FERRY LANDING DESIGN CRITERIA II: VESSEL TRACKING METHODS FOR FERRY LANDING DESIGN

WA-RD 267.1

Final Technical Report
October 1993

Washington State
Department of Transportation

Washington State Transportation Commission
Transit, Research, and Intermodal Planning (TRIP) Division
in cooperation with the U.S. Department of Transportation
Federal Highway Administration

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO.	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
WA-RD 267.1		

4. TITLE AND SUBTITLE	5. REPORT DATE
FERRY LANDING DESIGN CRITERIA II: VESSEL TRACKING METHODS FOR FERRY LANDING DESIGN	October 1993
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)	8. PERFORMING ORGANIZATION REPORT NO.
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9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. WORK UNIT NO.
Washington State Transportation Center (TRAC) University of Washington, JE-10 The Corbet Building, Suite 204; 4507 University Way N.E. Seattle, Washington 98105	11. CONTRACT OR GRANT NO. Agreement T9233, Task 23
12. SPONSORING AGENCY NAME AND ADDRESS	13. TYPE OF REPORT AND PERIOD COVERED
Washington State Department of Transportation Transportation Building, MS 7370 Olympia, Washington 98504-7370	Final Technical Report
	14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

This study was conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

16. ABSTRACT

Methods for recording the approach path and approach velocity of berthing vessels are developed and tested. Methods include video camera observations from shore, video camera observations of the radar screen, and global positioning system (GPS) tracking. The methods are tested on the Washington State Ferry Edmonds to Kingston crossing. The video methods are useful for preliminary studies to obtain approximate results and familiarize investigators with the berthing process. The GPS records provide more precise results with less data reduction effort than other methods. Twenty four berthing maneuvers are recorded. Analysis of the GPS record shows a consistent pattern of velocity reductions as the vessel nears the landing structure.

17. KEY WORDS	18. DISTRIBUTION STATEMENT
Ferry, vessel, port design, berthing, global positioning systems, ferry landing design, fender design, ferry terminal design	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22616

19. SECURITY CLASSIF. (of this report)	20. SECURITY CLASSIF. (of this page)	21. NO. OF PAGES	22. PRICE
None	None	204	

Final Technical Report

Research Project T9233, Task 23
Ferry Landing Design Criteria—Phase II

VESSEL TRACKING METHODS FOR FERRY LANDING DESIGN

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Washington State Transportation Commission
Department of Transportation
and in cooperation with
U.S. Department of Transportation
Federal Highway Administration

October 1993

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TABLE OF CONTENTS

Section	Page
Summary	vii
Chapter 1. Introduction	1
Chapter 2. Video Tracking Methods	2
Background	2
Remote Video Method	5
Radar Image Method	10
Results	17
Conclusion	24
Chapter 3. GPS Tracking Method	25
GPS Tracking Methodology	32
Chapter 4. Findings: Results of GPS Tracking Method	75
Chapter 5. Conclusions and Recommendations	82
Operational Conclusions	82
Case Study Conclusions	83
Recommendations	84
References	86
Appendix A. Literature Review	A-1
Appendix B. Software Narratives	B-1
Appendix C. Software Configurations	C-1
Appendix D. Recorded Throttle Settings	D-1
Appendix E. Excel Macro for Converting Raw Data to Spreadsheet Format	E-1
Appendix F. Summary of Individual Landings	F-1
Appendix G. Throttle Setting vs. Time from Landing Structure Plots	G-1

LIST OF FIGURES

Figure		Page
2.1	Layout of Edmonds Terminal	3
2.2	Schedule: Kingston-Edmonds	4
2.3	Remote Video Camera Locations	6
2.4	Location of Camera and Bearings of Landmarks from Counterweight Location	7
2.5	Location of Camera and Bearings of Landmarks from Fishing Pier Location	8
2.6	Path of Ferry — Remote Video Method	11
2.7	Path of Ferry — Radar Image Method (MV *Yakima*)	13
2.8	Path of Ferry — Remote Video Method and Radar Image Method	15
2.9	Distance vs. Speed Plot — Radar Image Method (MV *Yakima*)	18
2.10	Distance vs. Speed Plot — Remote Video Method (MV *Tillikum*)	19
2.11	Distance vs. Speed Plot — Remote Video Method (MV *Hyak*)	20
2.12	Distance vs. Speed Plot — Remote Video Method (MV *Tillikum #2*)	21
3.1	GPS Sphere Intersections	26
3.2	Pseudo-Random Code	28
3.3	Pseudo-Random Code Offset	28
3.4	GPS Receiver Clock Offset Correction	29
3.5	Schematic Diagram of Mobile GPS Equipment	31
3.6	Schematic Diagram for the Reference GPS Equipment	33
3.7	GPS Analysis Flow Chart	34
3.8	Antenna Location for Reference Receiver	36
3.9	Location for GPS Mobile Antenna	37
3.10	Typical Output File of GPSLAB	38
3.11	Typical Output File of POSTNAV2	41
3.12	Survey Monument at Edmonds (Base Coordinate)	43
3.13	Survey Monument at Kingston (Base Coordinate)	44
3.14	File Structure of POSTNAV2 Output Files	45
3.15	Excel Formatted Spreadsheet	46
3.16	Velocity vs. Distance from Edmonds Landing Structure	47
3.17	Velocity vs. Distance from Kingston Landing Structure	48
3.18	Velocity vs. Distance from Landing Structures (5,000 ft)	49
3.19	Velocity vs. Distance from Edmonds Landing Structure(300 ft)	50
3.20	Velocity vs. Distance from Kingston Landing Structure (300 ft)	51
3.21	Velocity vs. Distance from Landing Structures (300 ft)	52
3.22	Velocity Distribution Histograms at Edmonds Terminal	54
3.23	Velocity Distribution Histograms at Kingston Terminal	55
3.24	Total Velocity Distribution Histograms	56
3.25	Adjustments to Throttle Settings for Edmonds Landing — 720EXX2	57
3.26	Adjustments to Throttle Settings for Edmonds Landing — 720EYY3	58
3.27	Consistent Throttle Settings vs. Time from Landing Structure for Master A	59
3.28	Inconsistent Throttle Settings vs. Time from Landing Structure for Master A	60
3.29	Comparison of Throttle Settings vs. Time from Landing Structure for Masters A, B, and C	61

Figure		Page
3.30	Excel Converted File (*.CSV)	62
3.31	Landing Approaches at Edmonds	63
3.32	Landing Approaches at Kingston	65
3.33	Distance Distribution Histograms at Edmonds	67
3.34	Distance Distribution Histograms at Kingston	68
3.35	Current Effects at Edmonds	71
3.36	Current Effects at Kingston	73
4.1	Velocity vs. Distance from Landing Structure — Distorted Data	78

LIST OF TABLES

Table		Page
3.1	Tidal Current Speed and Tidal Direction	69
4.1	Relative Cumulative Frequencies of Velocities	79

SUMMARY

The purpose of this project was to develop a method for recording the approach path and approach velocity of ferries during their berthing maneuvers. This information will aid in improving both ferry landing designs and vessel operations policies.

The following methods were investigated: 1) video camera observation from shore; 2) video camera observation of vessel radar screens; and 3) satellite tracking using a global positioning system (GPS). These methods were tested on the Washington State Ferry System's Edmonds to Kingston crossing. Three berthing maneuvers were analyzed from shore-based video cameras' records, one from radar screen video records, and 24 from GPS records. Software was developed to automatically reduce the GPS data, plot landing paths, and display velocity information.

The researchers found the video methods useful in preliminary studies to obtain approximate positions (+/- 200 ft) and to familiarize themselves with the berthing process. However, GPS provided more precise positions (+/- 10 ft to 30 ft) with less data reduction effort.

Graphs of vessel velocity vs. distance from the landing structure indicate a pattern to the berthing maneuvers. The vessels crossed the Sound at 26 ft/sec to 29 ft/sec At approximately 1,500 ft from the landing, the vessels slowed. At 500 ft, the velocity was 10 ft/sec to 15 ft/sec; at 150 ft, the velocity was 6 ft/sec to 8 ft/sec and the vessel landed at less than 1 ft/sec. Vessel velocity was 7 ft/sec to 11 ft/sec near the outer landing aids (250 ft from the dock). Observations also showed that a pattern existed for throttle settings during berthing maneuvers. At approximately 1,500 ft from the dock, the throttle setting was reduced from full ahead to slow ahead. Later, the throttle was changed to slow astern, then half astern, then back to slow astern. After that, the throttle setting was varied as necessary to land the vessel.

The vessel paths varied by as much as 2,000 ft when the vessel was 5,000 ft from the landing; however, when the vessels were 1,000 ft from the landing, almost all landing tracks were within 200 ft of each other.

The researchers recommend that WSDOT make vessel tracking a regular part of the ferry landing design process to increase understanding of how vessels use landing aids and to obtain information on vessel approach velocities and approach paths. On the basis of these observations, WSDOT should design its outer landing aids (250 ft from the dock) for velocities of 12 ft/sec with a small angle of attack (the literature indicates that a 15 degree angle is often used).

CHAPTER 1

INTRODUCTION

Vehicular ferries are an important mode of transportation in many parts of the world today. Efficient ferry operation is of critical importance for communities where alternatives to vehicular and pedestrian traffic are limited. The vessels and landing structures must provide safe landings and short berthing times. The proper selection of vessel approach path and velocity is imperative for the proper design of landing structures and safe operation of vessels during berthing. However, little information is available on approach path or velocity of end berthing ferries.

This report will document the development of methods to record the approach of vessels into the landing structures. These methods were applied to provide an analysis of the approach path and velocity of Washington State Ferries (WSF) vessels in Edmonds and Kingston, Washington.

This study was divided into two parts. In the video tracking section, two video recording methods were utilized to track the vessels. In the GPS section, a global positioning system (GPS) was used to provide a more precise and accurate method of tracking the vessels.

Both methods were found to be helpful in providing information on final vessel berthing maneuvers. The GPS system was found to be more accurate and less labor intensive; however, the equipment costs were higher and more effort was required to initially establish the system. GPS is the preferred system when there are adequate funds and setup time.

CHAPTER 2

VIDEO TRACKING METHODS

Because GPS equipment was not acquired until after the researchers had begun the study, they first used video tracking methods to provide approximate velocities and approach paths of Washington State ferries. The basic principle of the video tracking method is that by determining azimuths from two known points to a single unknown point, one can calculate the location of that single point using basic trigonometry.

