Ship Simulation Transit Scenario Modeling & Ship Pilot Study of the Maritime Implications for Commercial Ship Transits of the Proposed Houston Ship Channel Gate Complex

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EXECUTIVE SUMMARY

Purpose

The purpose of this screening-level research is to explore the maritime implications for commercial ship transits of the US Army Corps of Engineers (USACE) proposed Houston Ship Channel Gate Complex (Gate Complex). This research analyzes the site location and design of the Gate Complex concept described in the USACE Galveston District and Texas General Land Office's (August 2021) "Coastal Texas Protection and Restoration Feasibility Study: Final Feasibility Report"[1] (Final Feasibility Report) and further described in the report's "Appendix D: Engineering Design, Cost Estimates, and Cost Risk Analysis" [2]. The Gate Complex analyzed is not the result of a planning, engineering, and design phase (PED) completed by the USACE, but rather the USACE Galveston District described the proposed siting and design tested as at the conceptual stage. The Gate Complex concept includes three asymmetric islands with two gate complexes each designed for one-way ship traffic, with dimensions of 650' wide and a depth of 60'. Figure 1 depicts the concept design and siting of the Gate Complex in the Bolivar Roads area of the Houston Ship Channel (HSC) and near the Galveston Ship Channel (GSC) from the Final Feasibility Report (page 84).

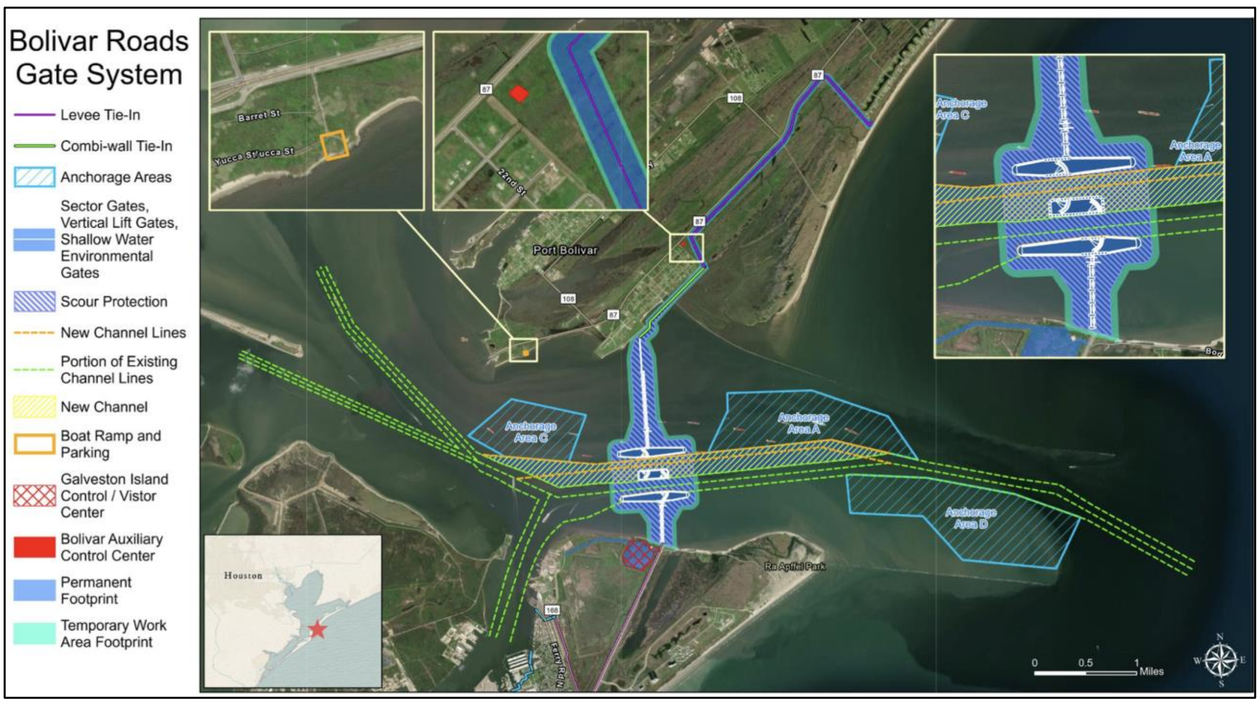

Figure 1. HSCGC Concept Depiction and Siting from the USACE Feasibility Study.

[1] USACE, Galveston District and Texas General Land Office. (August 2021). "Coastal Texas Protection and Restoration Feasibility Study Final Report".
[2] USACE, Galveston District and Texas General Land Office. (August 2021). "Coastal Texas Protection and Restoration Feasibility Study Final Report. Appendix D: Engineering Design, Cost Estimates, and Cost Risk Analysis".

Methodology

The Gate Complex was analyzed by performing 42 ship transit scenarios piloted by 14 Houston and four Galveston-Texas City pilots using ship simulators at San Jacinto Maritime College in LaPorte, Texas. Each scenario utilized two to three interactive piloted ship models, transiting inbound or outbound through a single or a double Gate Complex, using varying environmental conditions (wind, currents, & visibility). Varying ship models of tank vessels and cargo ships that transit the HSC and those proposed in the future were used along with varying starting positions and speeds. After each ship transit scenario, the pilots were interviewed to identify and describe any hazards. Roundtable discussions also occurred including with visitors from the USACE Galveston District. For more information, see the main report.

Summary of Research Findings

1. **The Gate Complex siting location is a hazard to transiting commercial ships.**
    a. The Gate Complex is too far west in the Bolivar Roads area of the HSC. The entrance is only ~0.6 nautical miles from the HSC turn at buoys 18 and 16, requiring a severe angle turn to align with the center of the Gate Complex. This hazard is aggravated by strong tidal currents (up to 2.5 knots) in the area affecting a ship's navigation and speed regulation. This resulted in multiple ship collisions near buoys 18 and 16, along with ship allisions or striking of the Gate Complex.
    b. The Gate Complex is too close to the GSC. The siting foreshortens the length of the turn, requiring a severe angle turn coming in and out of the GSC. This disrupted ship traffic, led to a near ship collision, and a ship allision with the Gate Complex.
2. **The Gate Complex design is a hazard to transiting commercial ships.**
    a. The 650' wide gate openings are too narrow. They require "perfect" piloting, leaving no room for error. On approach, ships must slow down, creating a chokepoint for ship traffic in the area. This led to a disruption in ship traffic. Additionally, aboard large vessels, visibility of the gate openings was obstructed.
    b. The asymmetrical three island design is a hazard. The ship's experience asymmetrical shearing forces causing the pilot to lose control of the ship when entering at an angle or unaligned with the center of the Gate Complex. Additionally, the rectangular center island has 90-degree edges that would cause extensive damage to a ship if contacted.

Summary of Alternative Gate Complex Siting and Design Considerations

1. Explore different siting locations of the Gate Complex. If siting in the Bolivar Roads area of the HSC, move the Gate Complex further to the east. Also, consider the siting impacts on the inner anchorages currently used by commercial ship transit activity.
2. The Gate Complex should have three symmetrical islands along with sloped sides protecting the walls. Widen the Gate Complex beyond the current 650' and make the depth the deepest possible consistent with safe engineering design.

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Disclaimer

The opinions expressed in this Greater Houston Port Bureau-commissioned report are not necessarily those of Greater Houston Port Bureau.

This research is provided to the Greater Houston Port Bureau as an independent review of a US Army Corps of Engineers' proposed Houston Ship Channel Gates Complex (HSCGC), located in Bolivar Roads area of the Houston Ship Channel. This is a screening-level or exploratory qualitative research of the HSCGC design and siting, meaning that the research team considered a large number of processes and factors, performing a minimum number of experimental ship simulations of transit scenarios given the limited resources, time, and budget. This research does not test a HSCGC design that is the result of a planning, engineering, and design phase (PED), nor utilizes other standards of engineering design. Rather, it is exploratory of the proposed HSCGC design and siting identified and described in the USACE Galveston District and Texas General Land Office's (August 2021) "Coastal Texas Protection and Restoration Feasibility Study: Final Feasibility Report"[3] and further described in the report's "Appendix D: Engineering Design, Cost Estimates, and Cost Risk Analysis" [4].

Only this one HSCGC concept was analyzed. The research did not consider alternative HSCGC concepts whether design or siting. Additionally, the Final Feasibility Report did not specify a design vessel. Therefore, a range of ship models were used including those that currently transit the Houston Ship Channel as well as some possible future vessels.

The purpose of this research is to inform, solicit, and stimulate local pilot input on the HSCGC utilizing simulated commercial ship transit scenarios. The ship pilots who participated in this research are independent contractors. Their opinions and recommendations are not the opinion, nor the policy of their association pilot groups. Nothing in this research is intended to represent the intent, policy, or opinion of the Galveston-Texas City Pilots, the Houston Pilots Association, nor the USACE-Galveston District.

[3] USACE, Galveston District and Texas General Land Office. (August 2021). "Coastal Texas Protection and Restoration Feasibility Study Final Report".

[4] USACE, Galveston District and Texas General Land Office. (August 2021). "Coastal Texas Protection and Restoration Feasibility Study Final Report. Appendix D: Engineering Design, Cost Estimates, and Cost Risk Analysis".

Research Project Participants List

Ship Pilot Research Participants		
Name	**Organization**	**Project Role**
Capt. Robert Thompson	Houston Pilots	Pilot
Capt. Clint Winegar	Houston Pilots	Pilot
Capt. Ryan Casas	Houston Pilots	Pilot
Capt. Marcus Maher	Houston Pilots	Pilot
Capt. Davis Reeder	Houston Pilots	Pilot
Capt. Michael Curtis	Houston Pilots	Pilot
Capt. Rohit Malhotra	Houston Pilots	Pilot
Capt. Jason Stancil	Houston Pilots	Pilot
Capt. William Kern	Houston Pilots	Pilot
Capt. John Bratcher	Houston Pilots	Pilot
Capt. Jason Briones	Houston Pilots	Pilot
Capt. Chad Prejean	Houston Pilots	Pilot
Capt. Jerimiah Walick	Houston Pilots	Pilot
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Capt. Anthony Booth	Galveston-Texas City Pilots	Pilot
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Introduction to Main Report

The purpose of this research is to conduct screening-level or exploratory qualitative research focusing on the maritime implications of the US Army Corps of Engineers (USACE) proposed Houston Ship Channel Gate Complex (HSCGC). The HSCGC conceptual design and siting analyzed are described in the USACE Galveston District and Texas General Land Office's (August 2021) "Coastal Texas Protection and Restoration Feasibility Study: Final Feasibility Report"[5] (Final Feasibility Report) and further described in the report's "Appendix D: Engineering Design, Cost Estimates, and Cost Risk Analysis" [6] (Appendix D).

The HSCGC concept analyzed is not the result of a planning, engineering, and design phase (PED) completed by the USACE, but rather the USACE Galveston District described the proposed design and siting tested as at the conceptual stage. The HSCGC concept includes three asymmetric islands with two gate complexes each designed for one-way ship traffic, with dimensions of 650' wide and a depth of 60'. According to the Final Feasibility Report, Appendix D, the gates are to remain open year-round and will be closed in the event of a tropical system threatening the coast. However, "[i]n the unlikely event, one of the gates will not open after a storm or there is a maintenance that requires the gate to be closed, navigation can continue through the other gate" (Appendix D: 6-16). Additionally, "Prior to any island construction, navigation [of commercial ships] will be shifted to the bypass channel. Upon completion of one of the gate-and-island complexes, traffic will be diverted to the newly constructed channel and gate opening" (emphasis added) (Appendix D: 6-17). Therefore, this research focuses on analyzing ship transit through two gate complexes with one-way ship traffic, as well as one gate complex with two-way ship traffic.

The research team recognizes that the HSCGC is intended for a 50-year lifespan, and what was tested is the concept in the feasibility report. This concept does not represent the final design, as Lt. General, Scott A. Spellmon, USACE, in the Chief's Report "Coastal Texas Protection and Restoration" (September 16, 2021), states a final design has not been selected.[7] Rather, Lt. General Spellmon states, "Further investigation, engineering, and design analysis will be needed in future phases." Thus, we tested the conceptual design and siting, and concur with the USACE that further research is required.

In addition to the commercial ship transit scenario simulations, the research team hosted visitors from the local USACE Galveston District. Our visitors included USACE Galveston District Commander, Col. Rhett Blackmon, accompanied by lead design engineers for the HSCGC, as well as the USACE project manager for "Mega Projects". The USACE visitors observed the

[5] USACE, Galveston District and Texas General Land Office. (August 2021). "Coastal Texas Protection and Restoration Feasibility Study Final Report".
[6] USACE, Galveston District and Texas General Land Office. (August 2021). "Coastal Texas Protection and Restoration Feasibility Study Final Report. Appendix D: Engineering Design, Cost Estimates, and Cost Risk Analysis".
[7] Lt. General, Scott A. Spellmon, Chief's Report "Coastal Texas Protection and Restoration". (September 16, 2021).

simulated commercial ship transit scenarios and joined the research team for roundtable discussions regarding the HSCGC, its construction and siting, as well as alternative design concepts. The pilots were able to share their perspective and conclusions they had drawn from the simulated commercial ship transit scenarios. They stated that tested HSCGC concept design and siting would negatively impact their piloting of commercial ships and pose a hazard to safe commercial ship transits.

The USACE leadership in attendance told the research team and the ship pilots that the HSCGC gate complex should *"not impede nor cause any disruption to normal marine traffic"*. The pilots and research team communicated to the attending USACE leadership, that critical problems exist with the proposed HSCGC concept, siting, and alignment of the complex that will impede, disrupt, and pose a hazard to commercial ship transits.

Below are three figures of the HSCGC design and siting that this research analyzed. Figure 1 depicts the concept design and siting of the HSCGC in the Bolivar Roads area of the Houston Ship Channel (HSC) and near the Galveston Ship Channel (GSC) from the Final Feasibility Report (page 84). Figure 2 depicts the overhead conceptual artist rendition of the HSCGC from the Final Feasibility Report (page 85). Figure 3 is the chartered siting of the HSCGC developed by the research team for this report.

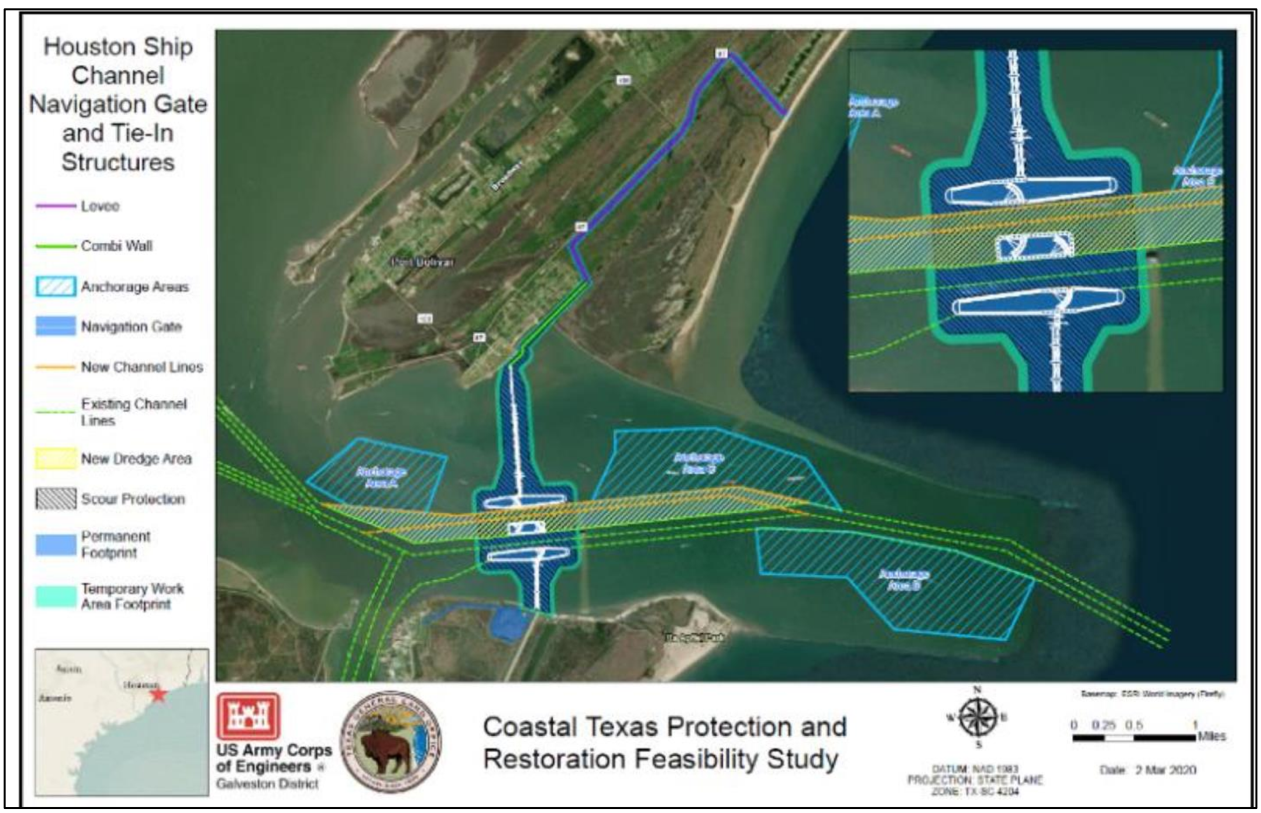

Figure 1. HSCGC Concept Siting from the Final Feasibility Report (page 84).

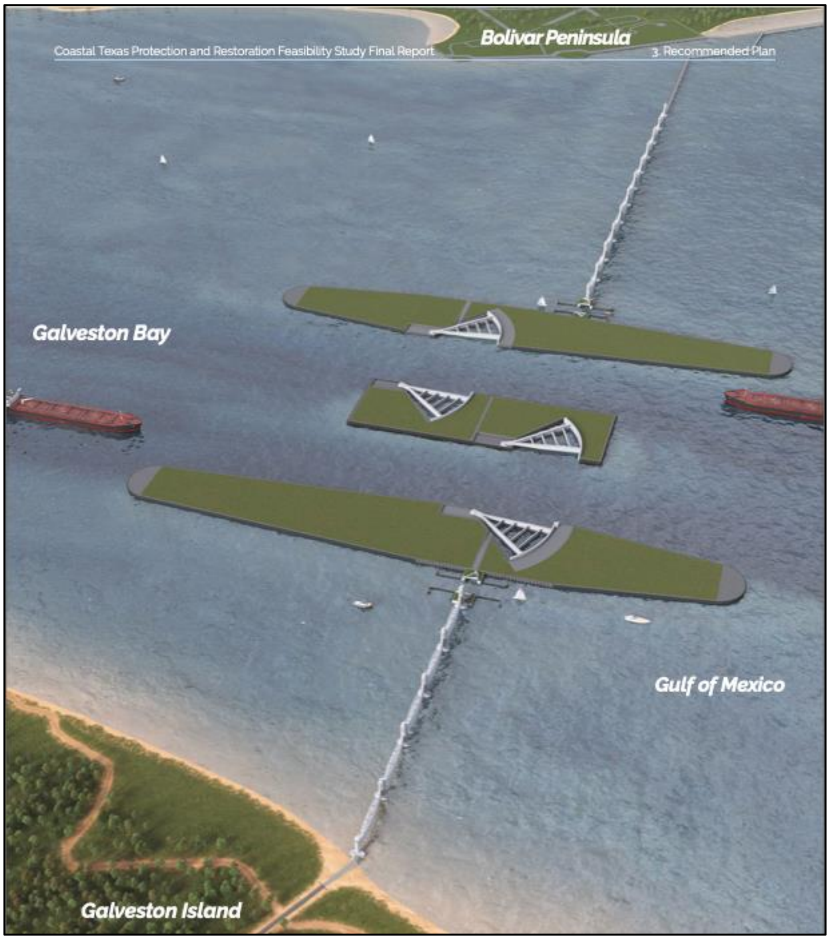

Figure 2. Overhead Conceptual Rendition of the HSCGC from the Final Feasibility Report (page 85).

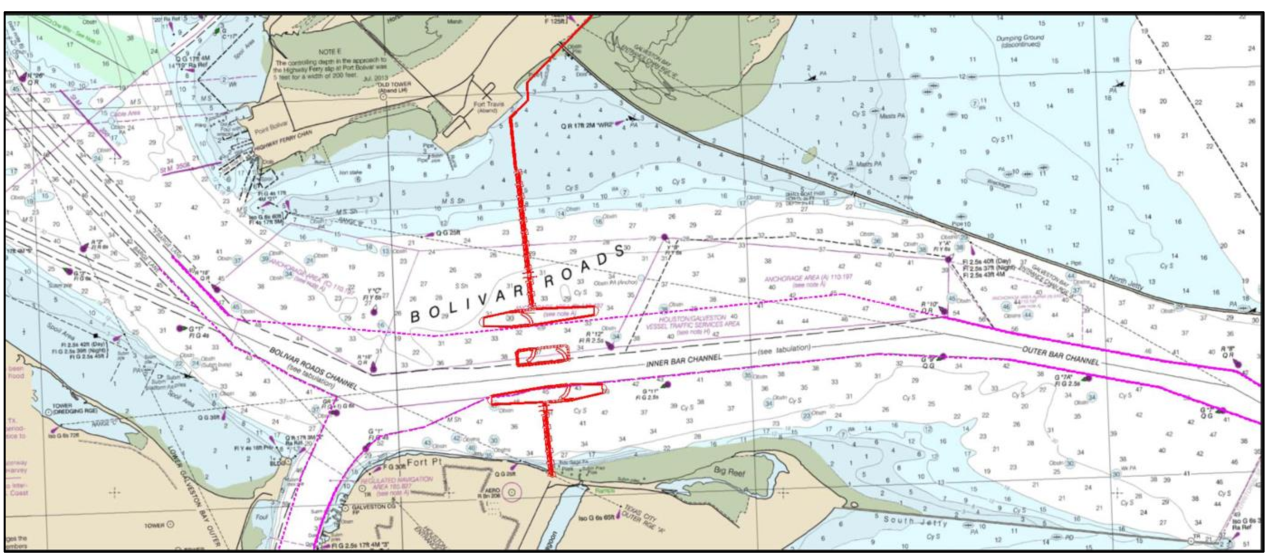

Figure 3. Charted siting of the tested HSCGC in the Bolivar Roads along with existing HSC.

Overview of Methodology

Over a period of six days during September 29-30 and October 3-6 of 2022, 42 commercial ship transit scenarios or “runs” were completed. The research used the Houston Pilots’-owned Kongsberg Full Mission Ship Simulators, located at the San Jacinto Maritime College in LaPorte, Texas.

Each run utilized two to three interactive piloted ship models, navigating through single and double gate complex transits. A total of 111 individually piloted ship transits were performed during these 42 runs. In each ship simulator, one pilot was conning the ship model, while one to three additional ship pilots assisted and observed depending on the number of ship pilots available during each session. In addition to evaluating transits of the gate complex, ship transit scenarios included analysis of ship meetings in the navigation channels on either side of the HSCGC. There were 42 ship meetings during which the skin-to-skin distance between the ships was recorded.[8] The skin-to-skin distances during the ship meetings are listed in “Appendix 1. Simulation Run Matrix 1.”

A wide variety of ship models were tested. The most frequent ship model tested was a Very Large Crude Carrier (VLCC) Suezmax-class (Model VLCC13). Its dimensions are 900’ length overall (LOA) X 164’ beam, which are common commercial ships in the HSC today. Another common commercial ship in the HSC that was tested was an Aframax-class tank vessel, with dimensions 820’ LOA X 144’ beam. We also tested the largest existing tank vessel that is currently using the HSC, a 2-million-barrel capacity VLCC with ~1,100’ LOA X 190’ beam. Additionally, three container ships were tested. The largest model tested may come to the HSC in the future is a container vessel with 23,000 Twenty-Foot Equivalent (TEU) container capacity, with dimensions 1,312’ LOA X 192’ beam. Except for one run, the same ship models were used in all the ship simulators during each transit scenario. This was done to prevent mistakes and confusion about which simulator had which ship model. The table below reports the dimensions and frequency of runs performed by each ship model.

[8] For ship-to-ship meetings when the distance was greater than 1,000’, the distance was not recorded.

Table 1. Ship Model Information and Run Frequency Per Ship Model

Model	Ship Type	LOA	Beam	Draft	DWT tons	# Runs
VLCC13	Tank Vessel (Suezmax)	900’	164’	40.4’ (Partially Loaded)	156,169 tons	23
VLCC14	Tank Vessel (Aframax)	820’	143.7’	48.9’	115,392 tons	10
CNTR33	Container Ship	1,102’	150.3’	39.5’ (Ballast)	99,210 tons	5
CNTR28	Container Ship	1,138’	140.4’	47.6’	110,387 tons	2
VLCC18	Tank Vessel	1,089’	190.3’	45.9’	306,200 tons	2
ULCV400	Container Ship	1,312’	192.3’	47.6’ (Partially Loaded)	246,050 tons (displacement)	1

The ship transit scenarios were designed with a wide range of objectives. Primarily, the objectives of each scenario were for piloted ships to navigate inbound or outbound through an open gate and to meet other ships before and/or after the HSCGC. The starting positions of the ships varied, but usually the starting position was 1-2 miles from the entrance of the HSCGC with starting speed at 8 to 10 knots depending on the ship and pilot input. The distance was selected to provide enough time and space for the ships to align and transit the gate complex, and to meet another ship either before or after the gate complex. The starting speed is typical for these ships in the HSC.

Environmental conditions varied during each run. Both flood and ebb currents were utilized at 2.5 knots. The currents used are based on the currents from the Houston Ship Channel, Project 11 simulation research study, completed in 2020. The USACE – Engineer Research and Development Center approved these currents for ship simulation research for Project 11 as a credible worst-case scenario, and these currents were also verified by the Houston Pilots as valid. Wind direction and velocity was primarily 135 degrees (southeast) at 20 knots. Additional wind directions included 345 degrees (20 and 30 knots), 270 degrees (20 knots), and 165 degrees (20 knots). These wind directions are typical, based on pilot input. The 30-knot velocity is extreme but was requested by the pilots and was used during Runs #33 and 34. Visibility conditions also varied. Primarily, scenarios utilized clear daytime conditions, but night-time as well as fog conditions during day and night were also used to test scenarios with limited visibility. The environmental conditions used during each scenario are listed in “Appendix 1. Simulation Run Matrix 2.”

After each ship transit scenario, the conning pilots were interviewed.[9] Interview questions focused on general description of the performed maneuver, hazard identification, as well assessing safety concerns for the ship transit scenario from the conning pilot’s perspective

[9] During scenario runs 27-30, GAR interviews were not completed. This is because the scenario runs were conducted to familiarize the Houston and Galveston pilots with the ship simulator along with the HSCGC.

using a Green-Amber-Red (GAR) score.[10] The GAR score used was a three-tiered ordinal Likert scale with increasing levels of concern for safety; 1 = Green (Low Concern for Safety), 2 = Amber (Moderate Concern for Safety / Caution), 3 = Red (High Concern for Safety / Unsafe). The GAR scores are presented in the table below along with the maritime interpretation.

The highest GAR score from each run is reported. The highest GAR score is used because up to three independently piloted ship models were used in each scenario. Each piloted ship model had different objectives, starting positions, pilots conning, and effects of current and wind direction varied depending on whether the ship was inbound or outbound.

Table 2. GAR Scale for Pilot's Assessment of the Ship Transit Scenario

Score	Scale Level of Concern for Safety	GAR	Maritime Interpretation
1	Low Concern for Safety; Safe	Green	Normal maneuver; Zero to a couple potential hazards of low concern; Routine ship handling
2	Moderate Concern for Safety; Caution	Amber	Caution when performing this maneuver; Multiple potential hazards of moderate concern; Cautionary, alert ship handling
3	High Concern for Safety; Unsafe	Red	Maneuver should probably not be performed; Unsafe; One or more hazards of high concern

The research was divided into three two-day sessions, with at least three and up to ten ship pilots taking part in each session. During the first two sessions we had only Houston Pilots take part (Runs #1 – 26). During the third session (Runs #27 – 42), we had both Houston Pilots and Galveston-Texas City Pilots take part in the research. The participating pilots had diverse levels of experience ranging from first year pilots to veterans with 35 years or more of experience piloting. A complete list of the 18 pilots that participated in the research is in the Research Project Participant List: 14 Houston pilots and 4 Galveston-Texas City pilots.

