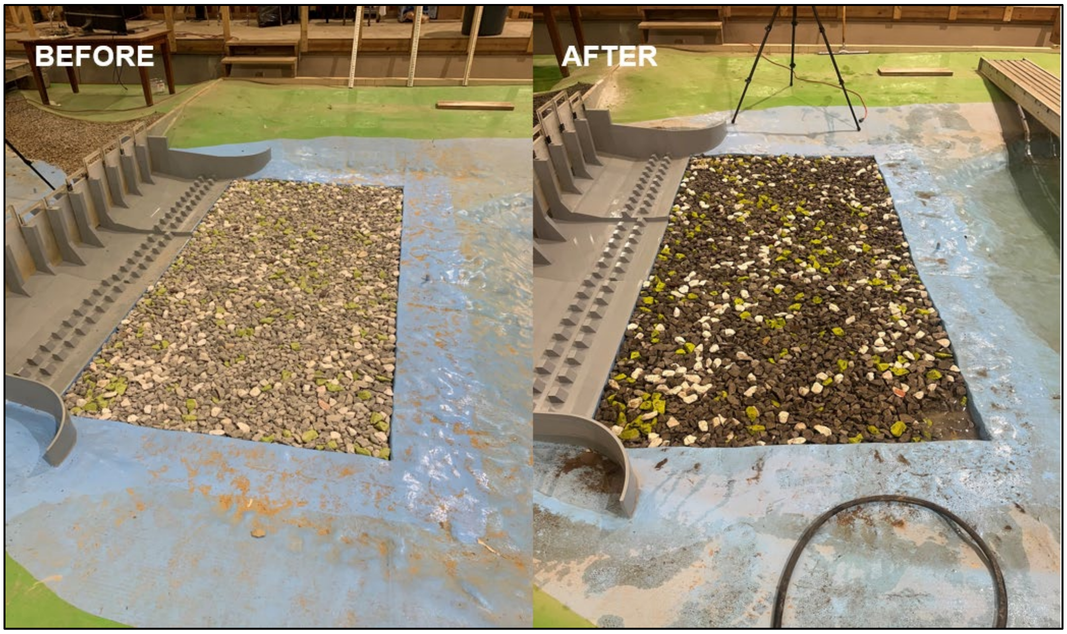
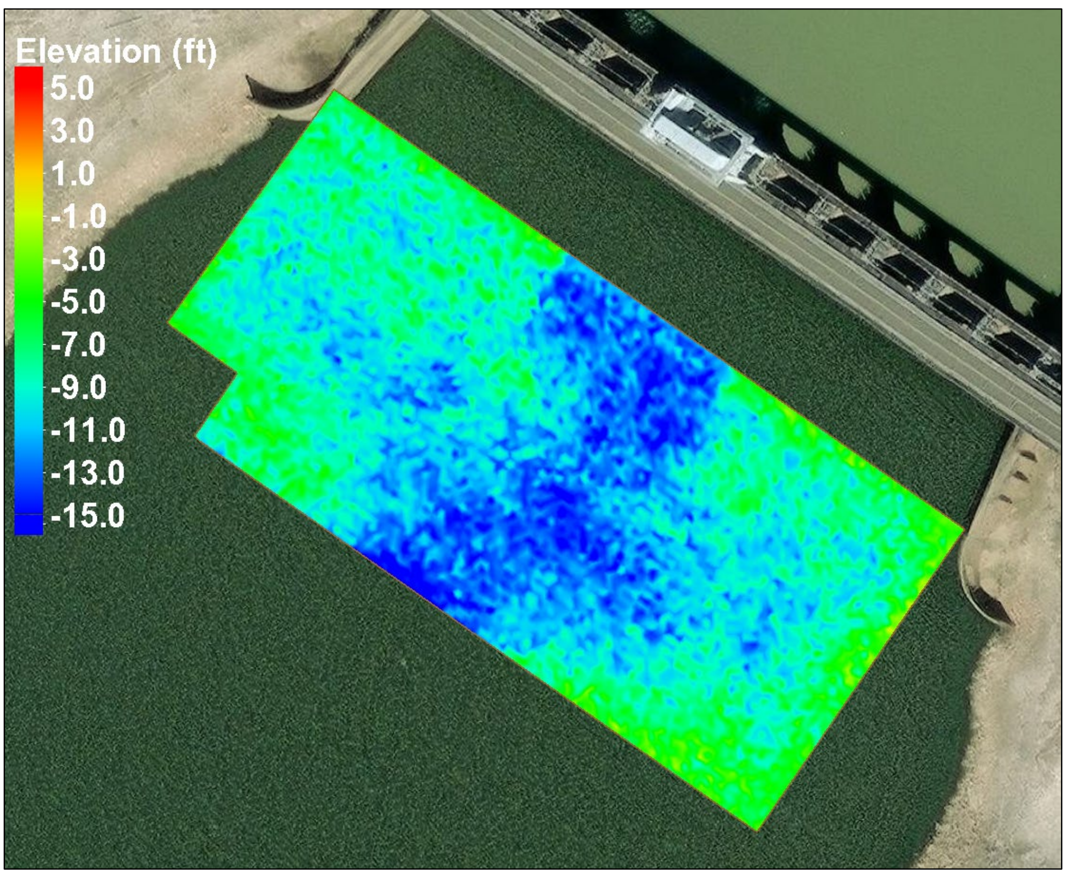


Figure 18. Pretest lidar from the Gradation A stone test.