With the aid of video cameras, approach and berthing maneuvers were recorded on videotape. Two methods were used to estimate the position of the ferry. In the first method, the remote video method, the ferry is positioned in relation to known landmarks, which are located with the aid of optical surveying methods. Information from videotapes is used in conjunction with the results of the optical surveys to provide a plot of the ferry's path as it approaches the berth. In the second method, the radar image method, the vessel's radar screen is recorded on videotape during the ferry's berthing maneuvers. The information from the image of the radar screen provides a heading of the vessel and a distance from the dock for specific times during the berthing maneuvers. This method also gives the position of the ferry as it approaches the berth.

This research was conducted at the Edmonds Ferry Terminal, which is located approximately 16 miles north of Seattle. This site was chosen because vessels operate approximately every 45 minutes, from 6:00 a.m. to 10:00 p.m., from Kingston, a community on the west side of the Puget Sound, to Edmonds. The organization of the Edmonds Terminal is shown in Figure 2.1. A typical schedule of the ferry service from Edmonds to Kingston is shown in Figure 2.2.

BACKGROUND

To estimate the ferry's location from videotaped observations, the researchers established bearings from the camera locations which were at the counterweight structure

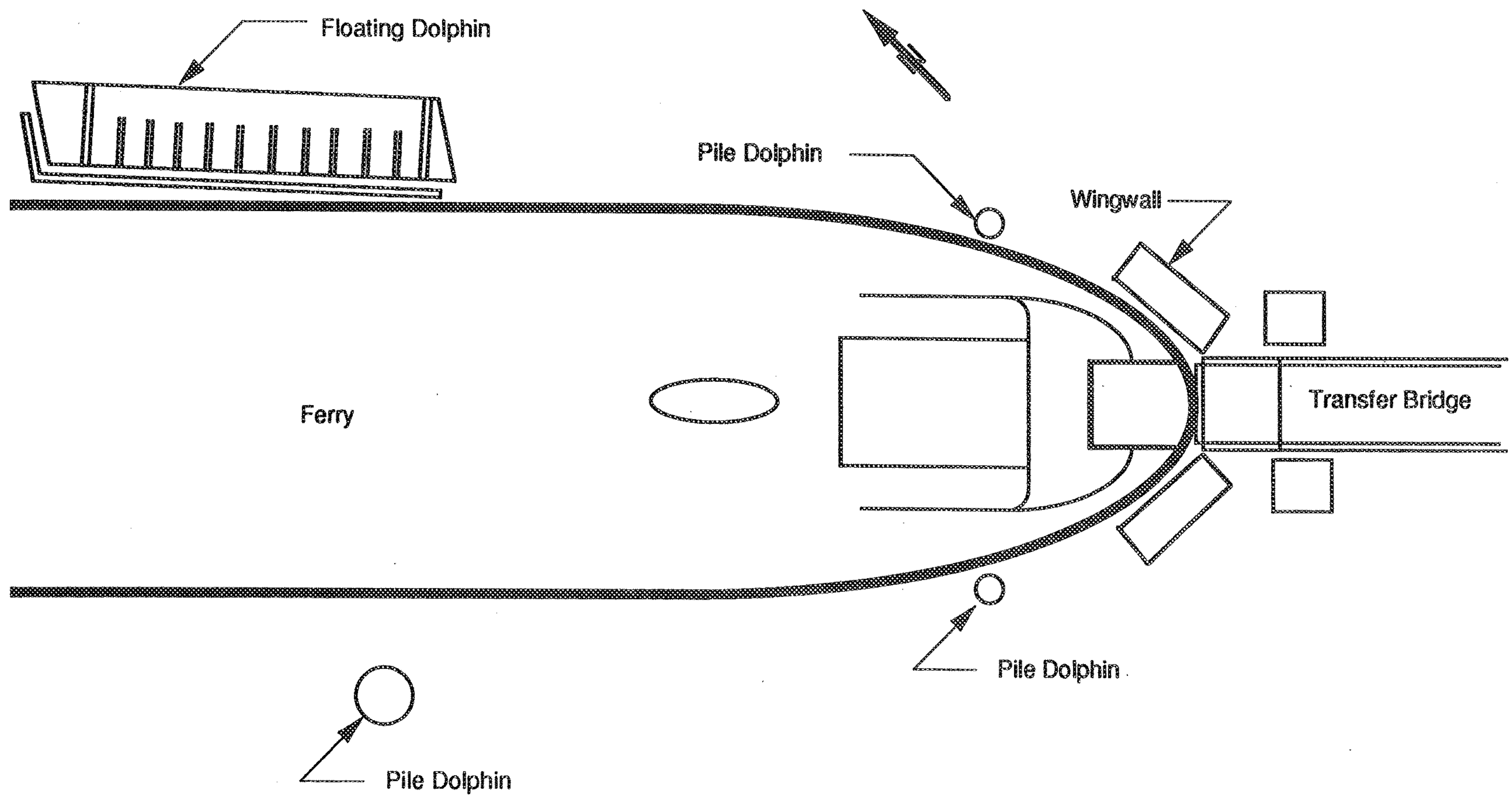
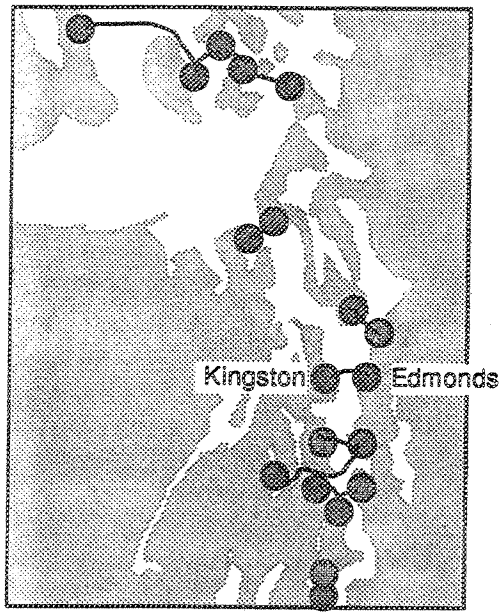


Figure 2.1 Layout of Edmonds Terminal



Edmonds-Kingston

Approximate crossing time 30 minutes

Monday thru Friday

Leave Edmonds		Leave Kingston	
5:50am	3:50	5:10am	3:10pm
6:30	4:30	5:50	3:50
7:10	5:10	6:30	4:30
8:00	5:50	7:10	5:10
8:40	6:30	7:50	5:50
9:25	7:20	8:40	6:30
10:10	7:55	9:25	7:15
10:50	8:40	10:10	8:00
11:30	9:15	10:50	8:35
12:10pm	10:35	11:30	9:55
12:55	11:45	12:10pm	11:10
1:40		12:55	
2:30		1:40	
3:10		2:25	

Saturdays, Sundays & Holidays

Leave Edmonds		Leave Kingston	
5:50am	3:50pm	5:10am	3:10pm
7:10	4:30	6:30	3:50
8:00	5:10	7:10	4:30
8:40	5:50	7:50	5:10
9:25	6:30	8:40	5:50
10:10	7::20	9:25	6:30
10:50	7:55	10:10	7:15
11:30	8:40	10:50	8:00
12:10pm	9:15	11:30	8:35
12:55	10:00	12:10pm	9:20
1:40	10:35	12:55	9:55
2:30	11:20	1:40	10:40
3:10	11:45	2:25	11:10

Figure 2.2 Schedule: Kingston-Edmonds

on the transfer bridge and at the fishing pier, approximately one-half mile south of the terminal (Figure 2.3), to selected fixed points and landmarks. They then noted the position of the ferry as it approached the landing. In particular, they noted the location of the vessel with respect to landmarks that were visible on the videotape.

REMOTE VIDEO METHOD

To preserve the observations and records, and to facilitate the analysis, the ferry's berthing maneuvers were recorded on videotape. One video camera was located below the counterweight tower and recorded a head-on view of the ferry's approach. A second camera was located at the fishing pier and recorded the side-view of the ferry's approach. The video cameras imprinted the recording time on the video image. The times on both cameras were synchronized before each landing operation. Before the videotapes were made, azimuths to known landmarks were established from both camera locations.

The survey equipment was set up at the counterweight camera's location (Edmonds Terminal), and bearings to four locations were taken. These four locations were as follows:

1. the north edge of the smallest dolphin on the terminal's south side,
2. the tallest pile in the 70-pile dolphin,
3. the edge of a clear-cut area on Bainbridge Island, and
4. the west end of the floating dolphin on the terminal's north side (Figure 2.4).

This process was repeated for the camera location at the fishing pier. Bearings were taken to the following nine locations (see Figure 2.5):

- three fixed light standards,
- three places on the hand rail of the fishing pier,
- the north edge of a beige metal booth,
- the south tip of Whidbey Island, and
- a floating buoy.

