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Use of AIS and AISAP for Analysis of Vessel Wakes in Charleston Harbor: A Case Study

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PURPOSE: This Coastal and Hydraulics Engineering Technical Note (CHETN) describes the uses of Automatic Identification System (AIS) data with the vessel traffic analysis capabilities of the AIS Analysis Package (AISAP) for vessel wake analysis. A case study was performed to demonstrate a cost-effective method for applying AIS data from Charleston Harbor, SC, to estimate relative wake energy contributions from vessel populations projected to call given the alternative scenarios in a deep-draft navigation feasibility study.

INTRODUCTION: The U.S. Army Corps of Engineers (USACE) performs a variety of studies that can benefit from the availability of AIS data that document the movement of vessels interacting with navigation systems. Since 2004, certain vessels are required to broadcast position data every 2 to 10 seconds (s) while underway and every 180 s while at anchor using AIS. Detailed identifying information (ship name, type, dimensions, etc.) are also transmitted every 6 minutes. The format and availability of AIS data are discussed in detail in ITU (2014).

The AISAP is being developed by the U.S. Army Engineer and Research Development Center (ERDC) to efficiently interpret and extract useful information from AIS data in support of USACE mission requirements. Vessel wake studies, such as those performed by Maynord, (2007) and Maynord et al. (2008), are performed to investigate shoreline impacts resulting from changes to navigation channels and will benefit from AIS derived information.

This case study demonstrates the use of AIS data and desktop methods to make relative comparison between harbor deepening alternatives proposed during the recent Charleston Harbor deepening feasibility study (USACE 2015). The estimated power contributed per unit length of wave crest is used as a proxy to determine whether selected project alternatives are likely to result in vessel-related shoreline erosion beyond that which would arise from the no-action alternative.

CHARLESTON HARBOR CASE STUDY: A reconnaissance study completed in 2010 identified a federal interest in deepening Charleston Harbor beyond its 45 foot (ft) authorized depth, triggering the “Post 45” harbor deepening feasibility study (USACE 2015). Deepening the channel will accommodate larger vessels that are expected to transit the region to meet increased cargo demands following the expansion of the Panama Canal Locks (USACE 2015).

The volume of cargo and vessel fleet composition carrying that cargo through Charleston Harbor was projected in 5-year increments from the year 2022 through 2037 during the Post 45 study. Cargo volume was held constant at each increment for all future project alternatives while the fleet composition was allowed to change with project depth. The future fleet composition was used in this effort to estimate energy contribution from vessel wakes. The study required a method to predict changes in vessel wake energy delivered to the shoreline resulting from changes in the vessel fleet composition.

A Post Panamax (PP) Generation III container vessel (beam: 158.3 ft; length: 1,200 ft; draft: 50.0 ft) was recommended as the design vessel for deepening Charleston Harbor. No PP Generation III vessels can access Charleston Harbor; thus, a PP Generation II (beam: 150 ft; length: 1200 ft; draft: 45 ft) was used as the pre-deepening design vessel for these analyses; its draft is set equal to the lesser of its design draft or the nominal harbor depth.

The Post 45 vessel classification scheme defined vessel classes by beam (USACE 2015). AIS data collected from 2010 to 2012 and obtained from the U.S. Coast Guard were filtered according the Post 45 scheme with AISAP to obtain vessel summary statistics. The observed vessel draft and length ranges are listed by vessel class in Table 1.

Table 1. AIS-derived 2010–2012 vessel class dimensions (USACE 2015).

Vessel Class	Beam (ft)	Typical Draft* (ft)	Typical Length (ft)
Sub Panamax	76–99	24–36	480–750
Panamax	99–110	29–39	685–950
Post Panamax Generation I	110–135	33–45	800–1020
Post Panamax Generation II	135–152	35–46	930–1130
Post Panamax Generation III	>152	-	-

*AIS contains a ship's design draft, which is the ship's maximum draft. AIS does not reflect the actual bow and stern sailing drafts.

The overall study footprint of this investigation is based on the current and maximum alternative channel widths evaluated during the Post 45 study. The greater study area was divided into four "areas of interest" as shown in Figure 1. Division was based on ship-speed patterns observed from AIS data in AISAP.