The before and after photographs in Figure 17 and the pre- and posttest lidar plots in Figure 18 and Figure 19 respectively indicate that there was no scour of the Gradation A stone downstream of the low Gate Bays 5 to 7 or the high Gate Bay 10 as has occurred previously in the prototype (see Figure 2). Figure 20 shows the difference plot from pre minus posttest lidar surveys which also shows no scour from the model test. The *red* and *blue* "dots" that are seen in Figure 20 are from slight movement of the rocks sliding and rolling during testing. Therefore, Gradation A stone would be suitable for stabilizing the areas of scour. However, since the Gradation A stone was relatively large, it was decided to test a smaller size stone compared to Gradation A, but larger than the R-5000 gradation previously installed in the prototype.

Figure 19. Posttest lidar from the Gradation A stone test.

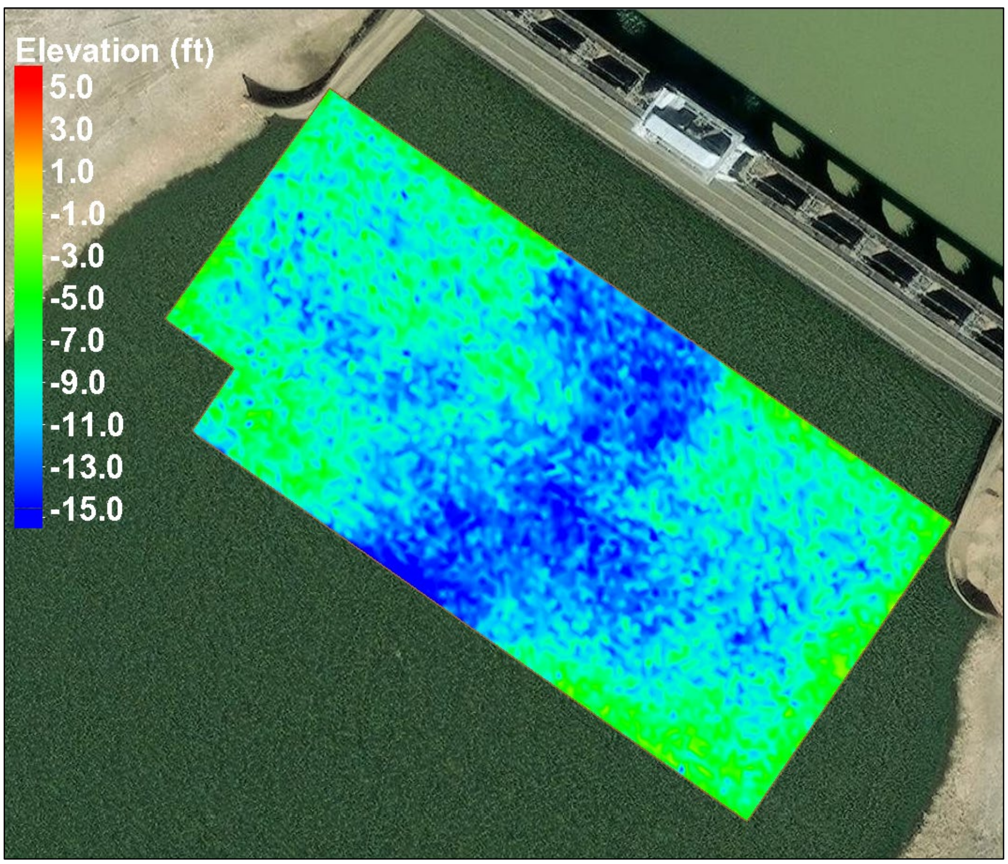
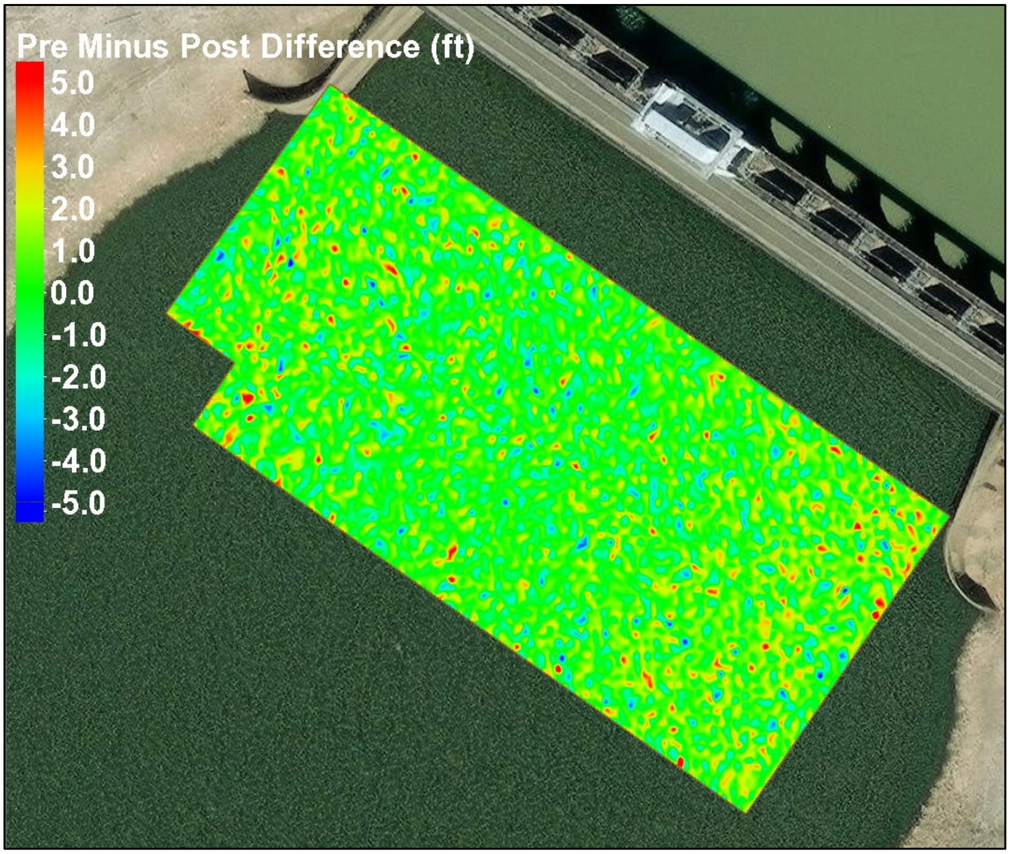