The pattern for each session was to begin with an initial transit scenario using two ships in clear daytime visibility and mild environmental conditions (e.g., no wind, one knot or less current). After the pilots completed an inbound and an outbound transit of the HSCGC to become familiar with its siting and effects on piloting ships, we increased the difficulty of the scenario by adding in wind and current as well as imposing restricted visibility, including fog at night. We also added a third ship and designed for the inbound and outbound ships to meet in the Houston Ship Channel at locations the pilots normally have commercial ship meetings. This escalation scheme in the research design extended to the use of ship model types. Initial ship transit scenarios utilized conventional tankers VLCC14 and VLCC13, while subsequent ship transit scenarios used larger VLCC and container ship models to increase the rigor in piloting through the gates due to visibility restrictions and poorer vessel handling characteristics. A

[10] GAR, a green rating is safe, an amber is caution or moderate concern, and a red rating is unsafe or high concern.

description of each of the 42 commercial ship transit scenarios are listed in Appendix 1. Simulation Run Matrix 1 reports the scenario's GAR score, gates used, ship models, starting speeds, starting position, ship objectives (inbound or outbound and gate), and ship meetings along with their distances reported as skin-to-skin. Simulation Run Matrix 2 reports the GAR score, gates used, ship models and objectives, along with environmental conditions of each transit scenario; the wind (direction in degrees / knots), current (flood or ebb and knots), and visibility (clear daylight, nighttime, and/or fog).

At the end of each day, the research team held a roundtable discussion to query all the pilots involved as well as any guests. This discussion was an opportunity for the pilots to talk about what they had experienced during the ship transit scenarios, share their opinions with each other and the research team about the HSCGC including identify hazards regarding its design and siting, as well as offer alternative considerations.

Summary of Research Findings

HSCGC Siting Potential Hazards

1. The HSCGC siting is too far to the west in the Bolivar Roads area of the Houston Ship Channel. The entrance to the HSCGC is only ~0.6 nautical miles from the Houston Ship Channel turn at buoys 18 and 16. This is too close, requiring a turn at a severe angle to make the turn and still align with the center line through either gate complex. While a hazard for both gate complexes, the hazard is worse for the north gate complex. This resulted in multiple ship collisions near buoys 18 and 16 as well as ship allisions with the gate complex.

2. The HSCGC is too close to the Galveston Ship Channel. The siting foreshortens the length of the turn, requiring a severe angle turn coming in and out of the Galveston Ship Channel and still align with the center line through either gate complex. Limiting the distance to navigate this turn led to ship allisions with the gates, and disruptions in the normal flow of commercial ship traffic in and out of the Galveston Ship Channel.

3. The HSCGC siting is subject to strong tidal flood and ebb currents (2.5 knots). These strong currents are a potential hazard for commercial ships attempting to line-up and adjust their speed to pass safely through the center of the gate complex, while simultaneously meeting other commercial ship traffic in the vicinity of the HSCGC.

4. The HSCGC siting is not aligned with the prevailing currents in the area. This is particularly the case for the northern gate complex. Being offset from the prevailing currents increases the difficulty for piloted commercial ships to pass through the gate complex. This also could increase water blockage, induce vortices, and eddy formation. Such developments are potential hazards for transiting commercial ships.

5. The HSCGC siting lacks a “bail-out” zone for approaching ships to abort passage into the gate complex. The gate complex can be seriously damaged by ships in extremis that lack an intentional grounding area.

HSCGC Design Potential Hazards

6. The 650’ width of the HSCGC is too narrow. Piloted ships that entered the HSCGC on an angle or unaligned with the center of the gate entrance, experienced substantial lateral suction forces and rotational moments on the ship due to the mass and pressure of the water trapped between the ship and the gate wall. These forces affect the capability of the pilot to safely control the heading and speed of the ship when passing through the HSCGC.

7. The HSCGC’s 650’ wide gate openings require “perfect” piloting, leaving no room for error. On approach, ships must slow down, creating a chokepoint for ship traffic in the area. Thus, impacting the spacing, timing, and navigation of ships for miles on either side of the HSCGC for ships inbound and outbound of the Houston and Galveston Ship Channels.

8. The asymmetrical three island design is a hazard. If entering at an angle or unaligned with the center of the HSCGC, the ship's experience asymmetrical shearing forces. Shearing forces from the pressure and mass of the ship's speed and displacement forces interacting with the gate's vertical sheet-pile walls were observed at the entrance and exit of the HSCGC. On multiple occasions, the pilot lost control of the ship due to these forces.

9. The rectangle center island of the HSCGC has "square" 90-degree edges that are a potential hazard and could create extensive damage to a ship if contacted.

10. The HSCGC's 650' gate openings can be obstructed from the view of a pilot from the bridge of a ship. Obstructed view was observed when testing the largest container ship and could potentially apply to other large ships with known forward visibility obstructions such as liquefied natural gas carriers.

11. During reduced visibility conditions such as in fog and at night, the tested HSCGC concept design is difficult to see without the assistance of electronic navigation aids.

12. Two-way commercial ship traffic through a single gate complex of the HSCGC is a hazard. The combined forces of two ships underway passing in the 650' wide single gate complex created unmanageable forces on the ships causing collisions between the ships and allisions with the side walls. This was particularly a problem at the asymmetrical entrance and exit of the gate complex as the ships experience shearing forces. These shearing forces caused ships to lose control, dangerously veering in the channel causing collisions with other ships and allisions with the gate complex.

Summary of Considerations for Future Research to Mitigate Hazards Associated with the HSCGC Siting and Design

Disclaimer: the following considerations for future research to mitigate hazards associated with the HSCGC siting and design are based on the commercial ships tested. The smallest ship tested was an Aframax tank vessel, with dimensions of 820' LOA X 144' beam. These considerations were the result of the roundtable discussions with the Houston and Galveston-Texas City ship pilots. These were not assessed as that was not within the scope of this research.

1. Future research should analyze vessel traffic to identify the impacts of this or any other HSCGC alternative. Research of commercial ship transits in the vicinity of the HSCGC should include but not be limited to consider the following:

    a. Whether daylight restrictions or other visibility restrictions should be required;
    b. whether greater distances for following other commercial ships should be required;
    c. whether greater distances for performing ship-to-ship meetings should be required;
    d. whether assist and/or escort tugboats should be required typical and emergency conditions;
    e. whether the pilot groups should request the USCG to establish moving safety zones for Suezmax and larger tank vessels;
    f. whether a commercial ship traffic control system should be required, especially at the intersection of the Houston and Galveston Ship Channels;
    g. and the effects that any or all of these potential changes will have on the capacity and efficiency of commercial ship transits.

2. A methodology should be developed to identify the maximum draft depth possible for a vessel to research the HSCGC during its 50-year lifespan.

3. A methodology should be developed to utilize a design test vessel with the maximum draft depth possible to research the HSCGC during its 50-year lifespan.

4. Research using physical modeling of the ships and HSCGC should be completed as the ship simulators are limited in terms of capturing volume of water. This should be consistent with existing USACE PED research. Including, using radio-controlled ships at approximately 1:100 scale should be considered for evaluating the far field approaches to the structure. Manned physical modeling at approximately 1:25 scale should also be considered to evaluate passage through the gate complex. The only comparable gated structure built by the USACE as part of a surge barrier is the Lake Borgne Structure near New Orleans, Louisiana. USACE research in support of that effort included piloted computer simulations, physical modeling, and a formal risk assessment.

5. More research is necessary during the planning stages including a formal risk assessment, and a commercial ship traffic study. Such research will help ship pilots along with stakeholders to better understand the effects the HSCGC could have on transiting commercial ship traffic.

6. During their visit, the USACE-Galveston District officials recommended that in order for the pilot groups to maximize their influence as stakeholders, they should organize, be unified, and stay local in working with the USACE-Galveston District.

Summary of Alternative HSCGC Siting and Design Considerations

Disclaimer: the following alternative considerations are based on roundtable discussions with the ship pilots based on their experience and conclusions they drew from the ship simulations. Analysis and testing of these alternative considerations were not conducted as they were outside the scope of this research. However, these considerations may help inform the planning, engineering, and design (PED) phase of future research.

HSCGC Siting and Ship Channel Alignment Considerations

1. Explore different siting locations for the HSCGC. Consider moving the HSCGC further east in the Bolivar Roads. There should be a substantial straightaway approach from either direction to the entrance of the gate complex.

2. Study and consider realigning the Houston and Galveston Ship Channels to create the straightest and longest ship channel possible for commercial ships to transit through the HSCGC. The longer and straighter the channel, the easier and fewer potential hazards it poses for pilots to align commercial ships to safely transit the gate complex.

3. Study and consider aligning the construction by-pass channel for efficient, unimpeded, two-way ship traffic for all channel users. The by-pass channel should be designed to ensure full continuity of uninterrupted two-way commercial ship traffic around the construction area.

4. The construction by-pass channel should be considered as an auxiliary gate complex even after the primary gate complexes are completed and in operation. This will could help limit traffic congestion through the proposed 650’ wide gate complex.

5. “Bail-out” zones should be considered for commercial ships in extremis to intentionally ground, rather than potentially have an allision with the gate complex.

6. Consider the siting impacts on the inner anchorages currently used by commercial ship transit activity. Alternative inner anchorage locations may not enable the safe execution of necessary activities, such as bunkering and pilot boarding during inclement weather.

HSCGC Design Considerations

7. Consider redesigning the HSCGC’s walls to create a sloped protection channel inside the gates, allowing a ship to ground in the channel before striking the gate walls. Alternatively, consider changing from a “no-touch” wall, to one where a transiting commercial ship can touch the side walls without doing extensive damage to the HSCGC or to the ship.

8. Consider designing three symmetrical islands for the HSCGC. Having three symmetrical shapes should reduce asymmetrical shearing forces on transiting commercial ships.

9. The HSCGC should have excellent navigation aids including inbound and outbound center line ranges.

Ship Simulation Results and Discussion

The results and discussion are divided into four sections. The first section focuses on the issue of the asymmetrical shearing forces on transiting commercial ships from the gate complex. This is demonstrated by examining the forces on the ships in the gate complex as depicted by the ship simulator. This section provides the context and explanation for why center line alignment when entering and exiting the tested HSCGC concept is important for transiting commercial ships. The second section analyzes run scenarios with two gates open and one-way traffic passing through the gates complex. Outbound commercial ships transited through the south gate, and inbound commercial ships transited through the north gate. In total, 12/42 scenarios used one-way traffic with both gates open. The third section analyzes 30/42 scenarios with only one gate open and two-way traffic passing through the single gate complex. A single gate with two-way traffic was analyzed because if one gate is not opening then navigation will continue through the opened gate, according to the Final Feasibility Report.[11] Additionally, once the first island and gate complex are completed, commercial ships will begin transiting through the single gate. The Final Feasibility Report does not state whether this will be single or two-way commercial ship traffic. Finally, the fourth section reports on the round table discussions that took place at the conclusion of each day among the pilots and when in attendance the various visitors.

Section 1. Asymmetrical Shearing Forces from the Gate Complex

Shearing Forces on an Aligned Tank Vessel Inside of the Gate Complex

In the example below, an Aframax-class tank vessel (800’ LOA x 138’ beam) is passing through the tested HSCGC at a speed of 10 knots over the ground while stemming a 2-knot current, thus making 12 knots through the water past the HSCGC. The vessel is perfectly aligned on the center line of the gate system with a distance to the gate wall of 300’ from the center of the vessel. The vessel is experiencing 91 tons of pressure forces from the gate wall. This is a large force on a moving vessel. This force is larger than the rudder force on this vessel. The gate is impeding the transit of the tank vessel, causing a significant shearing force on the vessel.

[11] Coastal Texas Protection and Restoration Feasibility Study. Appendix D: Engineering Design, Cost Estimates, and Cost Risk Analysis (August 2021)

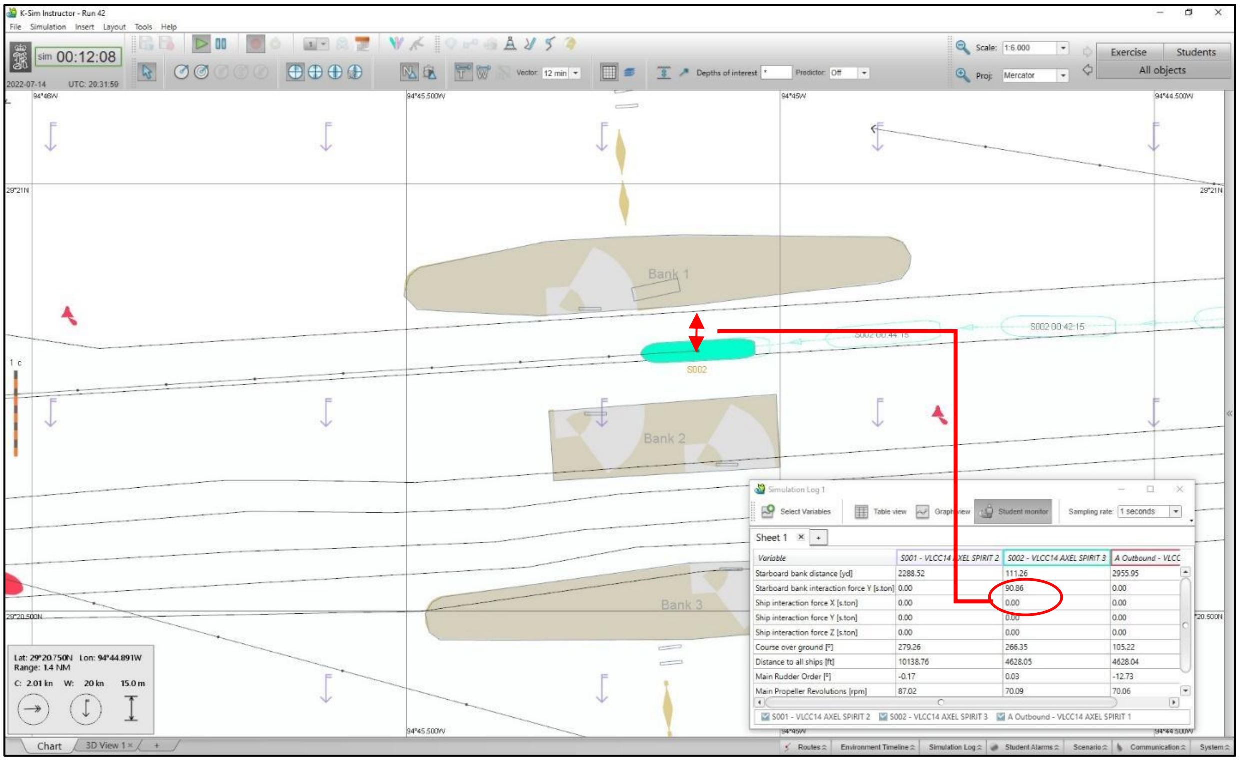

Figure 4. Aframax class tanker with 91 tons of bank force from gate system

Shearing Forces on an Unaligned Tank Vessel *Inside of the Gate Complex*

It is expected that vessels will become unaligned with the HSCGC's centerline while transiting through the gate, given random events, shipboard emergencies, and/or human error. Analysis of the shearing forces below on an unaligned tank vessel, passing through the tested gate system, shows that an Aframax-class tank vessel at a distance of 162' from the sidewall of the gate, at a speed through the water of 10.6 knots, generates 392 tons of shearing force on the vessel. This shearing force caused an out-of-control situation for this vessel.

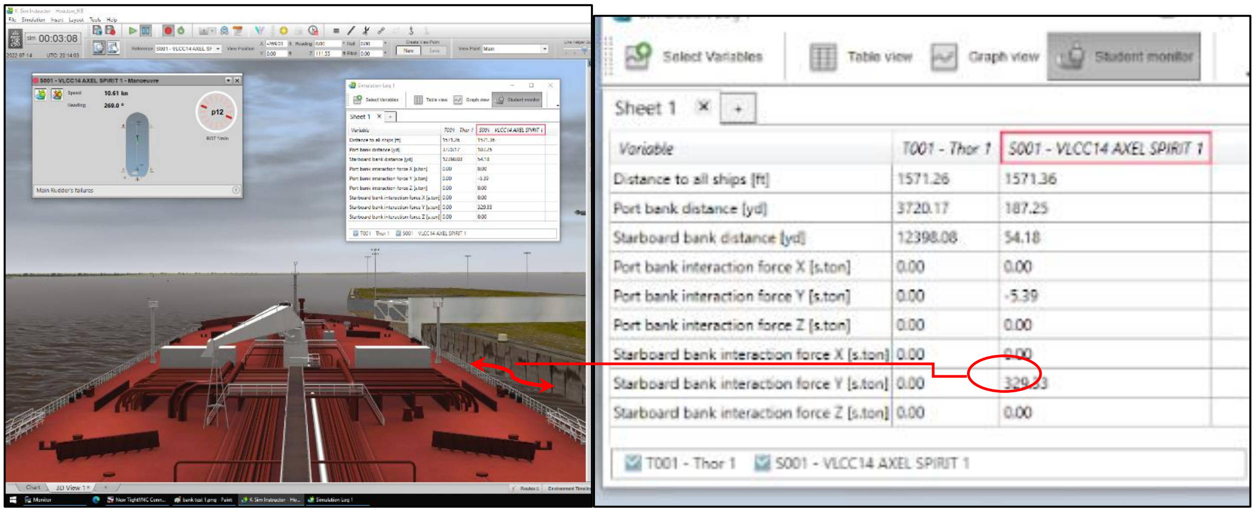

Figure 5. Shearing Forces on misaligned Aframax class tank vessel passing through the tested gate system

Example of a Vessel Out of Control Due to Shearing Forces inside of the Gate Complex

In the below example, the Aframax-class tank vessel (Red, A) was outbound through the HSC, transiting through the gate system, they are mis-aligned due to previous maneuvers with the other Aframax-class tank vessel outbound from the Galveston Channel (Turquoise C), which is closely following. This navigation setup causes the lead vessel (Red, A) to be misaligned and too close to the south wall of the gate system. The asymmetrical shearing forces due to close proximity to the oblong island wall upon entry of the HSCGC overwhelmed the piloting control of the vessel, and the vessel ran out of control, across the channel lanes and towards the north ship channel of the other gate.

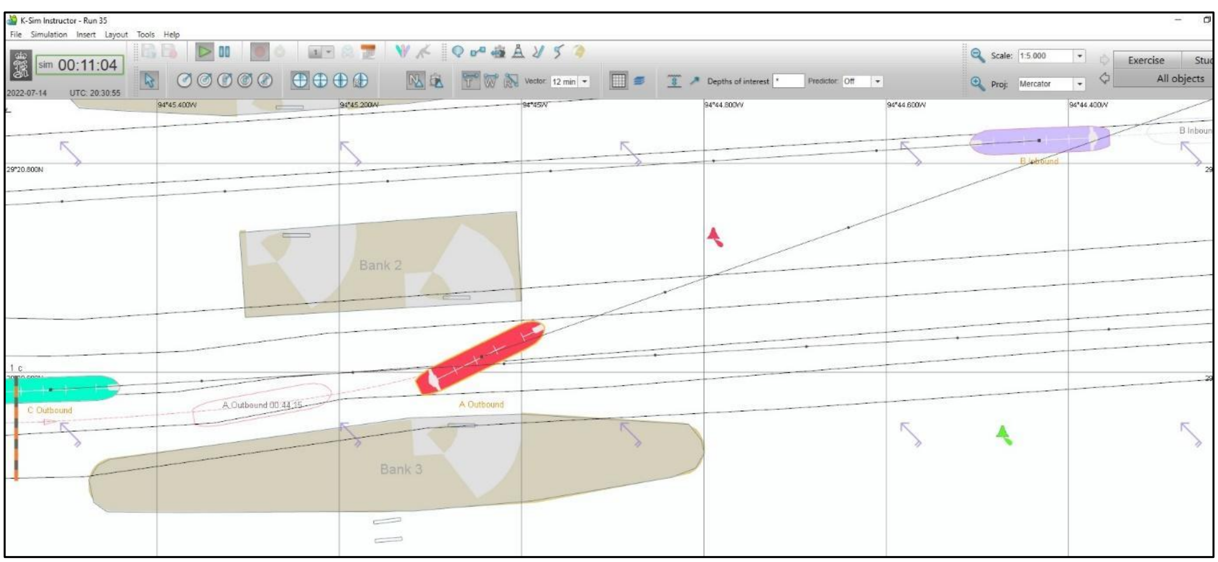

Figure 6. Outbound Vessel out of control due to shearing forces in the tested gate system

In summary, there are asymmetrical shearing forces acting on transiting commercial ships when entering and exiting the gate complex. These occur both when the transiting ship is on the center line and the shearing forces increase substantially if the transiting ship is misaligned due to the asymmetrical shapes of the islands. The outer islands are oblong, and the center island is a rectangle with substantially different lengths. The size and particularly the length of the islands in the gate complex need to be symmetrical to prevent shearing forces on transiting commercial ships.

Section 2. Commercial Ship Transit Scenarios with Both Gates Open and One-Way Commercial Ship Traffic

Commercial Ship Transit Scenarios with Both Gates Utilizing a Flood Current (2.5 knots)

Run#	GAR	Ship Models	Selected Pilot Comments
10	3	VLCC18	Outbound ship (started 2 miles to gate) failed to make the turn. Emergency ship handling as the ship was too heavy to control due to current and could not get lined up for the gates.
25	2	VLCC13	Outbound ship (started @ buoys 25/26) there is not enough distance between the turn and gate, so I cannot get aligned and end up entering at an angle.
26	1	VLCC13	Outbound ship (started @ buoy 18) purposefully did not go deep in the turn to try to better align with gate, still entered at a slight angle.
31	2	VLCC13	Outbound ship A (started @ buoys 25/26) to make the turn and align with gates had to use full-ahead and hard over. Tugboats assist should be used. Also, move the gates further east and widen them. Outbound ship C (started 1 mile in Galveston channel) would like to have a tugboat available. Gates should be moved east at least 0.5 miles. Need more room to steady up for the gates. Gates need to be widened.
32	2	VLCC13	Outbound ship A (started @ buoys 25/26) really affected by the current, no room for error once get within ½ mile of gate. We need a wider gate.

During the VLCC 13 model scenarios the pilots were able to successfully complete the transit with both gates open, but still 3 /4 scenarios were given a 2 Caution assessment. The pilots aboard the outbound ships commented that there is not enough distance between the turn at buoys 18 and 16 and get aligned with the opening of the gates. The pilots expressed that they want the gates moved further to the east to have a longer straighter channel to help them align with the gates. Also, multiple pilots commented that the gates should be widened.

An example of this issue occurred on run #25[12], displayed below in the series of figures. These show an outbound ship with a flood current (2.5 knots), in clear daylight conditions, with wind 135 degrees at 20 knots, starting at buoys 25/26 experienced a hazard of not being able to align

[12] The green track lines on the screenshot indicate target traffic that was unpiloted, including tugboats, dredges, and fishing vessels all common in the HSC. These add more realism to the scenario. The unpiloted vessel crossing the channel could have been a distraction, but it was not an obstacle, clearing the channel well before the ship began its turn at buoys 18 and 16.

with the entrance of the south gate. This in part was caused by the ship needing to get deep into the turn at buoys 18 and 16 when meeting an inbound ship. The outbound ship was using orders of full ahead and full rudder over, equivalent to emergency ship handling, to make the turn and try to get aligned with the gates, which they were unable to resulting them entering the gates at an angle. Thus, even with both gates open, such a maneuver requires “perfect” ship handling, leaving no room for error.

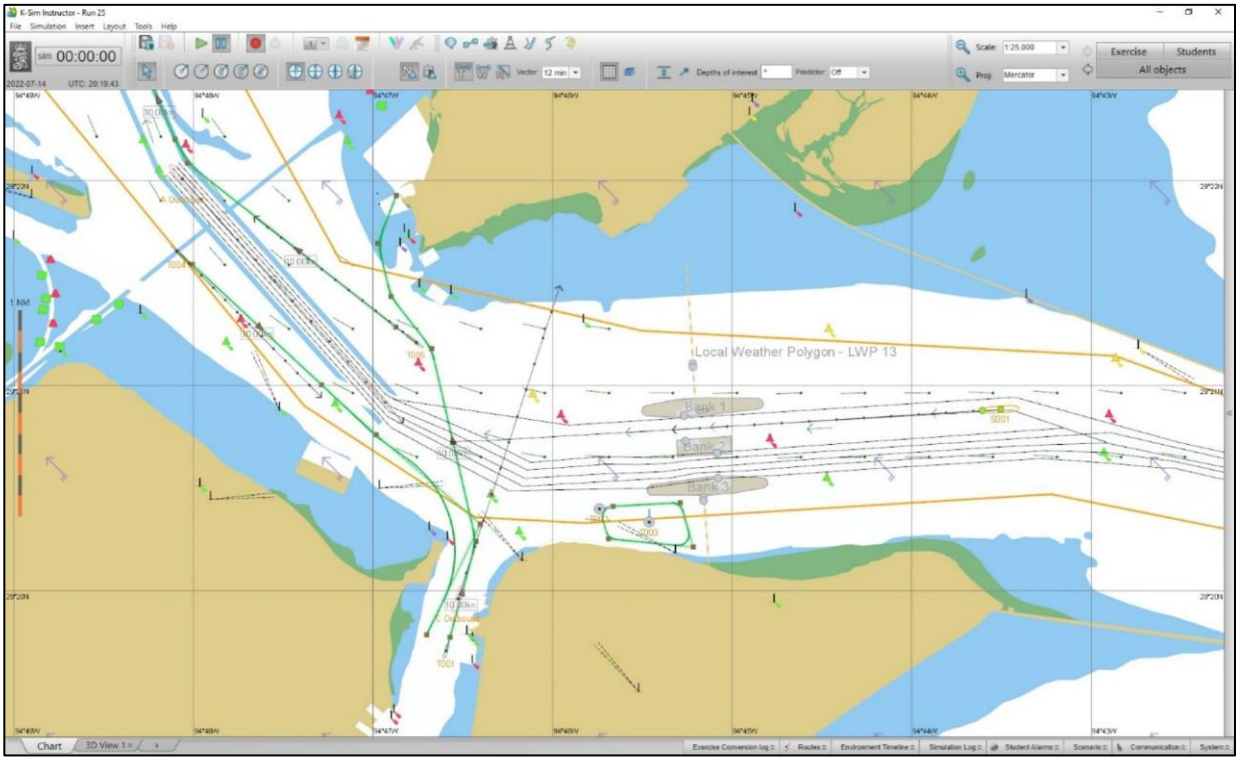

Figure 7. Run #25, Setup with outbound ship by buoys 25/26 on a flood current transiting through the outbound south gate

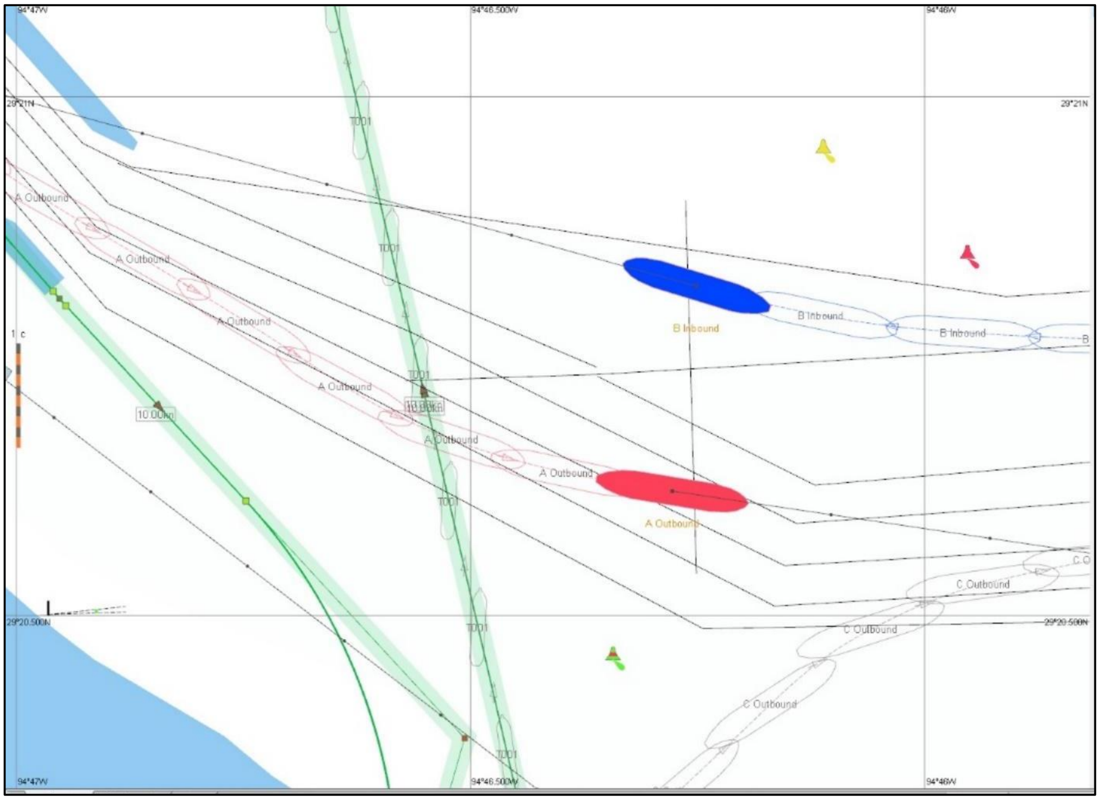

Figure 8. Run #25, Outbound ship has flood current, performing the turn at buoys 18 and 16, pilot using full ahead and full over to complete the turn

