ERDC/CHL TR-24-9

Coastal and Hydraulics Laboratory

Low Sill Control Structure

Physical Modeling Investigation of Velocities Downstream of the End Sill

Gary L. Bell, Cody M. Bryant, Thomas J. Pokrefke,
Cassandra Everett, and Cian E. C. Miller

May 2024

ERDC/CHL TR-24-9
May 2024

Low Sill Control Structure

Physical Modeling Investigation of Velocities Downstream of the End Sill

Gary L. Bell, Cody M. Bryant, Thomas J. Pokrefke, Cassandra Everett, and Cian E. C. Miller

US Army Engineer Research and Development Center (ERDC)
Coastal and Hydraulics Laboratory (CHL)
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

Final Report

Distribution Statement A. Approved for public release: distribution is unlimited.

Prepared for US Army Corps of Engineers (USACE)
New Orleans District
New Orleans, LA 70118

Under WIC 1L8F7L; “Low Sill Control Structure Physical Model Stilling Basin Velocity Investigation”

Abstract

The model investigation reported herein describes the process to measure velocities at various locations downstream of the Low Sill Control Structure using an existing 1:55 Froude-scaled physical model. To collect these measurements, an acoustic-Doppler velocimeter was deployed downstream of the structure at varying locations and depths. A total of 79 velocity measurements were taken across nine flow conditions (discharge, head and tailwater elevations, and gate openings) provided by the US Army Corps of Engineers, New Orleans District.

Contents

Figures and Tables

Figures

Tables

Preface

This study was conducted for US Army Corps of Engineers (USACE), New Orleans District (MVN), under WIC 1L8F7L, “Low Sill Control Structure Physical Model Stilling Basin Velocity Investigation.” The technical monitor for the MVN 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 (ERDC), Coastal and Hydraulics Laboratory (CHL), technical report describes the measurement of velocities downstream of the end sill of the Low Sill Control Structure (LSCS) on the Mississippi River. This report summarizes the deployment of acoustic Doppler velocimeters (ADVs) used to collect velocity data, the data processing methods used, and the velocities around the end sill.

1.1 Background

The LSCS is one of four structures that comprise the Old River Control Complex (ORCC). The ORCC allows the USACE New Orleans District (MVN) to maintain the required 70/30 lateral flow distribution between the Mississippi River and the Atchafalaya River, respectively, as mandated by congress. In the 2019 to 2020 year, a scour hole was discovered just downstream of the LSCS's end sill. More significantly, the scour holes that could cause undermining were discovered in the area downstream of Gate Bay 10.

The deepest part of the scour hole is approximately 50 ft downstream from the end sill.[1] In 2021, R-5000 (W50 of 2,200 lb stone) riprap was added in the wet to the deepest areas using a 9 ft blanket thickness. MVN stated in the design document that "since high water season is near, we recommend using R5000 which will provide adequate scour protection for velocities up to ft/sec."[2] A 2022 survey has revealed that some of the riprap placed in 2021 was missing below the stilling basin and had apparently deposited just downstream of the original scour holes (Figure 1). Note that the 2022 scour is very similar to scour holes observed in 2019, 2020, and 2021. Figure 2 shows the approach channel to the LSCS in the existing physical model (Sharp et al. 2022) and the ORCC overview. Figure 3 displays the stilling basin (USACE 1954).

---

[1] 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.

[2] USACE-MVN (US Army Corps of Engineers–New Orleans District). 2024. *Low Sill Outflow Scour Holes Rehab Design*. Draft Report. New Orleans, LA: USACE-MVN.

Figure 1. Bathymetric surveys downstream of the Low Sill Control Structure (LSCS).

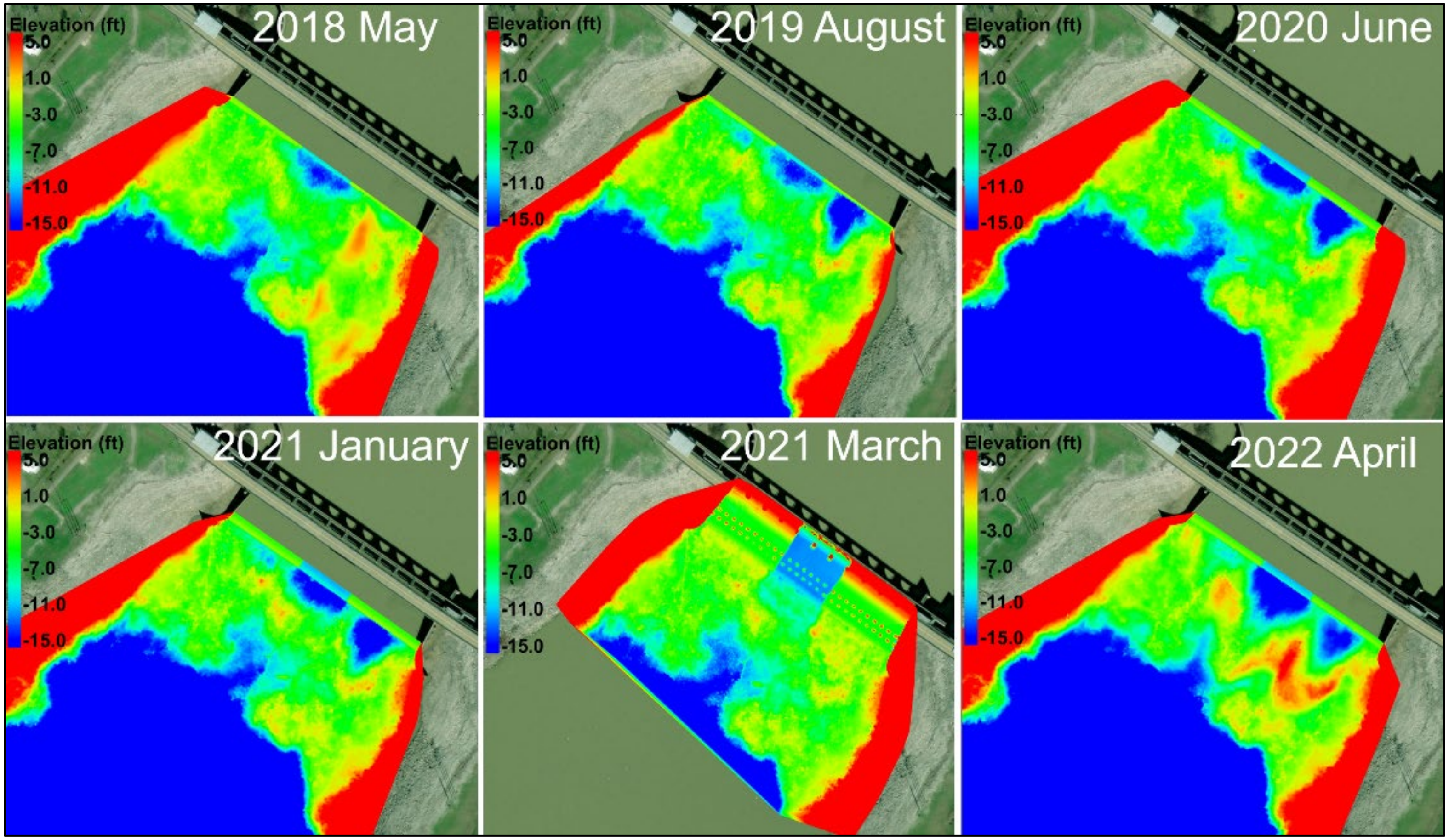


Figure 2. View from the upstream end of the LSCS approach channel (*left*) and the Old River Control Complex (ORCC) overview (*right*).