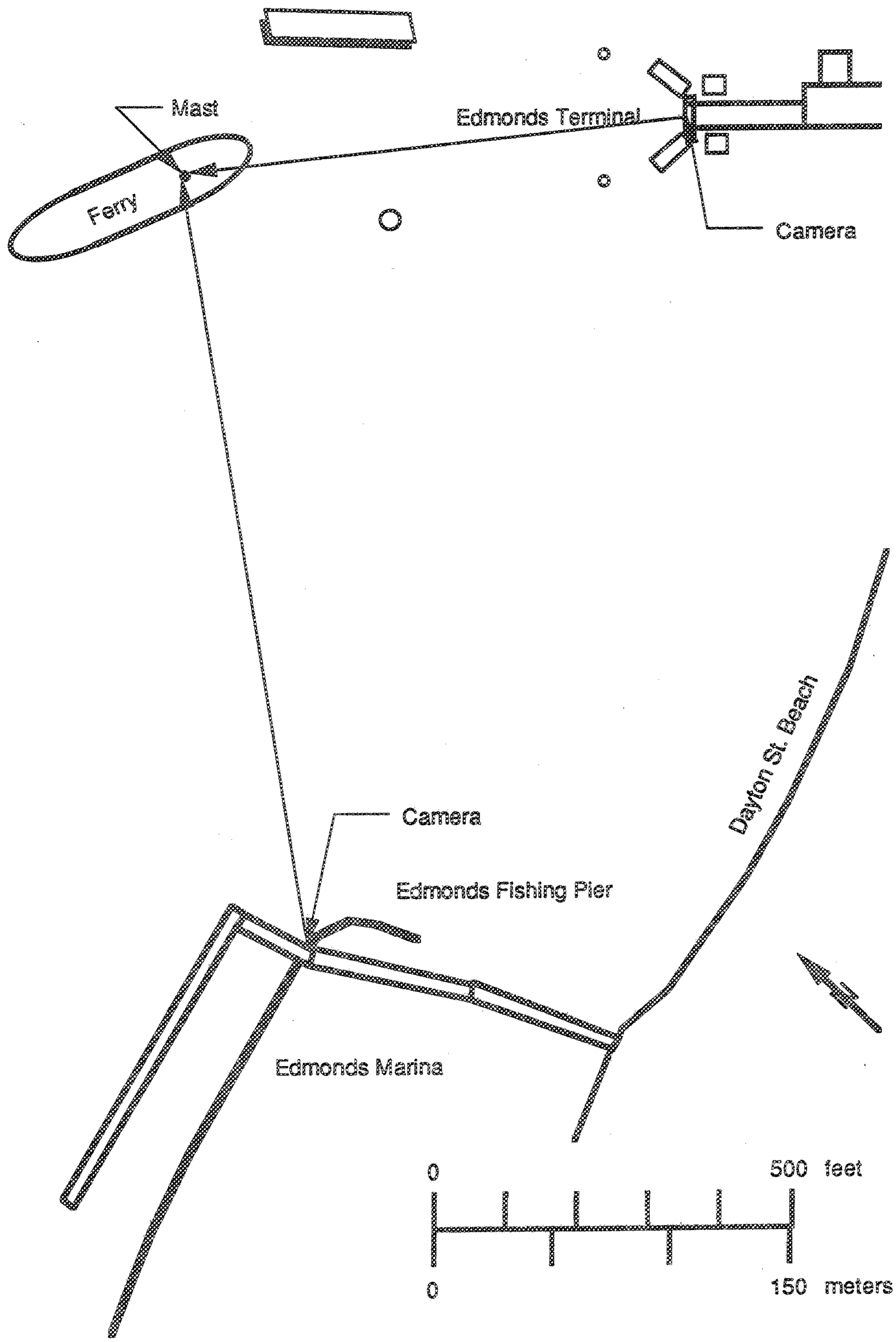


Figure 2.3 Remote Video Camera Locations

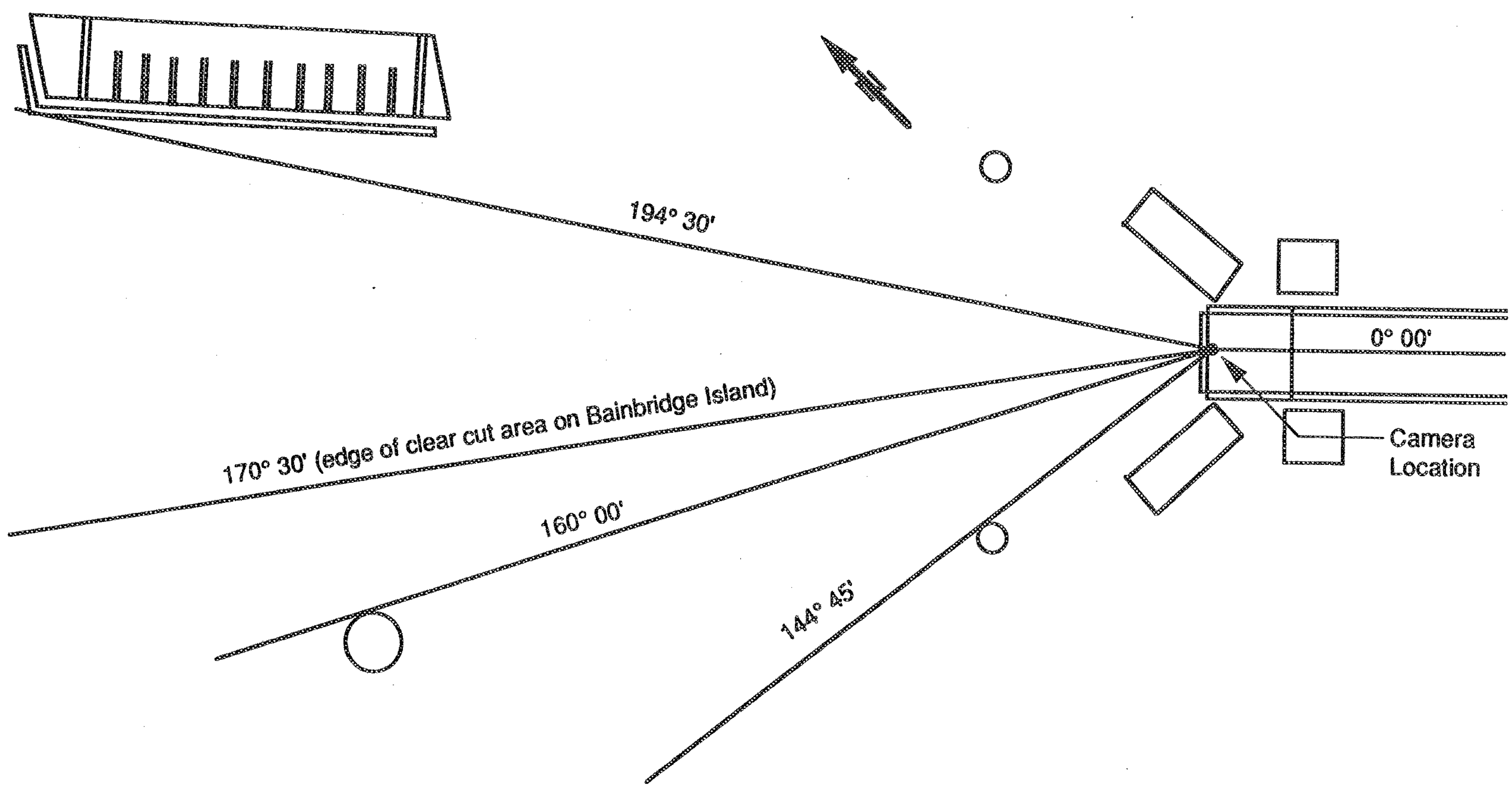


Figure 2.4. Location of Camera and Bearings of Landmarks from Counterweight Location

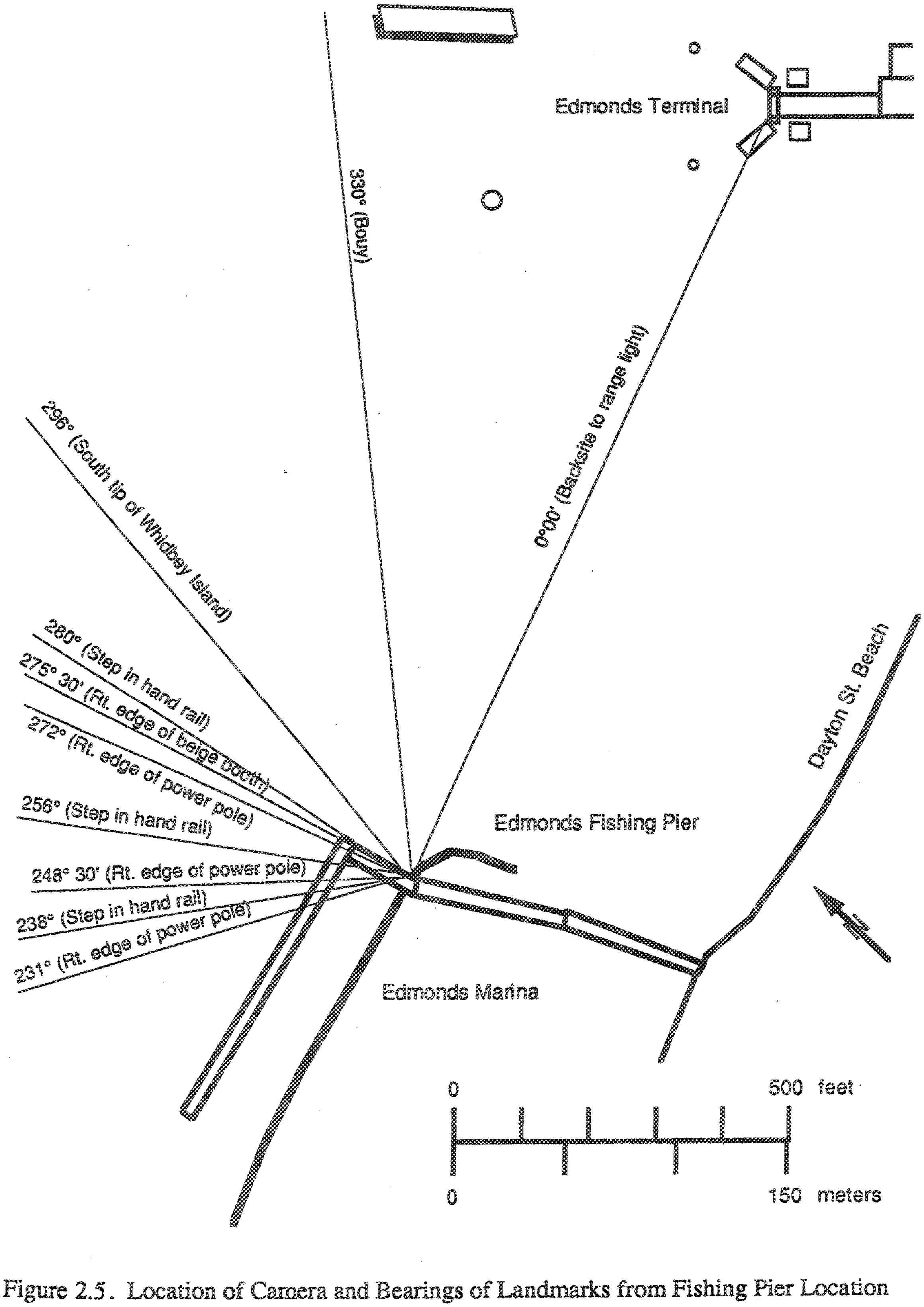


Figure 2.5. Location of Camera and Bearings of Landmarks from Fishing Pier Location

Before the azimuth between the vessel and the cameras could be estimated from the video image, a relationship had to be established between lengths measured on the video image and horizontal angles from the camera location. The following process was used:

1) The measurement on the video image was taken between two landmarks of known azimuth.
2) This measurement was divided by the angle separating the two landmarks.
3) The result of this division yielded the angle subtended per unit measurement on the video display.

This process was repeated for the other video camera separately because the cameras' lenses were set to different focal lengths.

Next, the azimuth between the vessel and the cameras was estimated. Because the vessel was moving, it was critical that the azimuths be estimated at the same time from each camera location. The following process was used:

1) At time T, the position of the ferry was estimated by identifying a fixed point on the ferry (i.e., the flag pole) in relation to a landmark on the video display.
2) The length on the video image was measured from the fixed point on the ferry to the landmark..
3) This length was then multiplied by the angle subtended per unit measurement.