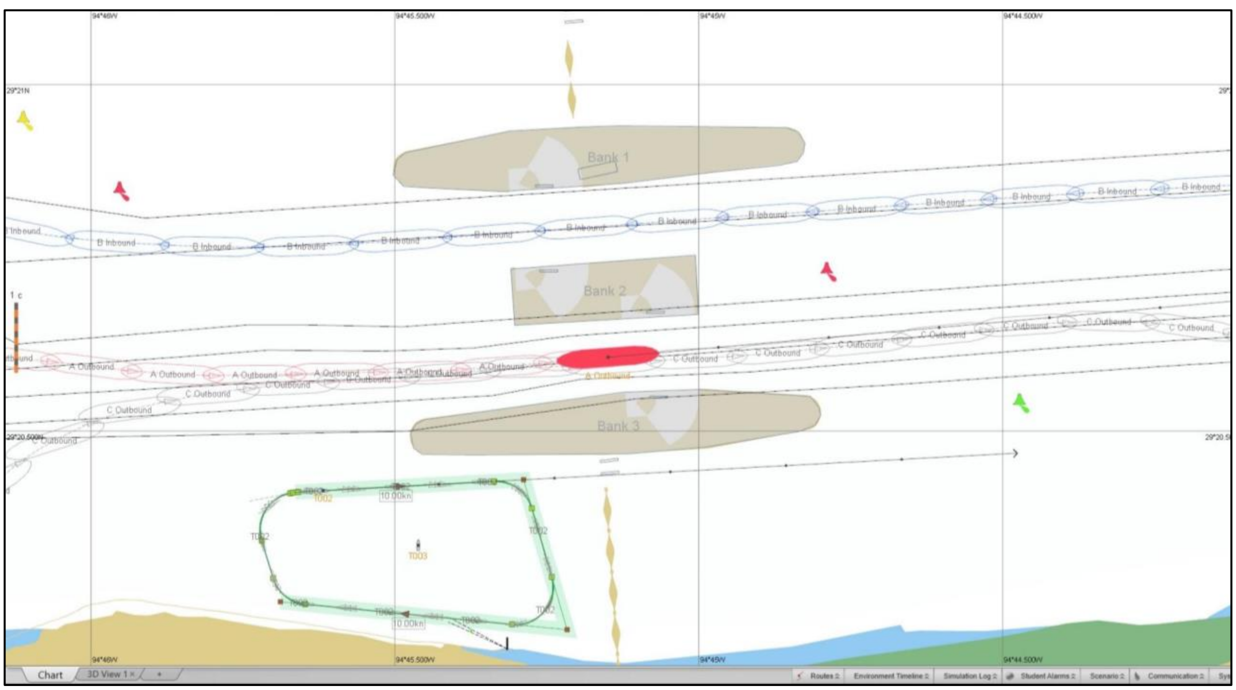

Figure 9. Run #25, Outbound ship has flood current, could not get aligned with gates after turn, entered gate system at an angle

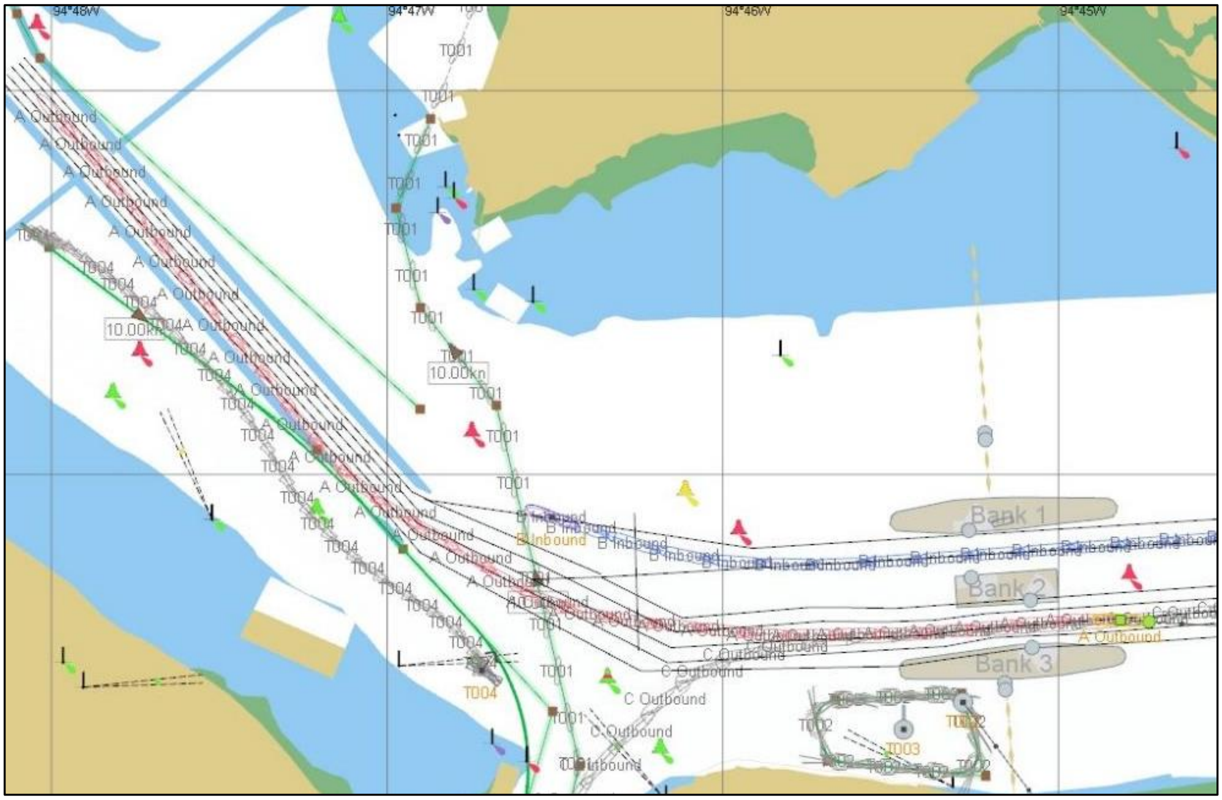

Figure 10. Run #25, Outbound ship has flood current, could not get aligned with gates after turn at buoys 18 and 16, entered gate system at an angle

This hazard of making the turn at buoys 18 and 16 and trying to get aligned with the gate is demonstrated by Run #10. During this run the VLCC18 model was used for all the ships. This ship is larger than the current ships coming into the HSC, but with the changes being made as part of Project 11, the plan is for this ship to come into HSC. VLCC18 is ~1,089' LOA X ~190' beam, with a loaded draft of 45' 11''. The conditions were the same as Run #25 of a flood current (2.5 knots), in clear daylight conditions, with wind 135 degrees at 20 knots, and the outbound ship starting at buoys 25/26. The result was the ship ran aground because it could not make the turn safely due to trying to coordinate meeting an incoming ship near buoys 18 and 16 while getting aligned with the outbound south gate entrance.

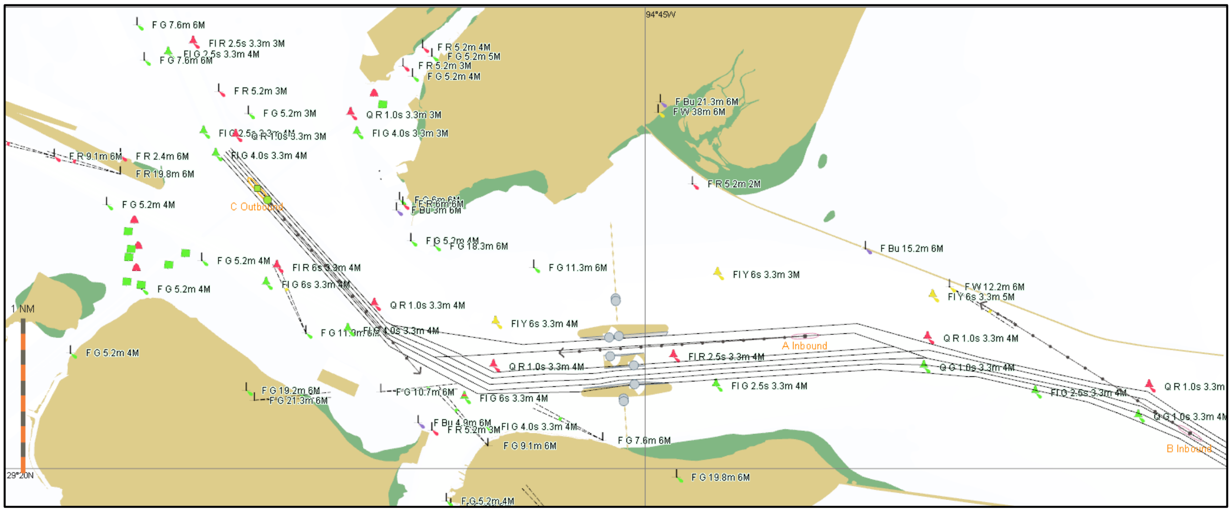

Figure 11. Run #10, Setup with outbound ship by buoys 25/26 on a flood current transiting through the outbound south gate

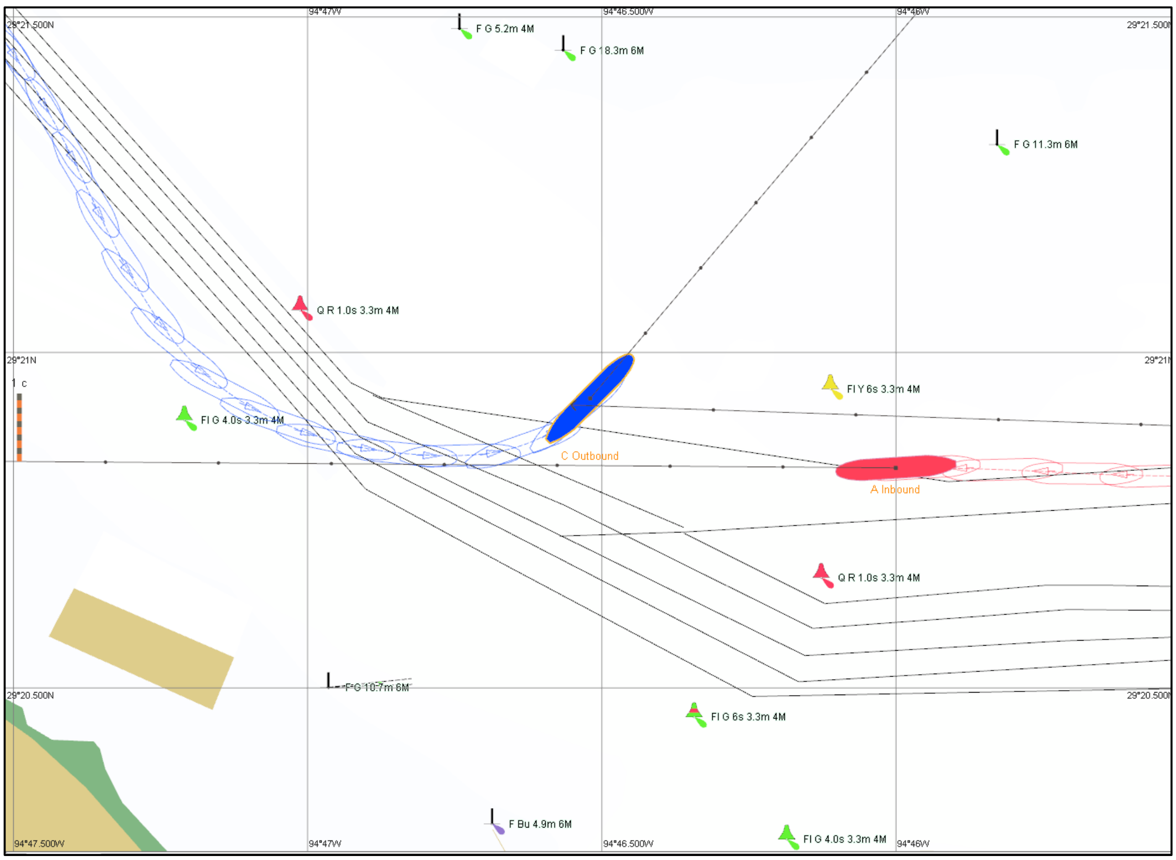

Figure 12. Run #10, Outbound ship running aground because it was unable to make the turn at buoy 18 while meeting an incoming ship and getting aligned with the south gate while on a flood current (2.5 knots). Resulting in the pilot choosing to intentionally ground the ship.

During Run #10, GAR Score 3 High Concern, according to the pilot on the outbound ship, they had to use emergency ship handling as the ship was too heavy to control due to current and could not get lined up for the gates.

A third example of the hazard of an outbound ship getting aligned with the south gate entrance on a flood current (2.5 knots) is from run #31. This scenario used the common test model of VLCC13 that is frequently seen by the Houston Pilots. The Galveston-Texas City pilots were in attendance during this session and took part as they piloted an outbound ship from the Galveston Channel that went through the south gate prior to the outbound ship from Houston.

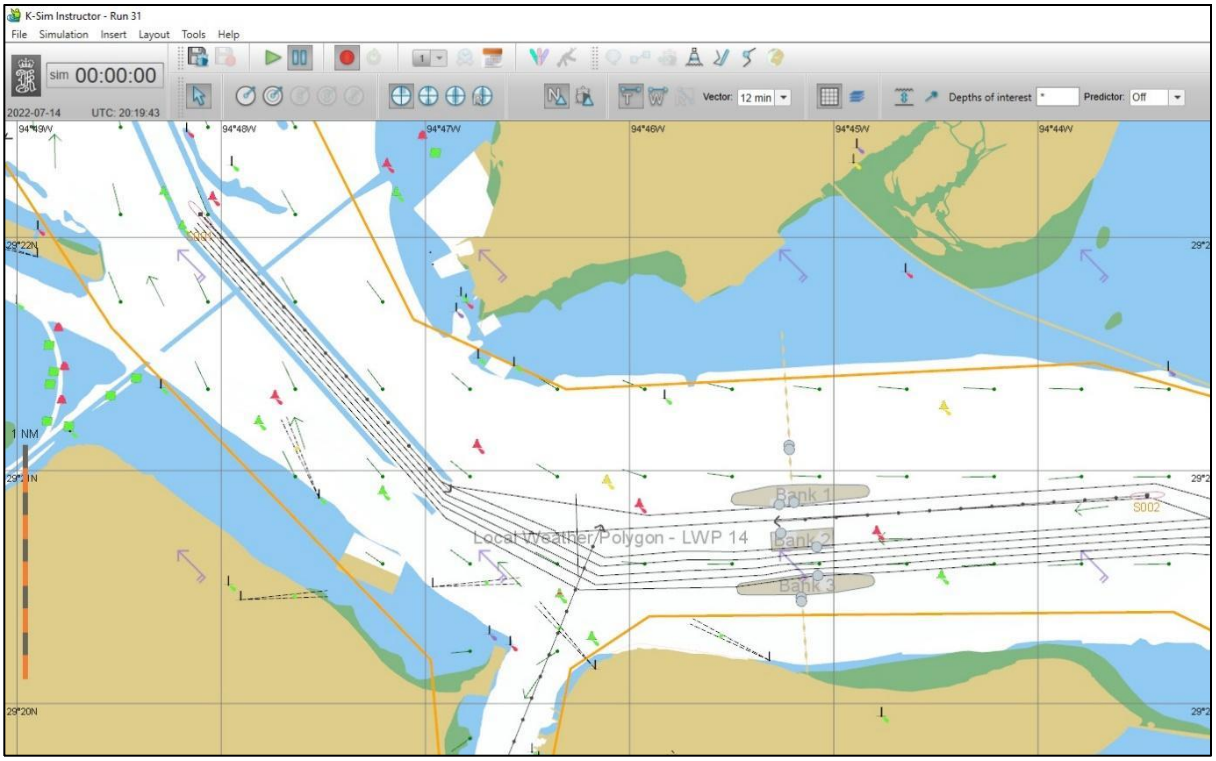

Figure 13. Run #31, Setup with outbound ship by buoys 25/26 on a flood current transiting through the outbound south gate

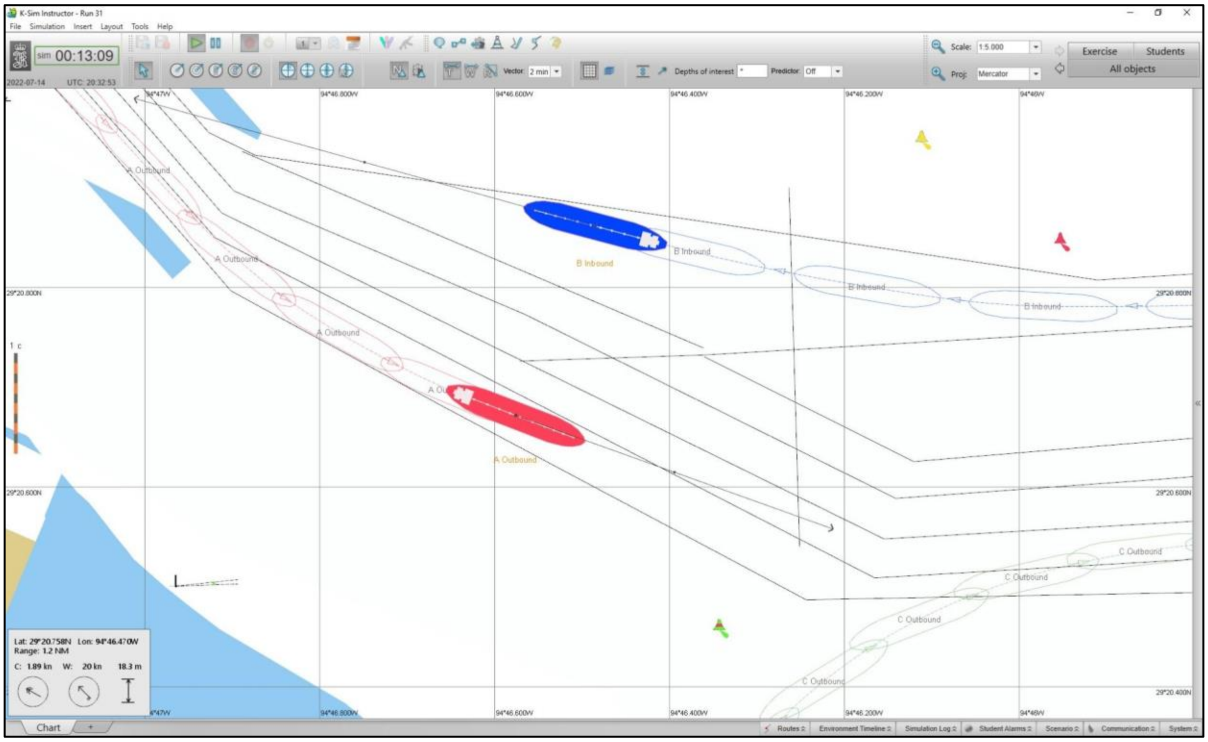

Figure 14. Run #31, outbound ship meeting inbound ship between buoys 18 and 16 making the turn deep in the HSC trying to recover to align with the south gate entrance

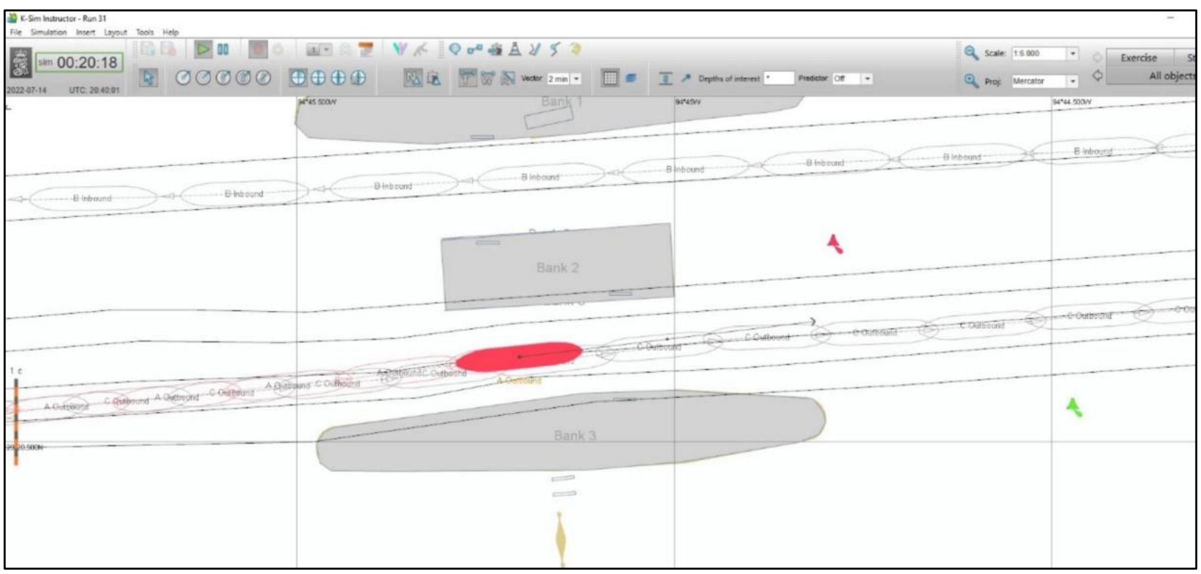

Figure 15. Run #31, outbound ship transiting through the south gate at a slight angle

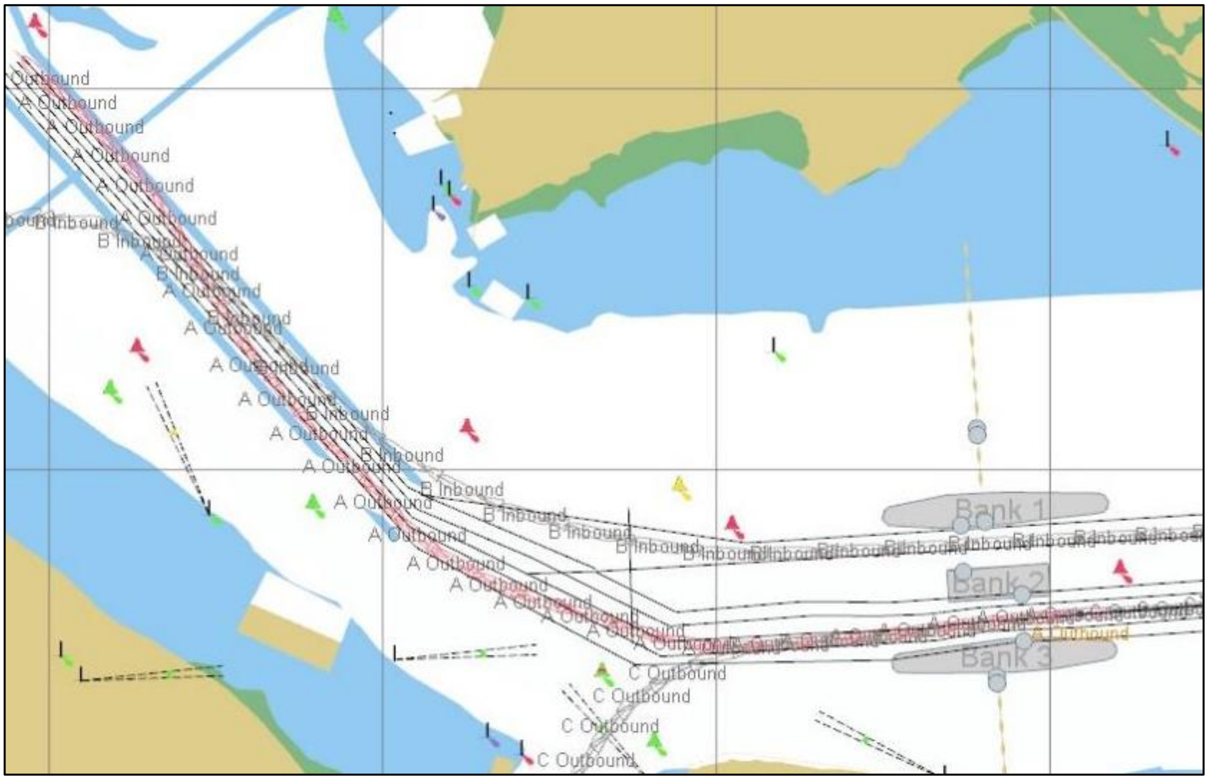

Figure 16. Run #31, outbound ship has flood current, could not get aligned with gates after turn at buoys 18 and 16, entered gate system at an angle

Runs #10, 25, and 31 are all examples of a similar hazard of an outbound ship in a flood current not being able to align with the entrance of the south gates. Overall, these scenarios demonstrate that given the design and siting of the HSCGC, there is a hazard for outbound vessels in a flood current.

In order to address this hazard, the pilots made multiple recommendations. These include lengthening the distance after the turn at buoys 18 and 16 to the entrance of the gate system by moving HSCGC to the east in Bolivar Roads; widening the gate system; and the use of transit assist tugboats. Additionally, run #10 demonstrates the issue of the HSCGC site lacking a "bail-out" zone for approaching vessels to abort passage into the gates. The gates can be seriously damaged by vessels in extremis that lack an intentional grounding area. Vessels being poorly aligned for safe passage of the gate system, can run out of control into the gate structure itself. So, rather than colliding with the inbound vessel or alliding with gates, the pilots in this situation will choose to intentionally ground their vessels.

Commercial Ship Transit Scenarios with Both Gates Open on an Ebb Current (2.5 knots, 1 knot)

Run#	GAR	Ship Models	Selected Pilot Comments
11	3	VLCC18	Inbound ship was full ahead and full over the entire way. It was difficult but was successful in getting straightened up for the gates. Outbound ship was unable to get onto center line until inside of the gates. The degree of turn is too great, it requires big bells, full ahead and full over. Tugboats are necessary with this size of ship. I would pick 4 on the GAR scale if possible.
13	2	VLCC13	Outbound ship (started 1.5 miles to gate) high concern with aligning up with gates, too short of distance after turn. NOTE: Ebb Current at 1 knot
14	2	VLCC13	Inbound ship requires "perfect" piloting. NOTE: Ebb Current at 1 knot
15	2	VLCC13	Inbound ship after passing through the gates the current is strong. Outbound ship set hard to starboard side due to bank suction.
33	2	VLCC13	Inbound ship should make the gate wider. I had to show more caution than normal maneuver. Outbound ship from HSC, definitely had to be cautious.
35	3	VLCC14	The two outbound ships (A at buoy 18 and C 1 mile from Galveston opening) nearly met before the gates. Ship A (outbound) had strong bank effect and lost control of the engines. Almost hit the gate. This was a very unsafe maneuver. It ended with a meeting between ships A & B at one ship length outside of the north gate. The skin-to-skin distance between ships was 150'. Ship C (outbound from Galveston) there is not enough distance between Galveston channel and the gate. We need more time and distance to line up safely. One way to compensate is to make the gate wider.
42	2	VLCC14	Inbound ship we are working without a safety net. We have to be sure to line up perfectly for the gate entrance. The gate should be widened.

In these scenarios both gates are open, and the current is ebbing at 1 knot or 2.5 knots. The results of all four scenarios using the VLCC13 were GAR scores of 2 Caution. The substantially smaller VLCC14 resulted in GAR scores of 2 Caution during run #42 and 3 High Concern during run #35. Finally, using the largest test vessel VLCC18 also resulted in a GAR score of 3 High Concern during run #11.

During scenarios #13 and 14, the purpose of these runs was to familiarize the pilots with the simulator and HSCGC. Both gates were open and a one knot ebb current and no wind were utilized. The pilots involved in these scenarios gave them a GAR score of 2 Caution. They commented that this will require “perfect” piloting. Also, they stated that the distance between the turn at buoy 18 and 16 and the gates is not enough to get aligned with the gates. This issue becomes more pronounced when the current is increased, and wind is added.

During run #33 had a scenario of three ships, one outbound from HSC transiting through the south gate, one outbound from Galveston Channel also transiting through the south gate, and a third inbound ship transiting through the north gate headed to Galveston. This scenario utilized an ebb current (2.5 knots) and a wind from the northwest (335 degrees at 30 knots). The visibility was clear daylight.