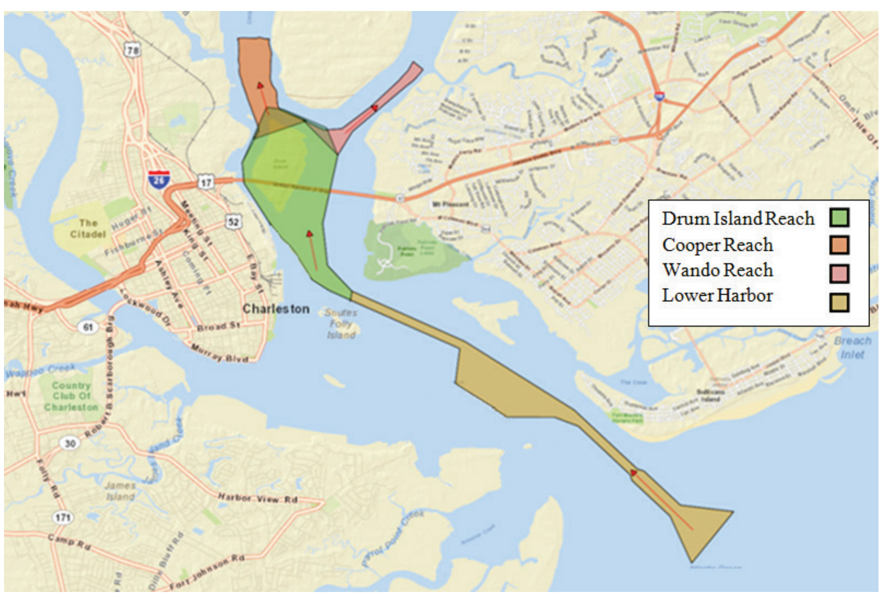

Figure 1. Four areas of interest in the study area. Arrows indicate the inbound transit direction.

Bank-to-bank bathymetry data collected in 2012 provided baseline channel depths relative to mean lower low water (MLLW), with the shallowest water in the Cooper Reach at the minimum maintained depth of 45 ft. Uniform deepening was assumed to occur throughout each AOI in each deepening scenario relative to the actual depth of each reach as determined from cross-section surveys).

ESTIMATING VESSEL WAVE HEIGHT: Estimates of vessel-generated wave heights and power were determined for the vessel traffic in the harbor as presently maintained. Vessel unit wave energy contributions are used as a proxy for total energy delivered to the shoreline from ship traffic.

The empirical model proposed by Kriebel and Seelig (2005) for generalized commercial vessels, consisting of Equations 1–5, was used to estimate vessel-generated wave heights from AIS data:

$$\frac{gH}{v^2} = \beta\left(F^* - 0.1\right)^2 \left(\frac{y}{L}\right)^{-\frac{1}{3}} \tag{1}$$

$$\beta = 1 + 8 * \tanh^3\left[0.45\left(\frac{L}{L_e} - 2\right)\right] \tag{2}$$

$$F* \;=\; F_{L*}\exp^{(\alpha * d/D)} \tag{3}$$

$$a = 2.5\left(1 - C_B\right) \tag{4}$$

$$F_L = \;v / \left(g * L\right)^{1/2} \tag{5}$$

where:

- g = gravitational constant, feet per second squared (ft/s^2)
- H = vessel generated wave height, ft
- v = ship velocity relative to water, feet per second (ft/s) (ship velocity from AIS)
- L_e = entrance length, ft, per Maynord (2007)
- C_B = block coefficient, 0.6–0.8 for Cargo Ships, per PIANC (2002)
- β = hull coefficient based on L_e
- F^* = modified Froude number
- y = distance from sailing line, ft (sailing line location from AIS)
- L = vessel length, ft (from AIS)
- D = depth of water, ft
- α = hull coefficient based on C_B
- d = vessel draft, ft (from AIS)
- F_L = length-based Froude number.

