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Hands-Free Mooring for Inland USACE Locks, Phase I: Technical Screening

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PURPOSE: The US Army Corps of Engineers (USACE) Engineer Research and Development Center (ERDC) was asked to evaluate hands-free mooring (HFM) as an option for improving the safety and efficiency of lock operations at USACE locks within the United States. The focus of this research is assessing HFM solutions for barge tows on USACE inland waterway locks. This Coastal and Hydraulics engineering technical note (CHETN) describes the approach and findings from Phase I of this HFM research effort, which was funded through the Navigation Systems Research Program. Phase I includes defining the problem this research effort intends to address, understanding current mooring practices at USACE locks, gathering information on similar systems already in use, and developing design concepts and criteria.

INTRODUCTION: USACE operates navigation lock chambers at nearly 200 sites across the United States. During the operation of a lock, referred to as a *lockage*, a barge tow enters the lock chamber. Once the barge tow is in the chamber (Figure 1), it must be secured to the lock wall (a process called *mooring*) so the lock chamber can be safely filled or emptied. At USACE locks, a barge tow is moored to the lock wall with a line (usually a rope) that a deckhand attaches either to a stationary mooring bitt or to a floating mooring bitt that travels vertically with the rise and fall of the water level in the lock chamber and is situated in a slot constructed in the lock wall. The line that secures the tow to the lock wall is also referred to as a *hawser*. During a lock operation, these lines resist the hydraulic forces, known as *hawser forces*, acting on the barge tow during a lock filling and emptying (F/E) operation. During the F/E operation, the mooring line can experience tension. If this tension exceeds the breaking strength of the mooring line, the mooring line will break, putting the deckhands and lock staff at risk of being struck and injured by the parted line. Overall, the traditional mooring process is labor-intensive and time-consuming. This HFM research effort is aimed primarily at reducing or eliminating the danger to deckhands and lock staff during the mooring process and the F/E operation.

Figure 1. McAlpine Lock (USACE Louisville District) with an upbound barge tow entering the chamber.

LOCK OPERATIONS: As a barge tow enters the lock chamber, the tow pilot stops the tow to allow a deckhand to secure a mooring line from the lead barge to a mooring bitt (Figure 2). When the mooring line is secured (usually with several wraps or parts), the tow pilot applies forward power that places the mooring line in tension. This mooring line prevents forward motion. Next, a second mooring line at the stern of the tow is secured, preventing backward motion. Mooring with opposite lead mooring lines limits upstream and downstream movement of the tow during the F/E process. Deckhands visually monitor the condition of the mooring lines during the F/E process.