The result of this scenario is a GAR score of 2 Caution. Both outbound ships from HSC and Galveston entered the south gate at an angle and traveled across the center line in the gate. This was most pronounced for the ship outbound from HSC that transited from below the center line after performing the turn at buoy 16 to transiting above the south gate centerline extension. The inbound ship transited above the center line in the gate in order to limit the angle and thus make a safer and easier turn into Galveston Channel. Transiting off the center line in the gates and especially at an angle is a potential hazard as shown above in Figures 4 and 5. This is because the walls in the gate system cause shearing forces, and if the ship is unaligned, it can cause the ship to lose control as shown in Figure 5.

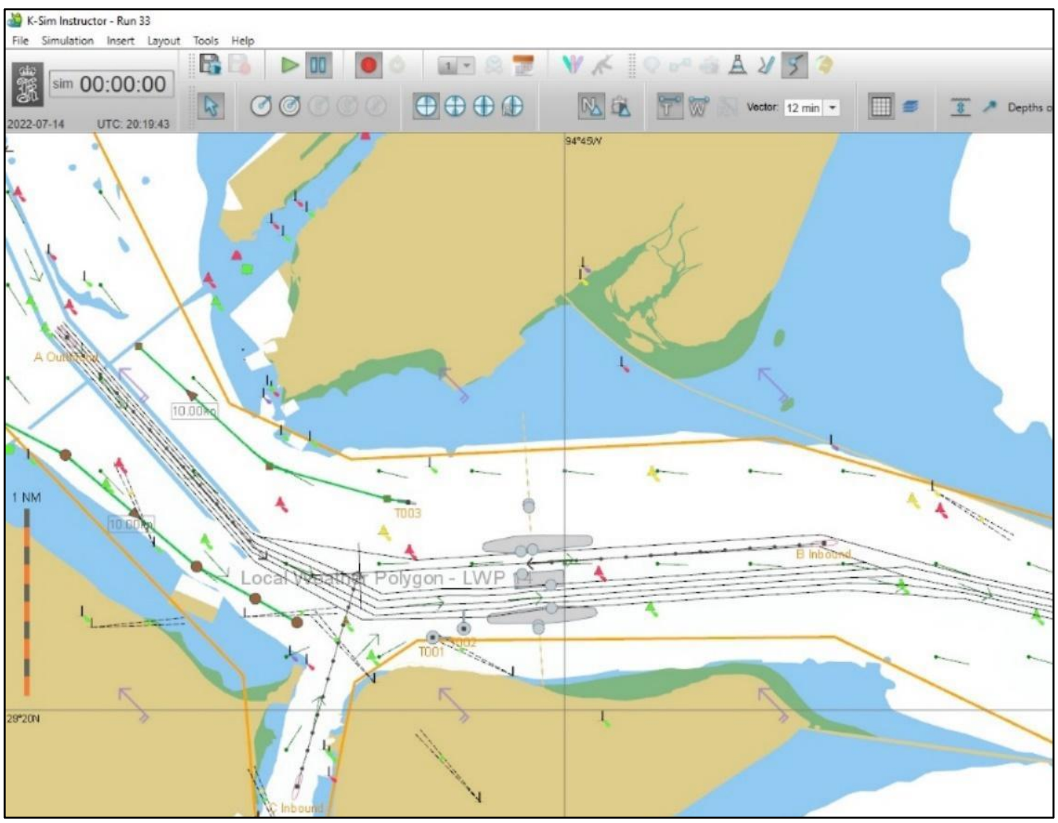

Figure 17. Run #33, Setup two outbound ships transiting south gate, inbound ship transiting north gate to Galveston, Ebb current (2.5) knots, wind at 335 degrees at 30 knots, daylight

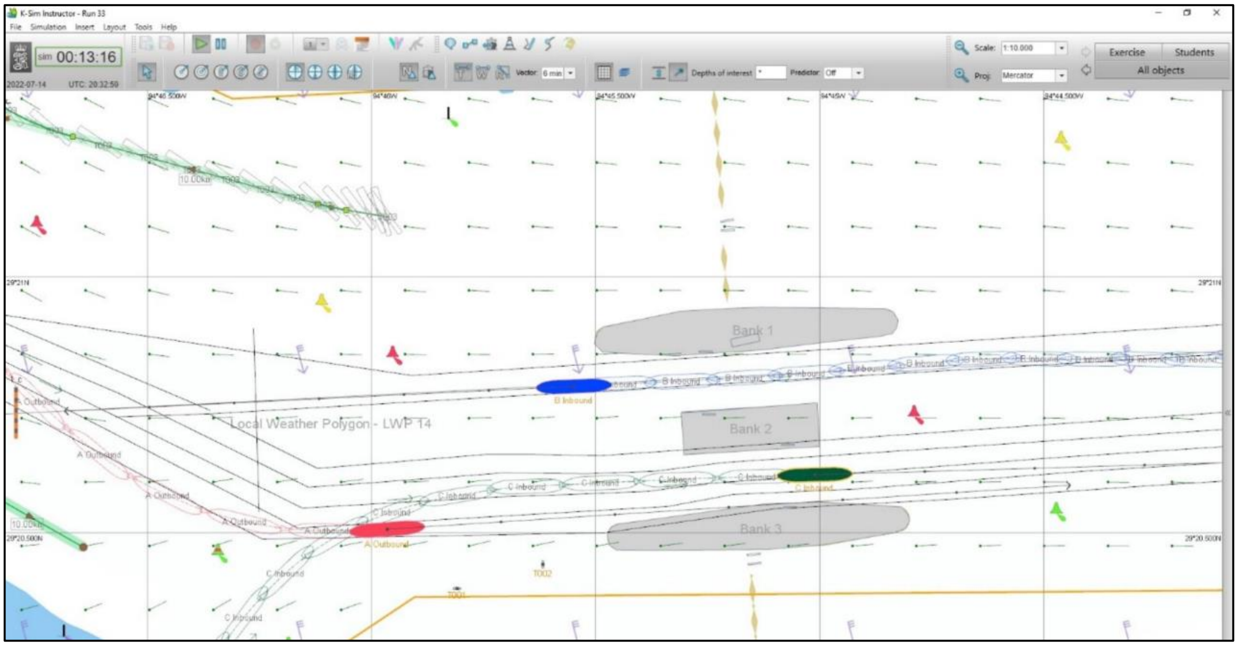

Figure 18. Run #33, Inbound ship with ebb current transited north gate above center line, Outbound ship from HSC transiting below center line about to enter south gates at angle

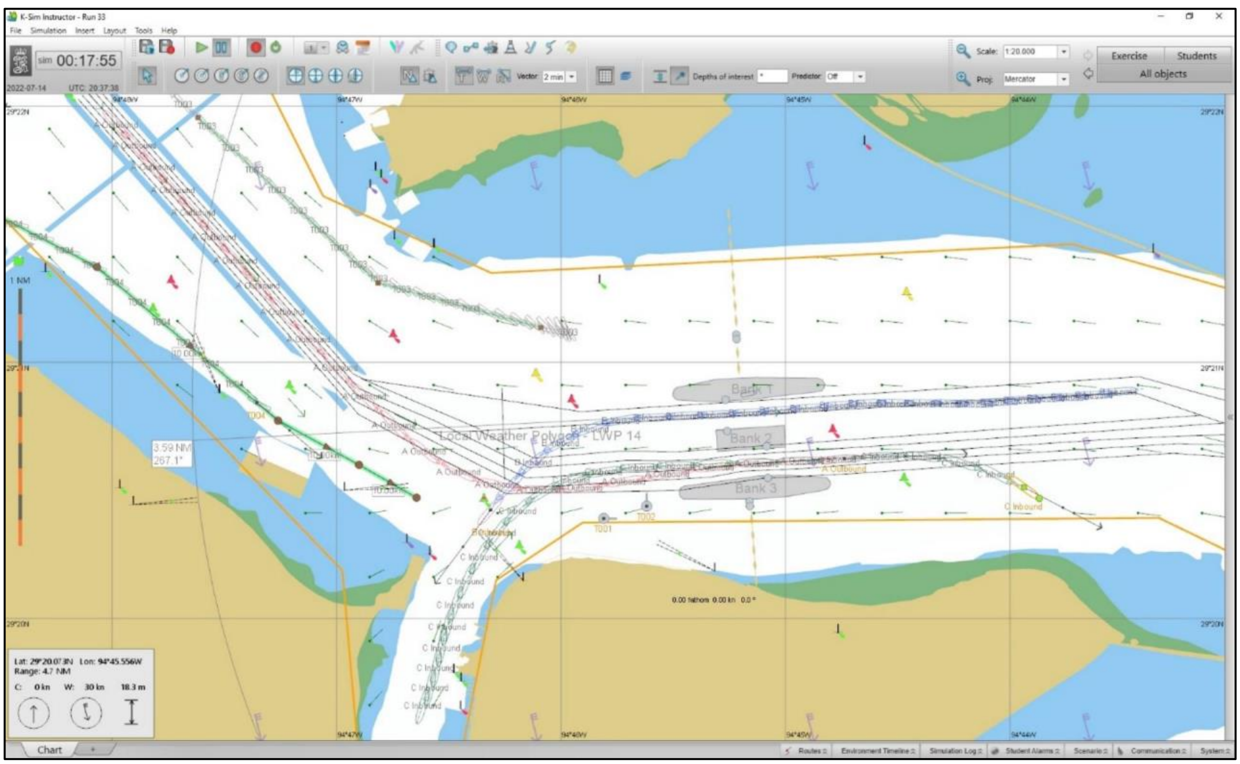

Figure 19. Run #33, Inbound ship with ebb current transited north gate above center line, outbound ship from HSC entered south gate at an angle transiting from below to above center line in the gate system

During run #35 there were multiple near collisions between ships and an allision between an outbound ship and the gate system. The scenario was an outbound ship starting above buoy 18 in the HSC, an outbound from Galveston Channel starting about a mile from the HSC intersection. Both outbound ships are to transit through the south gate. The inbound ship is to transit through the north gate. The VLCC14 model is used for all ships. There is an ebb current (2.5 knots) and wind is 135 degrees at 20 knots during daylight.

The result of this scenario is a GAR score of 3 High Concern. Both outbound ships from HSC and Galveston almost had a collision on approach to the south gate. Emergency ship handling was required. This caused the outbound HSC ship to enter the south gate system misaligned and at an acute angle. The piloted ship, experiencing shearing forces from the bank and attempting to not have an allision with the gate, had a near allision with the center island of the gate system. Again, emergency ship handling was required. The pilot aboard the ship outbound from HSC describe the maneuver as very unsafe and described losing control of the ship due to bank effect. Fortunately, they were able to regain control before colliding with the inbound ship transiting into the north gate.

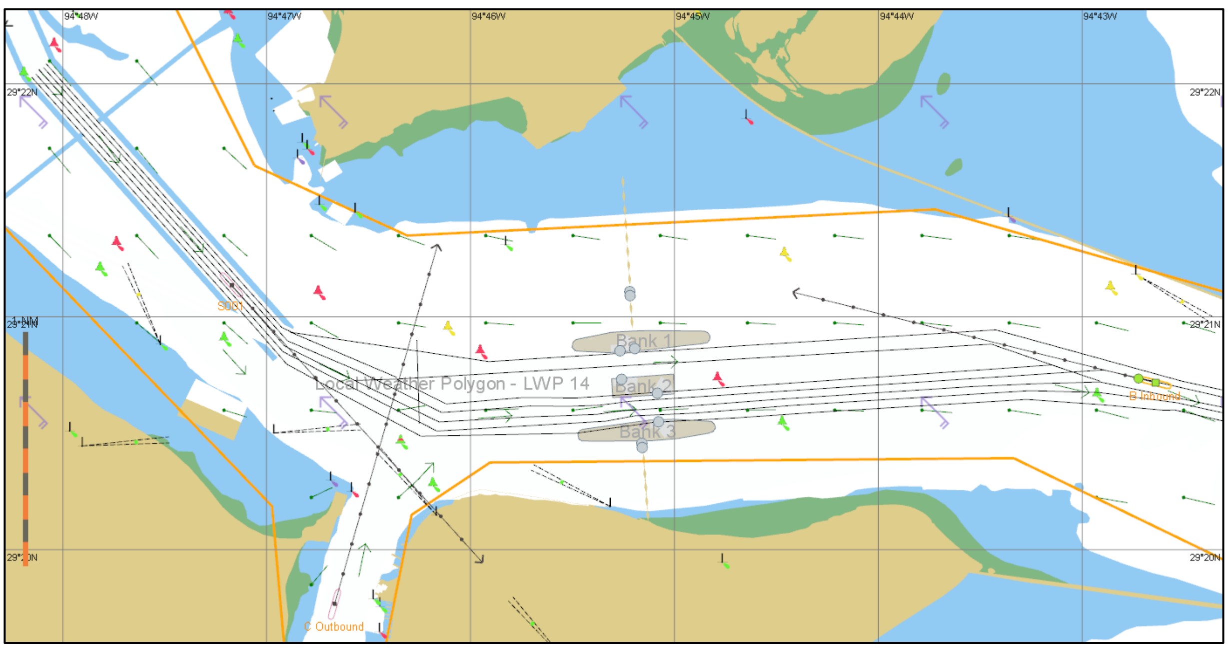

Figure 20. Run #35, Setup of two outbound ships from HSC and Galveston Channel transiting through south gate, one inbound ship transiting north gate, Ebb current (2.5) knots, wind at 135 degrees at 20 knots, daylight

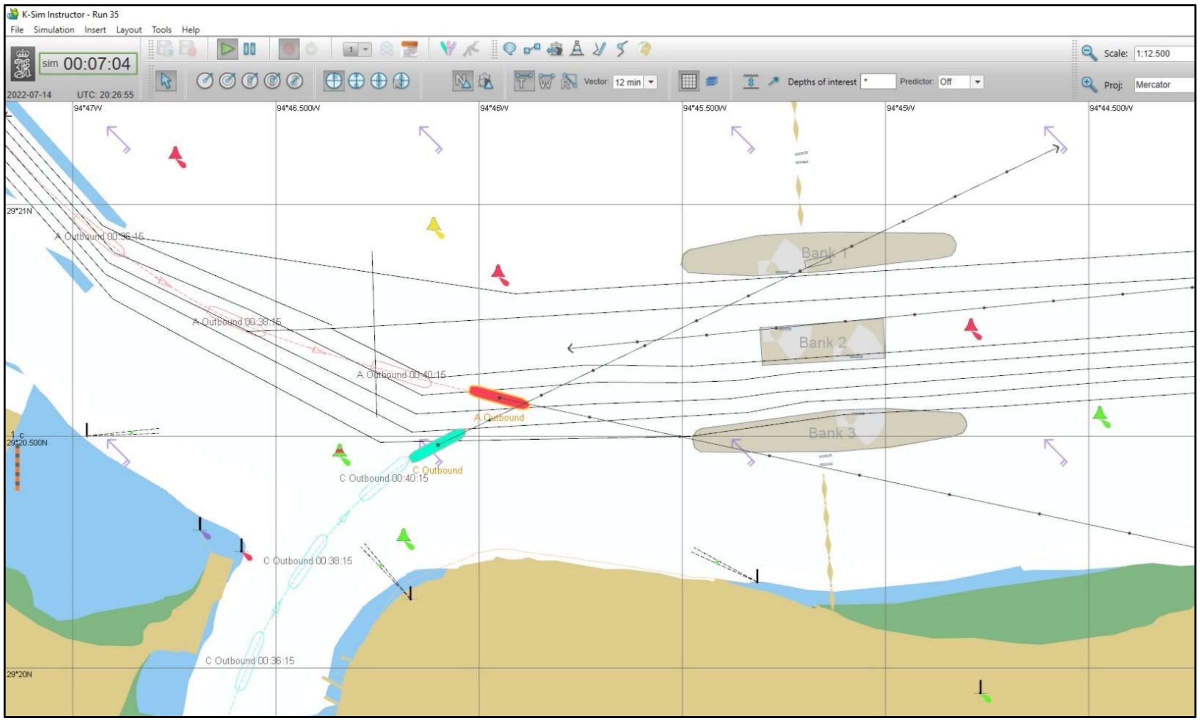

Figure 21. Run #35, outbound ship from HSC transits in front of outbound ship from Galveston Channel with a near missed collision

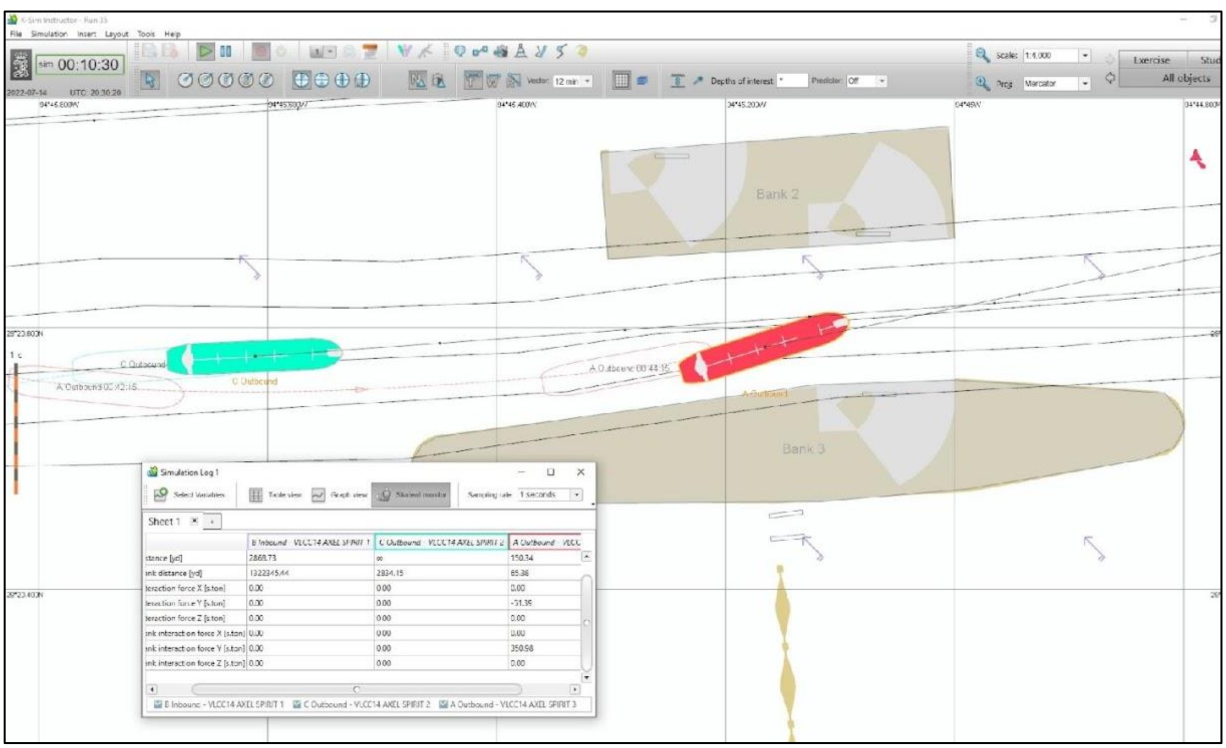

Figure 22. Run #35, outbound ship from HSC transiting in south gate at an angle and feels shearing forces from the bank effect

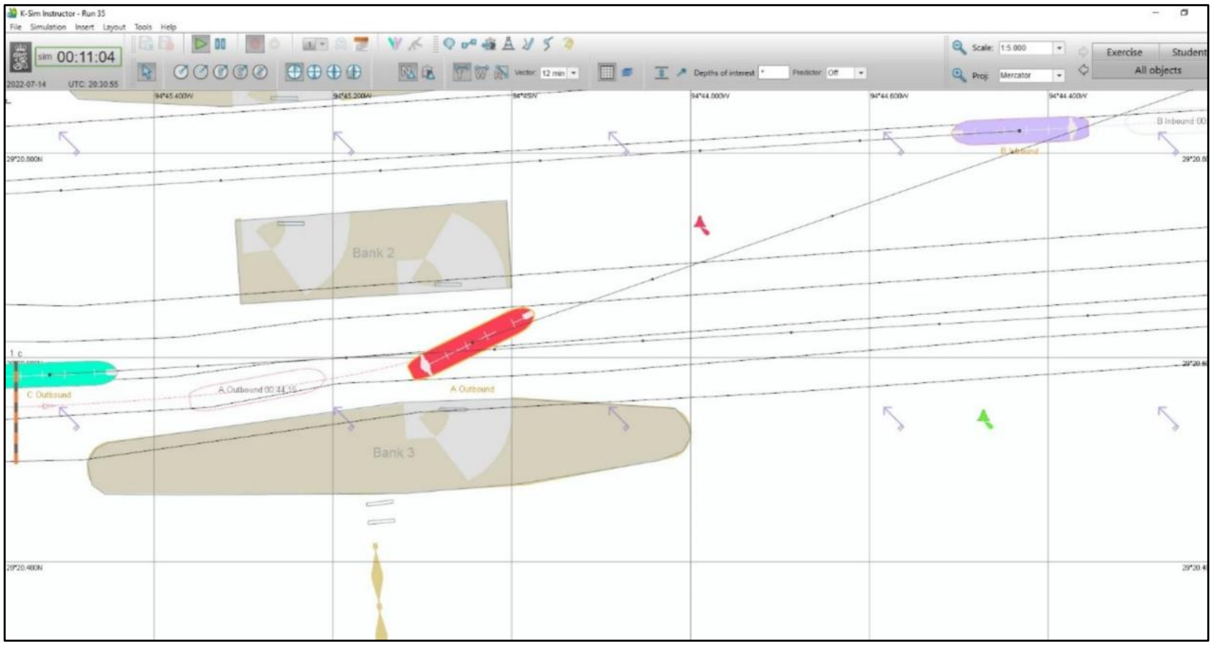

Figure 23. Run #35, outbound ship from HSC nearly allides with center island of gate system due to losing engines from shearing bank effect

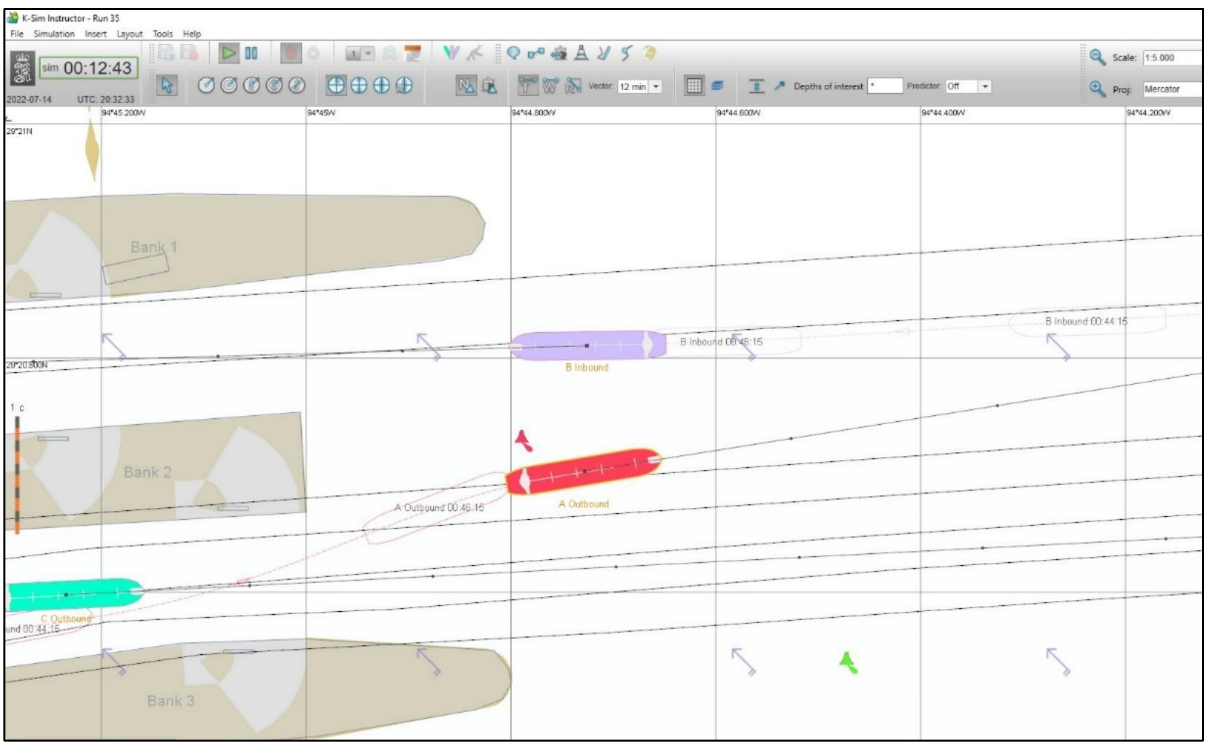

Figure 24. Run #35, outbound ship from HSC nearly collides with inbound ship on center line through north gate crosses above traffic line for gate system

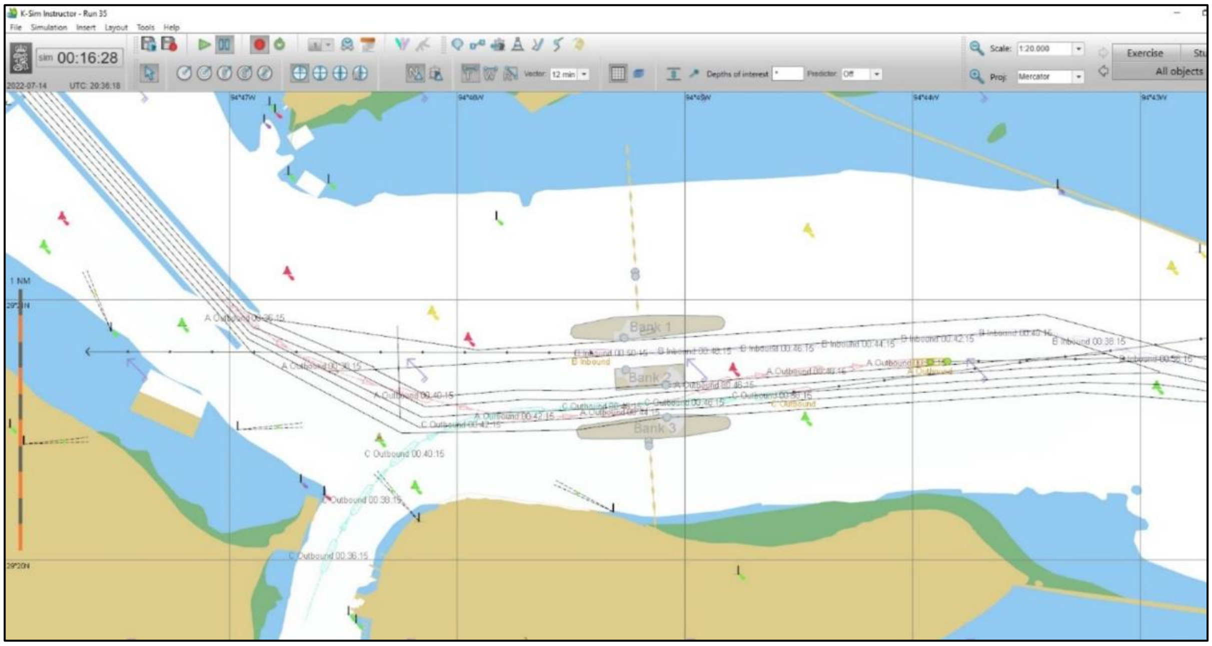

Figure 25. Run #35, completed run shows the near collisions between outbound HSC ship and other ships, as well as near allisions between the outbound HSC ship and the gate system

Run #42 was another scenario with both gates open using an ebb current (2.5 knots). This scenario also used VLCC14, the wind is 135 degrees at 20 knots, and it was during daylight. There were two inbound ships and one outbound ship used in this scenario. The inbound ship experienced shearing forces from the bank even though it was on the center line as it passed through the north gate. The outbound ship was misaligned when passing through the south gate, and experienced strong shearing forces from the bank. The result of this scenario is a GAR score of 2 Caution.