ESTIMATING VESSEL WAKE POWER: The method employed by Maynord et al. (2008) was used to quantify estimates for the total vessel fleet wave action in 2011 and for future projections. Wave heights were converted to total wave power using equations 6–11 (USACE 2008):

$$\theta = 35.27\left(1 - exp^{(12(F-1))}\right) \tag{6}$$

$$C = v * cos(\theta) \tag{7}$$

$$F = v / (g * D)^{1/2} \tag{8}$$

$$C^2 = (g * L_w / 2 * \pi) * tanh\ (2 * \pi * D / L_w) \tag{9}$$

$$E = \rho * g * H^2 / 8 \tag{10}$$

$$P = (C/2)\ E \tag{11}$$

where:

F = Froude number
θ = angle of wave propagation, degrees
C = wave celerity (phase velocity), meters per second (m/s)
v = ship velocity relative to the water, m/s (ship velocity from AIS)
E = wave energy at y, J per square meter (m^2)
P = wave energy flux, or wave power, through a vertical plane perpendicular to wave propagation direction for deep water, W/m
ρ = density of water, 1025 kilograms per cubic meter (kg/m^3) for salt water)
g = gravitational constant, meters per second squared (m/s^2)
H = vessel-generated wave height, m^2
L_w= wavelength, m.

Equation 9 is the dispersion relationship and was used to estimate wavelength to determine whether the vessel-generated waves are shallow water, transitional, or deep-water waves. The calculated wavelengths ranged from 16.5 to 75.5 ft (5 to 23 m) in the 45 ft (13.7 m) channel depth. The available depth is greater than half the wavelength; vessel-generated waves in this case can be classified as deep water waves, and the use of Equation 11 to estimate power is appropriate.

APPLYING AIS DATA: Vessel length, draft, and velocity parameters used in Equations (1–5) were determined directly from AIS data. AISAP was used to analyze 5,794,032 vessel position reports representing 26,614 transits made by 1,550 unique vessels as listed in Table 2. Transits observed in 2011 are listed in Table 3. Projected vessel transit counts for the first and last year of this study (2022 and 2037, respectively) are listed in Table 4.

Table 2. Vessel and transit counts by vessel classes (January 2010–March 2012).

Vessel Class	Beam (ft)	No. Vessels	No. Transits	No. Reports
Sub Panamax	76–98.9	241	1,151	433,115
Panamax	99–109.9	704	6,121	2,432,210
PP Generation I	11 –134.5	60	891	350,361
PP Generation II	135–152	38	276	108,161
PP Generation III	>152	-	-	-

Table 3. Total annual vessel transits during 2011 for each reach.

Vessel Class	Full Channel	Lower Harbor	Drum Island	Cooper	Wando
Sub Panamax	438	419	412	232	274
Panamax	6,290	6,150	6,198	2,442	4,321
PP Generation I	1,503	1,458	1,499	145	1,317
PP Generation II	349	331	331	76	317
PP Generation III	0	0	0	0	0

Table 4. Future total estimated vessel transits in the entire AOI.

Vessel Class	Year	No Deepening	3 ft Deepening	5 ft Deepening	7 ft Deepening
Sub Panamax	2022	700	700	700	700
Panamax	2022	6,630	5,898	5,873	5,860
PP Generation I	2022	5,009	5,009	5,009	5,009
PP Generation II	2022	1,160	1,160	1,160	1,160
PP Generation III	2022	90	90	90	90
Sub Panamax	2037	1,050	1,050	1,050	1,050
Panamax	2037	10,077	7,259	7,060	7,009
PP Generation I	2037	4,188	4,050	4,018	3,996
PP Generation II	2037	3,130	3,068	3,051	3,051
PP Generation III	2037	1,198	1,170	1,170	1,170

Vessel speed and dimension averages, listed in Tables 5 and 6, were needed to determine vessel-generated wave heights with the Kriebel and Seelig model (2005). Charleston Harbor AIS position data for 2010, 2011, and January–March of 2012 were partitioned by the vessel beam classification established in the Post 45 cargo projection. It was assumed that draft-constrained vessels (all PP generations) will increase draft as the harbor is deepened (Stolker and Verheij 2006). The average vessel dimensions from the AIS data and deepening scenarios led to the development of typical vessel dimensions by class in Table 5.