The result of the calculation of step 3 was added or subtracted from the bearing of the landmark, yielding the approximate bearing from the vessel at time T. This procedure was repeated at regular intervals during the berthing maneuver.

Hence, for a given time, T, the researchers knew approximate bearings from the ferry to both the fishing pier camera and the counterweight camera. The camera locations were plotted on a map. Radial lines were drawn representing the bearings from each location. The intersection of the radial lines yielded the approximate location of the ferry at time T. In this way, a series of intersections were plotted. These intersections indicated the path of the ferry as it approached the landing structure. An example of the results are shown in Figure 2.6. (Video images for the final 600 to 800 feet (183 to 244 meters) before berthing were not available at the counterweight structure because, for safety reasons, the camera had to be removed from under the counterweight as the vessel approached.)

RADAR IMAGE METHOD

The ferry's position as it approached the berth was also estimated using the radar image method. In this method, a portable video camera recorded the image on the radar screen in the pilot house. The record of the radar images was supplemented by pilot house observations. During the final berthing, a member of the research team observed the approach from the pilot house. Throttle position, radar position, engine speed, gyro reading, and significant and atypical actions were recorded on the soundtrack of the video tape. Later, the videotapes were viewed on a video monitor and traced onto clear sheets. The outline of the land masses and the dock were included to indicate the tracing's orientation. Tracings were prepared for intervals of 15 or 30 seconds. If possible, the radar's gyro reading and scale of the radar image were also noted. In this way, the researchers obtained a series of plots (tracings) with a position at given times. Information from each sheet was plotted on a map of the area surrounding the Edmonds Terminal. Each position included distance from the dock, heading, time of day, and date. The result was a series of points that represented the approach path of the ferry. A sample plot that was produced by this method is shown in Figure 2.7. For comparison, the recorded landings from both methods can be seen in Figure 2.8.

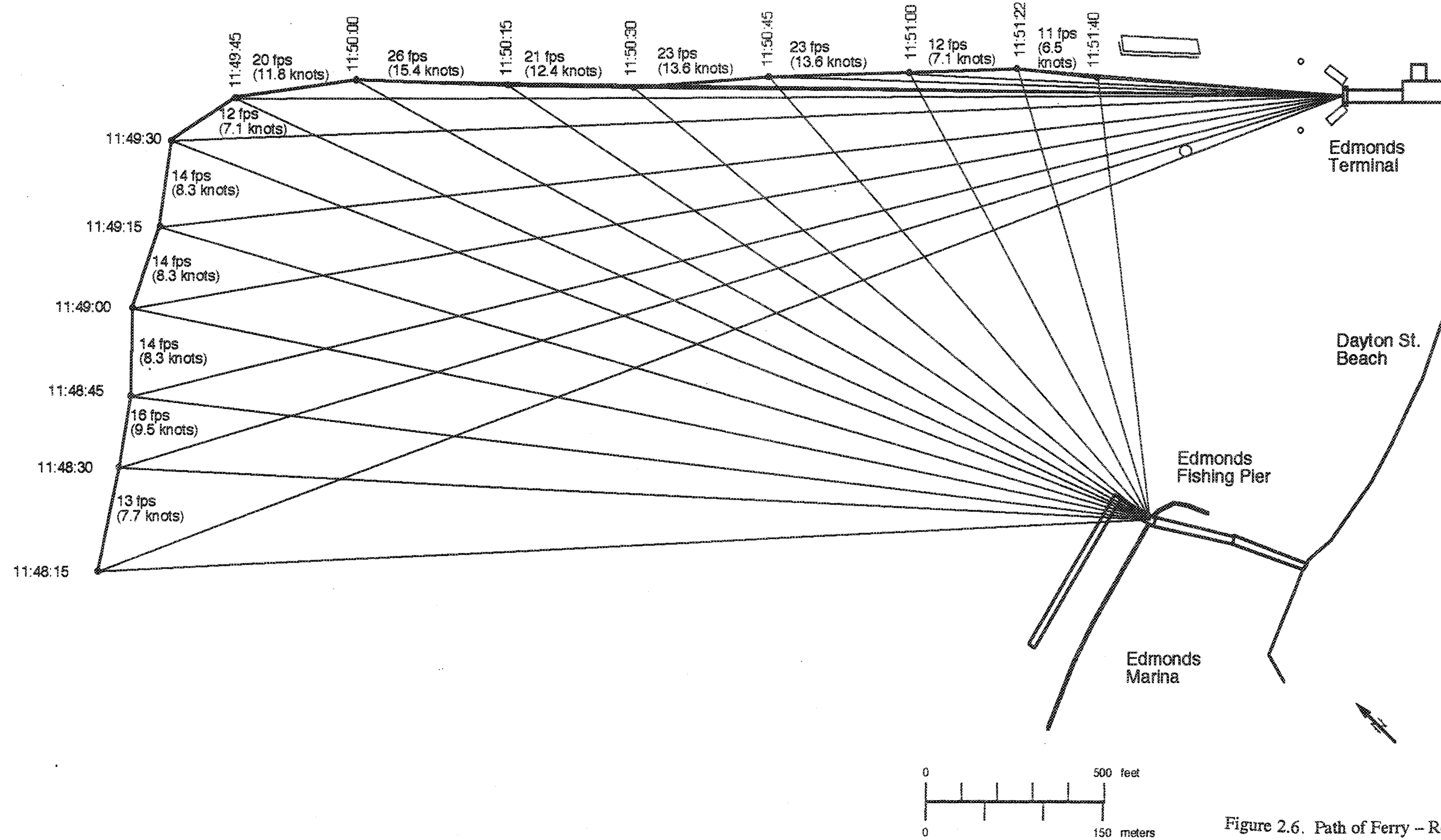


Figure 2.6. Path of Ferry – Remote Video Method

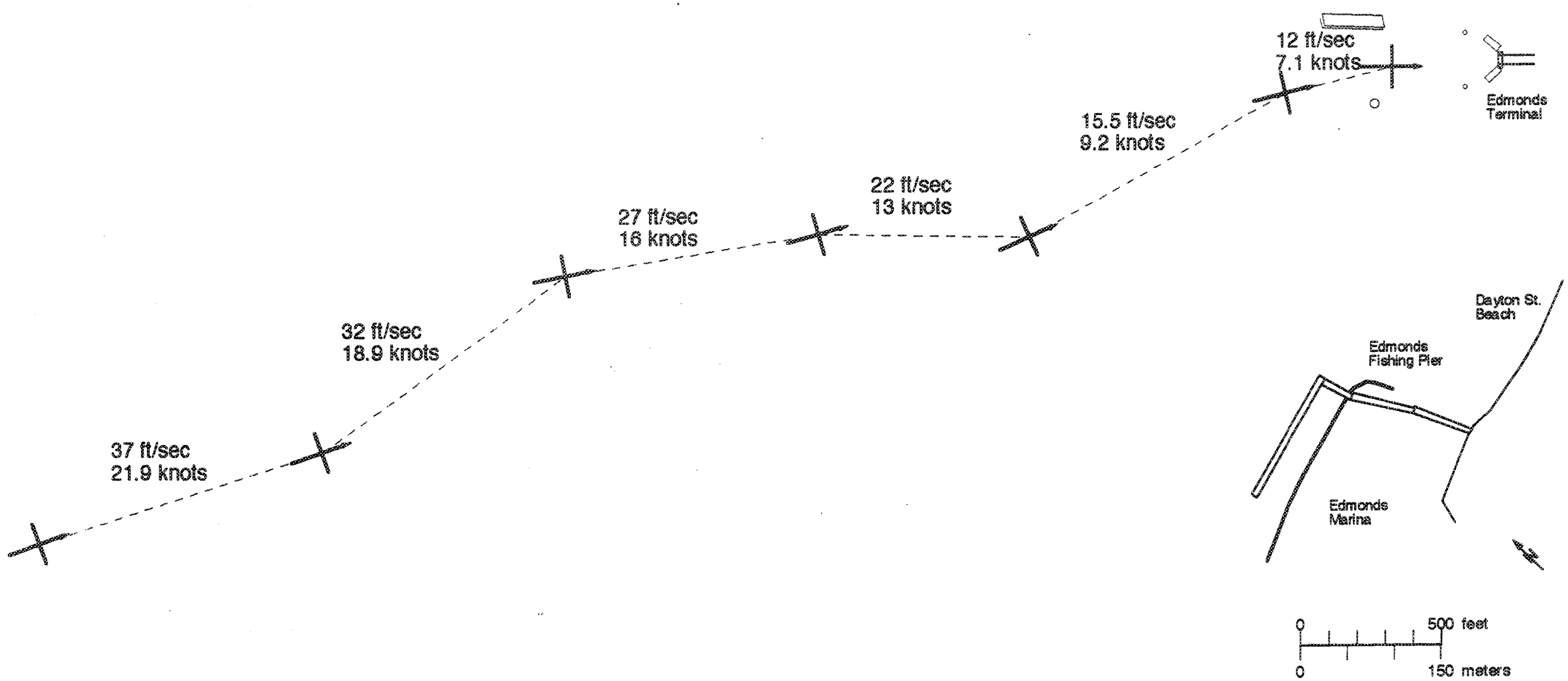


Figure 2.7. Path of Ferry – Radar Image Method (MV *Yakima*)