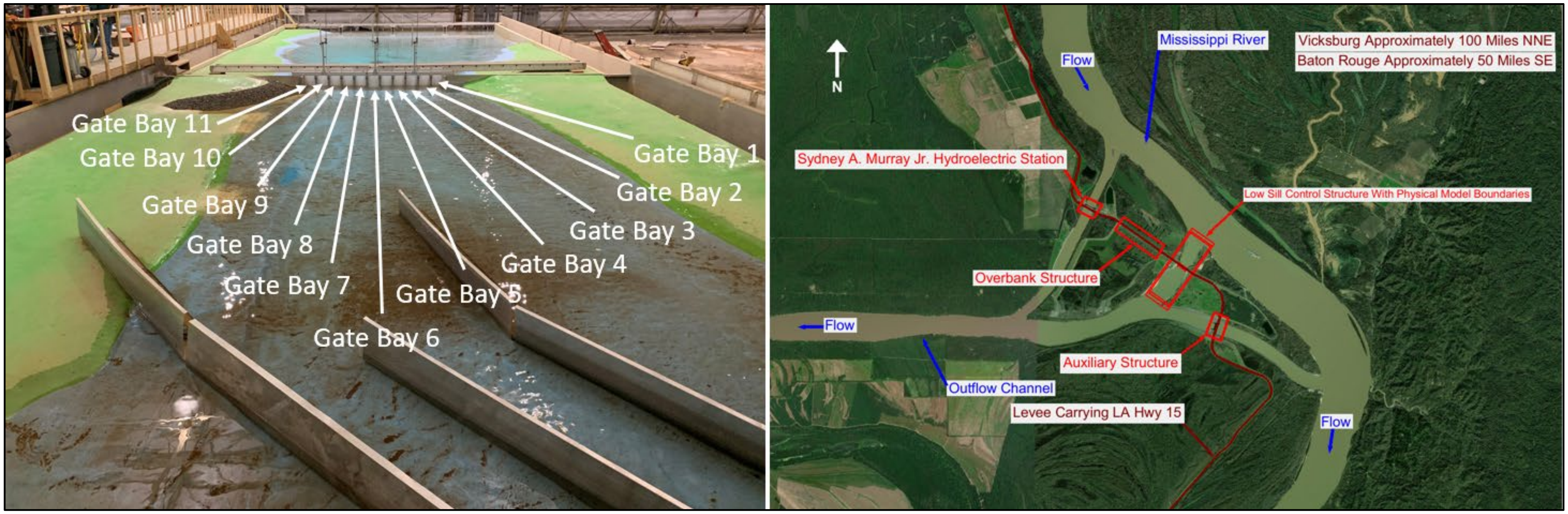
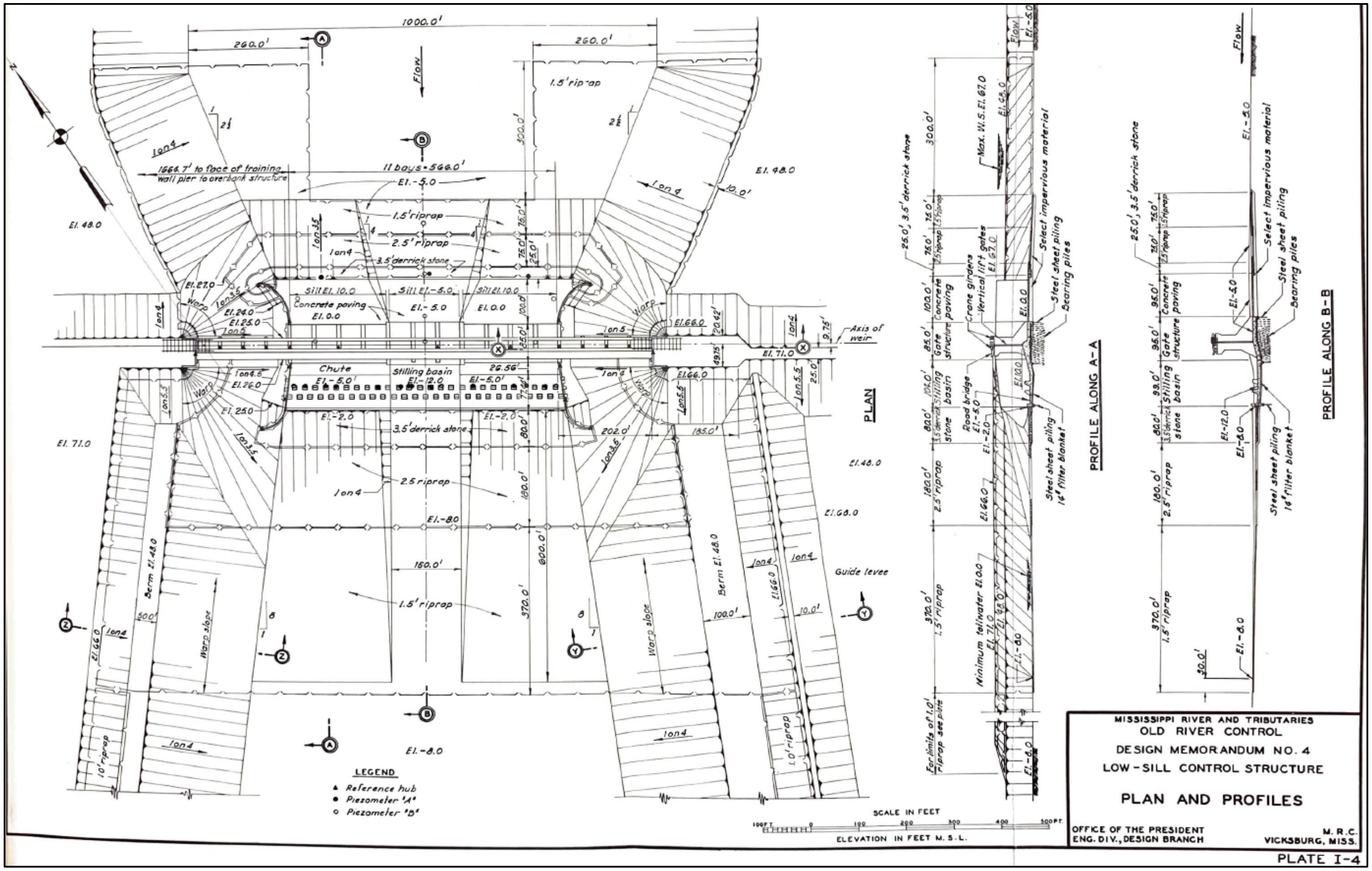


Figure 3. LSCS plan and profiles. (Image reproduced from USACE 1954. Public domain.)



From the roughly 16 months between when rock was placed and when the survey was performed in 2022, the LSCS was closed about 8 months. During this period, the discharge through the LSCS only exceeded 100,000 cfs for short times in January 2022 and March 2022. The LSCS discharge only exceeded 100,000 cfs for 33 days between January 2021 and April 2022. This caused concern as the 2022 survey revealed rock movement even though discharge through the structure was relatively low.

In 1976, Waterways Experiment Station (WES) performed tests of the LSCS stilling basin end sill on scaled riprap using a 1:36 section model. These experiments were halted due to urgency to use the model for ongoing repair operations for the stilling basin. One gradation with a W50 of 2,286 lb applied in a blanket 8.5 ft thick was evaluated. This gradation is less than their goal of a W50 of 2,900 lb based on projected average velocities of 19 ft/s at the stilling basin end sill when the structure is operated in orifice control (flow under the gates set at a certain height). It is also smaller than the recommended W50 when the structure is operated with all gates fully open and projected average velocities are at 22 ft/s (USACE 1976).