Table 5. Vessel dimensions for vessel wake analysis.					
Timeframe	**Deepening**	**Vessel Class**	**Draft (ft)**	**Length (ft)**	**Beam (ft)**
2011 and Future*	No Deepening	Sub Panamax	30.1	611.4	89.8
2011 and Future*	No Deepening	Panamax	34.6	816.4	104
2011 and Future*	No Deepening	PP Generation I	38.9	906.7	126.2
2011 and Future*	No Deepening	PP Generation II	40.5	1,030.9	141.3
2011 and Future*	No Deepening	PP Generation III	43	1200	158.3
Future*	3 ft Deepening	Sub Panamax	30.1	611.4	89.8
Future*	3 ft Deepening	Panamax	34.6	816.4	104
Future*	3 ft Deepening	PP Generation I	41.9	906.7	126.2
Future*	3 ft Deepening	PP Generation II	43.5	1,030.9	141.3
Future*	3 ft Deepening	PP Generation III	46	1200	158.3
Future*	5 ft Deepening	Sub Panamax	30.1	611.4	89.8
Future*	5 ft Deepening	Panamax	34.6	816.4	104
Future*	5 ft Deepening	PP Generation I	43.9	906.7	126.2
Future*	5 ft Deepening	PP Generation II	45.5	1,030.9	141.3
Future*	5 ft Deepening	PP Generation III	48	1200	158.3
Future*	7 ft Deepening	Sub Panamax	30.1	611.4	89.8
Future*	7 ft Deepening	Panamax	34.6	816.4	104
Future*	7 ft Deepening	PP Generation I	45.9	906.7	126.2
Future*	7 ft Deepening	PP Generation II	47.5	1,030.9	141.3
Future*	7 ft Deepening	PP Generation III	50	1200	158.3

*Future includes all forecast years including 2022, 2027, 2032, and 2037.

Vessel speed over ground (SOG) was determined by class and reach from AIS data. The average and standard deviation over the full AOI as shown in Table 6. Vessel speeds were highest in the lower reach of the harbor.

Table 6. Average speed and standard deviation in the AOI.						
	2010		**2011**		**2012***	
Vessel Class	**SOG (knots)**	**σ**	**SOG (knots)**	**σ**	**SOG (knots)**	**σ**
Sub Panamax	9.8	2.3	10.1	2.1	9.4	2.6
Panamax	10.1	2	10.3	1.9	10.4	2.1
PP Generation I	9.8	1.5	10.1	1.6	10	2
PP Generation II	9.7	1.5	9.3	2	9.3	2.6

*January through March 2012 were included in this study.

The vessel dimension data in Table 5 and the speed data in Table 6 were used in Equations (1–5) to calculate wave heights for class representative vessels in Charleston Harbor listed in Table 7.

It was necessary to account for the difference between vessel speed through the water and SOG. To conservatively estimate generated wave heights, vessel SOG measured by AIS was adjusted by adding a reach-dependent current speed ranging from 1.38 to 2.1 ft/s This speed was the average of 50 acoustic Doppler current profiler (ADCP) measurements at least 10 minutes in duration made on 8 May 2012 to observe that month's greatest tidal current. Transits were also assumed to be made at MLLW, which artificially constrained the flow area of the channel. A distance from the AIS-estimated sailing line of 975 ft was selected for alternatives comparison, based on a desired y/L ≈ 1, consistent with the method used by Kriebel and Seeling (2005) in the formulation of Equation (1). Vessel block coefficient was selected according to typical values for cargo ships from the *Guidelines for the Design of Fender Systems* (PIANC 2002).

Table 7. Wave heights (inches) produced by vessel class at a reference point near the edge of the federal channel 975 ft from sailing line at low tide.