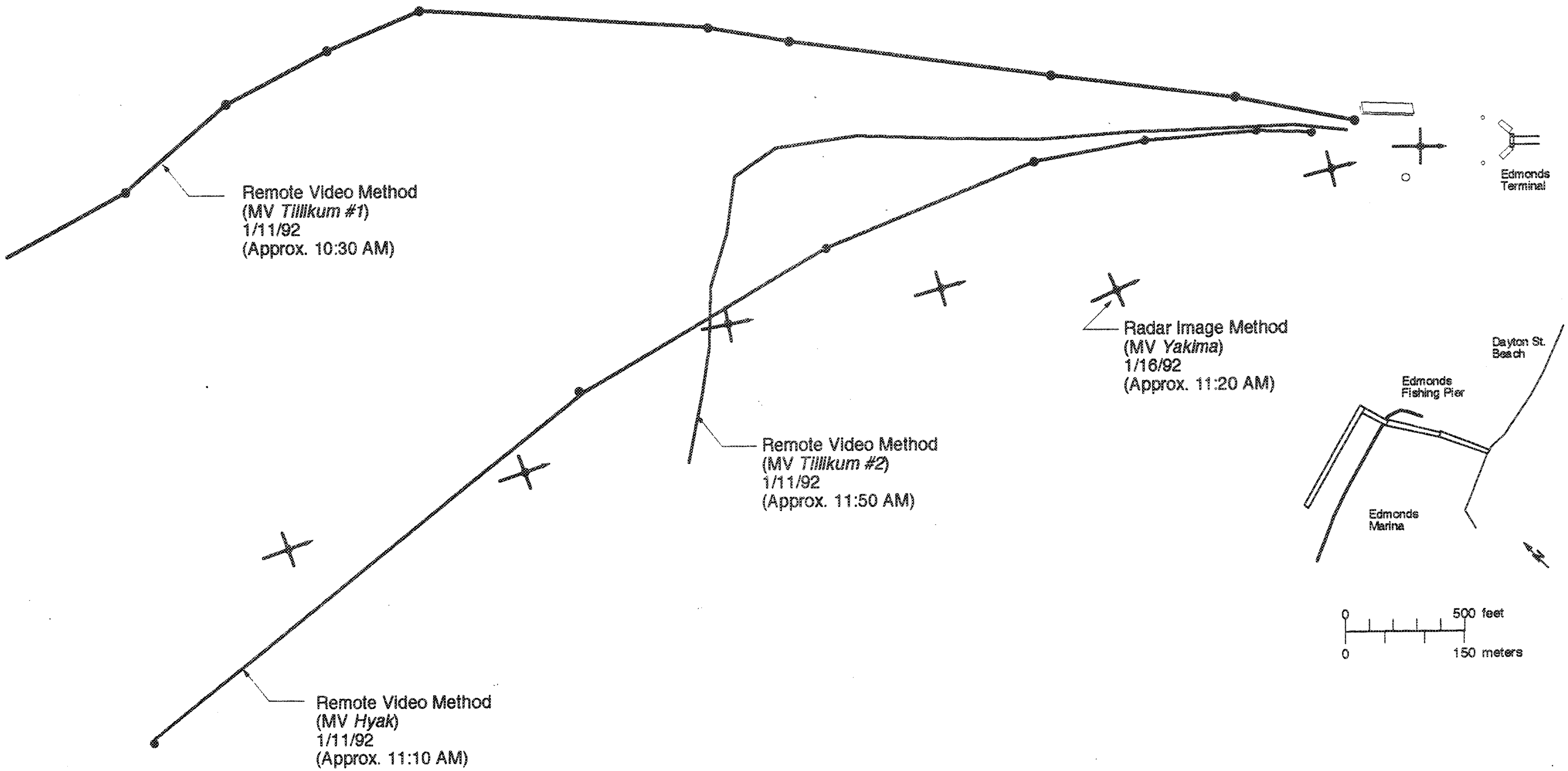


Figure 2.8. Path of Ferry – Remote Video Method and Radar Image Method

RESULTS

The researchers conducted further analyses on the remote video images to obtain the velocities desired for developing more accurate design criteria. Each ferry's path could be divided into segments (see Figure 2.6). The distance traveled per segment was obtained from the plot. To calculate an approximate velocity for each segment, the distance was divided by the time required to traverse that distance. These velocities were plotted against distance from the landing structure (Figures 2.9, 2.10, 2.11, and 2.12). The results indicated apparent fluctuations in the vessel's velocity as it approached the landing structure. It is probable that the actual velocity did not fluctuate and that the fluctuations seen in the results were caused by errors that will be discussed later. In some cases, the measured speed of the vessel exceeded its rated speed, especially at long distances from the cameras (for example, see Figure 2.10). This was further indication that the accuracy of this method is somewhat limited. The vessels' rated maximum speed was 17 knots (29 ft/sec) for the MV *Yakima* and MV *Hyak*, and 13 knots (22 ft/sec) for the MV *Tillikum*.

Many factors influenced the accuracy of these results. Both the remote video method and the radar image method incorporated the use of video recordings. Thus, all of the data were processed by viewing images from a video monitor. This often caused difficulty in locating objects because of the limited clarity of the image on the video monitor.

The remote video method introduced the following possibilities for error:

1. When estimating the vessel's position, the researchers compared the position of the vessel to the position of a defined landmark. However, it was often difficult to locate the landmark and the vessel's flagpole on the video image because the vessel blocked the line of sight to the landmark.

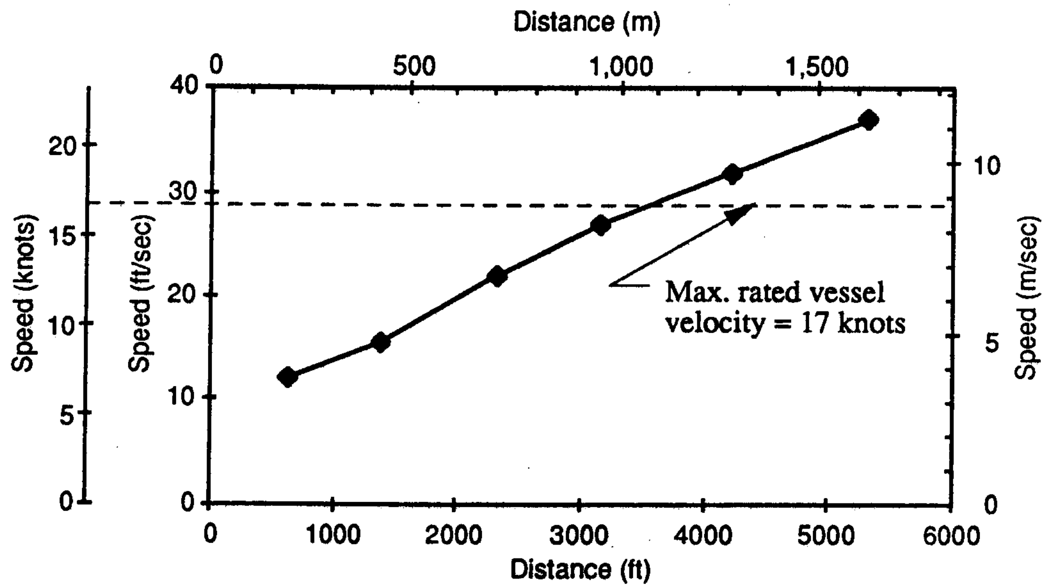


Figure 2.9. Distance from Landing Structure vs. Speed Plot - Radar Image Method (MV *Yakima*)

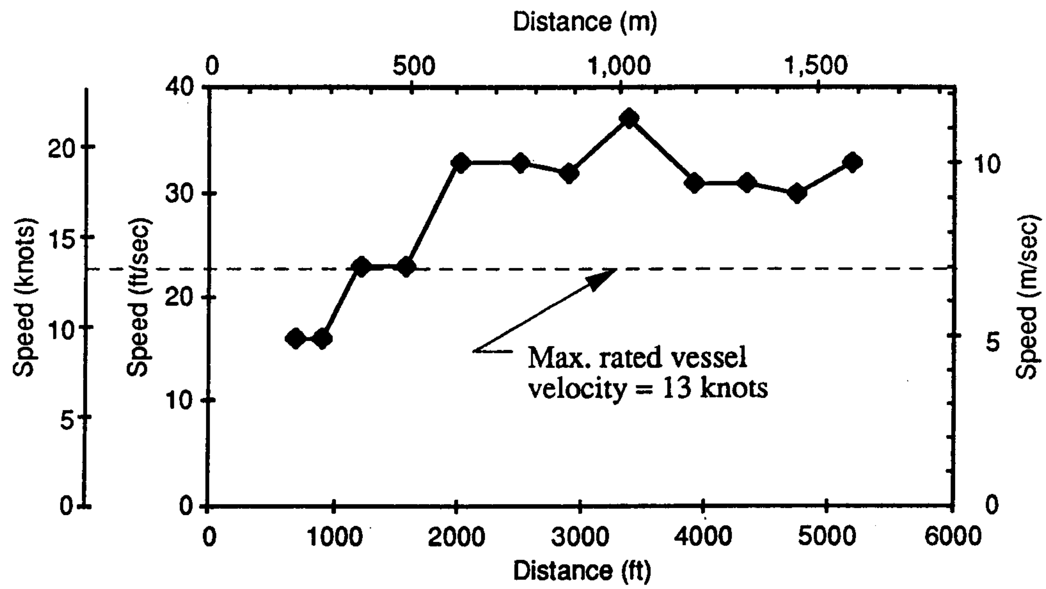


Figure 2.10. Distance from Landing Structure vs. Speed Plot - Remote Video Method (MV *Tillikum #1*)

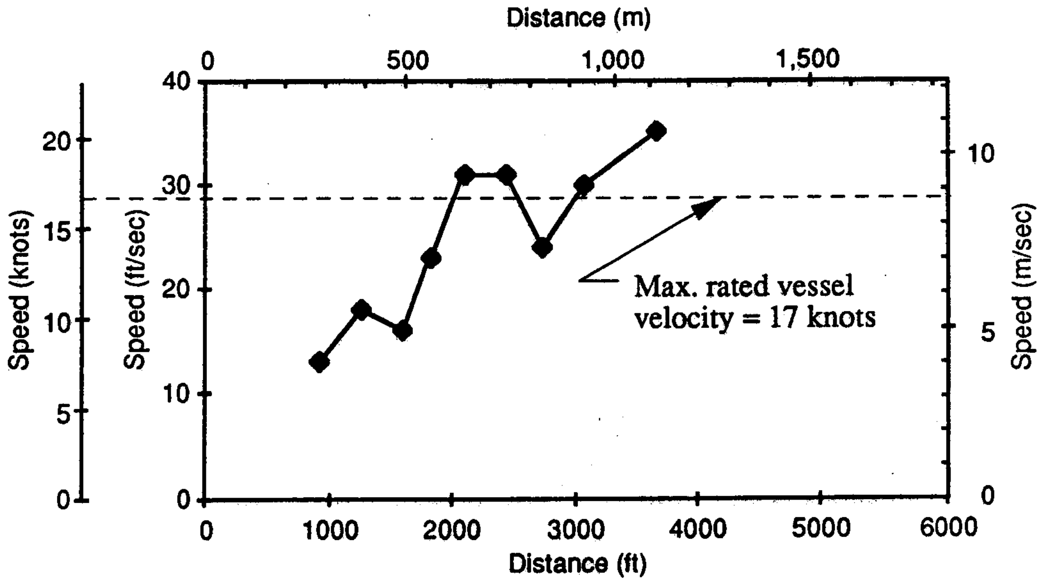


Figure 2.11 . Distance from Landing Structure vs. Speed Plot - Remote Video Method (MV *Hyak*)