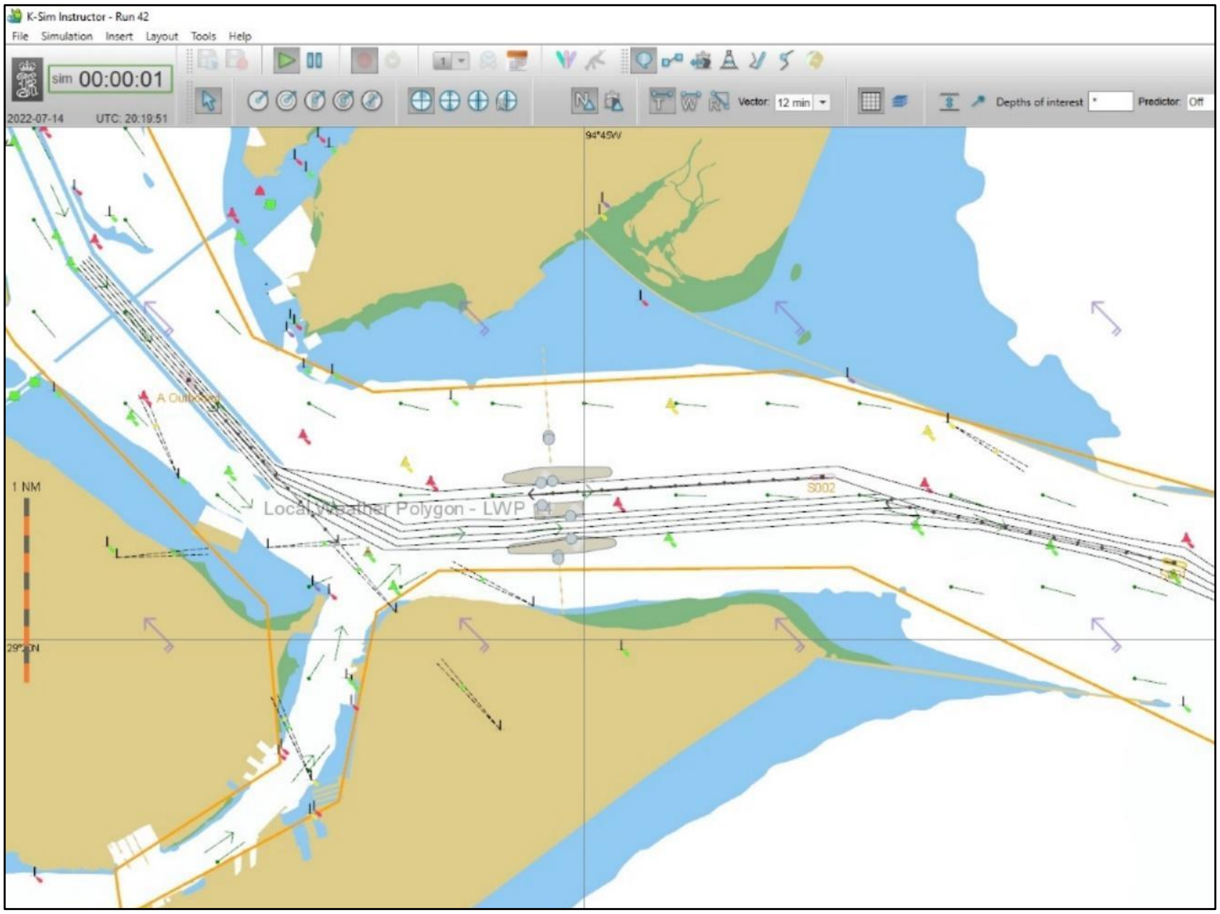

Figure 26. Run #42, setup outbound ship in HSC transiting to south gate, two inbound ships transiting to north gate, ebb current (2.5 knots), wind 135 degrees at 20 knots, daylight

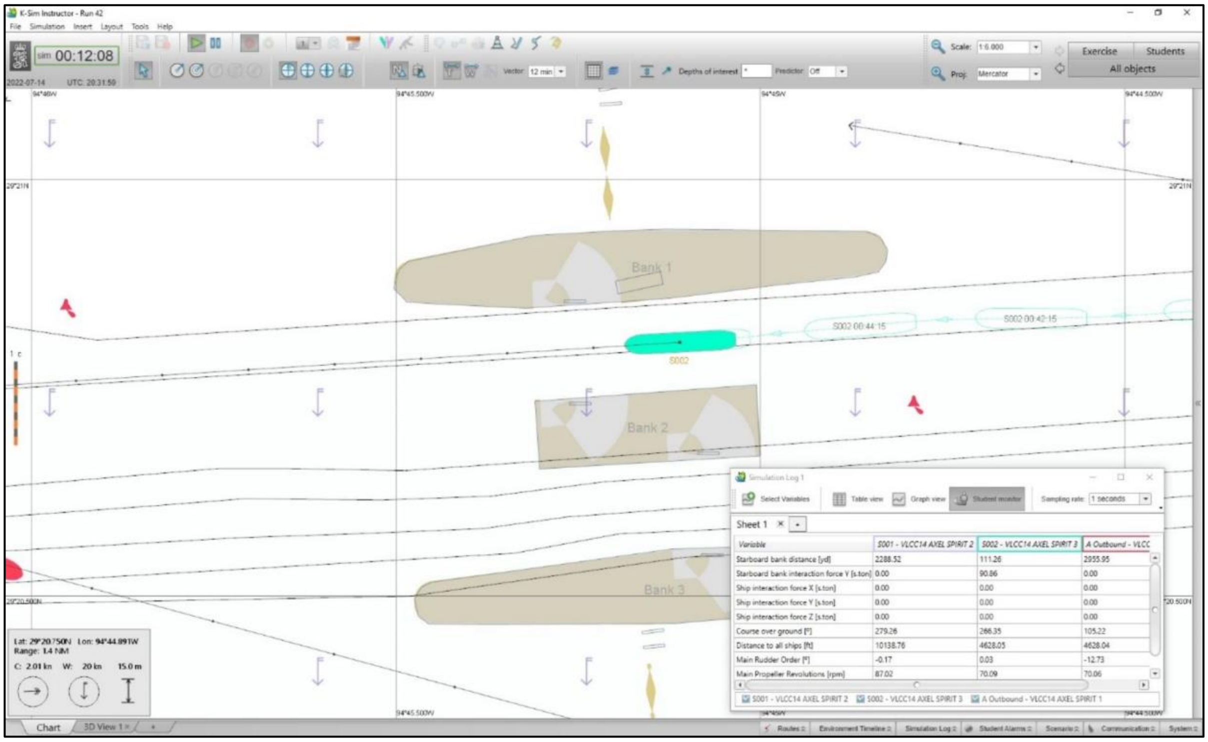

Figure 27. Inbound ship experiencing shearing forces from the banks even on center line

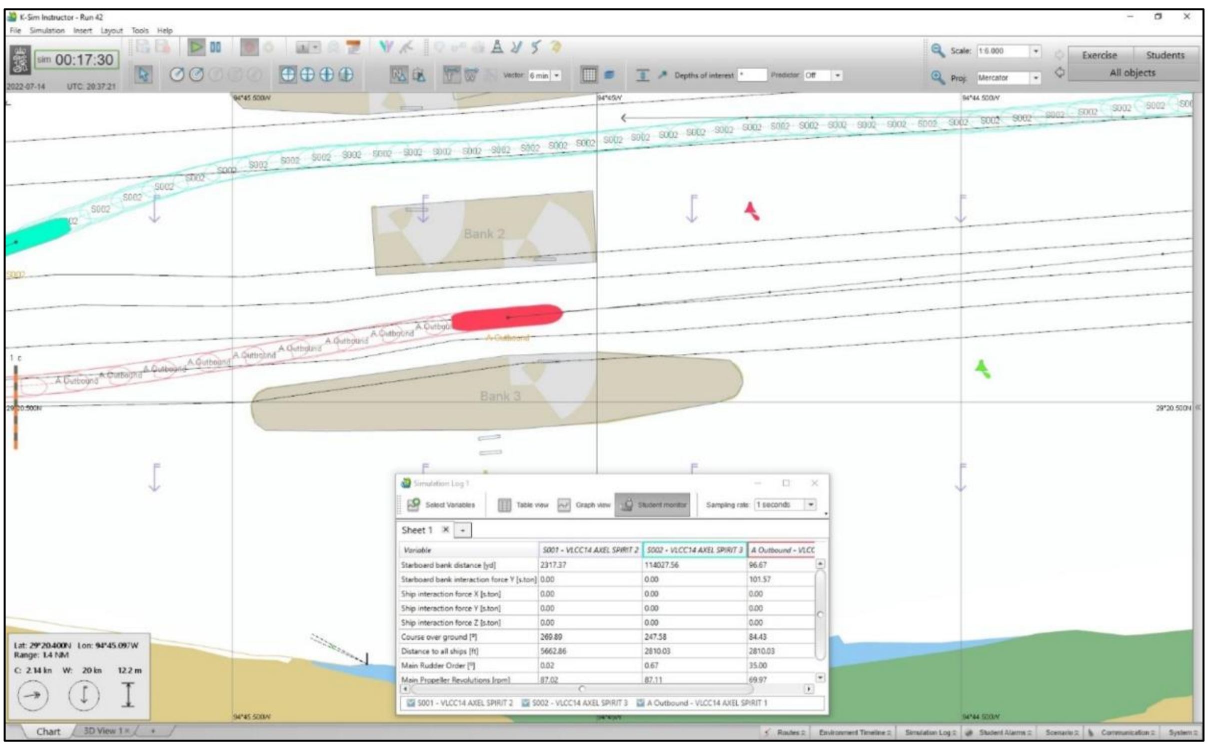

Figure 28. Outbound ship experiencing shearing forces as entered south gates at an angle

The result of these maneuvers led to multiple recommendations from the pilots. They stated that the gates need to be widened. This is to prevent the shearing forces on the ships when transiting in the gates, which are especially a hazard when the ship is misaligned inside of the gates. Also, the center island should be the same shape as the outer islands. The recommendation is that all three islands of the gate system should be symmetrical. Symmetrical design of the gate islands should create equal shearing forces on the ship, rather than what is currently being experienced with a rectangle middle island and two rounded oblong outer islands.

In summary, even with both gates open and utilizing one-way traffic through the gates complex, the HSCGC are sited too close to the HSC turn at buoys 18 and 16. Because the distance is too short for commercial ships transiting, particularly outbound on a flood current, the HSCGC is a hazard. Additionally, as the HSCGC islands are not symmetrical there are shearing forces on the transiting ships. These shearing forces exist even if the ship is in the center of the gate complex and can be a hazard. If the transiting ship is misaligned upon entering the gate complex, which can happen for various reasons including routine meetings with other ships up to a mile away from the HSCGC, then the shearing forces can be substantial and can cause the pilot to lose steering control over the ship. Thus, the asymmetrical islands are a hazard.

Section 3. Commercial Ship Transit Scenarios with One Gate Open and Two-Way Commercial Ship Traffic

Scenarios with North Gate Only Open on a Flood Current (2.5 knots)

Run#	GAR	Ship Models	Selected Pilot Comments
1	2	A CNTR33; B VLCC14	Outbound ship emergency ship handling the entire transit. Off of center line due to flood current. Difficult to get aligned with north gate entrance. Inbound ship stated that tugboat assist most likely required to safely complete the maneuver.
2	3	VLCC14	Outbound ship it was difficult to get aligned w/north gate. I was hard over the entire time, made a S curve course. I was too far to the right of buoy 16 and ended up almost hitting the south gate. I had to take extreme measures to miss alliding with the gate. Inbound ship stated that meeting near the gate system is not safe. We were trying to meet with a ship that was off course.
3	2	VLCC14	Outbound ship was heavily affected by the current. I struggled to get aligned with the gate's entrance. Second outbound ship. In order to compensate for the other ship traffic, I ended up over 600' outside of the channel.
4	3	VLCC14	Due to limited visibility from fog, all three ships reported could not see the gates until right on them. This meant the ships could not align with the entrance of the gates, rather, they could only get lined up once inside the gate complex. Collision! Second outbound ship and inbound ship collided near buoy 18. The inbound ship had completed its transit through the north gate and had met the first outbound ship. When the second outbound ship was aligning with the north gate it collided with the inbound ship. The pilots stated the collision was due to visibility issues and current. They reported it was difficult to make the turn at buoy 18 and on the outbound ship that had the collision, they stated that if they were transiting through the south gate, they would have had more time and space to maneuver.
5	3	VLCC13	The pilots on both outbound and inbound ships reported it was difficult to line up on the center line of the gate complex. This was because they had to transit through the north gate on a flood current. Outbound ship got too far to the starboard side of the channel and was aground on the Texas City side. I ran aground on that side in order to avoid buoy 18 and obstructing the meeting with the inbound ship. If I was not going through the north gate, I would

			not have grounded, "north gate directly led to grounding, no other hazards besides that". Inbound ship after going transiting through the north gate, I tried to line back up to meet the outbound ship at buoy 18. I didn't line up properly. This was caused by the north gate causing me to not have enough time to line up. Buoy 16 is too close to the gate complex.
9	3	VLCC13	Outbound ship and second inbound ship met in the north gate complex. The two ships almost collided in the gate complex. The second inbound ship almost had an allision with the wall. The outbound ship reported that they were not aligned entering the north gate. Rather, they entered the north gate complex at an angle and off centerline. The flood current made it more difficult to line up properly with the north gate complex.
12	3	VLCC13	Both the inbound and outbound ships reported that they could not see the gate complex until they were right on it due to limited visibility from night/fog conditions. Pilots on both ships reported that there was no room for error and utilized the full capabilities of the pilots. Overall, this type of maneuver is too high risk considering the visibility conditions and what could happen if we crashed. Inbound ship reported that they got too close to the walls in the north gate complex. The outbound ship was set off the center line course from the flood current. It was difficult for them to get aligned with the gates.
18	2	VLCC13	Outbound ship reported that the meeting went as planned and that they had enough time and space to meet outside of the HSCGC and to get aligned. The inbound ship reported that exiting the north gate had to increase to full ahead to make meeting at buoy 18. This transit scenario took place after buoy 18 was moved further north widening the channel for ship meetings.
19	3	VLCC13	This scenario was conducted in limited visibility due to night and fog conditions. The outbound ship reported that the center line in the HSCGC should be lit. They had a hard time getting aligned on the center line when transiting the gate. During fog conditions, tug escort could be required. The inbound ship reported that the limited visibility was of high concern for this scenario.

20	2	ULCV400	Outbound ship had difficulty getting aligned with the center line of the gate complex. The meeting with the other ship was fine. Inbound ship reported that it was challenging to get aligned with the center line of the gate complex. That this is important because the ship, especially one of this size of beam, has to transit straight through the gate complex.
21	3	VLCC13	Outbound ship reported I should have been going faster to prevent meeting the second incoming ship in the gate complex. I turned too soon to meet the first inbound ship and had to adjust my speed and approach. In real life, I would have tried to have let the second inbound ship come through the gate complex before meeting them inside of the gate complex. On the second inbound ship that met inside the gate complex, it reported that without perfect piloting this would have ended up as a collision between the two ships in the gate complex. I had to slow down to compensate for the current.
22	2	VLCC13	Outbound ship reported that negotiating meeting conditions has to be done earlier than usual piloting. We need appropriate navigation aids. The second inbound ship had to utilize hard over and dead slow during the meeting with the outbound ship to prevent a collision. The gates need to be wider. The gates should be wider to help with ship meetings near the gate complex, also the channel should be made wider. I picked up more speed near the gate complex because I prefer to have more speed to transit the gate.
37	3	VLCC14	The outbound ship had a near allision with the north gate. It used emergency ship handling. But the bank suction on the stern nearly caused the allision. The second inbound ship reported there was no safety margin, it was piloting right on the edge. We need two 1,200' wide gates. We always have a bail out when piloting, but there is no emergency bail out around the gates. The meeting causes embarrassed navigation as it prevents us from aligning to transit the gate. The bank suction caused the vessel to leave the center line, so I had to use emergency ship handling. The first inbound ship reported that there are major concerns with the gate complex. We need a safety zone to prevent ships from meeting in and near the gate complex.

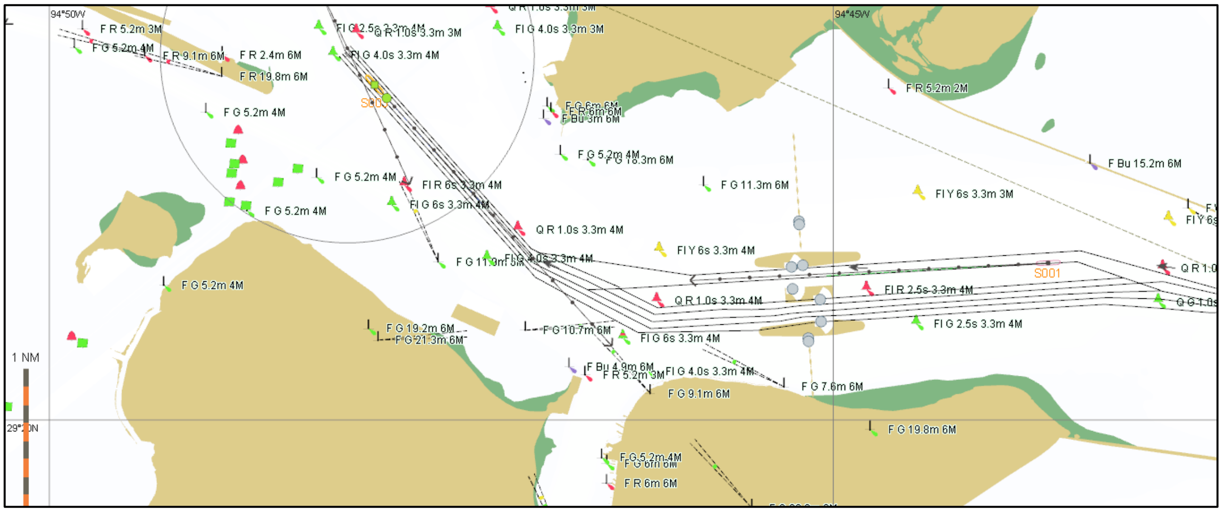

Figure 29. Run #4, Setup Two Outbound Ship and One Inbound, North Gate Only on a Flood Current (2.5 knots), Limited visibility with Fog conditions

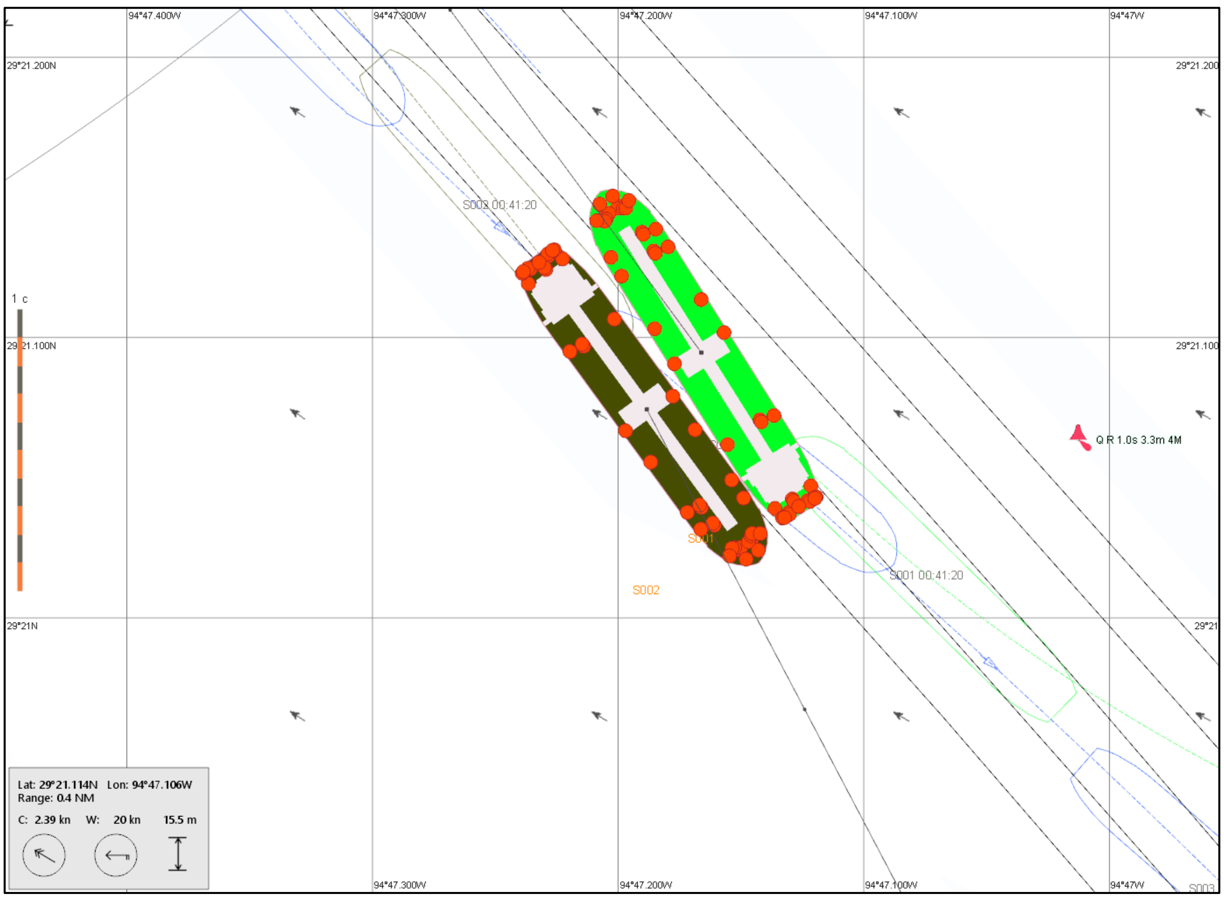

Figure 30. Run #4, Second Outbound Ship and Inbound collision near buoy 18

During Run #4, GAR score 3 High Concern, the outbound and inbound ships had a collision near buoy 18. This collision was between two Aframax-class tank vessel models, which was the smallest vessel tested. There was limited visibility due to fog conditions. The inbound ship had completed its transit through the north gate and had met the first outbound ship. When the second outbound ship was aligning with the north gate, it collided with the inbound ship. The pilots stated the collision was due to visibility issues combined with the flood current. They reported it was difficult to make the turn at buoy 18, and thus the outbound ship had the collision. They stated that if they were transiting through the south gate, they would have had more time and space to maneuver. Therefore, two-way commercial ship traffic should not utilize a single gate complex. Instead, a single gate-complex should only utilize one-way commercial ship traffic.

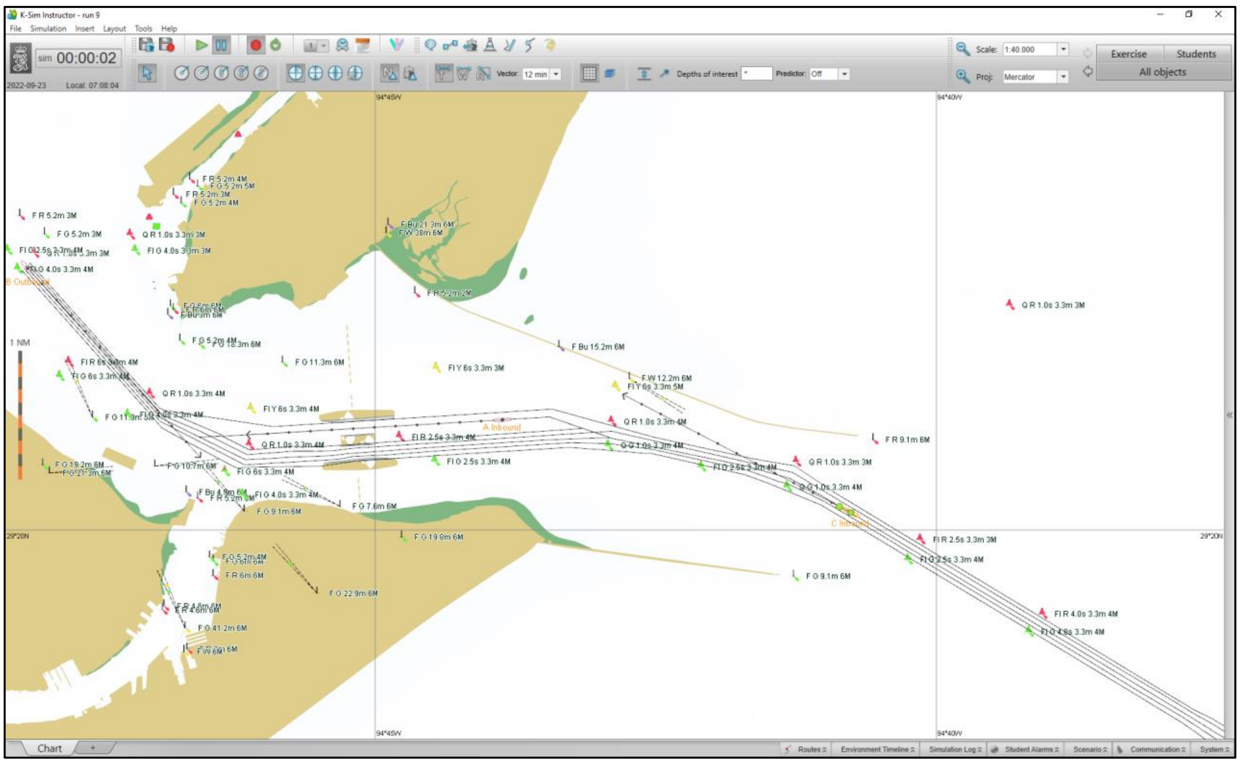

Figure 31. Run #9, Setup Two Inbound Ships and One Outbound ship, Flood Current (2.5 knots), clear daylight conditions

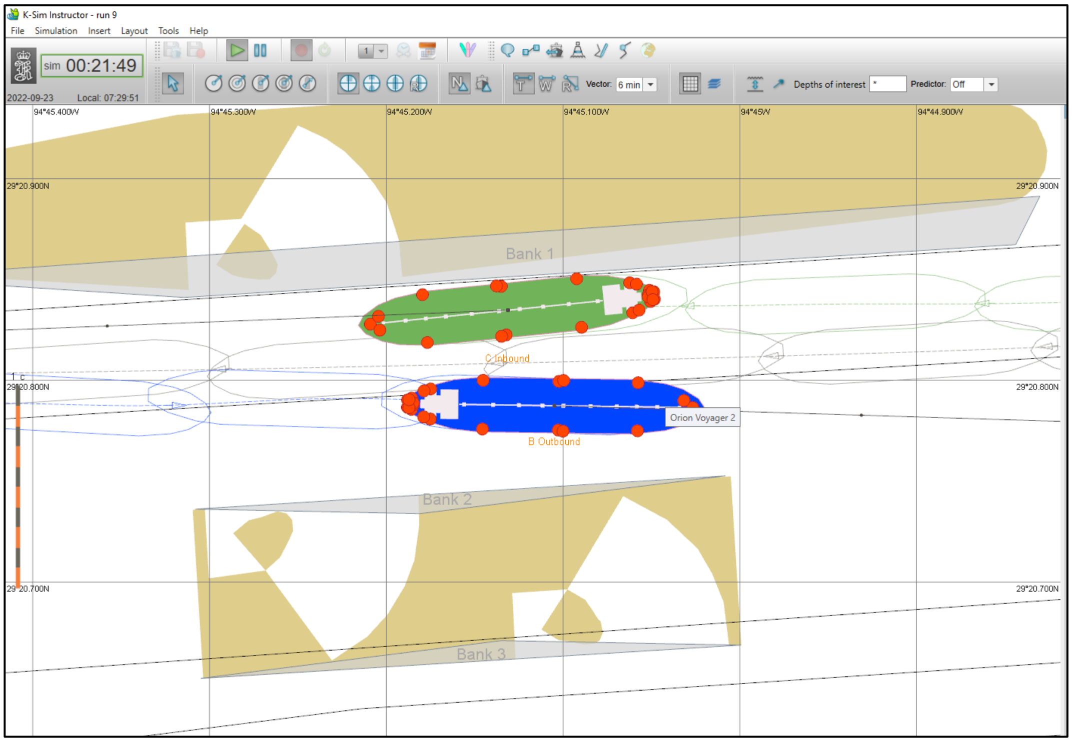

Figure 32. Run #9, Near Collision between Outbound ship and Second Inbound Ship in North Gate, Skin-to-Skin 70'

During Run #9, GAR score 3 High Concern, the outbound and second inbound ships had a near collision inside of the north gate. This was with the Suezmax class of tank vessel and in clear daylight conditions. The first inbound ship had completed its transit through the north gate and had met the outbound ship. When the outbound ship was aligning with the north gate on the center line it unexpectedly collided with the second inbound ship inside of the gates. The outbound ship reported that they were not aligned when entering the north gate. Rather, they entered the north gate complex at an angle and off centerline. The flood current made it more difficult to line up properly with the north gate complex. This event was unplanned. The starting position of the outbound ship was near buoys 25/26 and the starting position of the second inbound ship was near buoys 7/8. This is further evidence that two-way commercial ship traffic should not simultaneously use a single gate complex, but instead, utilize a one-way traffic scheme when sharing a single gate.