Deepening Depth		Existing Conditions	Future* Conditions	Future* Conditions	Future* Conditions	Future* Conditions
Vessel Class	**AOI**	**N/A**	**No Deepening**	**3 ft Deepening**	**5 ft Deepening**	**7 ft Deepening**
Sub Panamax	Full Channel	1.78	1.78	1.62	1.53	1.45
Panamax	Full Channel	2.51	2.51	2.24	2.09	1.95
PP Generation I**	Full Channel	1.80	1.80	1.87	1.91	1.95
PP Generation II**	Full Channel	1.30	1.30	1.35	1.37	1.40
PP Generation III**	Full Channel	-	1.28	1.32	1.34	1.36
Sub Panamax	Lower Harbor	4.49	4.49	4.13	3.93	3.75
Panamax	Lower Harbor	7.30	7.30	6.62	6.24	5.89
PP Generation I**	Lower Harbor	5.35	5.35	5.52	5.63	5.72
PP Generation II**	Lower Harbor	4.24	4.24	4.36	4.44	4.51
PP Generation III**	Lower Harbor	-	4.34	4.43	4.49	4.54
Sub Panamax	Drum Island	0.83	0.83	0.74	0.69	0.64
Panamax	Drum Island	0.69	0.69	0.58	0.53	0.48
PP Generation I**	Drum Island	0.61	0.61	0.63	0.65	0.66
PP Generation II**	Drum Island	0.50	0.50	0.51	0.53	0.54
PP Generation III**	Drum Island	-	0.47	0.48	0.49	0.50
Sub Panamax	Cooper Reach	0.55	0.55	0.48	0.45	0.41
Panamax	Cooper Reach	0.66	0.66	0.55	0.50	0.45
PP Generation I**	Cooper Reach	0.79	0.79	0.82	0.84	0.86
PP Generation II**	Cooper Reach	0.08	0.08	0.09	0.09	0.09
PP Generation III**	Cooper Reach	-	0.07	0.07	0.07	0.07
Sub Panamax	Wando Reach	0.56	0.56	0.49	0.46	0.42
Panamax	Wando Reach	0.51	0.51	0.43	0.38	0.35
PP Generation I**	Wando Reach	0.19	0.19	0.20	0.21	0.21
PP Generation II**	Wando Reach	0.12	0.12	0.13	0.13	0.14
PP Generation III**	Wando Reach	-	0.10	0.11	0.11	0.11

*Future includes all forecast years including 2022, 2027, 2032, and 2037.
**Draft varied based on the available minimum depth as indicated in Table 3.

RESULTS: Wave heights were determined to increase up to 0.4 inch (in.) in deepened harbor scenarios. Panamax and smaller vessels produced wave heights that decreased up to 1.4 in. with increasing channel depth. As expected, larger vessels generated larger waves during transit. Vessels with draft-to-depth ratios that decreased following deepening generated smaller waves.

The Post 45 study assumes that a changing fleet of vessels will carry a fixed volume of cargo through the harbor. The number of vessels using the harbor thus increases with projected cargo volume for all alternatives (Tables 3 and 4) based on known port capacities, expected growth, and call patterns of vessels predicted to transit the Cooper and Wando Rivers, with the greatest port growth expected to occur along the Cooper River.

Table 8 lists annual wave power estimate of generated per meter of wave crest by the vessel population in each reach for 2011. Actual and projected fleet populations (Table 4) were used to convert wave heights to wave power along the line of interest at 975 ft from the sailing line (Table 9) for the entire fleet per year for each alternative relative to the calculated 2011 baseline (Table 8).

Table 8. Total annual power of 2011 fleet (Panamax through PP Generation III). Power values are for relative comparison only and are not representative of total harbor-wide power.

AOI	Power* (kW/m of wave crest)
Full channel	0.0891
Lower harbor	0.8864
Drum Island	0.0057
Cooper	0.0018
Wando	0.0018

The vessel population forecasts for the Sub Panamax fleet were assumed to increase consistently over time and grow consistently for all deepening scenarios. The impacts of Sub Panamax vessel were considered to be independent from the Panama Canal expansion and harbor deepening, and these were not considered in the comparison of alternatives.

Any scenario with harbor deepening results in a projected reduction in vessel traffic volume that outweighs increases in vessel size compared to the no-action alternative. This results in a lower relative energy contribution in any deepened scenario compared to no-action. The results listed in Table 9 indicate that effects of vessel traffic growth will be lessened by harbor deepening.

Table 9. Change in annual power of future scenarios for 2011 fleet (Panamax through PP Generation III).

AOI	Year	No Deepening	3 ft Deepening	5 ft Deepening	7 ft Deepening
Full channel	2022	32.7%	8.4%	1.4%	-4.1%
Lower harbor	2022	34.3%	12.2%	6.0%	1.1%
Drum Island	2022	47.0%	21.1%	13.8%	8.7%
Cooper*	2022	145.8%	128.6%	122.2%	118.4%
Wando	2022	-4.2%	-30.3%	-42.6%	-52.1%
Full channel	2037	86.1%	27.5%	16.5%	9.2%
Lower harbor	2037	90.1%	34.5%	24.6%	18.0%
Drum Island	2037	103.1%	43.6%	32.3%	25.4%
Cooper*	2037	156.8%	121.4%	105.7%	94.5%
Wando	2037	42.6%	3.2%	-15.4%	-29.8%

*Vessel traffic is expected to increase greatly in the Cooper River due to expansion of upstream ports.