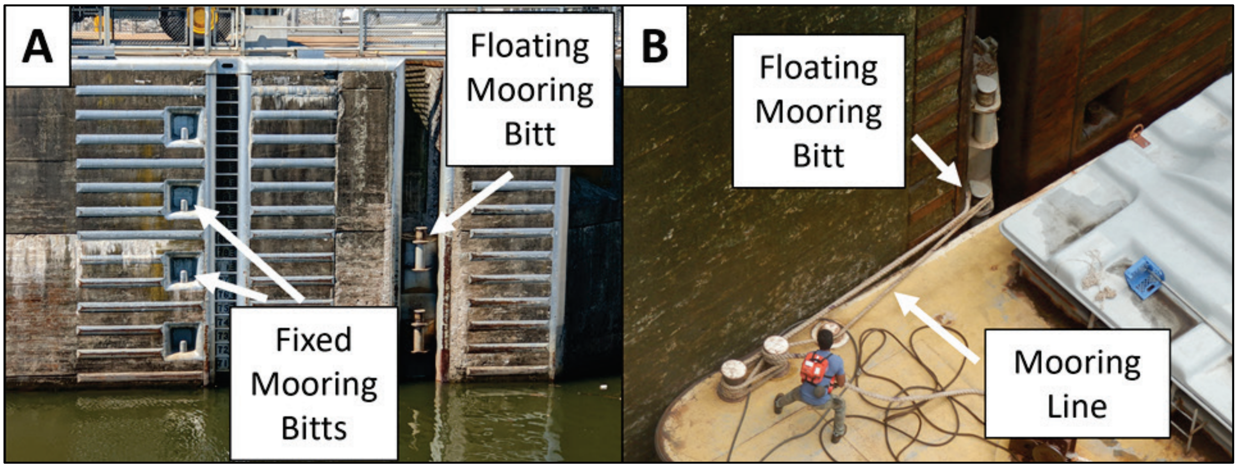

Figure 2. Typical fixed and floating mooring bitts (*A*) and a common mooring operation (*B*).

EXISTING HANDS-FREE MOORING (HFM) SYSTEMS: HFM is a concept that has been employed at ports throughout the world. The Port of Ngqura (South Africa), Port Hedland (Australia), the Port of Narvik (Norway), and the Port of Beirut (Lebanon) all have HFM systems. The locks on the Saint Lawrence Seaway (SLS) all experienced similar problems with conventional mooring methods. HFM systems have been in service on the SLS locks since 2014 and have increased the safety of vessel mooring during lock F/E operations. In March 2021, the USACE HFM team observed the operation of the HFM systems at Eisenhower and Snell Locks on the SLS. These HFM systems use multiple Cavotec MoorMaster units to secure the ships that traverse these locks. Figure 3 shows the Cavotec MoorMaster in service at Eisenhower Lock on the SLS. The MoorMaster system uses vacuum pads connected to articulating arms to secure a vessel. The pads are pressed against the ship hull, and once a seal has been established around the pads, a vacuum is created between the pads and the ship hull, which creates a strong connection. The articulating arms are connected to tracks located in vertical slots in the lock wall that allow the vacuum pads to travel vertically as the water level in the lock chamber rises or falls during lock F/E operations. At both Eisenhower and Snell Locks, three MoorMaster units have been installed on one of the lock walls. Most of the vessel traffic on the SLS locks consists of ships that have large, relatively clean, and undamaged hulls that serve as the connecting surfaces for the vacuum pads. This deep-draft ship traffic is significantly different from the typical shallow-draft navigation traffic that uses USACE inland locks.