Physical model tests by Rothwell and Grace (1977) found that higher tailwater levels produced lower velocity values. Thus, low tailwaters combined with gate operation constraints (Gate Bays 4 and 8 are not operated due to Gate Bay 4 being inoperable) could lead to higher velocities downstream of the LSCS especially in the outer gate bay areas. The approach flows have higher velocities on the descending left bank that could also be contributing to the increased velocities downstream of Gate Bay 10. Therefore, prior to testing in the physical model, determining which flows in the prototype may have caused the scour that occurred downstream of the LSCS from 2018 to 2019 and again from 2021 to 2022 became imperative.

To select the flows for testing, the LSCS operational data from 2018 through 2022 was reviewed. That data includes the LSCS daily headwater elevation, tailwater elevation, head, total discharge, and specific gate settings for the 11 gate bays on the structure. Once specific dates were selected for the testing program were chosen, MVN provided individual discharge values for each gate bay on that date. The selection of specific dates to use in the testing was critical to ensure that conditions used would produce flows that have sufficient energy to cause scour downstream of the end sill. Based on the surveys presented in Figure 1, the data analysis was focused on 2018–2019 and 2021–2022 time frames.

1.1.1 2018–2019 Time Frame

From May 2018 to August 2019 major scour occurred in the three areas downstream of the end sill (Figure 1). From the right-descending bank line to the left, the scour holes increased in size and depth. A review was conducted of the data and information for the period of May 2018 through August 2019, which includes the period during which the prototype studies were conducted. For the 2018 and 2019 data, all flows below 40,000 cfs were omitted since those flows are too low to cause any large scale downstream scour. Initially, the review focused on the tailwater elevations, but very few days or times had low tailwaters. Therefore, the LSCS gate settings were considered as a basis for possible causes of the downstream scour that occurred in 2018–2019. The focus was the times the high bays (Gate Bays 1–4 and 8–11 are at a sill elevation of 10 ft; Gate Bays 5–7 are at a sill elevation of −5 ft) were operating because they were carrying sufficient flow to cause downstream scour (few occurrences of low tailwater elevations for this time frame).

Reviewing the 2018–2019 flow analysis for low tailwaters (or times when the high bays were open) produced three significant dates—11 August 2018, 1 March 2019, and 22 August 2019—that should be considered for testing to understand the downstream velocity magnitudes. The reasoning for using these three dates are

- on 11 August 2018 the tailwater was relatively low (17.8 ft), and Gates 2, 3, 9, and 10 were operating at 14.65 ft;
- on 1 March 2019 all gates (except for Gates 4 and 8) were open, and Gates 1, 2, 3, 9, 10, and 11 were open much wider than Gates 5–7; and
- 22 August 2019 had the lowest tailwater for 2019 while Gates 2, 3, 9, and 10 were operating at either 4.2 ft or 7.36 ft.

1.1.2 2021–2022 Time Frame

The scour detected in January 2021 as well as the outflow channel configuration following the March 2021 repair are shown on Figure 1. The review of the flow data and information for the 2021 to 2022 time period concluded that the low tailwater conditions are likely the major cause of the scour that occurred after the March 2021 riprap placement since no high flows occurred in that period. However, many of the low tailwater conditions occurred at either zero (all gates closed) or extremely low discharges with only one or three gates open. Therefore, the results of the analysis for 2021–2022 suggest that five dates—12 May 2021, 13 January 2022, 19 January 2022, 7 March 2022, and 15 March 2022—should be considered for testing to understand the downstream velocity magnitudes. The reasoning for using these five dates are

- on 12 May 2021 Gates 1, 2, 3, 6, 9, 10, and 11 were operating;
- on 13 January 2022 the tailwater was relatively low and Gates 2, 3, 6, 9, and 10 were operating;
- on 19 January 2022 the tailwater was relatively low and Gates 2, 3, 6, 9, and 10 were operating;
- on 7 March 2022 the tailwater was relatively low and Gates 2, 3, 6, 9, and 10 were operating; and
- on 15 March 2022 Gates 2, 3, 5, 6, 7, 9, and 10 were operating.

Finally, MVN added a hypothetical flow condition to the test plan to determine whether a higher flow event with larger gate bay openings would cause high downstream velocities. The nine flow conditions evaluated in this study will be discussed in Section 2.3.

1.2 Objectives

The objective of this study is to provide velocity measurements to MVN from the existing physical LSCS model to assist in the stone size selection to prevent potential future scour downstream of the stilling basin. The evaluation of the proposed stone sizes for the scour hole repair work will be completed by filling the existing scour holes downstream of the structure to the planned grade of rock placement and measuring the velocities for those conditions.

1.3 Approach

Following similar physical modeling techniques deployed in Bell et al. 2020, rock (pea gravel cemented in place) was placed in the model downstream of the structure to match the repair elevations from the March 2021 repair survey. Velocities were measured using an ADV. The instrument specifications can be found in Nortek 2018.

2 Testing Process and Setup

2.1 Existing Model

The existing model is a Froude-scaled 1:55 undistorted fixed-bed model (scale conversions shown in Table 1).

Table 1. 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	$Q_r = L_r^{2.5} = 55^{2.5} = 22{,}434$