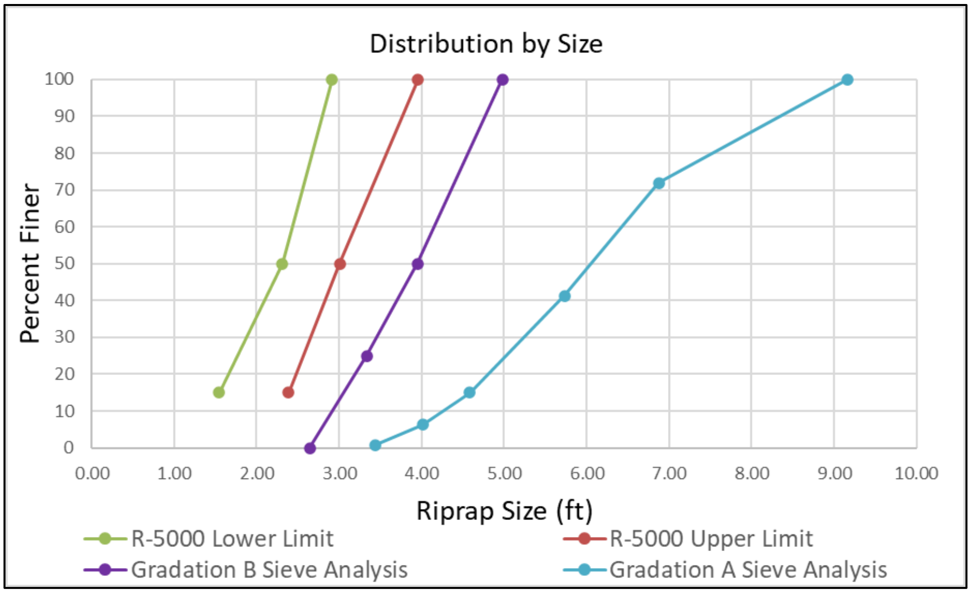
Figure 20. Difference lidar plot of pretest minus posttest bathymetry from the Gradation A test.



3.3 Gradation B Tests

The next model gradation tested was selected to be slightly larger than the R-5000 gradation previously used in the prototype and in the verification test in Section 3.2. The maximum size of the Gradation B stone was about 5 ft (prototype), the median size was about 4 ft (prototype), and the minimum size was about 2.5 ft (prototype). The gradation curve of the stone used is shown in Figure 21 along with the R-5000 and Gradation A gradations. The gradation curves show that about 50% of the stone included in Gradation B is smaller than the maximum R-5000 stone upper limit. Figure 17 also shows that Gradation B is significantly smaller than Gradation A with all of Gradation B stone fitting within about the smallest 20% of Gradation A. It is obvious that all of Gradation A stone is larger than the R-5000 stone. This gradation analysis was also performed on a sample of Gradation B stone using the CHL SEDLAB. The Gradation B stone was installed in the recess constructed downstream of the LSCS and molded to conform to the March 2021 prototype survey.

Figure 21. Gradation B curve.



As was the case for the Verification and Gradation A tests, all tests were conducted using the stepped hydrograph shown in Figure 4. During the Gradation B tests there was no major movement in the areas of concern. Figure 22 shows photographs of the test area before and after the experiment and it is obvious that no movement took place during the testing. The pretest and posttest lidar results are shown in Figure 23 and Figure 24, respectively. Comparing the two figures indicates that Gradation B was stable for the flow conditions tested (Figure 25).

Figure 22. Before and after testing of Gradation B.

Figure 23. Pretest lidar from the Gradation B stone test.