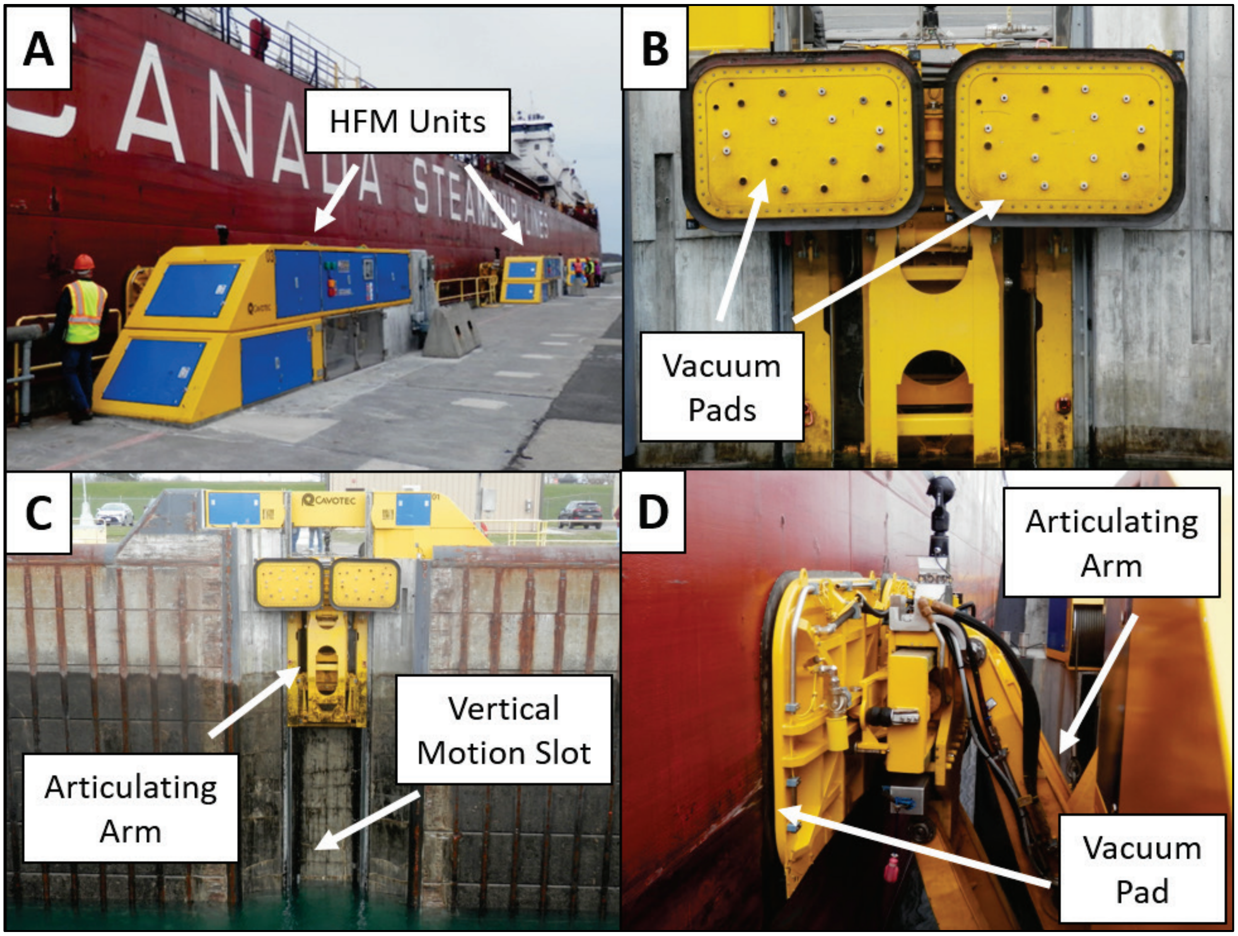

Figure 3. Hands-free mooring (HFM) system in service on the Saint Lawrence Seaway (SLS) at the Eisenhower Lock, including HFM units on the lock wall (*A*), the two vacuum pads for a single HFM unit (*B*), the articulated arm and vertical motion slot for a single HFM unit (*C*), and the HFM unit connected to a ship hull (*D*).

CHALLENGES WITH USACE LOCKS: In 2019, USACE locks completed over 400,000 lockages (including both commercial and recreational vessels) using traditional mooring methods. The types of barge tows that traverse through USACE locks, even within a single day at a lock, vary widely across all waterways (Figure 4). These differences are produced by different barge types and sizes (based on the type of cargo) and tow configurations. The draft of the barge tow can also vary based on the maximum allowable draft of the waterway and the loading condition (i.e., empty or loaded) of the barge. The draft of the barge poses a challenge to HFM because of the resulting amount of usable freeboard (i.e., the distance from the waterline to the top of the barge's edge). The HFM systems in use at the time of this research (i.e., in 2021) primarily use the freeboard area as the connection point. However, barge tows, which are shallow-draft vessels, often have much less freeboard than seagoing (i.e., deep-draft) vessels, which typically have a minimum freeboard size of around 6.5 feet. For barge tows, the freeboard can vary from 6 inches to 11 feet, depending on the waterway and water elevation.

Figure 4. Various barge tow configurations at USACE locks.