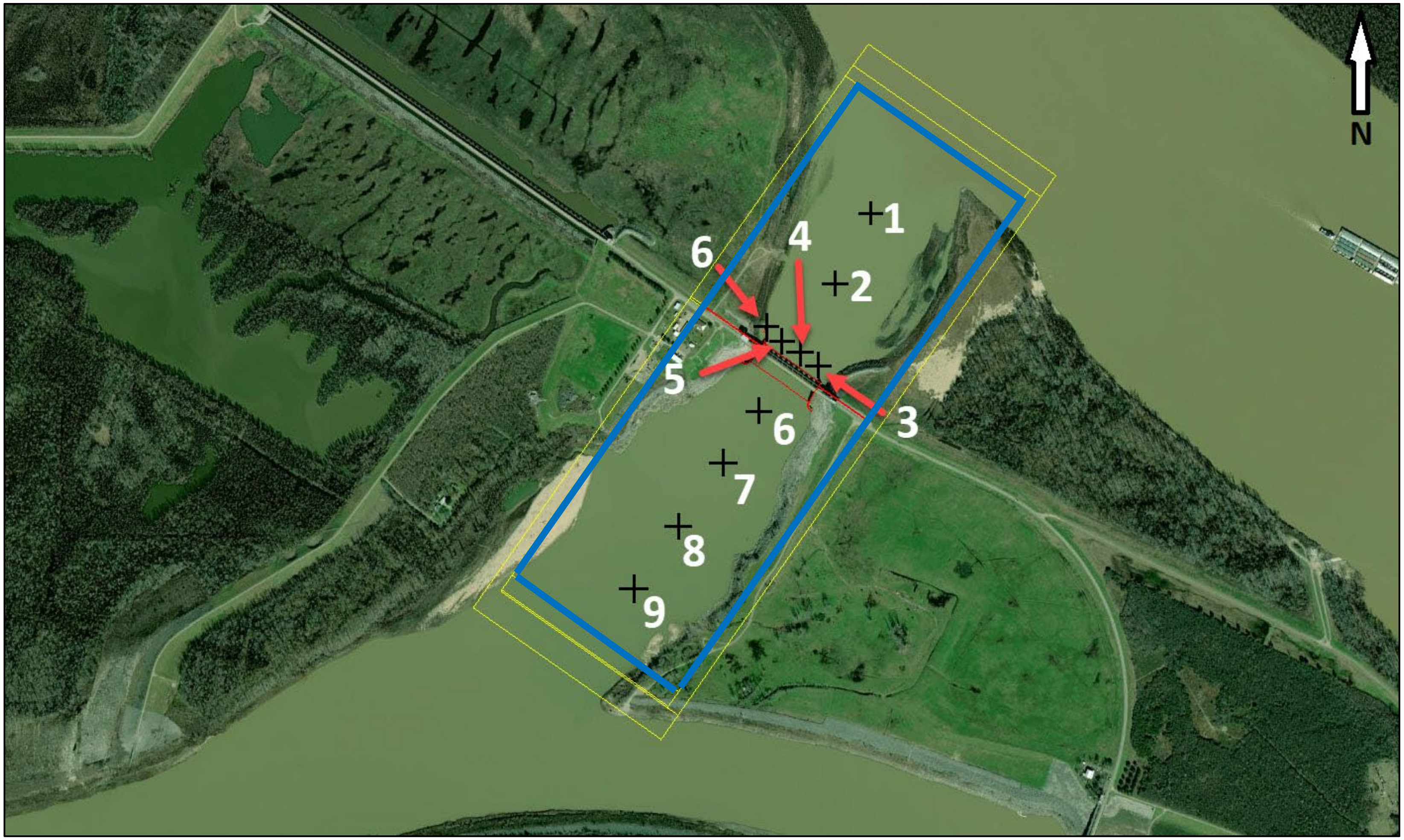
2.2 Data Collection and Instrumentation

The flow rate in the model was measured using a Builder's Iron Foundry (BIF) Venturi meter (20 in Model 0181 Serial Number 97548-1) and manometer. The water surface elevations were measured with a Leroy Type-A point gage (error ± 0.001 ft) in a 5 in × 5 in stilling bucket at 10 gage locations. The tailwater used is the average of Gages 7 and 8.

Headwater elevation was monitored by Gage 2, which is approximately in the same location of staff gages that are used to monitor the headwater at the structure (Figure 4). The spaces between the upstream and downstream foam limits (larger *rectangle spaces* upstream and downstream of the structure) are for the head and tail bays, respectively.

A side-looking Nortek Vectrino ADV with one transmit transducer and four receiver transducers were used to measure 3D water velocities. The side-looking ADV was chosen due to the high velocity environment that the instrument would be collecting data in (Nortek Support 2021). An ADV uses the Doppler Effect—the change in frequency that is received when either the source or receiver is moving—to generate a 3D velocity profile (Williams et al. 2022). The Nortek Comprehensive Manual for Velocimeters states "a factory-calibrated velocimeter should have a scale-factor bias that is less than 1% of the measured velocity" (2021, 26) The signals were collected and stored with Vectrino Software.

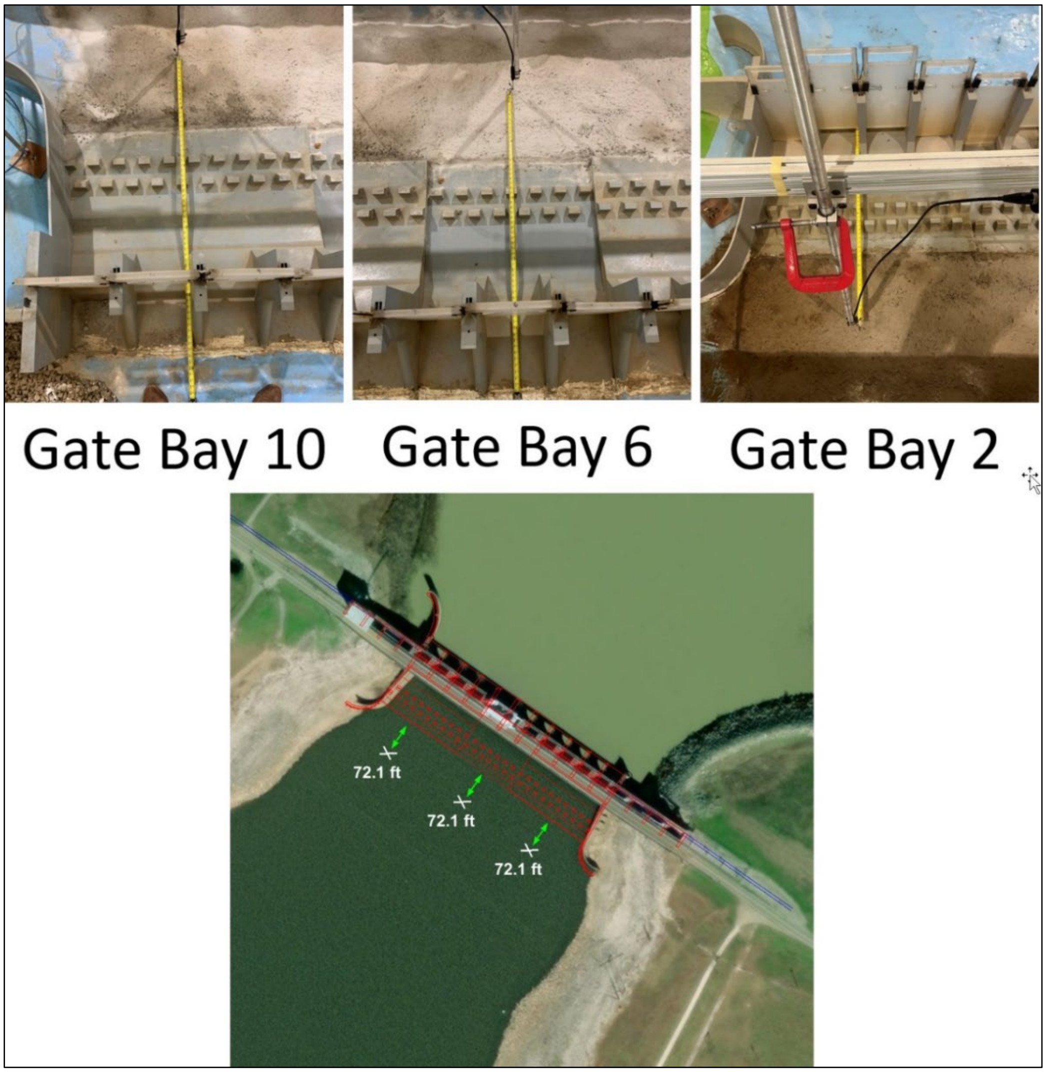
Figure 4. Gage locations in the model (the physical model limits are outlined in *yellow* and the bathymetry limits are defined in *blue*).



The ADV was placed approximately 72.1 ft (prototype) downstream of Gate Bays 2, 6, and 10 (Figure 5). The velocity data collected was used for three purposes:

a. Velocities were measured 4.6 ft (prototype) above the channel bed as a measurement of the “bottom” velocity. This distance was used as a factor of safety to ensure that the ADV was not damaged.
b. Another velocity measurement was made 10 ft (prototype) above the bed.
c. The final velocity measurement was taken at a depth of six-tenths of the water column to obtain a depth-averaged velocity, which is subsequently used to compute a Froude Number. The six-tenths depth started from the water surface.

Figure 5. Acoustic Doppler velocimeter (ADV) locations in the physical model.



2.3 Boundary Conditions and Model Operation

Figure 6 shows that the existing bathymetry downstream of the end sill in the physical model is nearly identical to the January 2021 survey before the stone repair in March of 2021. To extract velocity data that would indicate potential scour from the time rock was placed in March 2021 to April 2022, modifications to the existing bathymetry in the fixed-bed model downstream of the end sill were required. The existing scour holes downstream of the structure were filled with pea gravel to the elevations of the March 2021 survey. The rock was then lightly dusted with cement for stability during model testing. Figure 7 shows the pre–cement application (note that all rock is not placed at the time the photograph was taken) and post-cement application. A lidar survey was conducted on the final product and the comparison is shown in Figure 8. The physical model bathymetry was slightly higher than the March 2021 repair in some areas downstream of Gate Bays 5–11. Overall, the difference between the two were ± 1 ft (prototype).

Nine flow conditions were tested (Table 2). These flows were explained in Section 1.1 and are based on low tailwater (T.W.) conditions or times when the high bays were operating. Also, the hypothetical flow condition was requested by MVN to consider larger gate bay openings.