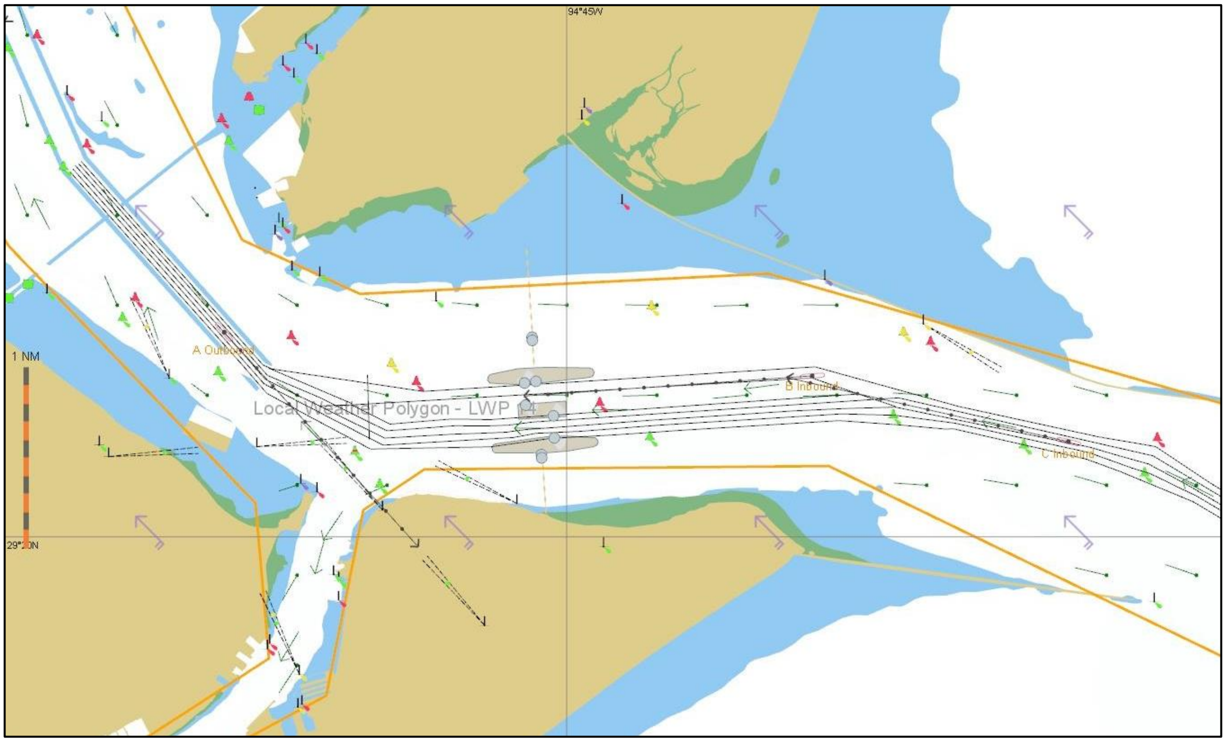

Figure 33. Run #37, Setup Two Ships Inbound and One Outbound North Gate Only, Flood Current (2.5 knots), clear daylight conditions

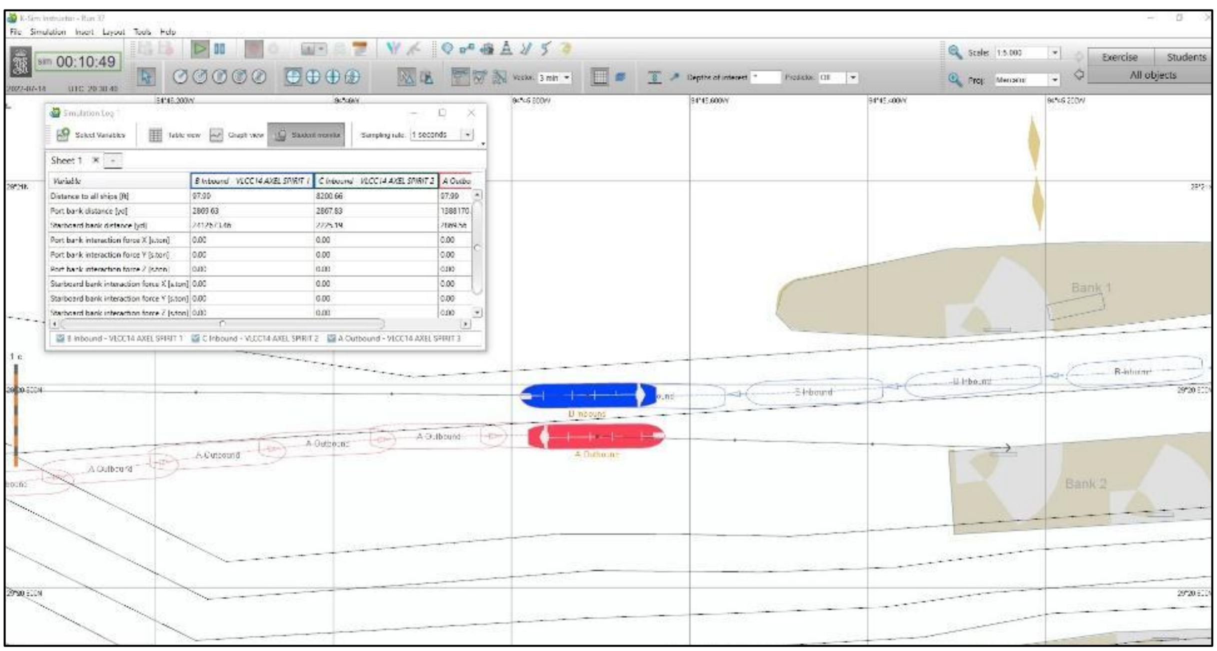

Figure 34. Run #37, Unsafe Meeting between Outbound and First Outbound Ships near the North Gate, Skin-to-Skin 95'

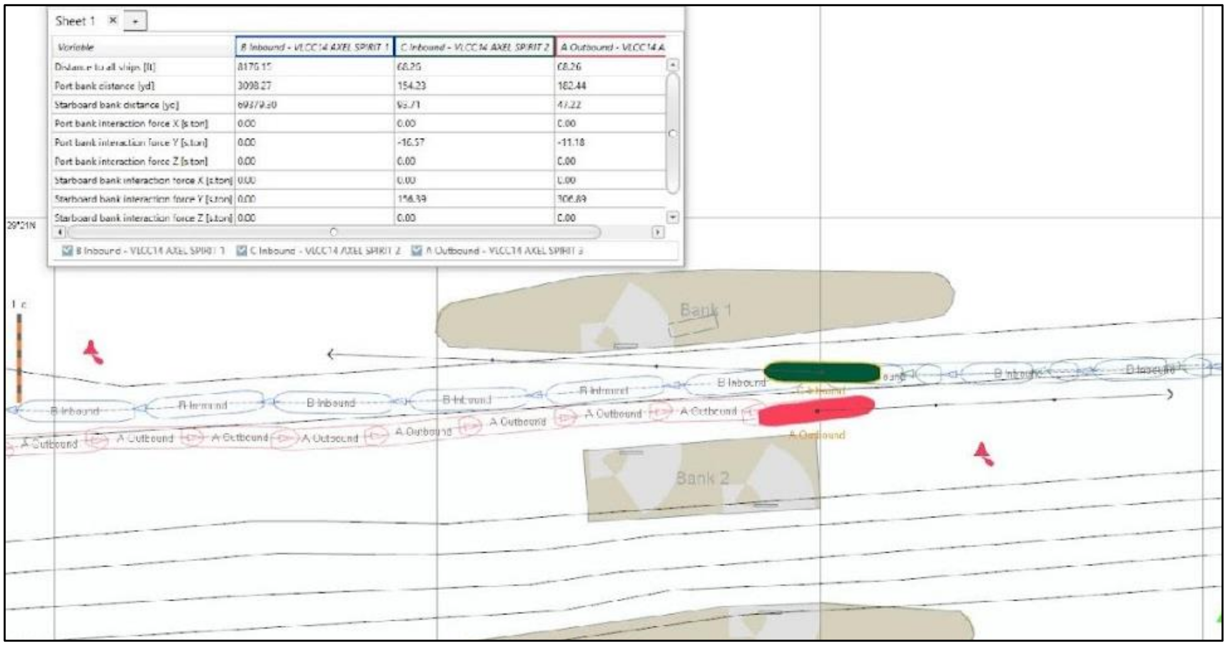

Figure 35. Run #37, Unsafe Meeting Inside of North Gate with Shearing Force Calculations Inbound Ship (Green) 156 tons, Outbound Ship (Red) 307, Skin-to-Skin 65'

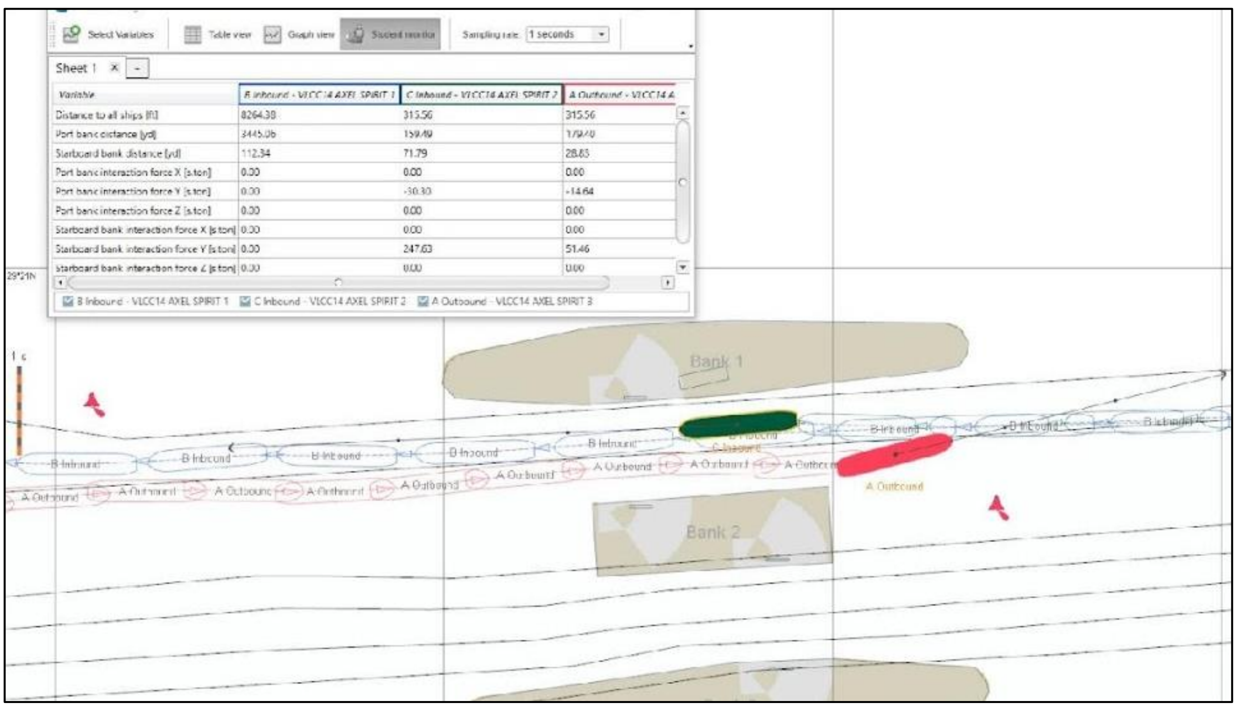

Figure 36. Run #37, Result of Unsafe Meeting in Gate with Shearing Force Calculations, Inbound Ship (Green) 248 tons, Outbound Ship (Red) 51 tons

During Run #37, GAR score 3 High Concern, the outbound and first inbound ship got too close on their meeting inside of the north gates as the skin-to-skin distance was 95’. The second inbound ship then had a near collision inside of the north gate with the outbound ship. This led to shearing forces on the ships that caused the outbound ship to momentarily lose steering control and be pushed towards the inbound ship. The ship model was a common Aframax-class tank vessel and in clear daylight conditions. This is further evidence that the islands of the gate complex need to be symmetrical to prevent shearing forces upon the ships. Also, that ships transiting need to utilize both gates. The pilots also commented that they should have bail out areas nearby the gate complex. In this extremis case, the pilots realized they were potentially going to collide in the gates. Instead, they prefer being able to bail out nearby the gate complex.

Overall, the results of the transit scenarios using only the north gate complex during a flood current clearly demonstrate that a single gate cannot be used for two-way commercial ship traffic. The results demonstrate that ship meetings in and near the gate complex are a hazard to commercial ships. This is in part due to the shearing forces on the ships caused by asymmetrical islands in the gate complex.

Scenarios with South Gate Only Open on an Ebb Current (2.5 knots)

Run#	GAR	Ship Models	Selected Pilot Comments
6	3	VLCC13	Outbound ship relied on emergency ship handling. They had a difficult time lining up on the center line of the gate complex. They went too far south in order to have a safe meeting with the inbound ship, but this prevented them from getting lined up on the south gate for transit. Inbound ship had to use full over and full ahead. I had to make aggressive maneuvers in order to make room for the meeting. It caused the ship to leave the channel. Overall, had a difficult time lining up with the gate due to the current.
7	3	VLCC13	Both ships report losing sight of the gate complex. These were during clear daytime conditions. The outbound ship had an allision with the gate complex. I bounced off the gate walls. I had a problem getting aligned due to the current and losing sight of the gate complex. The gates need to be wider. The inbound ship had to compensate because of concerns about an out-of-control ship that had just struck the walls in the gate complex.
8	3	VLCC13	Outbound ship reported that it is not safe to meet within at least a mile of the gates. Whoever is coming through the gate complex needs to yield to the oncoming ship to allow them to line up on the center line of the gate complex. The inbound ships reported that the gate complex greatly affected their navigation and capability to meet the other ships safely. Lining up the ships is difficult on the center line of the south gate complex on an ebb current. The channel needs to be straightened. We need at least a mile straightaway to align with the gate complex. We need to either move the gate complex or change the entire channel to create more room and a straightaway for the ships to get aligned.
16	2	VLCC13	On the outbound ship, the run went well. There were no problems with the meeting. I was able to get out of the way of the inbound ship. On the inbound ship, I was opposing the wind and current. This created uncertainty of my approach. It was hard to prepare for entry into the gate complex. The meeting though went as arranged.
17	3	VLCC13	All the ships reported that the limited visibility due to fog conditions was a problem for their visibility. Outbound ship reported that there was no room for error. I had to rely on my full pilot capabilities. I had to rely on full bells. The meeting was difficult. It was too difficult to get lined up for the gate entrance. If I had any faulty or failed equipment, I would have crashed.

			On the inbound ship, we had to change our meeting from one whistle to two whistles. This was because of the current combined with the siting of the gate. I have a lot of concern for this scenario. I did not want to meet prior to buoy 16.
23	3	VLCC13	Outbound ship went dead ahead slow in order to allow the ship outbound from Galveston channel to safely exit ahead of me. On the inbound ship, we agreed to meet on two whistles when I discovered the inbound ship was headed to Galveston. First inbound ship went to Galveston channel. There was a miscommunication. It will be risky to meet around the intersection between the HSC and Galveston. We will need to have strong communication between the pilot groups. On the second inbound ship I was going faster than I planned. I had to stay full ahead to maintain control in the current and be aligned with the gates. I would want the capability to anchor. Also, tug assist is needed. There will be difficulties of meeting ships inbound and outbound of Galveston.
24	3	VLCC13	Outbound ship had to reduce to slow ahead due to the outbound ship from Galveston crossing in front. Headed outbound, the turn is too extreme of an angle. I was out of shape to enter the gate due to the turn. The problem was worsened because of needing to slow down to let the ship out of Galveston pass first. Second outbound ship from Galveston Channel, I had to manage my speed and increase to 12 knots so I could get ahead of the Houston outbound ship. I had to speed up to meet the inbound ship not in the gates. I want tug escort help to control the speed. The ship was squeezed up against the walls of the gate due to the current. This required all of the piloting capabilities. The inbound ship reported that emergency ship handling was required immediately. This was required in order to ensure a safe meeting and to get aligned with the gates. We changed the meeting agreement twice due to the current.
34	3	VLCC13	Outbound ship almost crashed into the first inbound ship on the first meeting. This was in part due to miscommunication. I had to use full ahead. The meeting in the gates was preventable. We then crashed into the second inbound ship after the gates. The second inbound ship crashed into the outbound ship. We were out of position. We were a victim of the current. The first inbound ship had a near crash with the outbound ship in the gates. We should not have met in the gate complex. The channel and gate complex needs to be wider. If they were wider, we could have compensated for a safer meeting.

36	3	VLCC14	Ship outbound from the HSC, had to compensate for traffic. I was relying on max, emergency ship handling. We need wider gates. The bank effect is strong passing through the gates. Ship outbound from Galveston, we relied on emergency ship handling to come in behind the outbound ship from HSC. Inbound ship narrowly averted a collision in the second meeting with the ship from Galveston. We didn't have enough room in the gates. If the gates were wider, we would have considered meeting inside but instead we had a near collision.

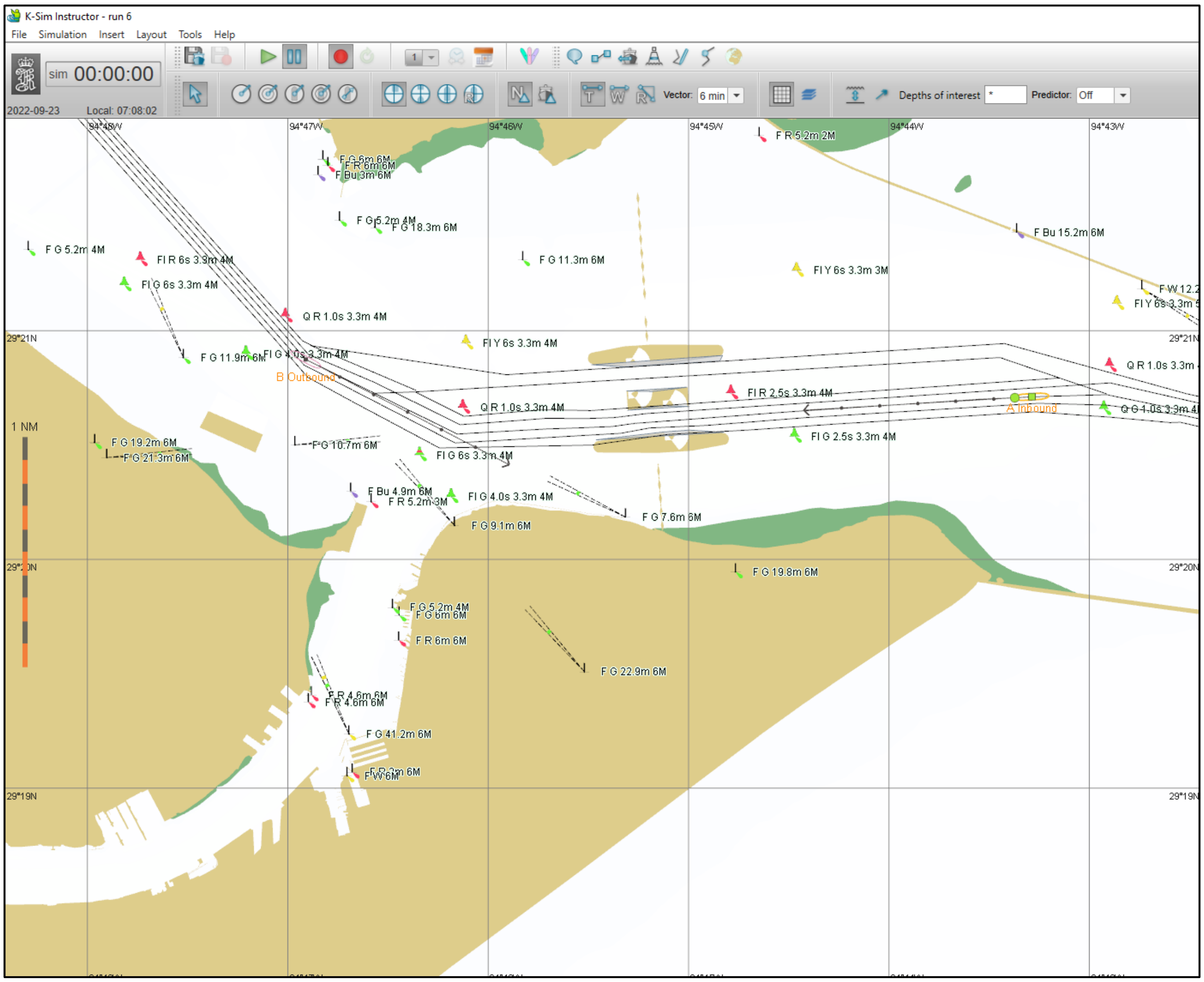

Figure 37. Run #7, Setup Inbound and Outbound Ship Transiting South Gate on an Ebb Current (2.5) knots, clear daylight

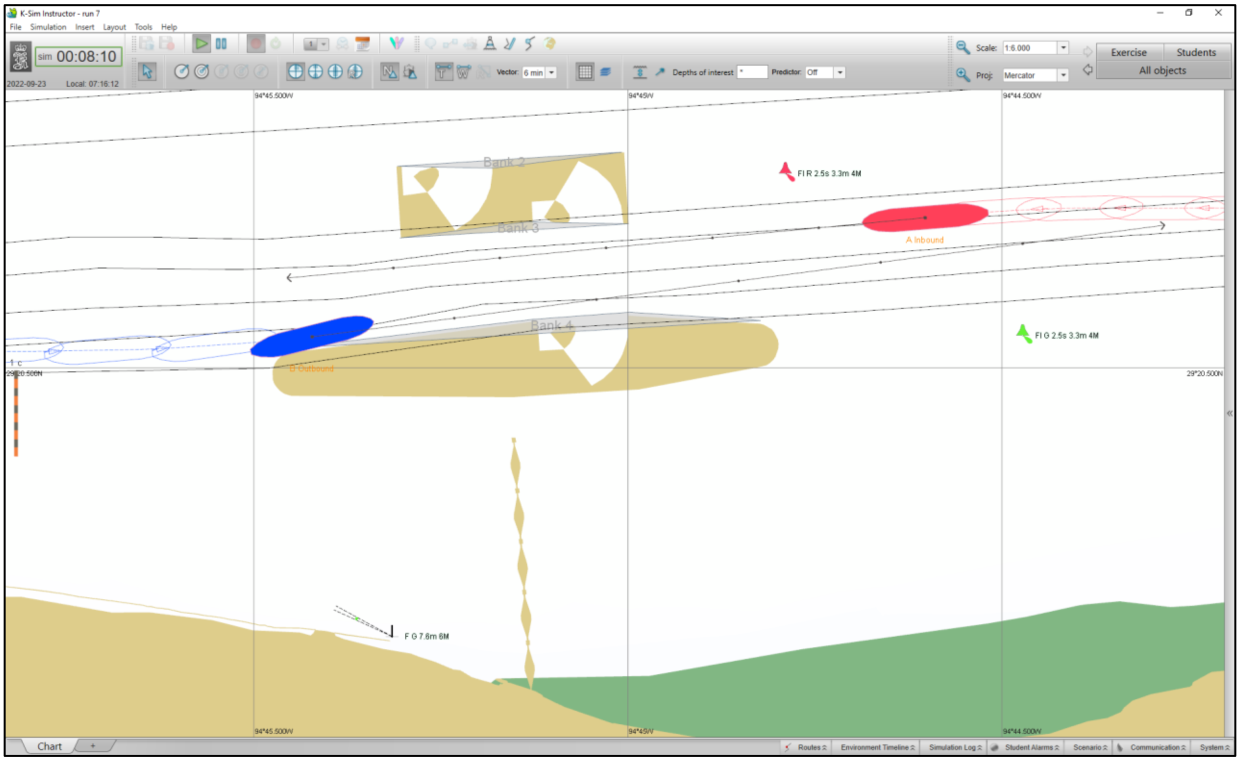

Figure 38. Run #7, Outbound Vessel Alisson with South Gate Island,

During Run #7, GAR Score 3 High Concern, the pilot was unable to successfully complete the turn outbound at buoys 18 and 16 from HSC in a 2.5 knot ebb current. This occurred using an Aframax-class tanker, which was the smallest test vessel. This simulation demonstrates that the distance from buoy #18 to the gate complex is foreshortened and needs to be extended. The ebb current (2.5 knots) further extends the turn requirements for vessels. Therefore, the gate complex is sited too far to the west in the Bolivar Roads, it needs to be sited further east and away from the turn at buoys 18 and 16 in the HSC.

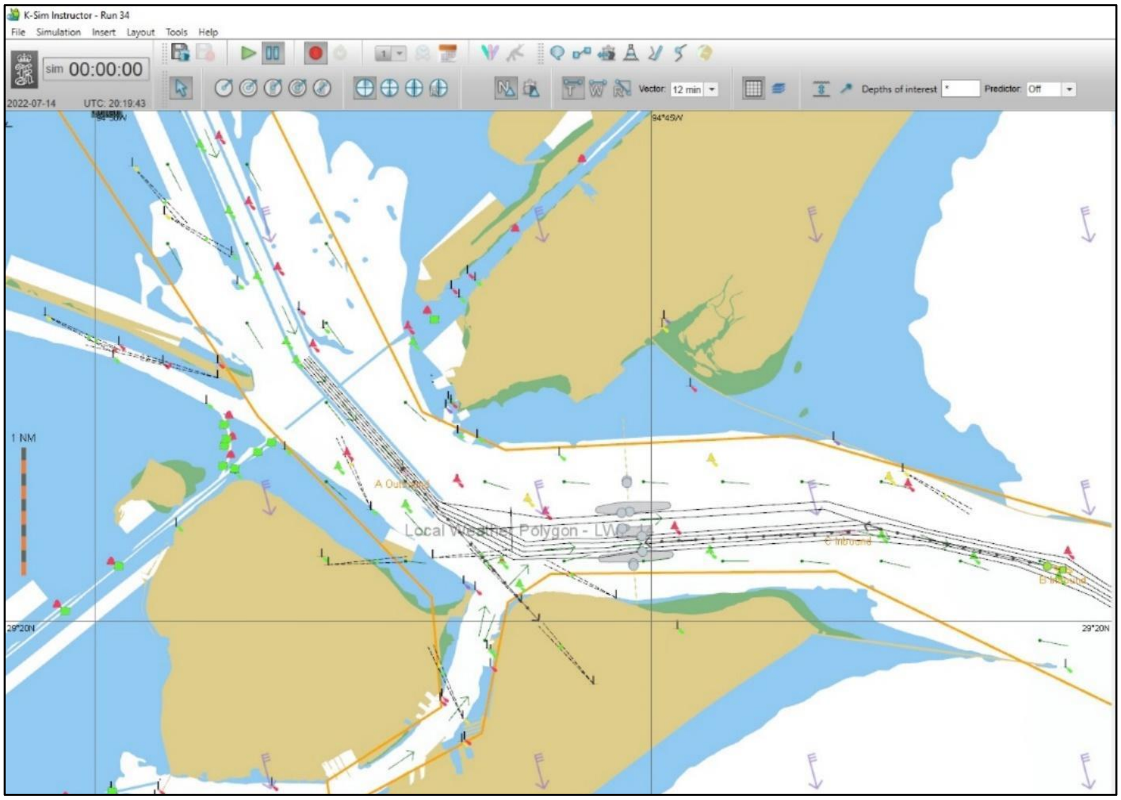

Figure 39. Run 34, Setup Outbound Ship and Two Inbound Ships Transiting South Gate Only on an Ebb Current (2.5) knots, clear daylight conditions