USACE locks have a wide range of designs that depend on site-specific details. These details include, but are not limited to, the water levels on each side of the lock, the technology and knowledge available when the lock was designed and constructed, and the types of river traffic expected to use the lock. Examples of such design variations include structural components such as the strength of the concrete, mooring locations, the type of mooring connection (i.e., fixed or floating mooring bitts), and the chamber size. USACE locks have chambers that are typically 84 or 110 feet wide and typically have nominal lengths of 600, 800, or 1,200 feet (USACE 2006).

USACE locks must also withstand various weather conditions. The most severe conditions are in northern areas where ice accumulates in and around the locks. Floating mooring bitts must be secured and cannot be used when ice is present, so the barge crews and lock staff must use the stationary pins to moor the barge tows. Some locks are subject to submergence from flooding, so any lock equipment that cannot be quickly moved from the lock must be able to recover to normal operations after being submerged, sometimes for an extended period.

The possibly limited and varying freeboards and variations in barge configurations and lock designs combine to create a unique and challenging use case for an HFM solution on the inland waterways. Based on market research, there is not currently a commercial off-the-shelf HFM solution that is ready for implementation on the inland waterway system.

PERSONNEL SAFETY: Deckhands who handle the mooring lines are at risk of being injured during every lockage (Figure 5). These risks include, but are not limited to, being struck by a line or by a mooring bitt that is pulled from the lock wall, falling overboard, and slipping. The 2018 *US Coast Guard–American Waterways Operators Annual Safety Report* (AWO 2018) shows that from 1994 to 2017, there were 281 barge tow crew fatalities—an average of almost 12 fatalities each year—with 6 fatalities occurring in 2017. The report further states that from 2006 to 2017, there were 169 barge tow crew injuries associated with mooring line handling or deckhands being caught in the mooring lines; 65 of those injuries were classified as severe. Lock staff members can also be at risk of injury during barge tow mooring if they are on the lock wall near the mooring lines overseeing the mooring process or, in some cases, assisting with line handling or are performing other activities on the lock wall during a lockage.

Figure 5. Deckhands and lock staff handling a mooring line at Emsworth Lock (USACE Pittsburgh).

HFM SYSTEM CONCEPTS: The USACE HFM team developed concepts to serve as potential HFM solutions. The nine developed concepts will be discussed in more detail in the section that follows, but the basic concepts are listed here:

- Vacuum
- Magnetic
- Winch
- Articulated arm
- Mechanical arm
- Inflatable bladder
- Bumper
- Wedge
- Horizontal stiff-arm

These concepts were categorized according to the number of walls that equipment would have to be installed on for the concept to function properly. The concepts that would require equipment to be installed on a single wall and would pull the barge tow toward that wall are shown in Figure 6.