Figure 6. Bathymetric comparisons (prototype versus model).

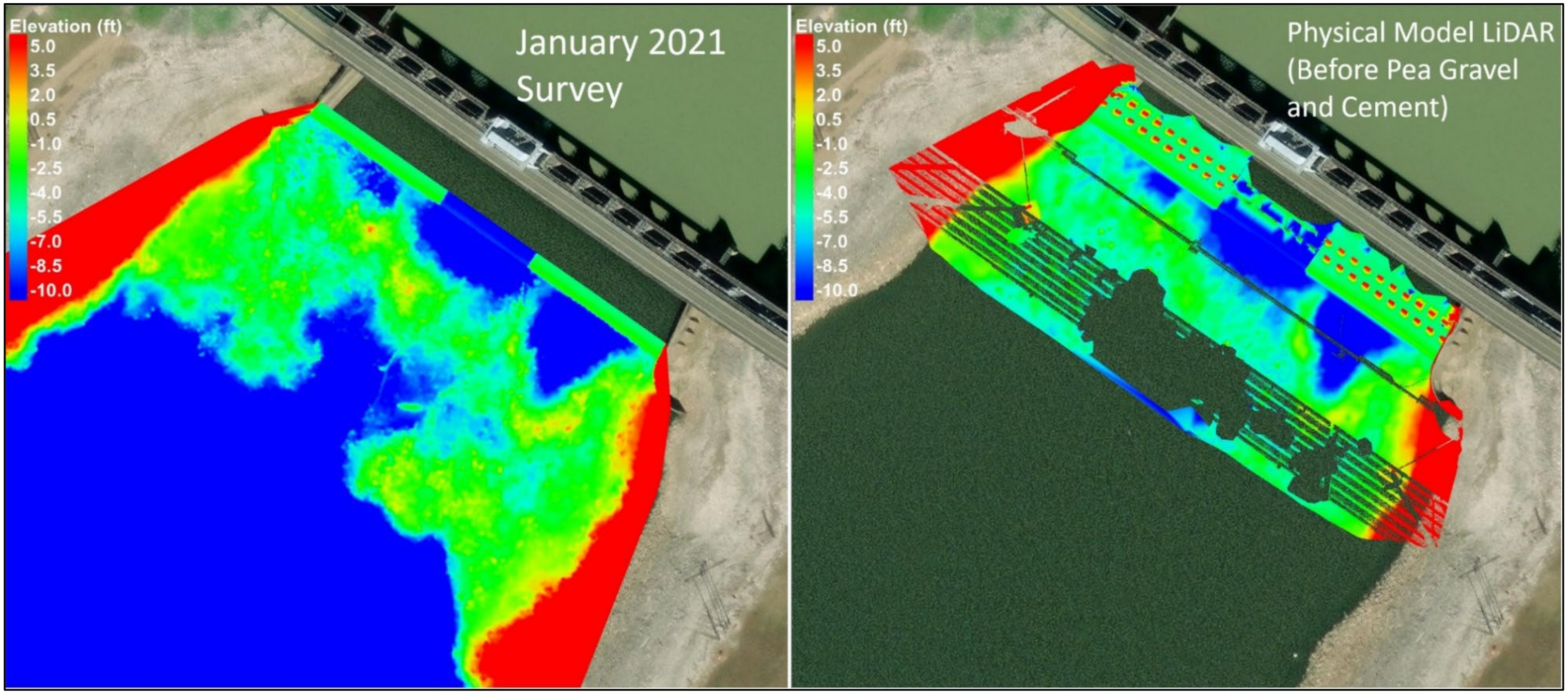


Figure 7. Model modifications (pre–cement dusting on the *left* and post–cement dusting on the *right*).

Figure 8. March 2021 survey versus physical model lidar.

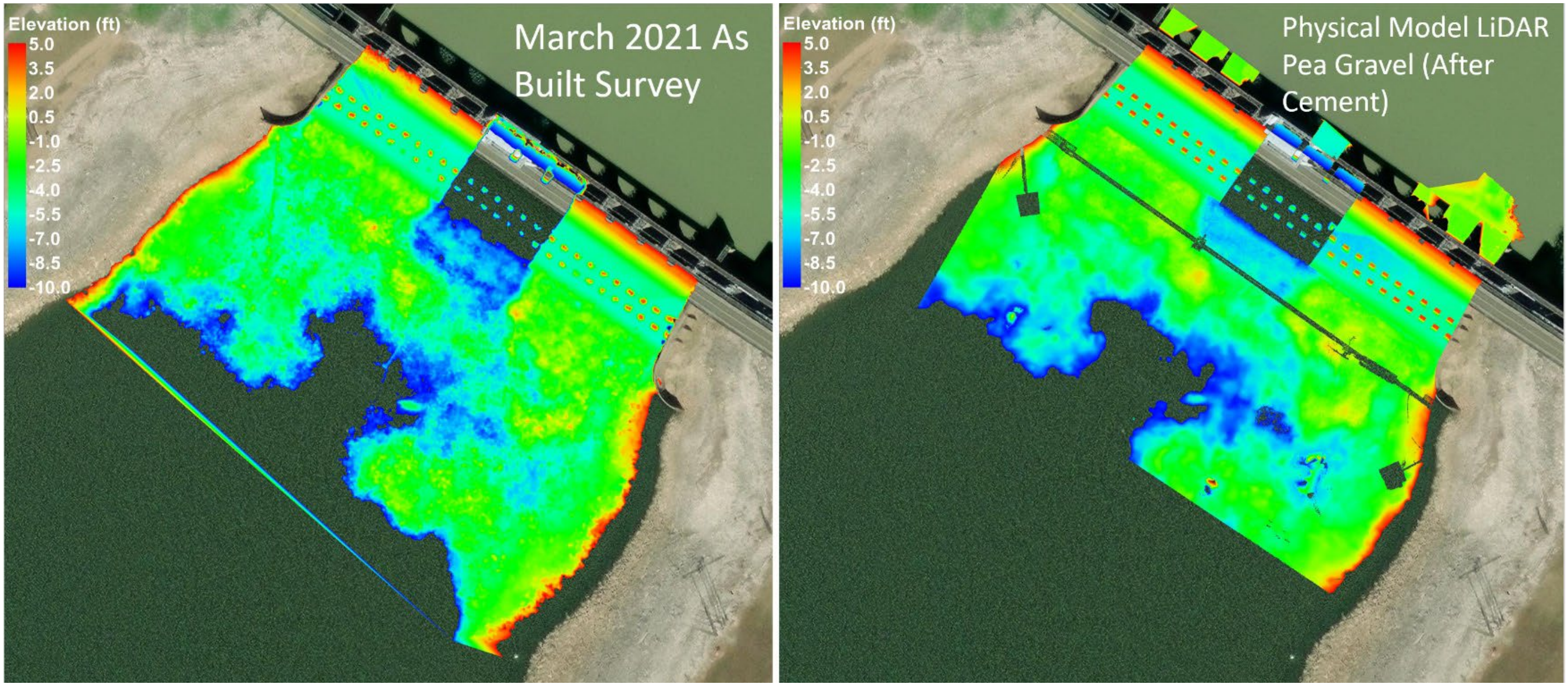


Table 2. Boundary conditions.