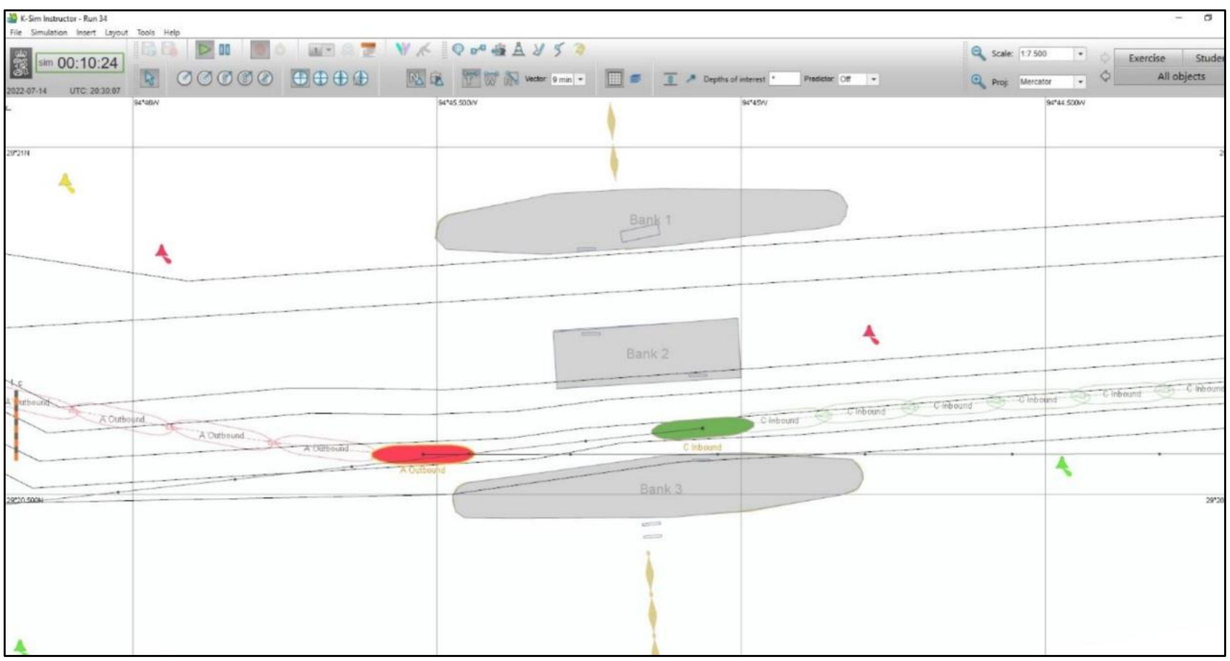

Figure 40. Run #34, Emergency Head-on Situation in the South Gate

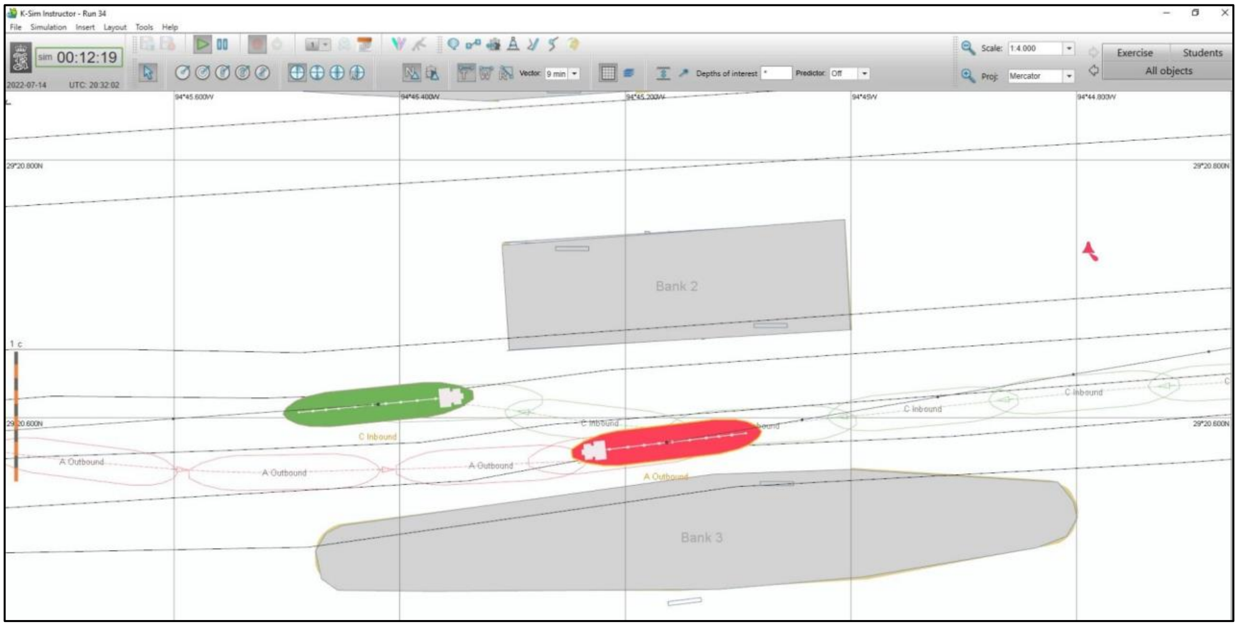

Figure 41. Run #34, Emergency Head-on Situation in the South Gate, Skin-to-Skin was 2'

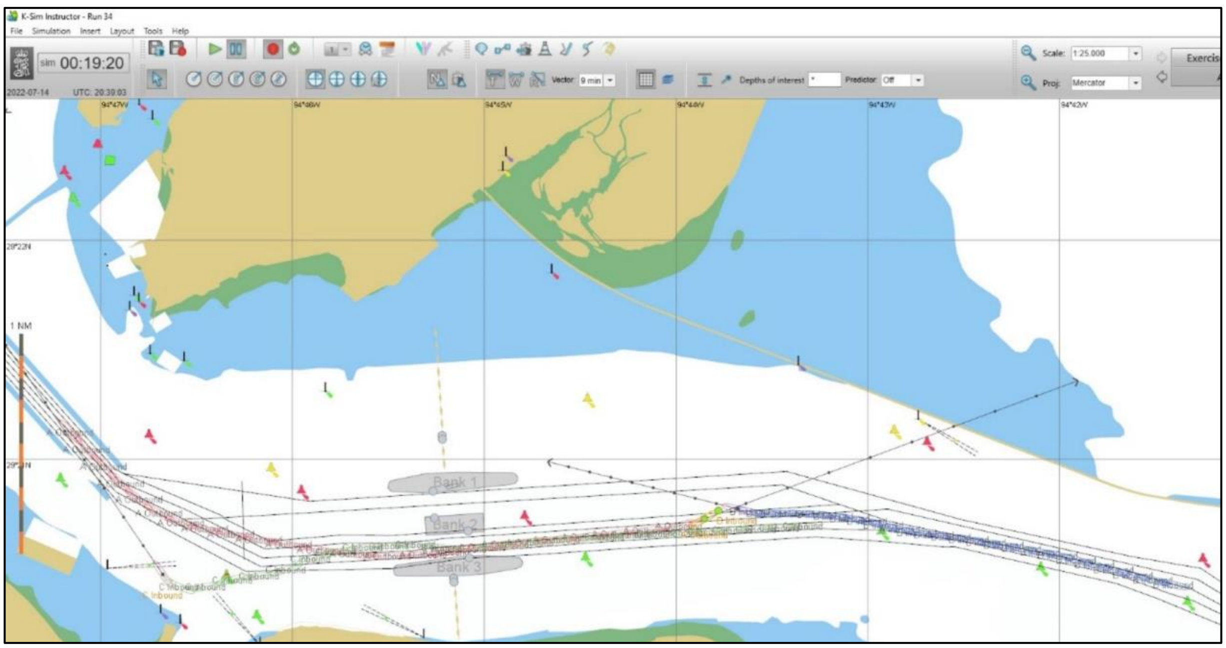

Figure 42. Run #34, End of Scenario, Outbound and Second Inbound Ship had Collision

During Run #34, GAR Score 3 High Concern, the outbound ship almost collided with the first inbound ship on the first meeting. This was in part due to miscommunication. The meeting in the gates was preventable. The second inbound ship collided with the outbound ship because it was out of position due to the current. The first inbound ship had a near collision with the outbound ship in the gates. Afterwards, the pilots discussed how the channel and gate complex needs to be wider. The pilot stated, "If they were wider, we could have compensated for a safer meeting."

Scenarios with Two Ships Meeting in North Gate Complex, No Current

Run#	GAR	Ship Models	Selected Pilot Comments
38	3	VLCC14	When the ships were skin-to-skin I could feel suction. The ships were too close. The simulator is limited and cannot truly reflect what occurs in these close proximity ship-to-ship meetings. It is not safe to meet another ship in the gates.
39	3	VLCC14	Meetings should not occur inside of the gates. There should be no meeting within 2 miles of the gates. The forces between the ships inside of the gates did not feel realistic. We need man model to better exemplify the issues. The gates need to be at least 1,200'. We need safety zones for emergency situations like this one. The ship-to-ship meetings in the gates is too dangerous. I would not meet another ship within 1.5 miles of the gate complex. Meeting in and around the gates is too dangerous. Additionally, we need the USCG to have a safety zone to prevent private boats from embarrassing our navigation. We cannot meet other ships or private boats in or around the gates. The USCG would need to monitor and prevent such meetings.
40	3	CNTR28	The gate complex is too narrow. The distance between following ships needs to be increased. The current distance of 1 mile is not enough. The pilots also reported losing visibility of the gates. The inbound ship had problems after the meeting due to stern suction. They also lost visibility of the gates due to the vessel (clear daylight conditions). We need at least 1.5 miles to align this ship with the gates. We should also change the walls of the gate so they can be touched by the ships. We cannot meet another ship inside of the gates. Risks are too high to even meet near and outside of the gates.
41	3	CNTR28	The gates are too narrow. The ship did not get over far enough for the meeting. We had a near collision in the gates. We need at least 120' for skin-to-skin meetings. I lost visibility of the gates. I veered off of centerline to compensate for the ship that was on center line to prevent us from colliding. I would not want to meet another ship in or around the gates. There is a lot of bank effect and pressure on the ship that means there is no safety margin.

To better understand the effects of shearing forces along with ship meetings in the gate complex, a series of transit scenarios were designed for ships to meet in the gate complex. This was done utilizing the Aframax class of tank vessel as well as a container ship. The results demonstrate that these commercial ships cannot plan to meet in the gate system, and that the current gate system has shearing forces that are a hazard to transiting commercial ships.

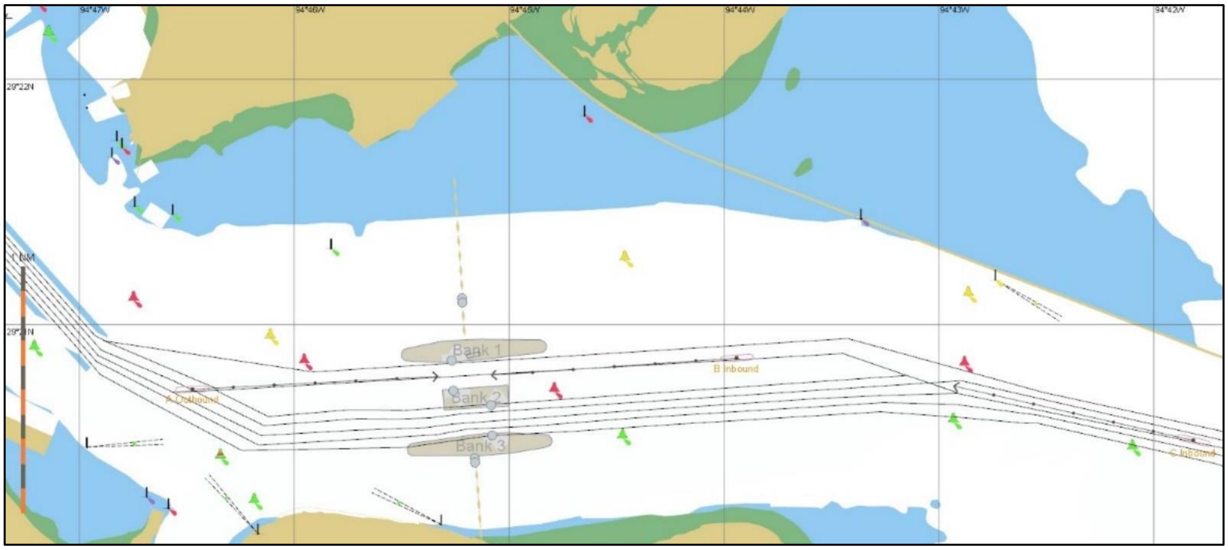

Figure 43. Run #39, Setup Aframax Tank Vessels One Outbound and Two Inbound, Meeting in North Gate, No Current, Daylight Conditions

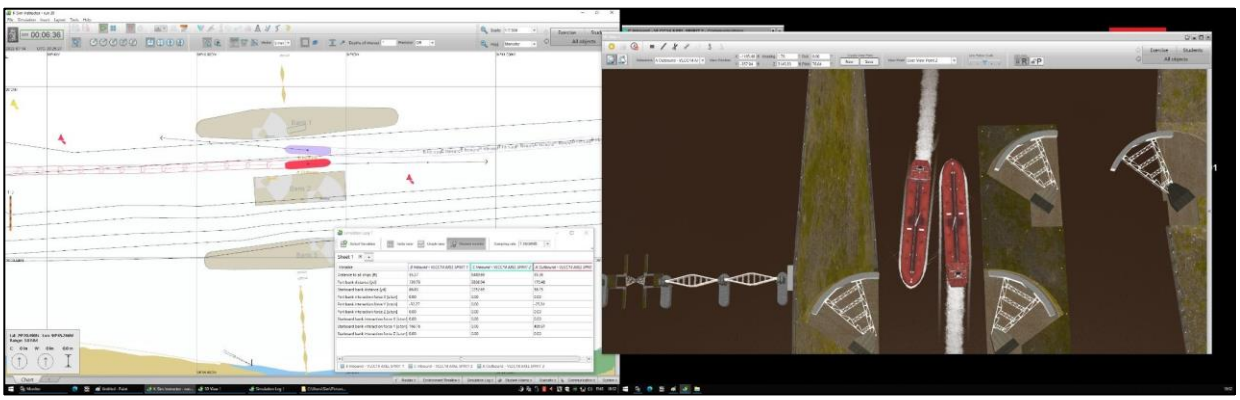

Figure 44. Run #39, Unsafe Meeting Between Outbound and Inbound Ships in North Gate with Overhead Visual View, Skin-to-Skin 55'

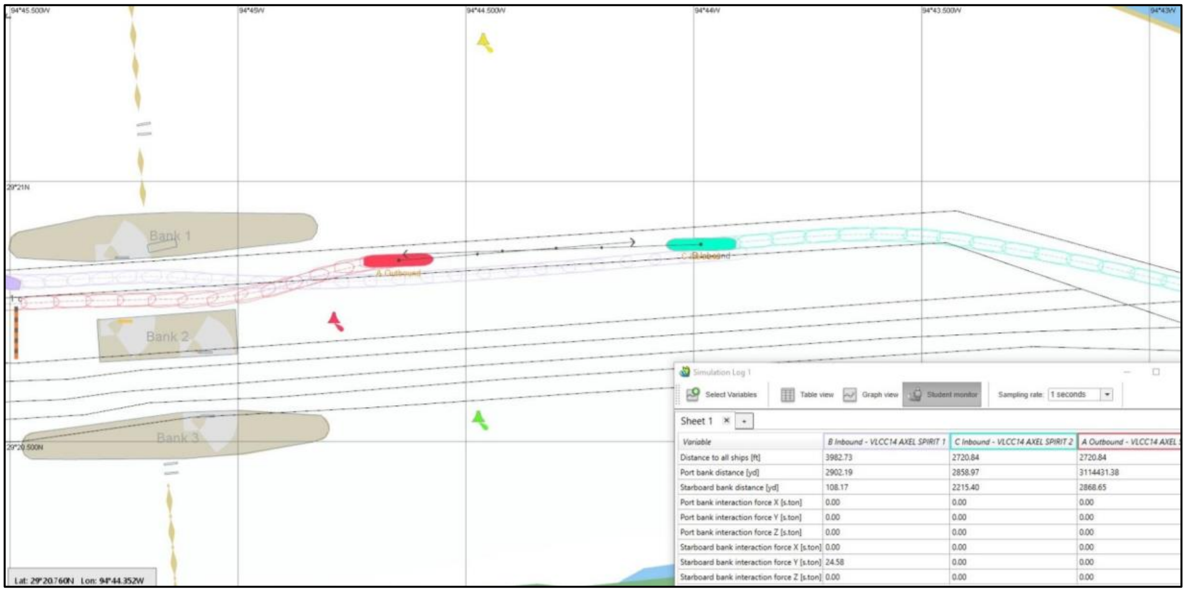

Figure 45. Run #39, Outbound Vessel Shears off Gate Wall towards Inbound Ship

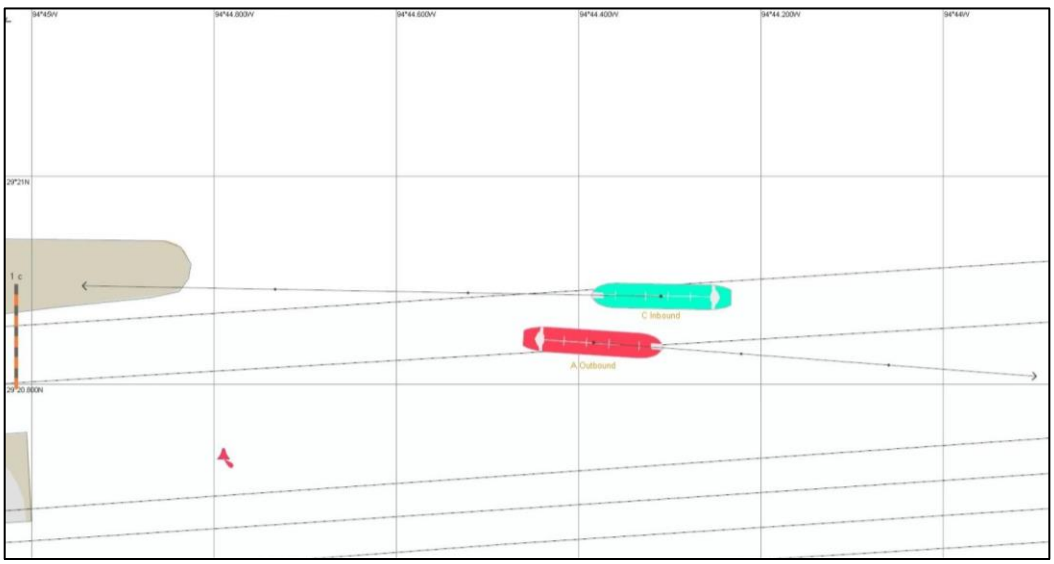

Figure 46. Run #39, Unsafe Meeting Between Outbound Ship Shearing off Gate Wall towards Inbound Ship, Skin-to-Skin 128'

Run #39, GAR sore 3 High Concern, had two Aframax-class tank vessel models meet in the north gate complex. The result was a near miss between the ships. The outbound ship experienced shearing forces and was out of position to meet the second inbound ship. After this transit scenario the pilots made multiple recommendations that there should not be any ship meetings within 2 miles of the gates during clear daylight conditions; that there should never be ship meetings inside of the gate complex; and the USCG should establish safety zones in and around the gate complex preventing non-piloted boat and ship traffic from meeting piloted commercial ships. Additionally, the pilots want to research the forces using man model simulation.

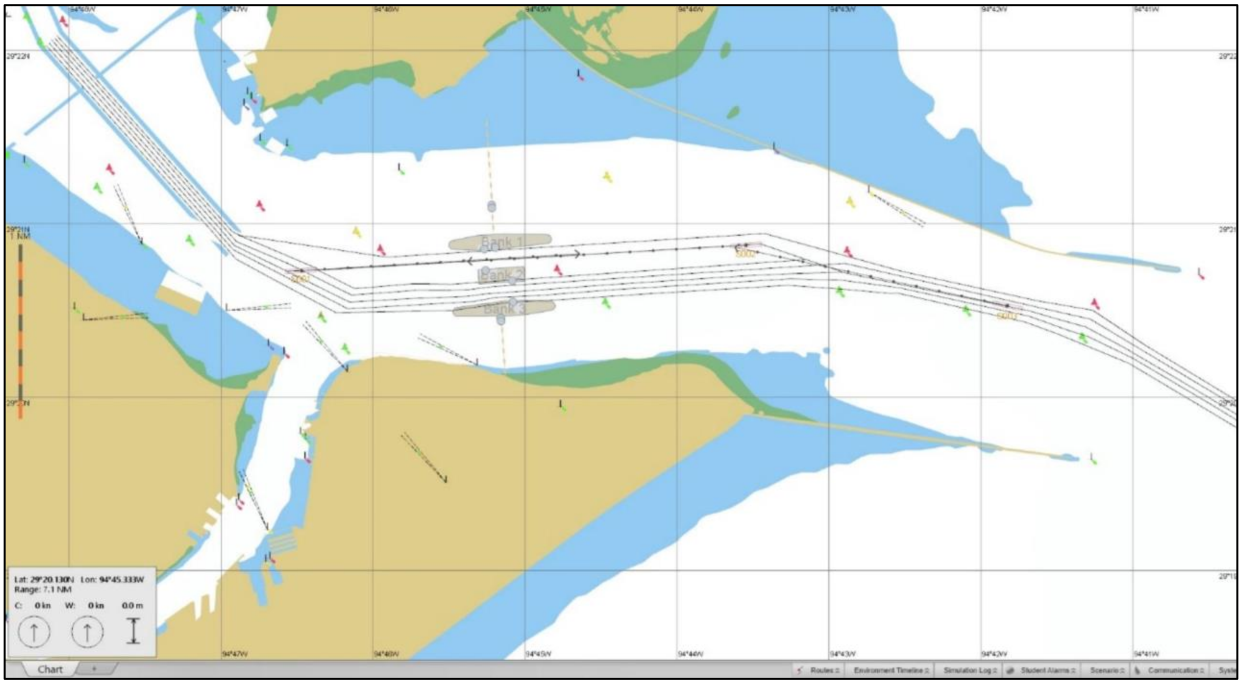

Figure 47. Run #40, Setup Container Ships One Outbound and Two Inbound, Meeting in North Gate, No Current, Daylight Conditions

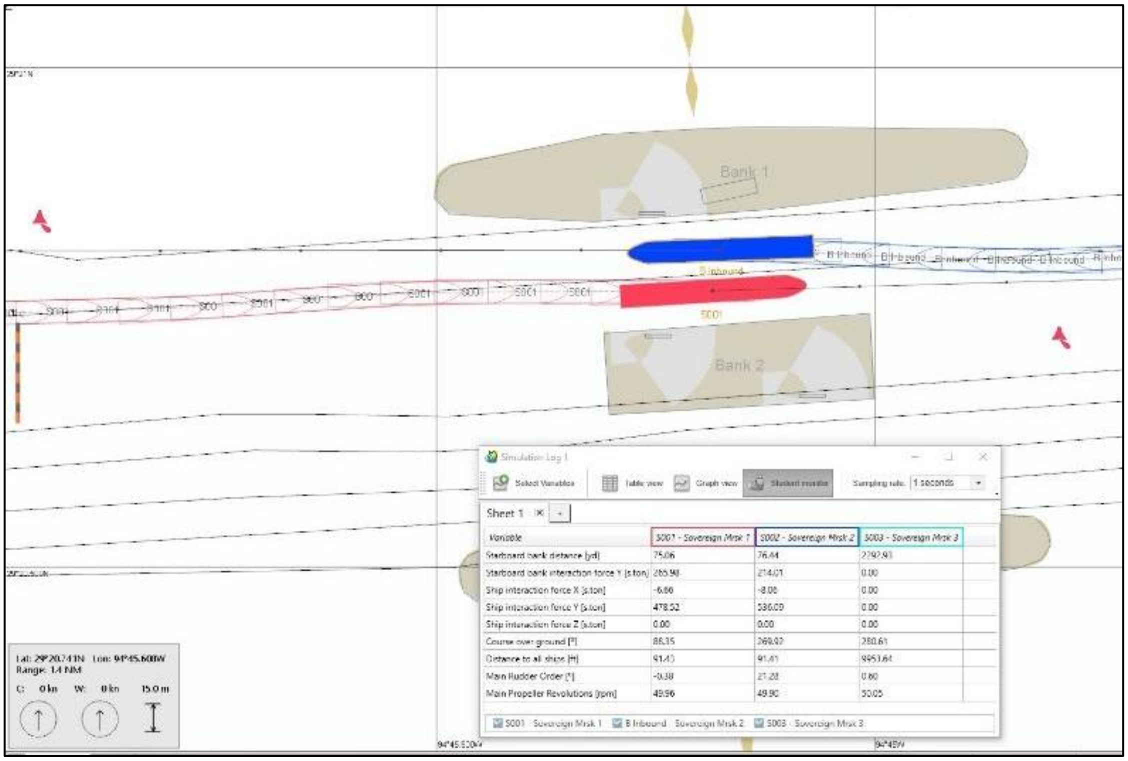

Figure 48. Run #40, Unsafe Meeting Between Container Ships in North Gate, Skin-to-Skin 90'

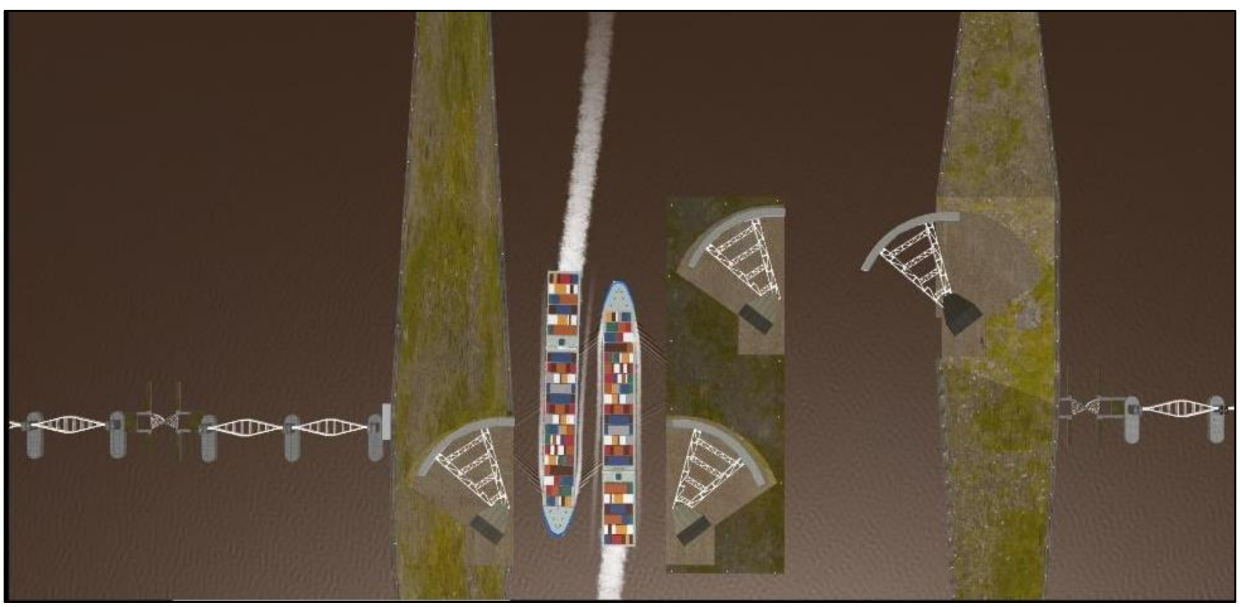

Figure 49. Run #40, Unsafe Meeting in North Gate, Overhead View, Skin-to-Skin 90'

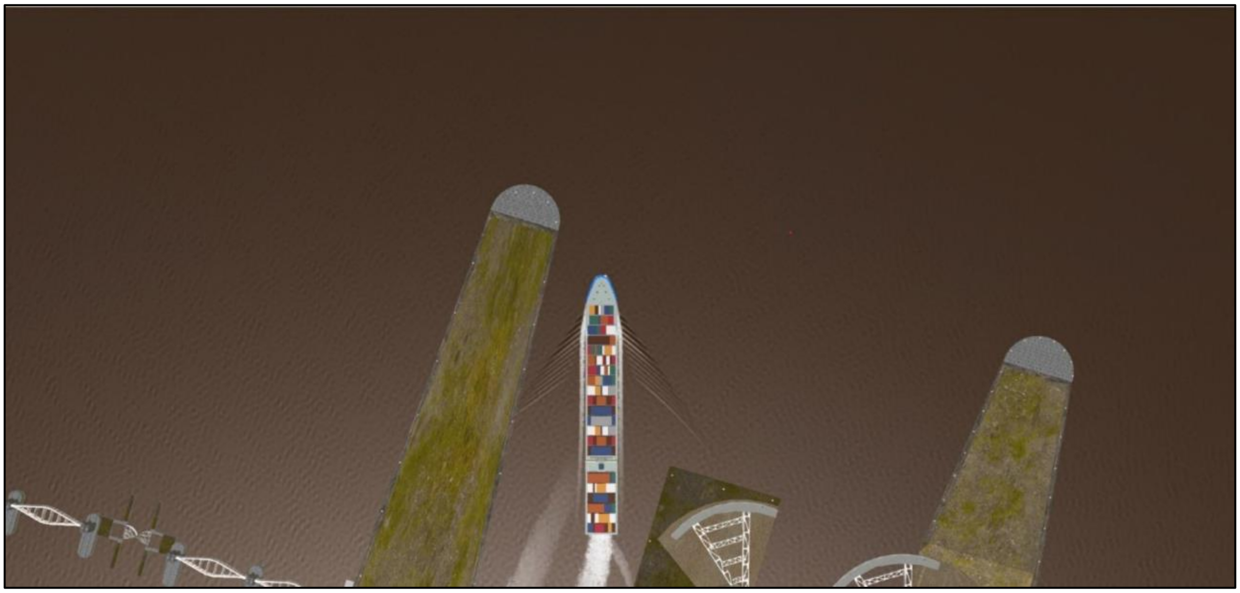

Figure 50. Run #40, Containership Shearing Out of Control after Meeting Outbound Ship in North Gate, Overhead View