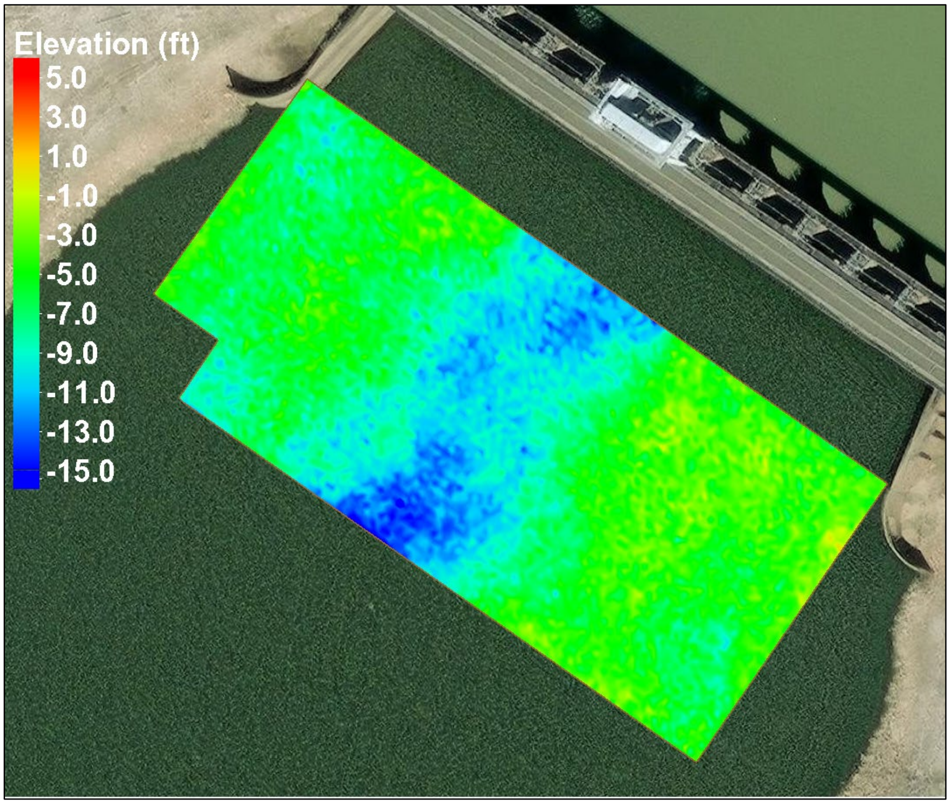


Figure 24. Posttest lidar from the Gradation B stone test.

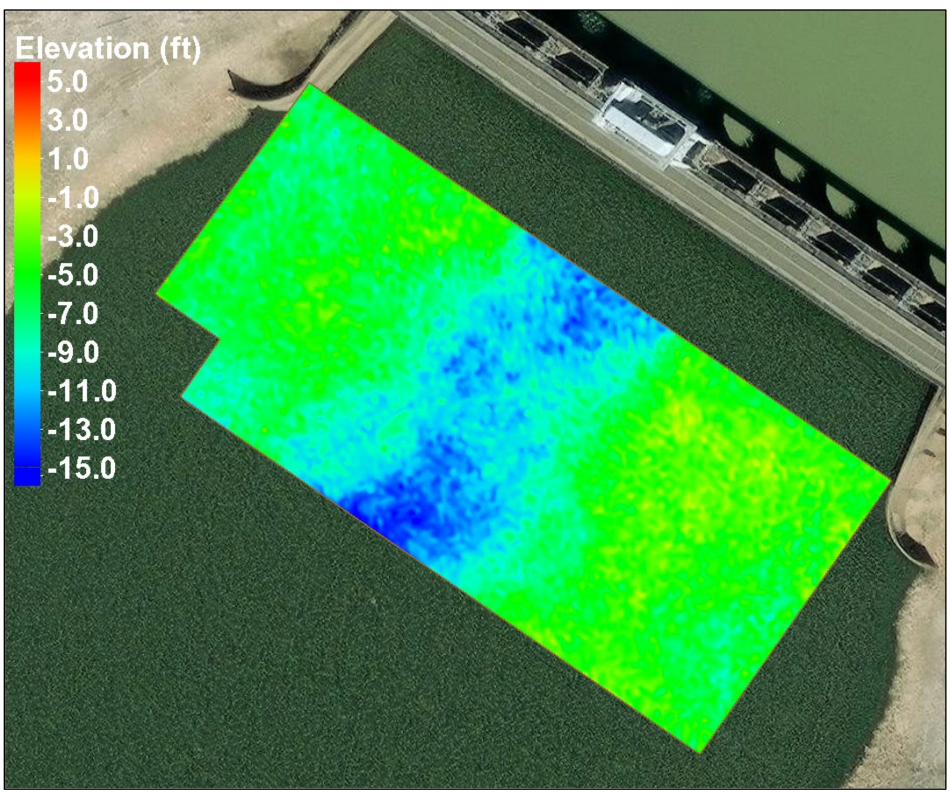
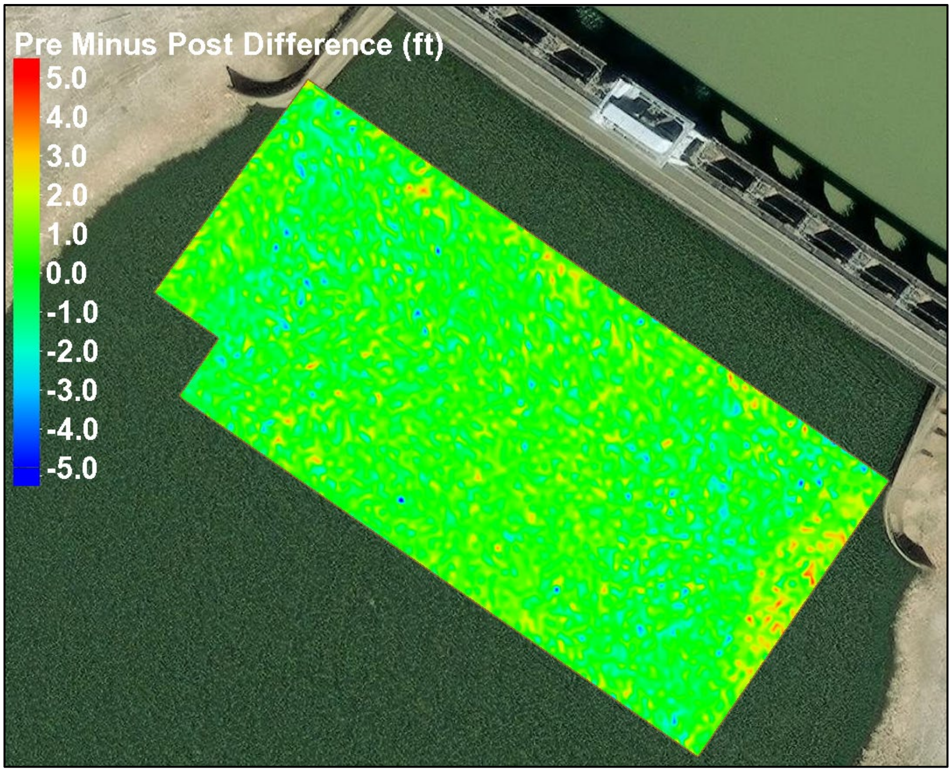