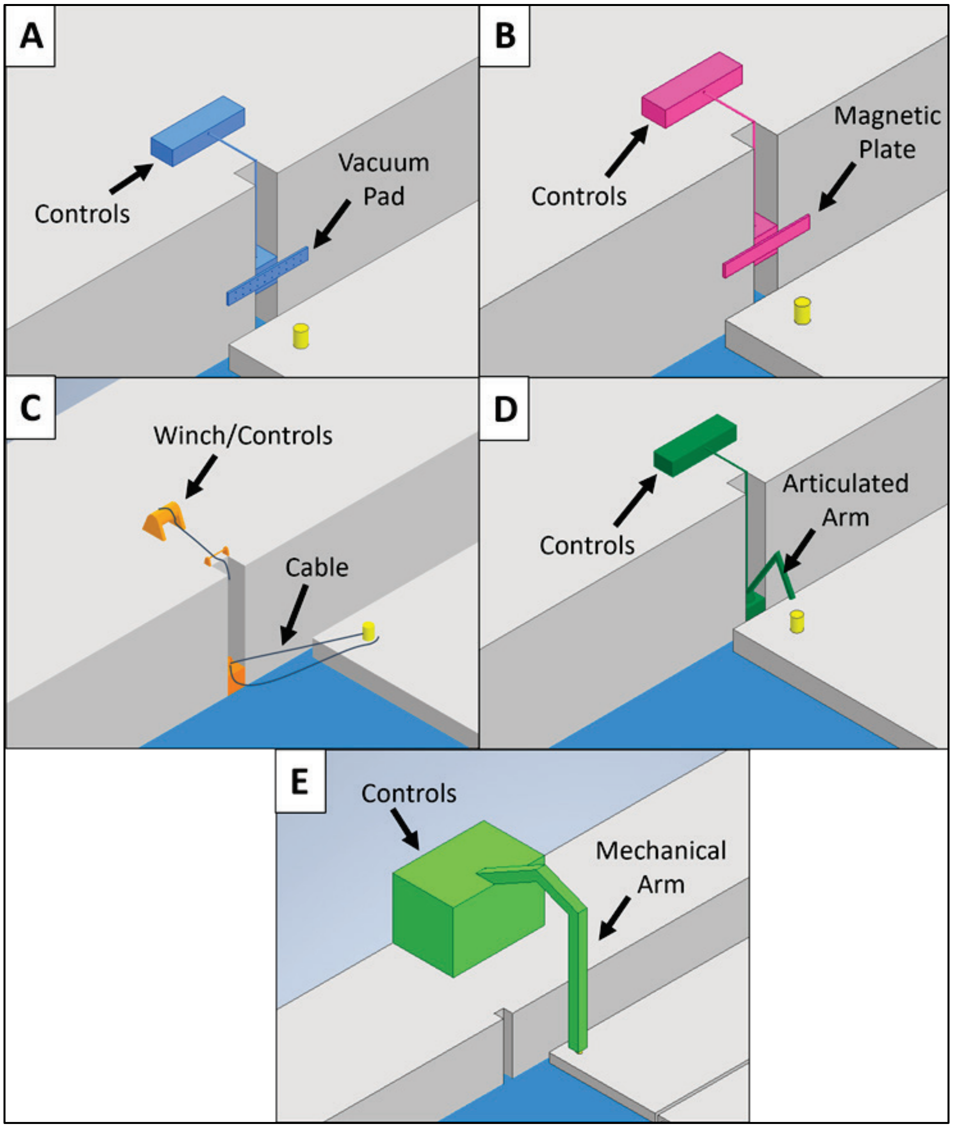

Figure 6. Single-wall HFM concepts, including vacuum pads (*A*), magnetic pads or plates (*B*), winch (*C*), articulating arm (*D*), and mechanical arm (*E*).

The single-wall concepts are as follows:

- Vacuum system (Figure 6*A*). A vacuum system is the concept in use on the SLS. This system employs one or more vacuum pads to connect to the barge surface. The vacuum pads are connected to an articulating arm that moves the pad to the required connection point. A vertical slot in the lock wall (potentially an existing slot for a floating mooring bitt) is required to allow the pad to move vertically as the chamber water level rises or falls during lock F/E operations.

- Magnetic system (Figure 6*B*). A magnetic system is analogous to the vacuum system but uses magnetic pads or plates, rather than vacuum pads, to connect to the barge.

- Winch system (Figure 6*C*). A winch system uses one or more winches connected to something like a floating mooring bitt to connect to a barge kevel.

- Articulated-arm system (Figure 6*D*). An articulating-arm system consists of an arm that can rotate and be lowered onto a barge kevel. The arm is controlled by two hydraulic cylinders. The arm is mounted in a slot, and the base of the arm floats to allow the arm to move vertically as the water level in the chamber rises or falls during lock F/E operations.

- Mechanical-arm system (Figure 6*E*). A mechanical-arm system is a robotic arm mounted to the top of the lock wall that can grab a barge kevel or a similar location.

The concepts that would require equipment to be installed on both walls and would push the barge tows toward the opposite wall are shown in Figure 7.