Discharge (Q; cfs)	Headwater (H.W.; ft)	Tailwater (T.W.; ft)	Head	Test Date	GATE 1	GATE 2	GATE 3	GATE 4	GATE 5	GATE 6	GATE 7	GATE 8	GATE 9	GATE 10	GATE 11
86,000	28.2	17.8	10.4	Saturday, 11 August 2018	CLOSED	14.65	14.65	CLOSED	14.65	14.65	14.65	CLOSED	14.65	14.65	CLOSED
199,000	60.7	43.6	17.1	Friday, 1 March 2019	19.28	19.28	28.96	CLOSED	7.36	14.65	7.36	CLOSED	28.96	19.28	19.28
61,000	39.0	19.9	19.1	Thursday, 22 August 2019	CLOSED	4.2	7.36	CLOSED	7.36	14.65	7.36	CLOSED	7.36	4.2	CLOSED
96,000	50.4	30.2	20.2	Wednesday, 12 May 2021	7.36	11.36	7.36	CLOSED	CLOSED	24.86	CLOSED	CLOSED	7.36	11.36	7.36
96,000	43.0	25.7	17.3	Thursday, 13 January 2022	CLOSED	14.65	14.65	CLOSED	CLOSED	24.86	CLOSED	CLOSED	14.65	14.65	CLOSED
101,000	46.2	27.5	18.7	Wednesday, 19 January 2022	CLOSED	14.65	14.65	CLOSED	CLOSED	24.86	CLOSED	CLOSED	14.65	14.65	CLOSED
126,000	50.4	30.4	20.0	Monday, 7 March 2022	CLOSED	19.28	19.28	CLOSED	CLOSED	24.86	CLOSED	CLOSED	19.28	19.28	CLOSED
169,000	53.4	33.4	20.0	Tuesday, 15 March 2022	CLOSED	11.36	19.28	CLOSED	24.86	24.86	24.86	CLOSED	19.28	11.36	CLOSED
243,320	57.0	37.0	20.0	Hypothetical	19.28	19.28	19.28	CLOSED	24.86	24.86	24.86	CLOSED	19.28	19.28	19.28

3 Physical Model Results

This chapter includes a discussion of the LSCS model results. For each flow condition, velocity data collected downstream of Gate Bays 2, 6, and 10 is discussed. The computed Froude Numbers for this flow downstream of the three gate bays are also presented when available. The velocities measured at 6/10 depth and channel elevations at those locations are the characteristic velocity and length, respectively, used to compute the Froude numbers. In areas where the depth was too shallow to obtain velocity measurements, n/a (not applicable) is listed.

3.1 Flow of 61,000 cfs

The 61,000 cfs flow has the next second-lowest tailwater elevation (19.9 ft) of the flows tested. The velocities along with comparison values from Rothwell and Grace (1977) are listed in Table 3. The bottom velocities vary from 10.3 ft/s to 19.1 ft/s with an average of 13.4 ft/s. The Froude numbers vary from 0.4 to 0.8.

Table 3. Velocity data and information for 61,000 cfs flow.

Measurement Location	Velocity—Prototype (ft/s)		
	Gate Bay 2 (4.2 ft open)	Gate Bay 6 (14.65 ft open)	Gate Bay 10 (4.2 ft open)
Bottom	10.3	19.1	10.8
10 ft above bottom	11.5	22.1	11.3
6/10 depth	n/a	21.4	12.1
Froude number	n/a	0.8	0.4

3.2 Flow of 86,000 cfs

The 86,000 cfs flow had the lowest tailwater elevation (17.8 ft) of the flows tested and the lowest head (10.4 ft) across the LSCS. The low tailwater only allowed for bottom velocities to be measured. The bottom velocities (shown in Table 4) vary from 14.5 ft/s to 18.2 ft/s for an average of 16.6 ft/s.

Table 4. Velocity data and information for 86,000 cfs flow.

Measurement Location	Velocity—Prototype (ft/s)		
	Gate Bay 2 (14.65 ft open)	Gate Bay 6 (14.65 ft open)	Gate Bay 10 (14.65 ft open)
Bottom	14.5	18.2	16.8
6/10 depth	n/a	n/a	n/a
Froude number	n/a	n/a	n/a

3.3 The 2022 Flow of 96,000 cfs

This 96,000 cfs flow occurred in 2022 and has a relatively low tailwater elevation (25.7 ft). The bottom velocities (shown in Table 5) vary from 19.5 ft/s to 20.5 ft/s and averaged 20.1 ft/s. The velocities 10 ft above the channel bed vary from 21.6 ft/s to 25.2 ft/s and averaged 22.8 ft/s. Data to calculate the Froude numbers downstream of Gate Bays 6 and 10 could not be measured due to the low tailwater. The Froude number downstream of Gate Bay 2 is 0.8.

Table 5. Velocity data and information for 96,000 cfs flow in 2022.

Measurement Location	Velocity—Prototype (ft/s)		
	Gate Bay 2 (14.65 ft open)	Gate Bay 6 (24.86 ft open)	Gate Bay 10 (14.65 ft open)
Bottom	20.5	19.5	20.4
10 ft above bottom	21.6	21.7	25.2
6/10 depth	24.7	n/a	n/a
Froude number	0.8	n/a	n/a

3.4 The 2021 Flow of 96,000 cfs

This flow occurred in 2021 and has the Gate Bays 1–3 and Gate Bays 9–11 operating with low Gate Bay 6. The bottom velocities (shown in Table 6) vary from 14.9 ft/s to 21.1 ft/s and average 17.1 ft/s. The velocities 10 ft above the bed vary from 16.3 ft/s to 21.2 ft/s and average 18.0 ft/s. The Froude numbers vary from 0.5 to 0.8.

Table 6. Velocity data and information for 96,000 cfs flow in 2021.

Measurement Location	Velocity—Prototype (ft/s)		
	Gate Bay 2 (11.36 ft open)	Gate Bay 6 (24.86 ft open)	Gate Bay 10 (11.36 ft open)
Bottom	14.9	21.1	15.3
10 ft above bottom	16.3	21.2	16.4
6/10 depth	16.3	24.0	17.7
Froude number	0.5	0.8	0.6

3.5 Flow of 101,000 cfs

This 101,000 cfs flow occurred when the tailwater was low (27.5 ft) and had the high Gate Bays 2, 3, 9, and 10 operating along with low Gate Bay 6. The bottom velocities (shown in Table 7) vary from 17.6 ft/s to 21.6 ft/s and average 19.7 ft/s. The velocities 10 ft above the bed vary from

20.8 ft/s to 23.6 ft/s and averaged 21.8 ft/s. The 6/10 depth velocities vary from 23.1 ft/s to 24.6 ft/s and average 23.7 ft/s.

Table 7. Velocity data and information for 101,000 cfs flow.

Measurement Location	Velocity—Prototype (ft/s)		
	Gate Bay 2 (14.65 ft open)	Gate Bay 6 (24.86 ft open)	Gate Bay 10 (14.65 ft open)
Bottom	17.6	19.8	21.6
10 ft above bottom	20.8	21.1	23.6
6/10 depth	23.1	23.4	24.6
Froude number	0.8	0.7	0.8

3.6 Flow of 126,000 cfs

This 126,000 cfs flow occurred when the tailwater was somewhat low (30.4 ft) and had Gate Bays 2, 3, 6, 9, and 10 operating. The bottom velocities (shown in Table 8) vary from 19.3 ft/s to 23.1 ft/s and average 21.0 ft/s. Downstream of Gate Bays 2 and 10 the bottom velocities are the highest of all the flows tested. The velocities 10 ft above the bottom vary from 21.5 ft/s to 23.6 ft/s and average 22.2 ft/s. Downstream of Gate Bay 2, the velocity is 31.2 ft/s. The corresponding Froude number of 1.0 indicates a high potential for bed scour. There were no measurements taken downstream of Gate Bays 6 and 10 at 6/10 depth.

Table 8. Velocity data and information for 126,000 cfs flow.