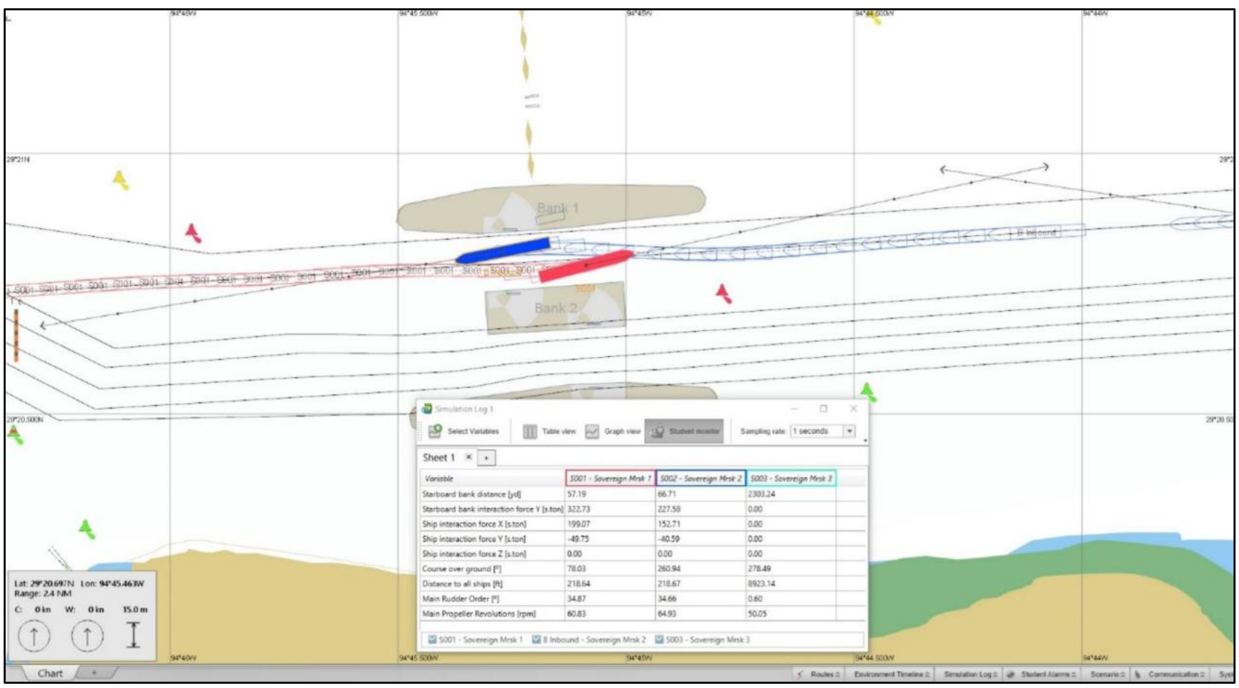

Figure 51. Run #40, Containerships Shearing Out of Control Along Gate Walls, Outbound (Red Ship) 322 tons Shearing Forces, Inbound (Blue Ship) 227 tons Shearing Forces

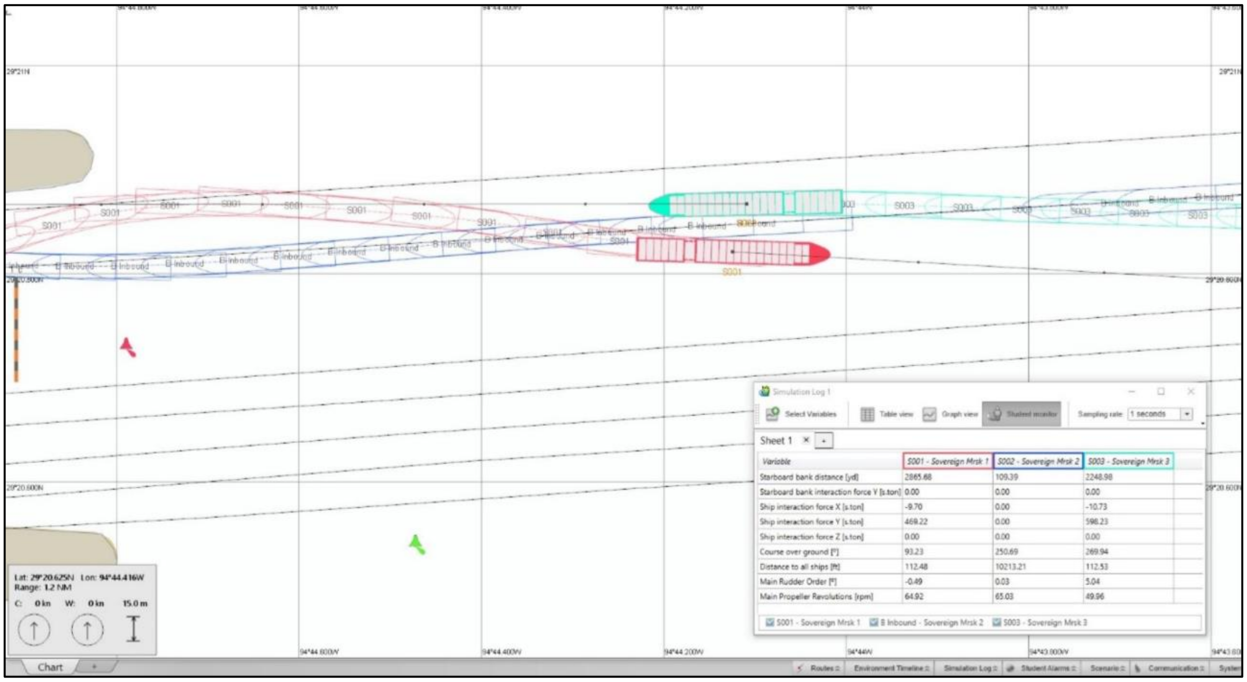

Figure 52. Run #40, Containerships in Emergency Maneuvers After Gate Shearing Event, Skin-to-Skin 112'

During Run #40, GAR sore 3 High Concern, two container ships, ~1,140 LOA X 140' beam, met in the north gate complex. The result was a near miss between the ships. Both ships afterwards experienced shearing forces. The outbound ship was out of position to meet the second inbound ship. After this transit scenario the pilots made multiple recommendations that the gate complex (650') is too narrow; that the distance between following ships needs to be increased as the current distance of 1 mile is not enough; and that the ships should be able to touch the walls of the gates in an emergency. The pilots also reported losing visibility of the gates during clear daylight conditions aboard these container ships.

Overall, the result of these planned meetings in the north gate complex demonstrated that these commercial ships should not meet in or near the gate complex. Even without current, and in clear daylight conditions, these meetings and transits through the gate complex were a hazard. Furthermore, testing these transits produced many beneficial recommendations such as increasing the following distance between commercial ships, establishing safety zones, widening the gates, the use of manned model simulations to test the designs, and designing the walls of the gates so that they are fendered or designed to reduce damage to vessels if contacted.

Locus

Appendix 1. Simulation Run Matrixes

Simulation Run Matrix 1: Scenario Setup, Objectives, and Meetings (Distances Skin-to-Skin)

#	GAR	Gates	Ship Models	Start Speed (kn)	Ship A Objective	Ship A Start	Ship B Objective	Ship B Start	Ship C Objective	Ship C Start	Meeting 1	Meeting 2
1	2	North Only	A CNTR33; B VLCC14	10	Outbound North Gate	3.5 miles to North Gate	Inbound North Gate	1.5 miles to North Gate	NA	NA	AB 677'	
2	3	North Only	VLCC14	10	Outbound North Gate	Buoy 18	Inbound North Gate	Buoy 7/8	Inbound North Gate	Buoy 5	AB 184'	
3	2	North Only	VLCC14	10	Inbound North Gate	0.5 miles to North Gate	Outbound North Gate	Buoy 18	NA	NA		
4	3	North Only	VLCC14	10	Inbound North Gate	0.5 miles to North Gate	Outbound North Gate	Buoy 18	Outbound North Gate	3 Miles to North Gate	AB 790'	AC Collided
5	3	North Only	VLCC13	10	Inbound North Gate	0.5 miles to North Gate	Outbound North Gate	2 miles to North Gate	NA	NA	AB 406'	

6	3	South Only	VLCC13	10	Inbound South Gate	0.5 miles to South Gate	Outbound South Gate	2 miles to South Gate	NA	NA	AB 380'	
7	3	South Only	VLCC13	10	Inbound South Gate	0.5 miles to South Gate	Outbound South Gate	Buoy 18	NA	NA	AB 163'	
8	3	South Only	VLCC13	10	Inbound South Gate	0.5 miles to South Gate	Outbound South Gate	2 miles to South Gate	Inbound South Gate	Buoys 7/8	AB 245'	AC 250'
9	3	North Only	VLCC13	10	Inbound North Gate	0.5 miles to North Gate	Outbound North Gate	2 miles to North Gate	Inbound North Gate	Buoys 7/8	AB 480'	AC 70'
10	3	Both Open	VLCC18	8	Inbound North Gate	0.5 miles to North Gate	Inbound North Gate	Buoy 7/8	Outbound South Gate	2 miles to North Gate		
11	3	Both Open	VLCC18	8	Inbound North Gate	0.5 miles to North Gate	Outbound South Gate	Buoy 18	Outbound South Gate	2 miles to North Gate		

12	3	North Only	VLCC13	10	Outbound North Gate	2 miles to North Gate	Inbound North Gate	0.5 miles to North Gate	NA	NA	AB 580'	
13	2	Both Open	VLCC13	8	Inbound North Gate	Buoy 9/10	Outbound South Gate	Buoy 18	NA	NA		
14	2	Both Open	VLCC13	8	Outbound South Gate	Buoy 18	Inbound North Gate	Buoys 9/10	NA	NA		
15	2	Both Open	VLCC13	8	Outbound South Gate	Buoy 18	Inbound North Gate	Buoys 9/10	NA	NA		
16	2	South Only	VLCC13	8	Outbound North Gate	1.3 miles to buoy 18	Inbound South Gate	1 mile to South Gate	NA	NA	AB 430'	
17	3	South Only	VLCC13	8	Outbound South Gate	1.3 miles to buoy 18	Inbound South Gate	1 mile to South Gate	NA	NA	AB 366'	
18	2	North Only	VLCC13	8	Outbound North Gate	2.2 miles to buoy 18	Inbound North Gate	1.1 miles to North Gate	NA	NA	AB 850'	

19	3	North Only	VLCC13	8	Outbound North Gate	2.2 miles to buoy 18	Inbound North Gate	1.1 miles to North Gate	NA	NA	AB 640'	
20	2	North Only	ULCV 400	8	Outbound North Gate	2.2 miles to buoy 18	Inbound North Gate	1.1 miles to North Gate	NA	NA	AB 745'	
21	3	North Only	VLCC13	8	Outbound North Gate	2.2 miles to buoy 18	Inbound North Gate	At Entry North Gate	Inbound North Gate	Buoys 7/8	AB 458'	AC 112'
22	2	North Only	VLCC13	8	Outbound North Gate	2.2 miles to buoy 18	Inbound North Gate	At Entry North Gate	Inbound North Gate	Buoys 7/8	AB 1,142'	AC 850'
23	3	South Only	VLCC13	8, C (6)	Outbound South Gate	Buoys 25/26	Inbound South Gate	1 mile to South Gate	Outbound Galveston South Gate	USCG Station Galveston	AB 85'	AC 576'
24	3	South Only	VLCC13	8, C (6)	Outbound South Gate	Buoy 25/26	Inbound South Gate Galveston	1 mile to South Gate	Outbound Galveston South Gate	USCG Station Galveston	BC 196'	AB 450'

25	2	Both Open	VLCC13	8, C (6)	Outbound South Gate	Buoy 25/26	Inbound North Gate	1 mile to North Gate	Outbound Galveston South Gate	USCG Station Galveston	AB 980'	
26	1	Both Open	VLCC13	8, C (6)	Outbound South Gate	Buoy 18	Inbound North Gate	North Gate Entry	Inbound North Gate	1.2 miles to North Gate	AB 920'	
27	NA	Both Open	CNTR 33	8, C (6)	Inbound North Gate	2 miles to North Gate	Outbound South Gate	2 miles to South Gate	Outbound Galveston South Gate	USCG Station Galveston		
28	NA	Both Open	CNTR 33	8	Inbound North Gate	2 miles to North Gate	Outbound South Gate	Buoy 25/26, 8 knots	Outbound Galveston South Gate	1 mile in Galveston Channel		
29	NA	Both Open	CNTR 33	8	Outbound South Gate	Buoy 25/26	Inbound North Gate to Houston	2 miles outside of North Gate	Inbound Galveston North Gate	1 mile to North Gate		
30	NA	Both Open	CNTR 33	8	Outbound South Gate	Buoy 25/26	Inbound North Gate to Houston	2 miles outside of North Gate	Inbound Galveston North Gate	1 mile to North Gate		

31	2	Both Open	VLCC13	8	Outbound Houston South Gate	Buoy 25/26	Inbound Houston North Gate	1 mile outside North Gate	Outbound Galveston South Gate	1 mile in Galveston Channel	AB 1,030'	
32	2	Both Open	VLCC13	8	Outbound Houston South Gate	Buoy 25/26	Inbound Houston North Gate	2 miles outside of North Gate	Inbound Galveston North Gate	1 mile to North Gate	AC 1,000'	
33	2	Both Open	VLCC13	8	Outbound South Gate	Buoy 25/26	Inbound North Gate to Houston	1 mile outside North Gate	Outbound Galveston South Gate	1 mile in Galveston Channel		
34	3	South Only	VLCC13	8	Outbound South Gate	Buoy 18	Inbound South Gate to Houston	2 miles outside South Gate	Inbound Galveston South Gate	1 mile to South Gate	AC 2'	
35	3	Both Open	VLCC14	8, C (6)	Outbound South Gate	Buoy 18	Inbound North Gate	Buoys 9/10	Outbound Galveston South Gate	1 mile in Galveston Channel	AB 150'	
36	3	South Only	VLCC14	8, C (6)	Outbound South Gate	Buoy 18	Inbound South Gate Houston	Buoys 9/10	Outbound Galveston South Gate	1 mile in Galveston Channel	AB 175'	AC 101'

37	3	North Only	VLCC14	8	Outbound North Gate	Buoy 18	Inbound North Gate	1 mile to North Gate	Inbound North Gate	2 miles to North Gate	AB 95'	AC 65'
38	3	North Only	VLCC14	8	Outbound North Gate	1 mile to North Gate	Inbound North Gate	1 mile to North Gate	NA	NA	AB 55'	
39	3	North Only	VLCC14	10	Outbound North Gate	1 mile to North Gate	Inbound North Gate	1 mile to North Gate	Inbound North Gate	2 miles to North Gate	AB 55'	AC 128'
40	3	North Only	CNTR 28	10	Outbound North Gate	1 mile to North Gate	Inbound North Gate	1 mile to North Gate	Inbound North Gate	2 miles to North Gate	AB 90'	AC 112'
41	3	North Only	CNTR 28	8	Outbound North Gate	1 mile to North Gate	Inbound North Gate	1 mile to North Gate	Inbound North Gate	2 miles to North Gate	AB 15'	AC 280'
42	2	Both Open	VLCC14	8, A (6)	Outbound South Gate	Buoy 18	Inbound North Gate Houston	2.5 miles to North Gate	Inbound North Gate	1 mile to North Gate		

Simulation Run Matrix 2: Scenario Environmental Conditions

#	GAR	Gates	Ship Models	Ship A Objective	Ship B Objective	Ship C Objective	Wind (Deg/knots)	Current (knots)	Visibility
1	2	North Only	A CNTR33; B VLCC14	Outbound North Gate	Inbound North Gate	NA	345 / 20	Flood 2.5 knots	Day
2	3	North Only	VLCC14	Outbound North Gate	Inbound North Gate	Inbound North Gate	270 / 20	Flood 2.5 knots	Day
3	2	North Only	VLCC14	Inbound North Gate	Outbound North Gate	NA	165 / 20	Flood 2.5 knots	Day
4	3	North Only	VLCC14	Inbound North Gate	Outbound North Gate	Outbound North Gate	135 / 20	Flood 2.5 knots	Night, Fog
5	3	North Only	VLCC13	Inbound North Gate	Outbound North Gate	NA	135 / 20	Flood 2.5 knots	Day
6	3	South Only	VLCC13	Inbound South Gate	Outbound South Gate	NA	135 / 20	Ebb 2.5 knots	Day
7	3	South Only	VLCC13	Inbound South Gate	Outbound South Gate	NA	135 / 20	Ebb 2.5 knots	Day

8	3	South Only	VLCC13	Inbound South Gate	Outbound South Gate	Inbound South Gate	135 / 20	Ebb 2.5 knots	Day
9	3	North Only	VLCC13	Inbound North Gate	Outbound North Gate	Inbound North Gate	135 / 20	Flood 2.5 knots	Day
10	3	Both Open	VLCC18	Inbound North Gate	Inbound North Gate	Outbound South Gate	135 / 20	Flood 2.5 knots	Day
11	3	Both Open	VLCC18	Inbound North Gate	Outbound South Gate	Outbound South Gate	135 / 20	Ebb 2.5 knots	Day
12	3	North Only	VLCC13	Outbound North Gate	Inbound North Gate	NA	135 / 20	Flood 2.5 knots	Night, Fog
13	2	Both Open	VLCC13	Inbound North Gate	Outbound South Gate	NA	None	Ebb 1 knot	Day
14	2	Both Open	VLCC13	Outbound South Gate	Inbound North Gate	NA	None	Ebb 1 knot	Day
15	2	Both Open	VLCC13	Outbound South Gate	Inbound North Gate	NA	135 / 20	Ebb 2.5 knots	Night, Fog

16	2	South Only	VLCC13	Outbound North Gate	Inbound South Gate	NA	135 / 20	Ebb 2.5 knots	Day
17	3	South Only	VLCC13	Outbound South Gate	Inbound South Gate	NA	135 / 20	Ebb 2.5 knots	Night, Fog
18	2	North Only	VLCC13	Outbound North Gate	Inbound North Gate	NA	135 / 20	Flood 2.5 knots	Day
19	3	North Only	VLCC13	Outbound North Gate	Inbound North Gate	NA	135 / 20	Flood 2.5 knots	Night, Fog
20	2	North Only	ULCV400	Outbound North Gate	Inbound North Gate	NA	135 / 20	Flood 2.5 knots	Day
21	3	North Only	VLCC13	Outbound North Gate	Inbound North Gate	Inbound North Gate	135 / 20	Flood 2.5 knots	Day
22	2	North Only	VLCC13	Outbound North Gate	Inbound North Gate	Inbound North Gate	135 / 20	Flood 2.5 knots	Night, Fog
23	3	South Only	VLCC13	Outbound South Gate	Inbound South Gate	Outbound Galveston South Gate	135 / 20	Ebb 2.5 knots	Day

24	3	South Only	VLCC13	Outbound South Gate	Inbound South Gate Galveston	Outbound Galveston South Gate	135 / 20	Ebb 2.5 knots	Night, Fog
25	2	Both Open	VLCC13	Outbound South Gate	Inbound North Gate	Outbound Galveston South Gate	135 / 20	Flood 2.5 knots	Day
26	1	Both Open	VLCC13	Outbound South Gate	Inbound North Gate	Inbound North Gate	135 / 20	Flood 2.5 knots	Day
27	NA	Both Open	CNTR33	Inbound North Gate	Outbound South Gate	Outbound Galveston South Gate	None	None	Day
28	NA	Both Open	CNTR33	Inbound North Gate	Outbound South Gate	Outbound Galveston South Gate	None	None	Day
29	NA	Both Open	CNTR33	Outbound South Gate	Inbound North Gate to Houston	Inbound Galveston North Gate	135 / 20	Ebb 2.5 knots	Day

30	NA	Both Open	CNTR33	Outbound South Gate	Inbound North Gate to Houston	Inbound Galveston North Gate	135 / 20	Ebb 2.5 knots	Night, Fog
31	2	Both Open	VLCC13	Outbound Houston South Gate	Inbound Houston North Gate	Outbound Galveston South Gate	135 / 20	Flood 2.5 knots	Day
32	2	Both Open	VLCC13	Outbound Houston South Gate	Inbound Houston North Gate	Inbound Galveston North Gate	135 / 20	Flood 2.5 knots	Night, Fog
33	2	Both Open	VLCC13	Outbound South Gate	Inbound North Gate to Houston	Outbound Galveston South Gate	345 / 30	Ebb 2.5 knots	Day
34	3	South Only	VLCC13	Outbound South Gate	Inbound South Gate to Houston	Inbound Galveston South Gate	345 / 30	Ebb 2.5 knots	Day
35	3	Both Open	VLCC14	Outbound South Gate	Inbound North Gate	Outbound Galveston South Gate	135 / 20	Ebb 2.5 knots	Day

36	3	South Only	VLCC14	Outbound South Gate	Inbound South Gate Houston	Outbound Galveston South Gate	135 / 20	Ebb 2.5 knots	Day
37	3	North Only	VLCC14	Outbound North Gate	Inbound North Gate	Inbound North Gate	135 / 20	Flood 2.5 knots	Day
38	3	North Only	VLCC14	Outbound North Gate	Inbound North Gate	NA	None	None	Day
39	3	North Only	VLCC14	Outbound North Gate	Inbound North Gate	Inbound North Gate	None	None	Day
40	3	North Only	CNTR28	Outbound North Gate	Inbound North Gate	Inbound North Gate	None	None	Day
41	3	North Only	CNTR28	Outbound North Gate	Inbound North Gate	Inbound North Gate	None	None	Day
42	2	Both Open	VLCC14	Outbound South Gate	Inbound North Gate Houston	Inbound North Gate	135 / 20	Ebb 2.5 knots	Day

Ship Simulation Transit Scenario Modeling & Ship Pilot Study of the Maritime Implications for Commercial Ship Transits of the Proposed Houston Ship Channel Gate Complex

Prepared for:
Greater Houston Port Bureau

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EXECUTIVE SUMMARY

Purpose

The purpose of this screening-level research is to explore the maritime implications for commercial ship transits of the US Army Corps of Engineers (USACE) proposed Houston Ship Channel Gate Complex (Gate Complex). This research analyzes the site location and design of the Gate Complex concept described in the USACE Galveston District and Texas General Land Office's (August 2021) "Coastal Texas Protection and Restoration Feasibility Study: Final Feasibility Report"[1] (Final Feasibility Report) and further described in the report's "Appendix D: Engineering Design, Cost Estimates, and Cost Risk Analysis" [2]. The Gate Complex analyzed is not the result of a planning, engineering, and design phase (PED) completed by the USACE, but rather the USACE Galveston District described the proposed siting and design tested as at the conceptual stage. The Gate Complex concept includes three asymmetric islands with two gate complexes each designed for one-way ship traffic, with dimensions of 650' wide and a depth of 60'. Figure 1 depicts the concept design and siting of the Gate Complex in the Bolivar Roads area of the Houston Ship Channel (HSC) and near the Galveston Ship Channel (GSC) from the Final Feasibility Report (page 84).

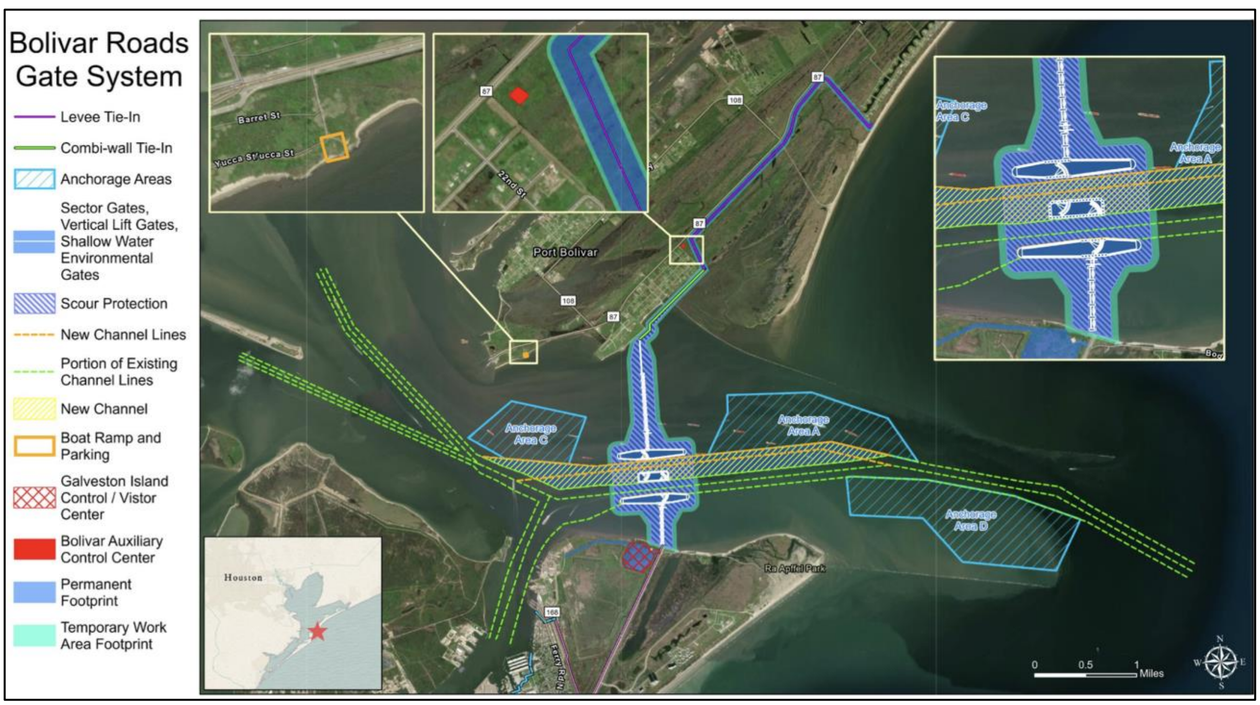

Figure 1. HSCGC Concept Depiction and Siting from the USACE Feasibility Study.

[1] USACE, Galveston District and Texas General Land Office. (August 2021). "Coastal Texas Protection and Restoration Feasibility Study Final Report".

[2] USACE, Galveston District and Texas General Land Office. (August 2021). "Coastal Texas Protection and Restoration Feasibility Study Final Report. Appendix D: Engineering Design, Cost Estimates, and Cost Risk Analysis".

Methodology

The Gate Complex was analyzed by performing 42 ship transit scenarios piloted by 14 Houston and four Galveston-Texas City pilots using ship simulators at San Jacinto Maritime College in LaPorte, Texas. Each scenario utilized two to three interactive piloted ship models, transiting inbound or outbound through a single or a double Gate Complex, using varying environmental conditions (wind, currents, & visibility). Varying ship models of tank vessels and cargo ships that transit the HSC and those proposed in the future were used along with varying starting positions and speeds. After each ship transit scenario, the pilots were interviewed to identify and describe any hazards. Roundtable discussions also occurred including with visitors from the USACE Galveston District. For more information, see the main report.

Summary of Research Findings

1. **<u>The Gate Complex siting location is a hazard to transiting commercial ships.</u>**
    a. The Gate Complex is too far west in the Bolivar Roads area of the HSC. The entrance is only ~0.6 nautical miles from the HSC turn at buoys 18 and 16, requiring a severe angle turn to align with the center of the Gate Complex. This hazard is aggravated by strong tidal currents (up to 2.5 knots) in the area affecting a ship's navigation and speed regulation. This resulted in multiple ship collisions near buoys 18 and 16, along with ship allisions or striking of the Gate Complex.
    b. The Gate Complex is too close to the GSC. The siting foreshortens the length of the turn, requiring a severe angle turn coming in and out of the GSC. This disrupted ship traffic, led to a near ship collision, and a ship allision with the Gate Complex.
2. **<u>The Gate Complex design is a hazard to transiting commercial ships.</u>**
    a. The 650' wide gate openings are too narrow. They require "perfect" piloting, leaving no room for error. On approach, ships must slow down, creating a chokepoint for ship traffic in the area. This led to a disruption in ship traffic. Additionally, aboard large vessels, visibility of the gate openings was obstructed.
    b. The asymmetrical three island design is a hazard. The ship's experience asymmetrical shearing forces causing the pilot to lose control of the ship when entering at an angle or unaligned with the center of the Gate Complex. Additionally, the rectangular center island has 90-degree edges that would cause extensive damage to a ship if contacted.

Summary of Alternative Gate Complex Siting and Design Considerations

1. Explore different siting locations of the Gate Complex. If siting in the Bolivar Roads area of the HSC, move the Gate Complex further to the east. Also, consider the siting impacts on the inner anchorages currently used by commercial ship transit activity.
2. The Gate Complex should have three symmetrical islands along with sloped sides protecting the walls. Widen the Gate Complex beyond the current 650' and make the depth the deepest possible consistent with safe engineering design.