Figure 25. Difference lidar plot of pretest minus posttest bathymetry from the Gradation B test.

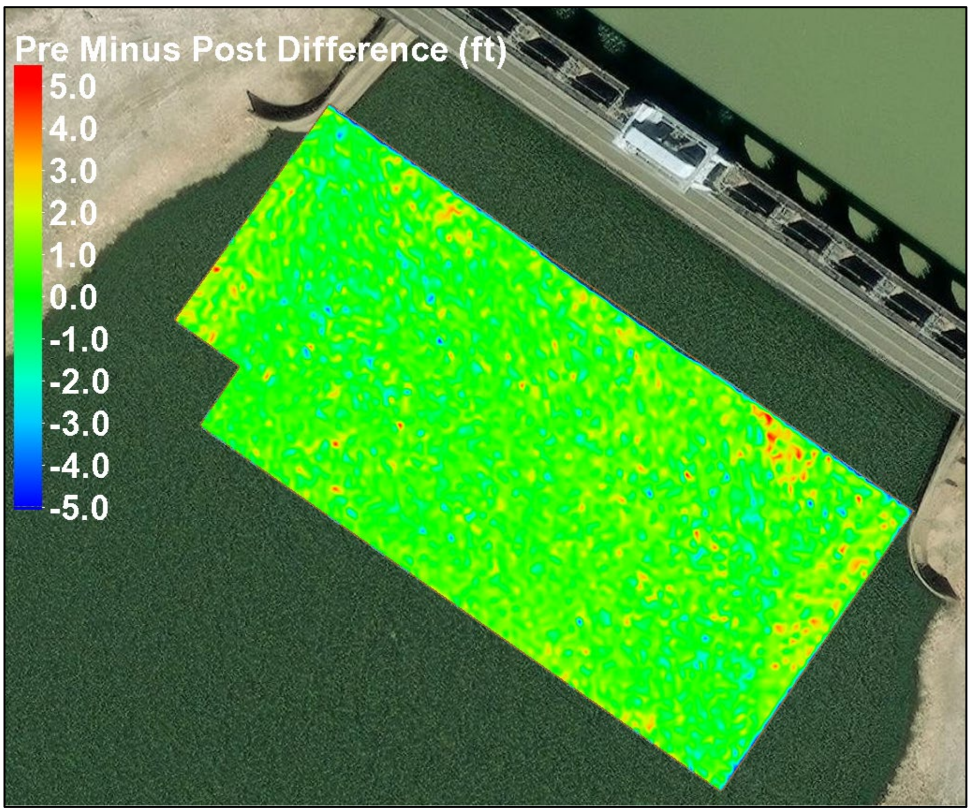


During this test there was a discussion with MVN relative to the susceptibility of Gradation B stone being scoured if the LSCS tailwater was lowered from the tested values. It was decided that conducting a short test to determine the effect of lowering the tailwater would provide MVN with some degree of confidence if such an event would occur in the prototype with this size stone.

Flow 2 (see Figure 4) was selected for this test. The flow was established on the model with a headwater elevation of 50.4 ft and a tailwater elevation of 30.4 ft with a LCSC discharge of 126,000 f^3/s. The model was held in a stable condition for a period of about 30 min on the model (equivalent to 3.7 hr prototype, see Table 2). The tailwater stage was lowered in approximately 2 ft increments holding those conditions for the 30 min until the next lowering was performed. It should be noted that the model inflow was monitored throughout this testing to ensure that the discharge through the LSCS remained relatively constant. This testing procedure continued until the tailwater was lowered a total of 10 ft. During the test there appeared to be some slight stone movement. At the end of the test a lidar survey was taken of the test area. A comparison was made with the bed configuration at the beginning of the Gradation B testing

(Figure 23) and the bed configuration at the end of the tailwater drawdown test. The differences between those two surveys are presented in Figure 26. While there appears to be some movement of stone approximately downstream of the areas aligned with Gate Bays 2 and 10, that movement is very localized with there does not appear to be any systematic movement of stone throughout the basin. It should be noted relative to the data shown in Figure 26 that red areas are indicative of bed scour since the figure is a plot of the difference of the initial bed configuration (pretest) and the posttest tailwater lowering.