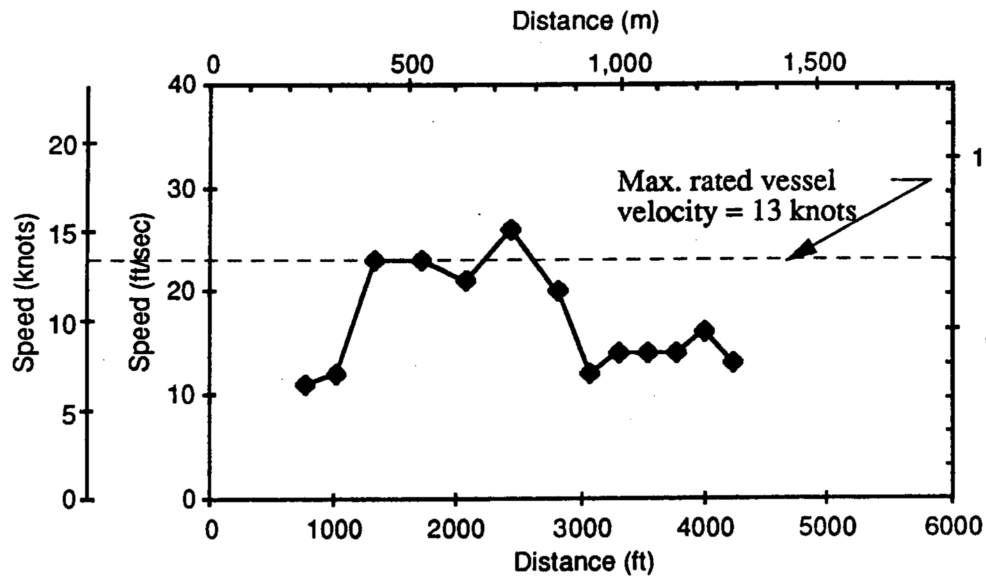


Figure 2.12. Distance from Landing Structure vs. Speed Plot - Remote Video Method (MV *Tillikum* #2)

By having to estimate these locations, the researchers lost the exact bearing of the vessel from the camera location.

2. The known landmarks were plotted on a map first. The vessel's heading was then plotted against these landmarks with a protractor. When the vessel was approximately 7,000 ft from the landing structure, the extended headings from each camera location intersected at an angle equal to approximately 10 degrees. With such a small angle of intersection, a drafting error of even 1 degree could produce an error in the vessel's position of as much as 200 ft (61 m). When the vessel neared the landing structure, these angles of intersection approached 90 degrees, decreasing the position error to approximately 50 ft (15 m). These errors could effect the accuracy of the calculated vessel velocity.

The radar image method introduced the following possibilities for error:

1. The recorded radar image was constantly in motion because the video camera was hand-held above the radar screen and, thus, could not be held steady.

2. The radar image projected an image of the Edmonds vicinity, including the landing structure itself. Given the scale, the researchers were able to estimate the position of the vessel with respect to the landing structure; however, the land images were blurred, affecting the accuracy of the distance measurements. Distances were estimated within ± 200 ft (± 61 m).

3. Errors propagated when the information was transferred from the monitor to clear sheets and then again from the clear sheets to the map.

Important information was acquired from the pilot house observations. The skipper mentioned that at times of high currents (which occur between high and low tide), the current force could alter the vessel's position if the berthing velocity were too low.

Therefore, berthing velocities might be noticeably faster during high currents than during low currents. Observers also noted that the vessel's masters usually reduced the throttle setting from "full ahead" to "one quarter ahead" at 0.25 miles (.40 km) from the landing structure. When a person was being trained to be in charge of the pilot house, the engines were reduced at three-eights of a mile from the landing structure.

This preliminary study, utilizing the remote video radar image methods, provided information regarding the approximate approach velocities and positions of the ferries. Using these two methods was advantageous in many ways: they did not require any special equipment or knowledge, they encouraged interaction with the crew members, and they allowed the research team to become familiar with the investigation site. These methods also provided a quick and easy way to determine a vessel's position within ± 200 ft. Disadvantages of using these methods included the following:

- The time required to process the video images (approximately 2 to 3 hours per landing),
- the fact that data for the final 600-800 ft of the vessel's approach were not available for analysis since the video equipment had to be removed for safety reasons when the vessel approached, and
- that the accuracy of vessel position was limited to ± 200 ft when the vessel was further than one mile from the landing structure.

The following suggestions could improve the accuracy of results, as well as reduce the time needed to process the data. When the radar image method is employed, a stand could be constructed to hold the video camera steady over the vessel's radar screen. The video camera could then be connected to a remote monitor so the camera operator could view the radar image while the vessel was in motion to ensure that the camera was focused and the recorded image was sharp. To improve the accuracy of the remote video method, rather than panning the horizon to follow the movement of the vessel, the camera could be held on one of the known landmarks while the vessel passed through the image.

Before the vessel blocked the view of the landmark, its location could be noted with a mark on the video screen. The camera would not be moved until the vessel's flagpole was out of view. This procedure would eliminate the need to estimate the positions of landmarks while they were viewed as moving in the video image.

CONCLUSION

Both the remote video and radar image methods provided approximate vessel velocities and positions. By locating vessels with these methods, the research team became familiar with ferry operations and the requirements for taking vessel position measurements. These methods required very little initial set-up time, were intuitively obvious, and were effective in providing approximate vessel positions. However, this research team chose to implement GPS to obtain more accurate approach velocities and positions. These new data will provide more accurate information about the vessel's final berthing maneuvers, which will aid in the design of more efficient and safer landing structures.

CHAPTER 3

GPS TRACKING METHOD

As mentioned in the previous chapter, GPS is capable of providing more accurate vessel positioning information than video tracking methods. This chapter describes the general principles of GPS, as well as specific information regarding the equipment used in this study.

The following description of GPS is a summary of Trimble Navigation's *GPS, A Guide to the Next Utility*. (1) GPS was developed by the U.S. Department of Defense (DoD), and will ultimately use a constellation of 24 satellites orbiting the earth at a distance of approximately 11,000 miles above the surface of the earth. Using GPS, one can determine a position on earth by measuring its distance from a group of satellites in space. Each satellite was placed into orbit by the United States Air Force, according to the GPS master plan, and is constantly monitored by the DoD. At the time of the publication of this thesis, 19 satellites were in orbit. The constellation is expected to be complete with a total of 24 satellites by March 1993. The DoD compares the satellites' actual altitude, position, and speed with a mathematical model of the orbits. Any variations are known as "ephemeris errors," which are caused by gravitational pulls from the moon and sun and by the pressure of solar radiation on the satellites'. These ephemeris errors are transmitted as data messages by the satellites to the receivers, with information about their exact orbital location and the system's health.

Four visible satellites are required to calculate an object's exact position. Knowing the distance from one satellite puts the object's position somewhere on an imaginary sphere that is centered on the satellite and at the known radius. Introducing a second satellite narrows the object's position to a circle since the intersection of two spheres creates a circle (Figure 3.1). The addition of a third satellite causes the three spheres to intersect at two points on the circle. At this point, the computers on board the

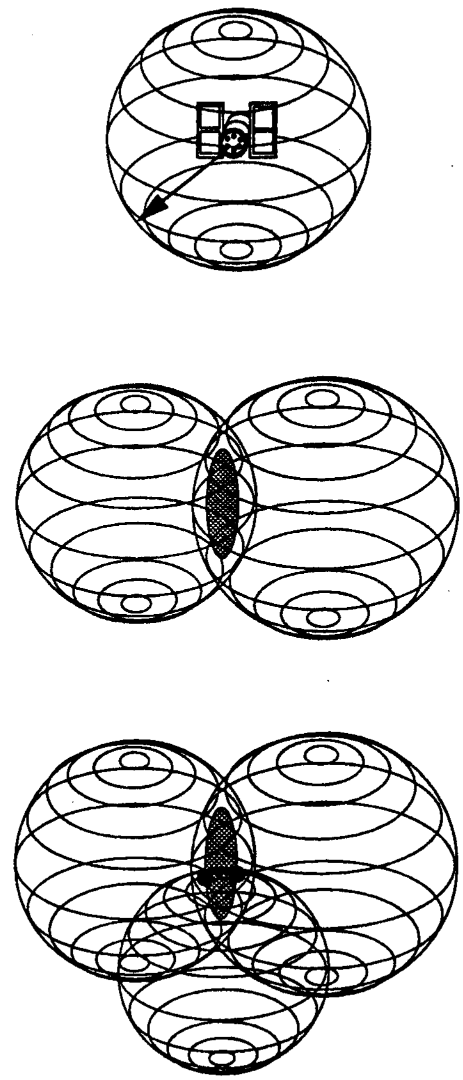


Figure 3.1. GPS Sphere Intersections [courtesy Trimble Navigation]

receivers can eliminate one of the two positions because one will not be close to the earth, or it may have an impossibly high velocity. The fourth satellite is needed to cancel out any timing errors, which will be discussed later.

Because GPS is based on the receiver's position relative to the position of the satellites, the distance between the two must be measured. This is done by measuring the time it takes for a radio signal to travel from a satellite to the receiver and multiplying that time by the speed of light (186,000 miles per second). To measure the travel time of the radio signal, the engineer must know exactly when the signal left the satellite. This is done with the help of pseudo-random codes (Figure 3.2). By synchronizing the satellites and receivers so that they are generating the pseudo-random codes at exactly the same time, the codes from the satellites and receivers can be compared at the receiver to determine when the identical codes were generated. The time difference is the time it took the radio signal to travel from the satellite to the receiver (Figure 3.3). Because of the extremely fast speed of light, very accurate clocks are needed to measure the offsets in the pseudo-random codes. The clocks on board the satellites are atomic clocks capable of nanosecond accuracy. However, the clocks on board the receivers are only moderately accurate, as the cost of the more accurate atomic clocks was prohibitive. The accuracy in the receiver clocks can be enhanced by the addition of a fourth satellite measurement, as mentioned before. With the addition of this fourth satellite, the receiver's computer can analyze the incoming data to determine whether the spheres intersect at a single point. If they do not, the computer assumes that the receiver's internal clock is offset from that of the satellite. At this point, the computer calculates the clock's offset and applies it to the measurements so the result is a single point (Figure 3.4).