Measurement Location	Velocity—Prototype (ft/s)		
	Gate Bay 2 (19.28 ft open)	Gate Bay 6 (24.86 ft open)	Gate Bay 10 (19.28 ft open)
Bottom	20.7	19.3	23.1
10 ft above bottom	21.5	21.6	23.6
6/10 depth	31.2	n/a	n/a
Froude number	1.0	n/a	n/a

3.7 Flow of 169,000 cfs

This 169,000 cfs flow occurred with Gate Bays 2, 3, 5, 6, 7, 9, and 10 operating. The bottom velocities (shown in Table 9) vary from 10.0 ft/s to 21.4 ft/s and average of 14.5 ft/s. The 21.4 ft/s bottom velocity downstream of Gate Bay 6 is the highest velocity for that gate bay of the flow conditions tested. The velocities 10 ft above the bed vary from 10.8 ft/s to 22.5 ft/s and average 16.3 ft/s. The velocities measured at 6/10 depth varied from 16.8 ft/s to 23.5 ft/s for an average of 19.1 ft/s.

Table 9. Velocity data and information for 169,000 cfs flow.

Measurement Location	Velocity—Prototype (ft/s)		
	Gate Bay 2 (11.36 ft open)	Gate Bay 6 (24.86 ft open)	Gate Bay 10 (11.36 ft open)
Bottom	10.0	21.4	12.1
10 ft above bottom	10.8	22.5	15.8
6/10 depth	16.8	23.5	16.9
Froude number	0.5	0.7	0.5

3.8 Flow of 199,000 cfs

This 199,000 cfs flow has the second lowest head differential across the LSCS (17.1 ft) of all the flows tested. Additionally, with Gate Bays 4 and 8 closed, this flow condition has smaller gate openings on the Gate Bays 5–7 than on Gate Bays 1–3 and 9–11. Therefore, significantly more flow passes through the high gate bays for this condition than through the three low gate bays. The bottom velocities vary from 11.3 ft/s to 19.9 ft/s and average 14.9 ft/s (Table 10). The measured velocities 10 ft above the bed vary from 14.6 ft/s to 24.3 ft/s and average 20.2 ft/s. The 6/10 velocities vary from 17.3 ft/s to 31.3 ft/s and average 26.5 ft/s.

Table 10. Velocity data and information for 199,000 cfs flow.

Measurement Location	Velocity—Prototype (ft/s)		
	Gate Bay 2 (19.28 ft open)	Gate Bay 6 (14.65 ft open)	Gate Bay 10 (19.28 ft open)
Bottom	19.9	11.3	13.6
10 ft above bottom	21.3	14.6	24.3
6/10 depth	30.8	17.3	31.3
Froude number	0.8	0.4	0.8

3.9 Flow of 243,320 cfs

The eight previously discussed flows occurred in the prototype and potentially created the scour that occurred downstream of the end sill from 2018 to 2019 and 2021 to 2022 as presented on Figure 1. MVN requested the addition of the hypothetical 243,320 cfs flow condition to consider a higher flow event with larger gate bay openings which would produce high downstream velocities. This test provides additional velocity data and information for comparison with those that created the documented prototype scour.

For this flow condition Gate Bays 4 and 8 are closed, Gate Bays 1–3 and 9–11 are open to 19.28 ft, and the Gate Bays 5–7 open to 24.86 ft. The bottom velocities (shown in Table 11) vary from 17.2 ft/s to 20.1 ft/s and average 18.9 ft/s. The velocities 10 ft above the bed vary from 17.9 ft/s to 22.0 ft/s for an average of 20.1 ft/s. The 6/10 velocities vary from 21.3 ft/s to 22.5 ft/s and average 21.7 ft/s.

As compared to the eight flows tested that occurred in the prototype and caused the scour in question, the hypothetical flow created conditions are very similar to those that caused the scour downstream of the LSCS.

Table 11. Velocity data and information for hypothetical flow.

Measurement Location	Velocity—Prototype (ft/s)		
	Gate Bay 2 (19.28 ft open)	Gate Bay 6 (24.86 ft open)	Gate Bay 10 (19.28 ft open)
Bottom	17.2	20.1	19.5
10 ft above bottom	17.9	22.0	20.3
6/10 depth	21.3	22.5	21.4
Froude number	0.6	0.6	0.6

Table 12 shows the timeline of the compilation of the information in Figure 1, the data on Table 2 through 11, and the LSCS daily headwater elevation, tailwater elevation, head, total discharge, and specific gate settings for the 11 gate bays on the structure. This table illustrates the potential of scour over time with measured bed velocities compared to bathymetric surveys from Figure 1.

Table 12. Timeline for the model and prototype data.

					Bottom Velocity (ft/s)		
Date	Discharge (cfs)	Headwater (ft)	Tailwater (ft)	Head (ft)	Gate Bay 2	Gate Bay 6	Gate Bay 10
May 2018	Prototype Survey (Figure 1)						
11 August 2018	86,000	28.2	17.8	10.4	<15.0	18.2	16.8
1 March 2019	199,000	60.7	43.6	17.1	19.9	<15.0	<15.0
22 August 2019	61,000	39.0	19.9	19.1	<15.0	19.1	<15.0
August 2019	Prototype Survey (Figure 1)						
March 2021	Prototype Survey (Figure 1)						
12 May 2021	96,000	50.4	30.2	20.2	<15.0	21.1	15.3
13 January 2022	96,000	43.0	25.7	17.3	20.5	19.5	20.4
19 January 2022	101,000	46.2	27.5	18.7	17.6	19.8	21.6
7 March 2022	126,000	50.4	30.4	20.0	20.7	19.3	23.1
15 March 2022	169,000	53.4	33.4	20.0	<15.0	21.4	<15.0
April 2022	Prototype Survey (Figure 1)						

4 Conclusions and Recommendations

4.1 Conclusions

The tests conducted and presented in this report provide velocity measurements to assist in selection of stone size to prevent future scour downstream of the LSCS end sill. This emergency effort was a time-sensitive study, thus velocities were collected from the existing physical model to provide insight for more appropriately-sized stone protection downstream of the LSCS. Previous scour protection designs were based on MVN experiences and used a design velocity of 17.5 ft/s and existing USACE guidance, which proved inadequate during operation of the LSCS. Therefore, the testing program used in this study was developed based on the LSCS operational data from 2018 through 2022. These data were analyzed for the selection of specific dates to ensure that the conditions chosen to have sufficient energy to cause scour downstream of the LSCS end sill. The analysis focuses on 2018–2019 and 2021–2022 timeframes due to the availability of pre- and post-scour surveys.

Of the nine flows tested, the highest bottom velocity measured downstream of Gate Bay 2 is 20.7 ft/s, downstream of Gate Bay 6 is 21.4 ft/s, and downstream of Gate Bay 10 is 23.1 ft/s. These velocity magnitudes support the conclusion that the scour tendencies observed downstream of the LSCS over time where the scour downstream of Gate Bay 6 is more extreme than downstream of Gate Bay 2. The scour downstream of Gate Bay 10 is more extreme than downstream of Gate Bay 6.

Additional analysis of the bottom velocity data provides useful velocity magnitudes to assist in the updated riprap design. The average bottom velocity for the nine flows at downstream of Gate Bays 2, 6, and 10 is 17.2 ft/s. The average bottom velocities downstream of Gate Bays 2, 6, and 10 are 16.1 ft/s, 18.7 ft/s, and 16.7 ft/s, respectively.