Figure 26. Difference lidar plot of pretest minus posttest bathymetry from the Gradation B tailwater drop test.



3.4 Riprap Repair Test

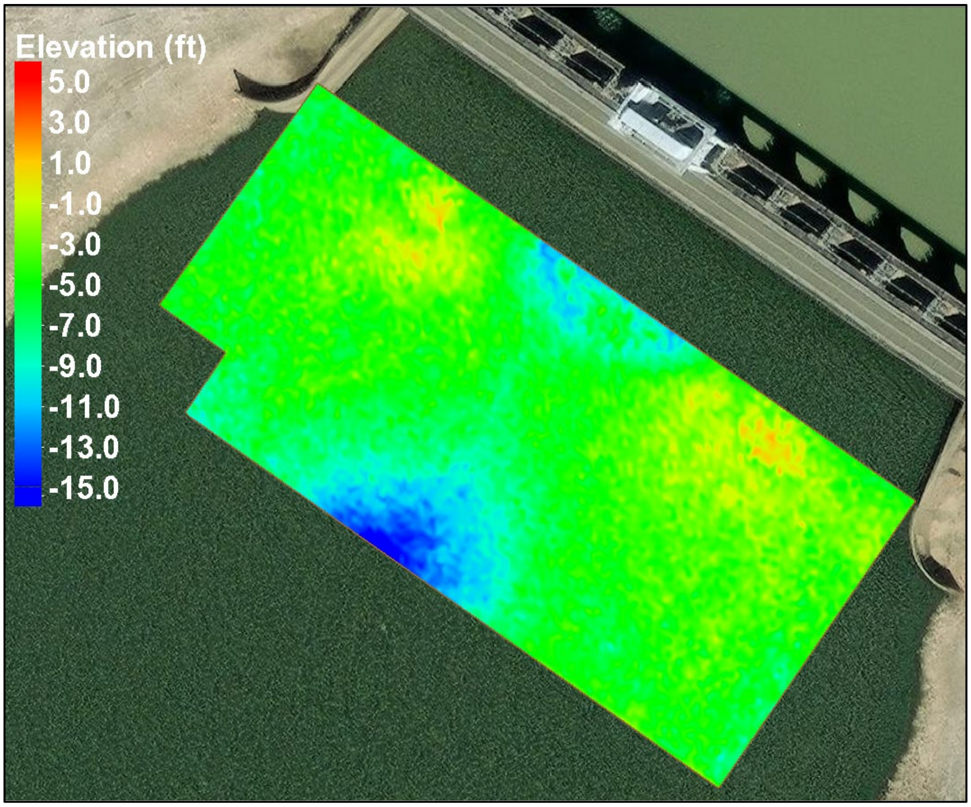
At the request of MVN, a test was conducted to determine the effects of installing Gradation B stone in the three scoured areas downstream of the end sill in the Verification Gradation stone test (Figure 12). Such a test would be indicative to the situation MVN had relative to the existing scour in the prototype (Figure 11). It should be noted that most of the stone downstream of the end sill was the modelled R-5000 stone from the verification test. Figure 27 shows the bed configuration at the end of the

Verification Gradation test with the three scour holes filled with Gradation B stone (the light-colored stone immediately downstream of the LSCS end sill looking to the north; circled in *red*) and Figure 28 shows the pretest lidar survey.

Figure 27. Scour holes filled with Gradation B stone.

A comparison of the Postverification Test lidar survey shown in Figure 12 above and the Pre-Riprap Repair Test shown in Figure 28 with the three scour holes filled with Gradation Stone B shows that the scour hole downstream of Gate Bays 1 to 4 was filled about 6 ft or 7 ft with the area raised from elevation −6 ft to elevation 0 ft. The scour hole downstream of gate bays 5 to 7 was filled about 10 ft with Stone B with the area raised from elevation −15 ft to elevation −5 ft. Downstream of Gate Bays 8 to 11 the scour hole at the end of the Verification Test was filled by about 6 ft with the area raised from elevation −5 ft to elevation +1 ft.

Figure 28. Pretest lidar from the Riprap Repair Test.



As was the case for all previous tests, the stepped hydrograph shown in Figure 4 was used on the Riprap Repair Test. During the test there was no noticeable or measurable movement of the Gradation Stone B in the three repair areas (Figure 29 shows the posttest lidar survey). Close examination of Figure 28 and Figure 29 supports the conclusion that no movement of the repair Stone B took place. The bed configuration at the end of the test being essentially identical to the beginning configuration.

Comparing the difference of the lidar surveys by subtracting the posttest survey from the pretest survey indicates very minor or virtually insignificant differences between the two surveys. A plot of the differences is presented in Figure 30. The few differences that are indicated on the figure are due to slight rock movement and lidar data measuring the top of a stone on one survey and the side of the stone on the other survey.

Figure 29. Posttest lidar from the Riprap Repair Test.