As previously stated, to eliminate error, the satellites transmit a pseudo-random code on a data message regarding their exact orbital location. However, this alone does not make the system error free. Other sources of error are difficult to eliminate. These sources include clock error, interference from the earth's ionosphere and troposphere

Figure 3.2. Pseudo-Random Code

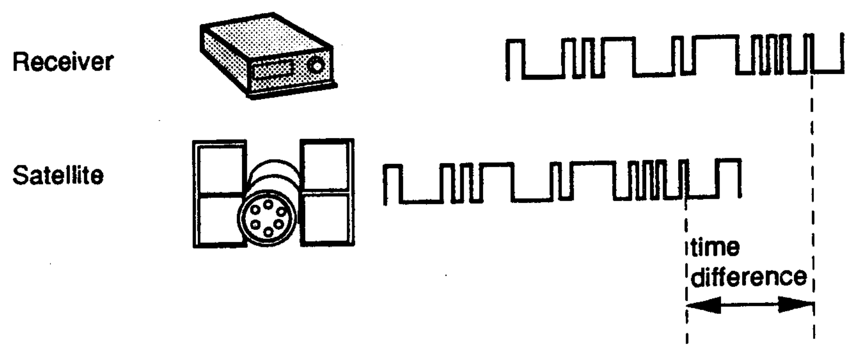


Figure 3.3. Pseudo-Random Code Offset
[courtesy Trimble Navigation]

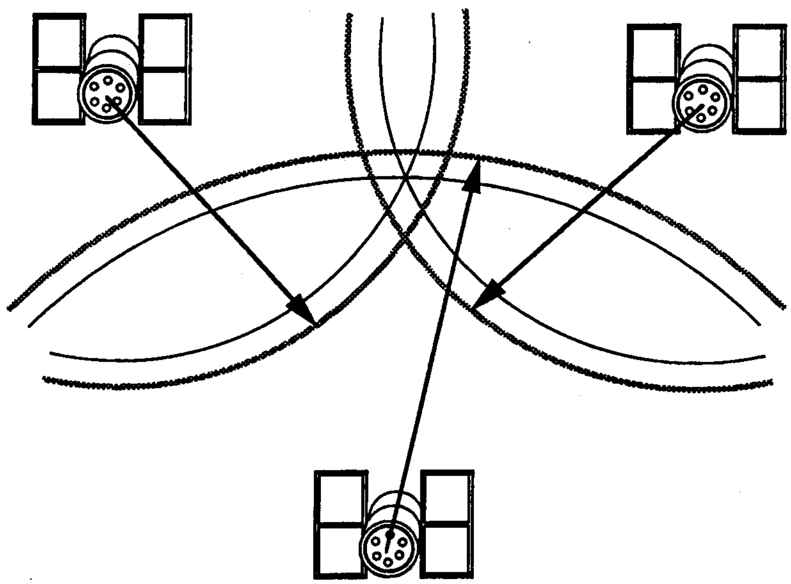


Figure 3.4 . GPS Receiver Clock Offset Correction
[*courtesy Trimble Navigation*]

(which alter the speed of light and therefore the speed of the GPS radio signals), and multipath error (which is destructive interference between the direct and reflected GPS signals). The implementation of advanced signal processing techniques and special antennae help minimize these errors.

The system alone is capable of estimating an object's position within approximately 100 m. However, to achieve a measurement accuracy between 1 and 3 meters, the researchers employed a technique called differential GPS. Two receivers are required for differential GPS: a reference receiver and a mobile receiver. With a GPS reference receiver set on a known location, the researchers used that receiver to calculate any errors that the satellite data might contain. This was done by comparing every satellite's updated position to the known location of the receiver. These correction factors were then applied to the mobile positioning data to provide the accuracy required. These correction factors verify most of the possible errors in the system.

To provide accurate vessel positioning and velocities, a specific configuration of global positioning equipment and software was utilized.

The mobile system incorporated the following equipment:

- Trimble Navigation's 4000 DL II mobile receiver,
- Trimble Navigation's external dome antenna with 30 m cable,
- Trimble Navigation's AC power adapter,
- Regulated power supply,
- Surge protector, and a
- DCI 386/25 personal computer.

A schematic diagram for connections is provided (Figure 3.5).

The reference equipment consisted of the following:

- Trimble Navigation's 4000 RL II reference receiver,
- Trimble Navigation's external dome antenna with 30 m cable,
- Regulated power supply,

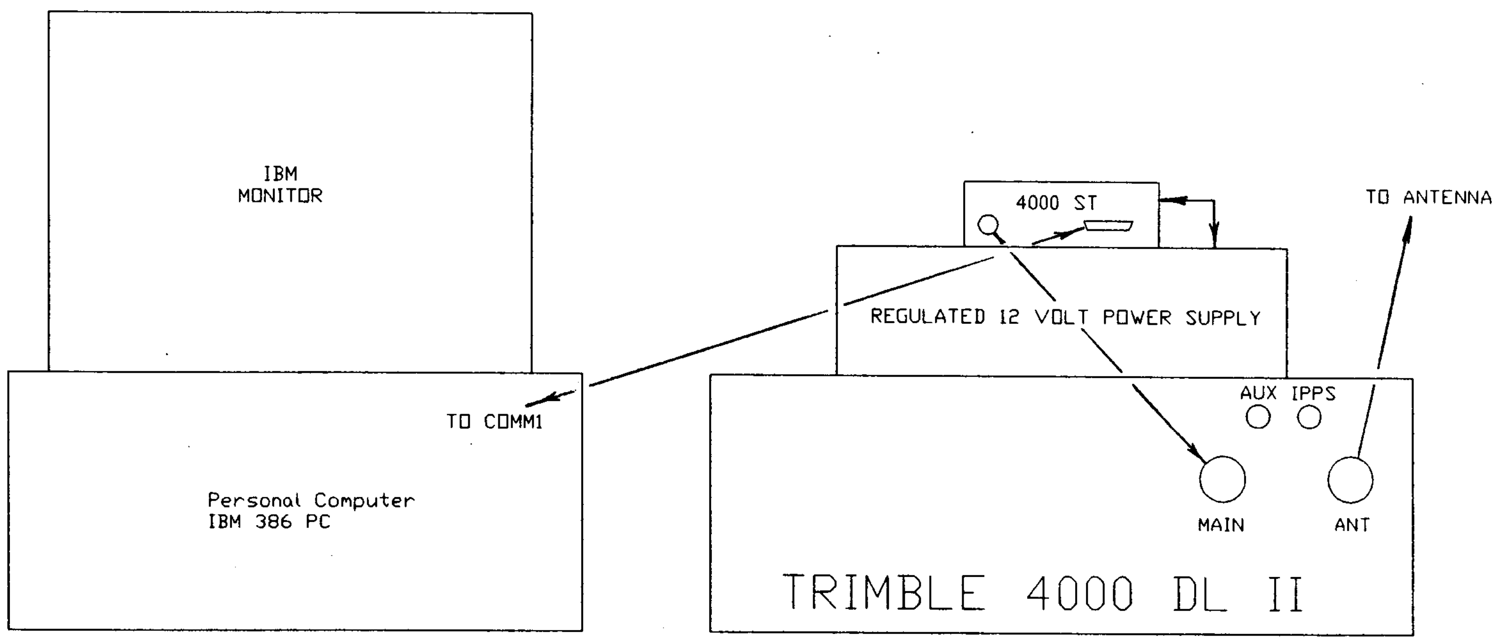


Figure 3.5. Schematic Diagram of Mobile GPS Equipment

- Surge Protector, and a
- DCI 386/25 personal computer.

A schematic diagram for the reference receiver connections is also provided here (Figure 3.6).

The mobile equipment was carried on and off the vessel at the beginning and end of each recording day. While in use, the mobile equipment was put in the wheelhouse on a chart table. The reference equipment sat undisturbed at the University of Washington. The methods of data collection and reduction are described in the following section.

GPS TRACKING METHODOLOGY

To obtain the approach path and velocity of WSF vessels, the previously described differential GPS system was employed from June 30 until July 23, 1992. Data were successfully collected for 24 landings: 12 at Edmonds and 12 at Kingston. Additional data were recorded for 16 more landings; however, the positioning data were not accurate because of poor satellite geometry or instrumentation error. All landings were recorded during calm and clear weather conditions, with the exception of one foggy morning.

The reference and mobile receivers were both linked to separate personal computers (PCs). The flowchart in Figure 3.7 gives an overview of the data collection procedure. Each of these PCs contained Trimble Navigation's GPSLAB software (2), which is capable of controlling each receiver's operations, as well as recording the positioning information to the remote PCs' hard drives. A narrative for using GPSLAB on an IBM PC is provided (Appendix B). This positioning information was then transferred from each of the previously mentioned PCs to another PC that contained Trimble Navigation's POSTNAV2 software. (3) A narrative for using POSTNAV2 on an IBM PC is also provided (Appendix B). The output from POSTNAV2 provides the differentially corrected positioning data accurate to 1 to 3 meters. Once differentially corrected, the output of POSTNAV2 was loaded into a spreadsheet application to provide