Due to variation between the maximum measured bottom velocities and the average bottom velocities the velocity data were reconsidered to determine a meaningful velocity magnitude to use for the riprap design. The authors concluded that any bottom velocity less than 15.0 ft/s would probably not cause scour and could be eliminated from further consideration for scour potential. This conclusion assumes that flow velocities at or below 15 ft/s are probably too low to move the size stone that has been placed downstream of the LSCS in the past. Using the Isbash formula (Isbash 1936) with velocities at or below 15 ft/s yield stone sizes smaller than the actual stone downstream of the LSCS. Therefore, measurements of the bottom velocities for the nine flows downstream of Gate Bays 2, 6, and 10 that have a magnitude of 15.0 ft/s or less were eliminated from consideration for riprap design parameters. Of the 24 original bottom velocity measurements, eight measurements between 10.0 and 14.9 ft/s were eliminated. Consequently, the average of the remaining bottom velocities is 19.6 ft/s. The revised average bottom velocities for Gate Bays 2, 6, and 10 are 19.7 ft/s, 19.8 ft/s, and 19.4 ft/s, respectively. These revised velocities are close to the 19 ft/s for orifice control on the LSCS with respect to movement of the downstream scour protection discussed earlier from USACE (1976).

The test results indicate that specific gate bay openings are critical for the determination of the bottom velocities. Regardless of the flow or gate bay location, a gate opening of 4.2 ft or 11.36 ft produced bottom velocities at or below 15 ft/s. Conversely, a gate setting of 24.86 ft (all of which were on Gate Bay 6) produced bottom velocities of at least 20 ft/s. Gate bay settings of 14.65 ft or 19.28 ft between small and large openings produced bottom velocities of 15 ft/s to 23 ft/s. The maximum bottom velocities on Gate Bays 2 and 10 (discussed above) that occurred on 7 May 2022 (126,000 cfs flow) were produced with a gate opening of 19.28 ft. The maximum bottom velocity on Gate Bay 6 that occurred on 15 March 2022 (169,000 cfs flow) was in part due to a gate opening of 24.86 ft.

4.2 Recommendations

A bottom velocity of 20 ft/s is recommended for determining the riprap stone size downstream of the LSCS end sill. Larger gate bay openings generally produce larger downstream bottom velocities, but the tailwater elevation does affect the bottom velocities. This interaction may be somewhat intuitive realizing that the smaller the gate bay opening (4.2 ft or 11.36 ft) the less discharge that would be passed through a gate bay and consequently the lower the bottom velocity. However, once the gate bay openings reach the range of 14.65 ft or 19.28 ft the bottom velocities can be in the critical range of 19–20 ft/s. For a gate bay opening of

24.86 ft, at least for Gate Bay 6 (and Gate Bays 5 and 7) bottom velocities of 19–20 ft/s are highly likely. Since the 24.86 ft gate opening are not used on any of the test conditions on any high gate bays, including the hypothetical condition, it was not determined whether such a gate opening on those high gate bays would produce bottom velocities in the 20 ft/s range.

The velocities collected here are good pieces of information when selecting stone sizes to protect against scour. However, if possible, it is recommended that a separate study be conducted that tests the proposed stone size in the existing physical model.

Bibliography

Bell, G. L, J. A. Sharp, L. M. Williams, H. E. Park, D. B. Bryant, and G. Savant. 2020. *Red River Structure Physical Model Study*. ERDC/CHL TR-20-20. Vicksburg, MS: US Army Engineer Research and Development Center–Coastal and Hydraulics Laboratory. https://dx.doi.org/10.21079/11681/38305.

Isbash, S. 1936. *Construction of Dams by Depositing Rock in Running Water*. Paris: International Congress on Large Dams.

Nortek. 2018. *The Comprehensive Manual for Velocimeters*. Rud, Norway: Nortek Manuals. https://www.nortekgroup.com/assets/software/N3015-030-Comprehensive-Manual-Velocimeters_1118.pdf.

Nortek User. 2021. "What Are the Differences between and Advantages of Side-Looking and Down-Looking Vectrino Probes?" *Nortek Support Group*, May 5, 2021. https://support.nortekgroup.com/hc/en-us/articles/360029820091-What-are-the-differences-between-and-advantages-of-side-looking-and-down-looking-Vectrino-probes-.

Rothwell, E. D., and J. L. Grace Jr. 1977. *Old river Existing Low-Sill Control Structure, Louisiana: Hydraulic Model Investigation*. TR-HL-77-2; Vicksburg, MS: US Army Engineer Waterways Experiment Station–Hydraulics Laboratory. https://hdl.handle.net/11681/13527.

Sharp, J. A., D. B. Bryant, and G. Savant. 2022. *Low-Sill Control Structure Gate Load Study*. ERDC/CHL Tr-22-8. Vicksburg, MS: US Army Engineer Research and Development Center–Coastal and Hydraulics Laboratory. http://dx.doi.org/10.21079/11681/44340.

USACE (US Army Corps of Engineers). 1954. *Detailed Design Memorandum–Low Sill Structure*. DM No. 4. Vicksburg, MS: US Army Engineer Waterways Experiment Station.

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

Williams, L., G. Bell, and D. Bryant. 2022. *Setup and Data Collection Process of an Acoustic Doppler Velocimeter (ADV) in a Laboratory Setting*. ERDC/CHL CHETN-XIII-4. Vicksburg, MS: US Army Engineer Research and Development Center–Coastal Hydraulics Laboratory. http://dx.doi.org/10.21079/11681/43741.

Abbreviations

ADV	Acoustic Doppler velocimeter
BIF	Builder's Iron Foundry
CHL	Coastal and Hydraulics Laboratory
ERDC	Engineer Research and Development Center
H.W.	Headwater
LSCS	Low Sill Control Structure
MVN	USACE New Orleans District
n/a	Not available
ORCC	Old River Control Complex
T.W.	Tailwater
USACE	United States Army Corps of Engineers
WES	Waterways Experiment Station

REPORT DOCUMENTATION PAGE

1. REPORT DATE
May 2024

2. REPORT TYPE
Final Report

3. DATES COVERED

START DATE
FY23

END DATE
FY23

4. TITLE AND SUBTITLE
Low Sill Control Structure:
Physical Modeling Investigation of Velocities Downstream of the End Sill

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

6. AUTHOR(S)
Gary L. Bell, Cody M. Bryant, Thomas J. Pokrefke, Cassandra Everett, and Cian E. C. Miller

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
US Army Engineer Research and Development Center (ERDC)
Coastal and Hydraulics Laboratory (CHL)
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

8. PERFORMING ORGANIZATION REPORT NUMBER
ERDC/CHL TR-24-9

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
US Army Corps of Engineers (USACE)
New Orleans District
New Orleans, LA 70118

10. SPONSOR/MONITOR'S ACRONYM(S)
USACE-MVN

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Distribution Statement A. Approved for public release: distribution is unlimited.

13. SUPPLEMENTARY NOTES
WIC 1L8F7L; "Low Sill Control Structure Physical Model Stilling Basin Velocity Investigation"

14. ABSTRACT

The model investigation reported herein describes the process to measure velocities at various locations downstream of the Low Sill Control Structure using an existing 1:55 Froude-scaled physical model. To collect these measurements, an acoustic-Doppler velocimeter was deployed downstream of the structure at varying locations and depths. A total of 79 velocity measurements were taken across nine flow conditions (discharge, head and tailwater elevations, and gate openings) provided by the US Army Corps of Engineers, New Orleans District.

15. SUBJECT TERMS
Acoustic Doppler velocimeter (ADV); Concordia Parish (La.) Diversion structures; Hydraulic engineering; Hydraulic structures; Low Sill Control Structure; Old River; Old River Control Complex; Physical model; Streamflow

16. SECURITY CLASSIFICATION OF:

a. REPORT	**b. ABSTRACT**	**C. THIS PAGE**
Unclassified	Unclassified	Unclassified

17. LIMITATION OF ABSTRACT
SAR

18. NUMBER OF PAGES
34

19a. NAME OF RESPONSIBLE PERSON
Gary L. Bell

19b. TELEPHONE NUMBER (include area code)
gary.l.bell@usace.army.mil

STANDARD FORM 298 (REV. 5/2020)
PREVIOUS EDITION IS OBSOLETE.
Prescribed by ANSI Std. Z39.18