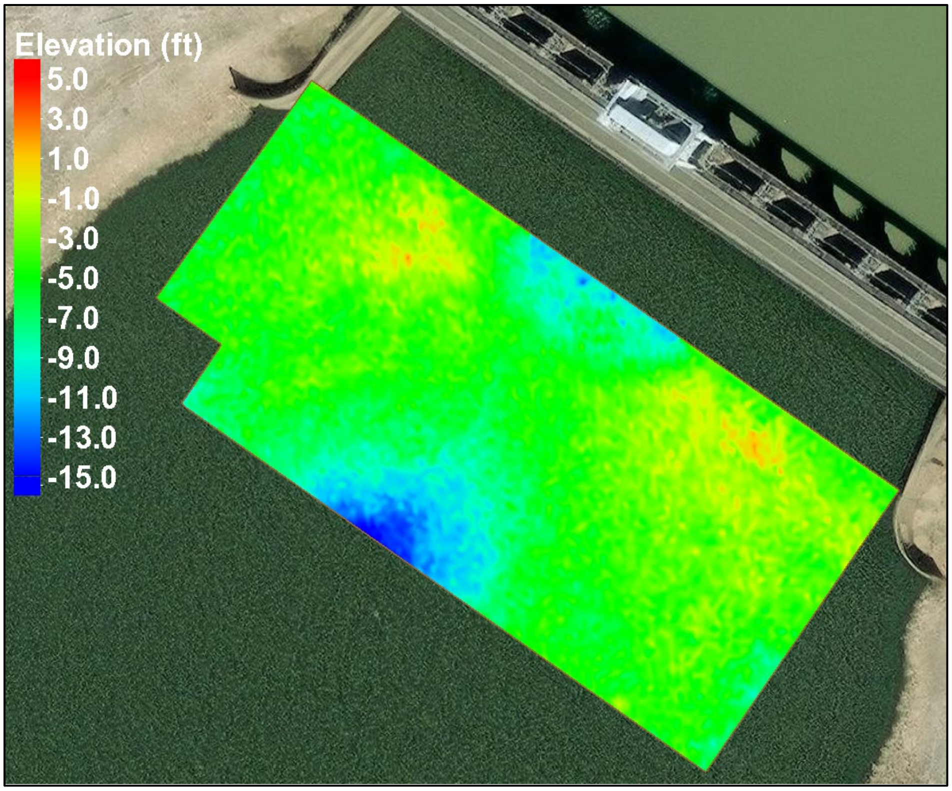
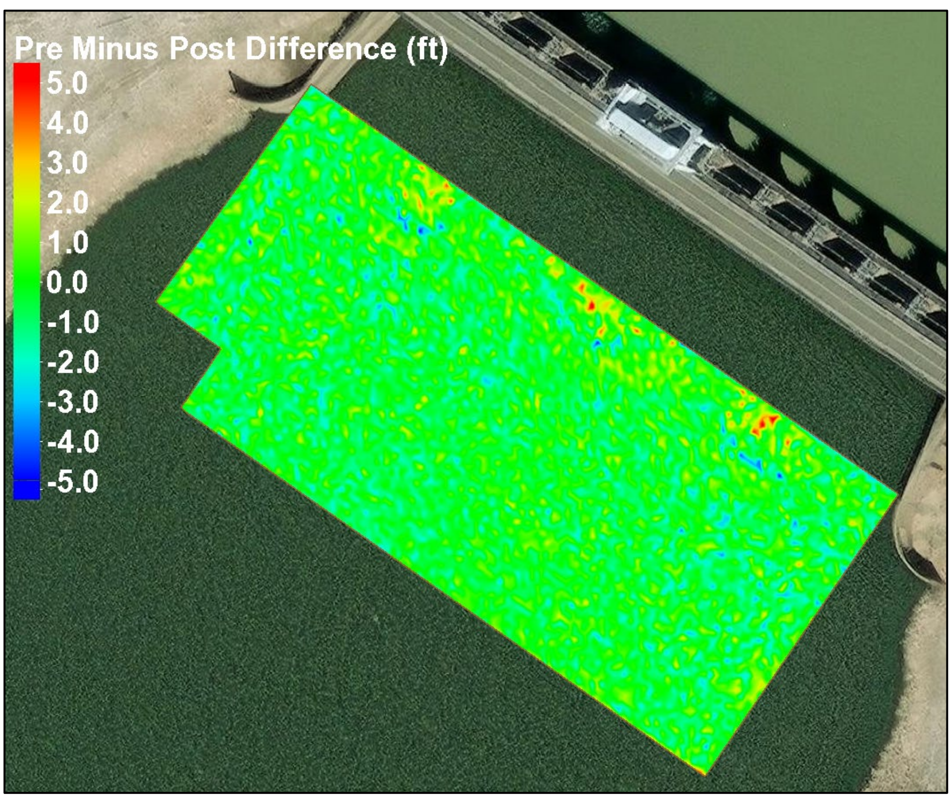


Figure 30. Difference lidar plot of pretest minus posttest bathymetry from the Riprap Repair Test.



4 Conclusions and Recommendations

4.1 Conclusions

The tests conducted and presented above were undertaken to model and analyze the stability of scaled riprap in the existing 1:55 Froude-scaled physical model. Three separate gradations of scaled riprap were tested; one gradation modeling the R-5000 previously used in the prototype and two gradations larger than the R-5000 gradation at varying boundary conditions (discharge, head and tailwater elevations, and gate openings).