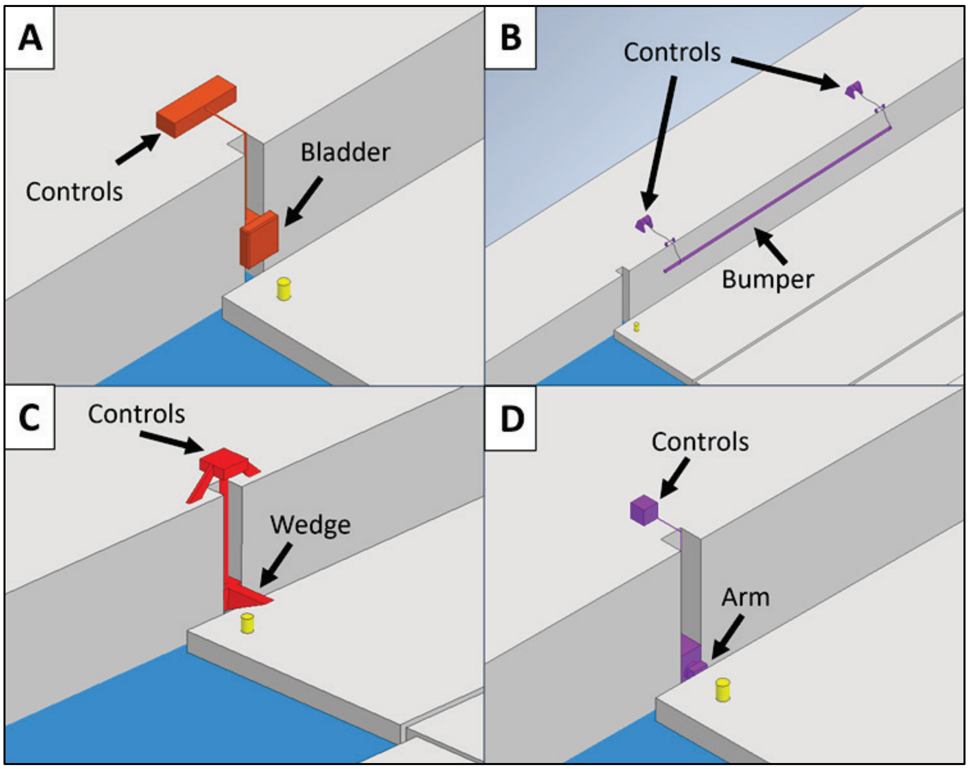

Figure 7. Dual-wall HFM concepts, including inflatable bladder (*A*), bumper (*B*), wedge (*C*), and stiff arm (*D*).

The dual-wall concepts are as follows:

- Inflatable-bladder system (Figure 7*A*). An inflatable-bladder system uses one or more bladders that can be lowered or otherwise positioned between the barge tow and the lock wall and inflated to push the barge tows to the opposite wall. This system requires compressors to inflate the bladders.

- Bumper system (Figure 7*B*). A bumper system consists of one or more bumpers on each lock wall that can be lowered or otherwise positioned between the barge tow and the lock wall. With this system, the barge tow is not necessarily secured to the lock walls; the barge tow is protected from directly impacting the lock walls by the bumpers. If sufficiently large bumpers are used, the barge tow can be secured.

- Wedge system (Figure 7*C*). A wedge system consists of one or more wedges that can be lowered between the barge tow and the lock wall to secure the barge by pushing the barge toward the opposite wall. This system requires a vertical slot in the lock wall for each wedge to provide an anchor.

- Horizontal stiff-arm system (Figure 7*D*). A horizontal stiff-arm system consists of one or more arms that can be extended (perhaps by a screw or telescoping action) to push the barge toward the opposite wall.

A list of considerations was developed to evaluate the pros and cons of each system. The considerations for each system were compiled into one list and became the criteria for selecting an HFM system.