DISCUSSION: AIS data allow for significantly more vessel observations than typical studies. Maynord (2007) observed 101 vessel transits over 6 days in 2005 in support of a harbor deepening study at the port of Savannah, GA. This amounts to a study that covers approximately 1% of the 7,782 vessels transiting the harbor that year (USACE 2005). In comparison, AIS data captured 8,358 transits (lower harbor), or 98%, of 8,531 transits reported to USACE in 2011 (USACE 2011).

With access to AIS data, the need for field observations can be reduced to specialized cases where AIS data are insufficient. Winkler (2012) discusses data quality concerns and methods being made by the U.S. Coast Guard to encourage improvement of data quality at the source of AIS transmission. In light of known AIS data quality issues, some form of validation of AIS data may be required. User-specified filtering based on vessel characteristics can be applied to exclude problematic data at little cost to accuracy, given the significant available coverage of AIS.

Wave height and power resulting from a vessel transit are influenced by factors including the ratio of vessel depth to vessel draft, hull shape, and the vessel's speed through the water. Total wave energy available to be delivered to the shoreline depends on the number of vessels, length of transit, and the distance to the shoreline. The changes in draft and available depth for larger Post Panamax vessel generations under deepening scenarios compared to existing conditions result in wave heights that are only marginally larger than those of existing traffic, while Panamax and Sub Panamax vessels generated marginally lower wave heights. However, the fixed future cargo projections across all deepening scenarios, and the loading efficiency gained in scenarios where Post Panamax vessels can call on the harbor, result in higher total available energy in the un-deepened scenario. This is due to the projected future requirement of relatively more ships in the no-action scenario to carry future projected cargo volumes. Present in all scenarios, but uninvestigated here, are the impacts of non-cargo vessels. It has been suggested[1] that wind-generated waves and waves generated by smaller displacement vessels (e.g., tugs and service craft) may be more important than container vessels for shoreline impacts in Charleston Harbor.

CONCLUSIONS: AIS technology has reached a point of maturing and widespread adoption that benefits USACE practitioners. Low-cost data are available over a wide spatial and temporal extent, making it a useful resource for planners, designers, and managers. New tools such as AISAP allow for rapid data acquisition, analysis, and visualization of millions of vessel reports. Access to AIS data now enables studies of all budgets and schedules to apply actual vessel traffic data in U.S. coastal regions. The method presented here may provide the basis for an efficient and objective standardized approach to comparative analysis of vessel wake effects of proposed feasibility study alternatives.

The AISAP tool was used with AIS data available in Charleston Harbor to estimate that the increase in wave heights for Post Panamax vessels transiting in deepened navigation channels were less than 0.5 ft. However, total energy input to the waterway resulting from vessel traffic increased by the greatest amount in the no-action alternative as compared to any deepening scenario. Available energy increases were due to greater numbers of vessels with lesser cargo

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[1] Teeter, A., H. Benson, and C. Callegan. Draft report. Shoreline Conditions near Hobcaw Point, Wando River, Charleston Harbor, South Carolina. (For more information, contact the author, Brandan Scully, Brandan.M.Scully@usace.army.mil.)

capacity required to transport projected cargo flows. Thus, it was determined that given the study projections for cargo growth and future vessel populations, shoreline impacts would likely be less in future scenarios where deepening was performed than in non-deepened scenarios.

ADDITIONAL INFORMATION: This Coastal and Hydraulics Engineering Technical Note (CHETN) was prepared as part of the USACE Coastal Inlets Research (CIRP) Program by Anne McCartney, formerly of the U.S. Army Engineer District, Charleston, SC (SAC), and Brandan Scully of the U.S. Army Engineer Research and Development Center, (CE-ERD). Additional information regarding the CIRP can be found at the CIRP website *http://cirp.usace.army.mil*.

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