The test on the Verification Gradation indicated that the model could reproduce the same scour and depositional trends as the prototype. The areas downstream of Gate Bays 1 to 4, 5 to 7, and 8 to 11 scoured with the area downstream of Gate Bays 5 to 7 being larger than the other two areas. As was the case in the prototype, the material scoured from the bed downstream of the end sill at Gate Bays 8 to 11 deposited immediately downstream of the scoured area.

In an effort to evaluate the amount of scour in the verification test the flows used in the testing were reviewed to determine the effect of time on the scour downstream of the end sill. As stated earlier, each of the seven flows on the testing “hydrograph” lasted for 7 hr (model) or about 2 days (prototype). The analysis of the 6 flows from the prototype indicated the following:

- Relative to the 11 August 2018 flow, the tailwater was at or below 17.8 ft for 8 days when the discharge varied from 50,000 cfs to 80,000 cfs.
- Relative to the 1 March 2019 flow of 199,000 cfs, there were 15 consecutive days in March with flow varying between 190,00 cfs and 200,000 cfs.
- Relative to the 22 August 2019 flow of 61,000 cfs, from June through August there were 29 days when the flow varied from 60,000 cfs to 150,000 cfs and tailwater varied from 19 ft to 20 ft.
- Relative to the 12 May 2021 flow of 96,000 cfs, there were 18 days in May when the discharge was greater than 88,000 cfs.
- For the 13 January 2022 flow of 96,000 cfs, there were 9 days in January where the flow was greater than 80,000 cfs.
- Relative to the flows on 7 and 15 March 2022 (126,00 cfs and 169,000 cfs, respectively), there were 28 days when the flow varied from 120,000 cfs to 170,000 cfs.

Therefore, during the period 2018 to 2019 the three flow dates above had at least 52 days in the prototype when the flow conditions were equal to or greater than on those three days. For the period 2021 to 2022 the four flow dates above had 55 days when the flow conditions were equal to or greater than on those four days. During testing using the seven flow conditions with the hypothetical flow added, the hydrograph lasted for slightly over 15 days prototype. This difference between the length of the model flow testing time to the actual time that those flow conditions were equal or exceeded in the prototype explains why the amount of scour during the Verification Calibration test varied from the prototype.

No movement of the riprap occurred during the tests on stone Gradations A or B. Since Gradation A was larger and consequently would probably be more costly and difficult to obtain from prototype quarries, Gradation B provides an adequate and better solution to the LSCS riprap scour problem. In discussions between MVN and CHL, it was agreed that Gradation B being larger than the R-5000 stone previously used in that prototype would provide the protection in the prototype as indicated in the model study. Additionally, the results of the tailwater lowering test on Gradation B stone provided support that this gradation would be adequate to maintain a stable riprap bed downstream of the LSCS.

This conclusion was reinforced by the Riprap Repair Tests where the Gradation B stone was installed in the three scoured areas downstream of the LSCS end sill. The test with the scoured areas at the end of the Verification Gradation stone test filled with Gradation B stone indicated that none of the Gradation B stone fill would be removed following the riprap repair.

4.2 Recommendations

Based on the results of the tests conducted during this study, it is recommended that a stone sized similar to Gradation B stone be used for future repairs of scoured areas downstream of the LSCS end sill. This recommendation is supported by the results of the Gradation B tests, the tailwater lowering tests on the Gradation B stone, and the Riprap Repair Test. In these three tests the Gradation B stone remained stable and indicated no tendency to be scoured.

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Bell, G. L., C. M. Bryant, T. J. Pokrefke, C. Everett, and C. E. C. Miller. 2024. *Low Sill Control Structure: Physical Modeling Investigation of Velocities Downstream of the End Sill*. ERDC/CHL TR-24-9. Vicksburg, MS: Engineer Research and Development Center–Coastal and Hydraulics Laboratory (CHL). http://dx.doi.org/10.21079/11681/48493.

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USACE (US Army Corps of Engineers) and WES (Waterways Experiment Station). 1976. *Old River Low Sill Structure Scour Protection*. Letter Report. Vicksburg, MS: Engineer Research and Development Center.

Abbreviations

ADV	Acoustic Doppler velocimeter
BIF	Builder's Iron Foundry
CHL	Coastal and Hydraulics Laboratory
ERDC	Engineer Research and Development Center
HL	Hydraulics Laboratory
LSCS	Low Sill Control Structure
MVN	USACE New Orleans District
ORCC	Old River Control Complex
SEDLAB	Sediment Laboratory
S.G.	Specific gravity
USACE	US Army Corps of Engineers
WES	Waterways Experiment Station
WSE	Water surface elevation

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14. ABSTRACT
The model investigation reported herein describes the process to model and analyze the stability of scaled riprap in the existing 1:55 Froude-scaled Low Sill Control Structure physical model. The existing model is a fixed-bed model, so modifications were made to create a testing section for the scaled stone. Three separate gradations of scaled riprap were tested at varying boundary conditions (discharge, head and tailwater elevations, and gate openings). Each test was surveyed using lidar for pre to posttest comparisons. It was found that Gradation B remained stable throughout the tests in the physical model.

15. SUBJECT TERMS
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