HFM CONCEPT EVALUATION: Multiple criteria were developed to evaluate and rank the proposed HFM concepts. These criteria were separated into two categories: screening criteria and ranking criteria. The screening criteria are parameters that a concept must meet. The ranking criteria are parameters that are preferred but are not absolutely required. For example, consider the following two questions concerning HFM concepts: Can the HFM concept safely moor a barge tow in a lock chamber, and can the HFM concept be applied at an existing lock with only small modifications to the lock required for proper installation? Navigation safety is essential during a lockage, so the question concerning mooring safety is a screening criterion for the HFM concepts. Minimal disturbance to normal lock operations and minimal construction during installation of the HFM system are preferred but not required, so the question concerning required modifications to the lock is a ranking criterion.

A design charette was held to discuss the proposed HFM concepts and determine how they ranked according to the identified criteria. The attendees included the USACE HFM team and stakeholders from multiple USACE districts (i.e., Louisville, Pittsburgh, and Nashville), the USACE Lakes and Rivers Division, and the navigation industry (Table 1). These stakeholders have extensive experience in the navigation industry and with the operation and management of USACE locks as well as the technical expertise associated with controls. During the screening criteria phase, the concepts requiring both lock walls were deemed to not meet one of the screening criteria (i.e., safely mooring the barge tow with various barge configurations), so they were removed from further consideration. The ranking criteria were applied to the remaining five HFM concepts: the vacuum, magnetic, winch, articulated-arm, and mechanical-arm systems. From the design charette, all remaining five HFM concepts were deemed feasible, according to the criteria.

Table 1. Design charette participants

Name	Affiliation	Job title
Jim Miller	USACE ERDC Construction Engineering Research Laboratory	Research mechanical engineer (HFM principal investigator)*
Jim Allen	USACE ERDC Construction Engineering Research Laboratory	Research engineer*
Locke Williams	USACE ERDC Coastal and Hydraulics Laboratory	Research mechanical engineer*
Natalie Myers	USACE ERDC Construction Engineering Research Laboratory	Planning specialist*
Allen Hammack	USACE ERDC Coastal and Hydraulics Laboratory	Research mechanical engineer*
Morgan Johnston	USACE ERDC Coastal and Hydraulics Laboratory	Research civil engineer*
Ryan Smith	USACE ERDC Construction Engineering Research Laboratory	Research civil engineer*
John Cheek	USACE Inland Navigation Design Center	USACE ERDC to district liaison*
Brian Holcomb	USACE Louisville District	Regional technical specialist†
David Seng	USACE Louisville District	IT specialist†
Gary Birge	USACE Louisville District	O&M specialist†
John Dilla	USACE Pittsburgh District	Ohio River section operations manager†
Walter Hart	USACE Detroit District	Regional technical specialist†
Kareem El-Naggar	USACE Great Lakes and Ohio River Division	Senior O&M manager†
Marty Hettel	American Commercial Barge Line	Vice president of government affairs†

Note: The information in this table was accurate as of July 2021.
*HFM team member.
†Stakeholder/expert reviewer

SUMMARY: The USACE Navigation Systems Research Program has begun a project to develop an HFM system for USACE inland navigation locks. Current mooring practices within USACE were observed to understand the challenges of implementing HFM throughout inland USACE locks. Existing HFM systems in use outside of USACE were observed and evaluated for possible implementation on USACE's inland locks. HFM concepts were developed, and evaluation parameters were established to assess the viability of those concepts. Five of the concepts were deemed feasible, so the HFM team will pursue a contract in the next phase of this research to solicit HFM concept proposals for USACE's inland locks.

ADDITIONAL INFORMATION: This CHETN was prepared by Ms. Locke M. Williams, research mechanical engineer, US Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory, Vicksburg, Mississippi. The study was funded by the USACE Navigation Systems Research Program. Questions about this CHETN can be addressed to Ms. Locke Williams at 601-634-2258 or *Locke.M.Williams@usace.army.mil*.

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