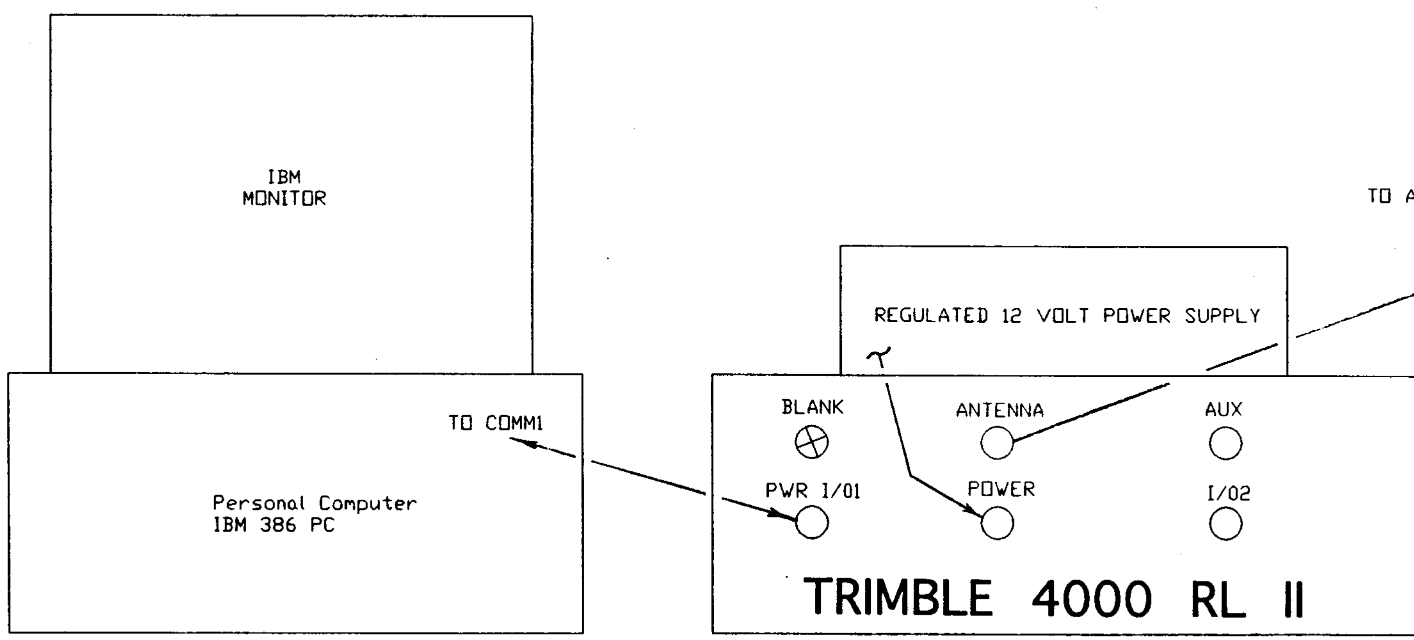


Figure 3.6. Schematic Diagram for the Reference GPS Equipment

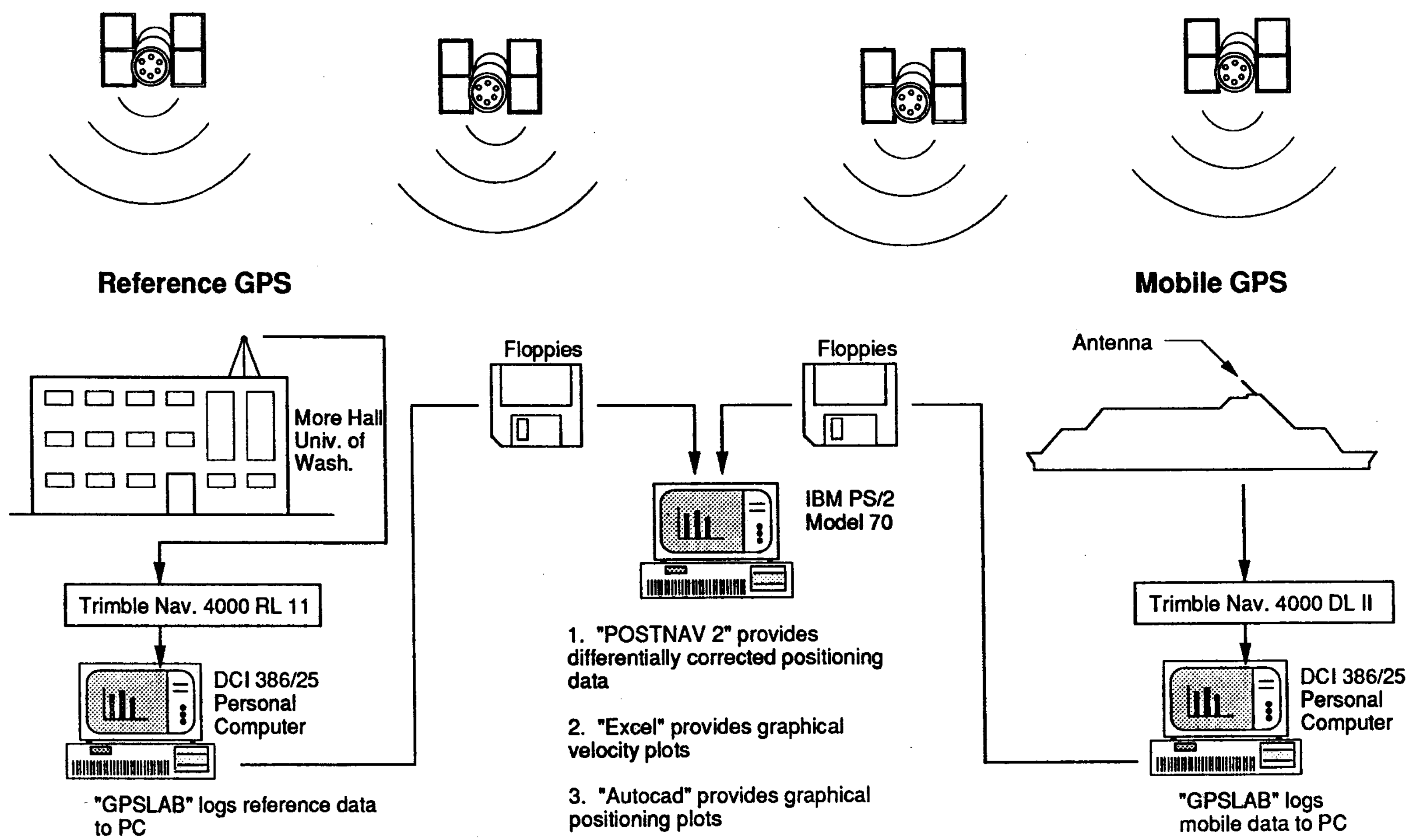


Figure 3.7. GPS Analysis Flow Chart

a graphical representation of the vessels' velocities as they approached the landing structure. In addition, AUTOCAD (4) was used to provide a graphical representation of the approach path of the vessels into the landing structure.

The reference receiver was positioned in More Hall on the University of Washington's campus. The external dome antenna was mounted over a predetermined survey point located on the roof (Figure 3.8). This position was later used to calculate the differential correction factors within POSTNAV2. The mobile receiver was located on the MV *Yakima*, which serviced the Edmonds to Kingston ferry route. The external dome antenna was secured to the hand rail on the right side of the number 1 wheel house (Figure 3.9). It was essential to position this antenna in an open area to minimize masks created by structures. Trimble Navigation's GPSLAB software was used to control all necessary settings and record positioning data from the 4000 RL II and the 4000 DL II to the DCI 386/25 personal computers. This data included latitude, longitude, and altitude positions accurate to within approximately 100 m. In addition to the calculated position, the file contains all transmitted data messages, including the satellite information that was described earlier. A typical output file of GPSLAB is shown in Figure 3.10.

Configuration settings controlled by GPSLAB that were found to be of critical importance to the operation of this system were as follows:

1. Sync Time (5 seconds) — The sync time is the time interval between positioning updates from the receivers. In our research, even though the receivers obtain positioning data from the satellites continuously, the receivers will only output a position every 5 seconds. This sync time was chosen because of the limited hard drive storage on the PCs. For example, one landing would require approximately 360 kb of disk storage, if a 5 second output rate were used, for both the reference and the mobile receivers. A sync time of 5 seconds was chosen to minimize the amount of data stored to the PCs hard drives. However, an epoch time of 1 second

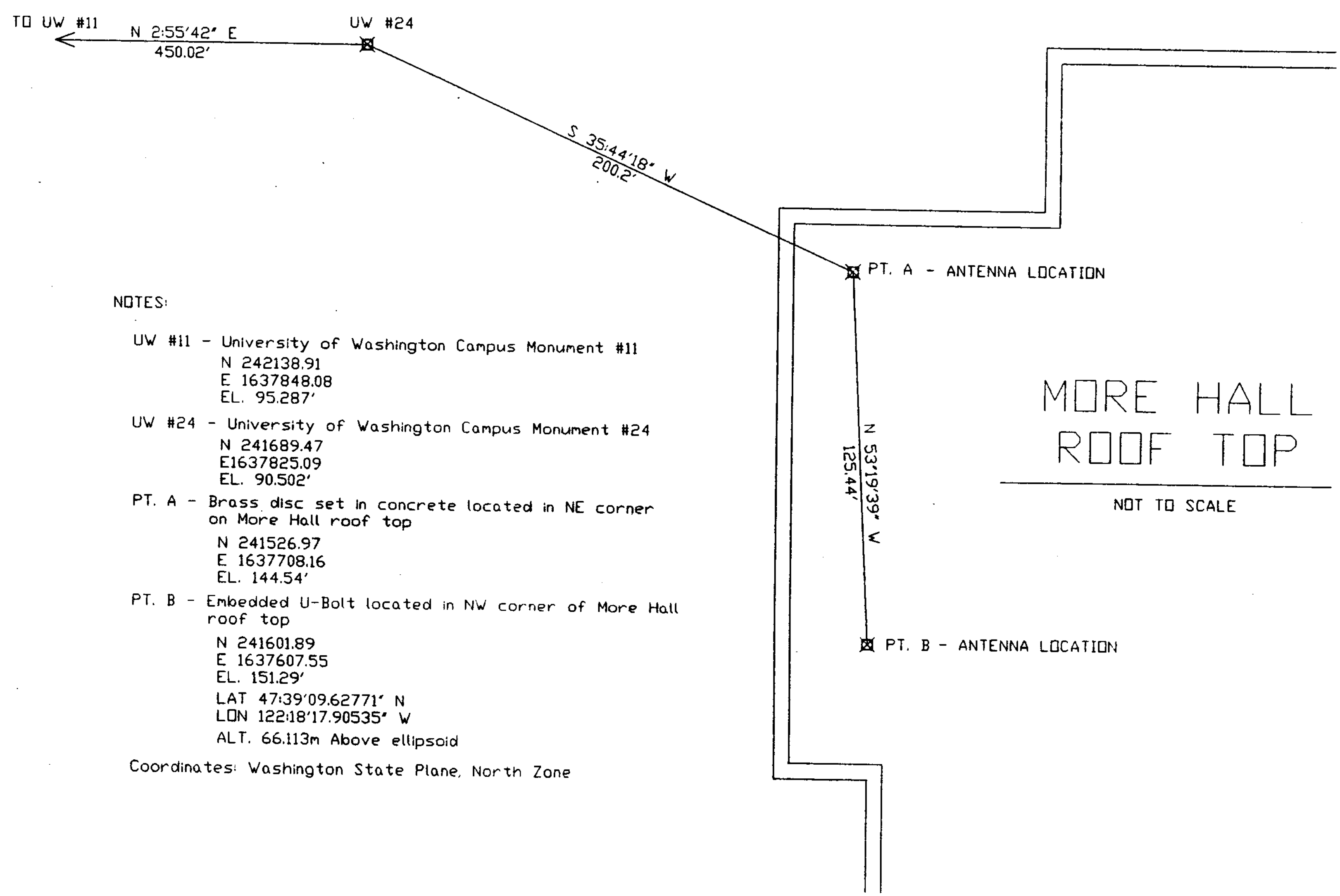


Figure 3.8. Antenna Location for Reference Receiver

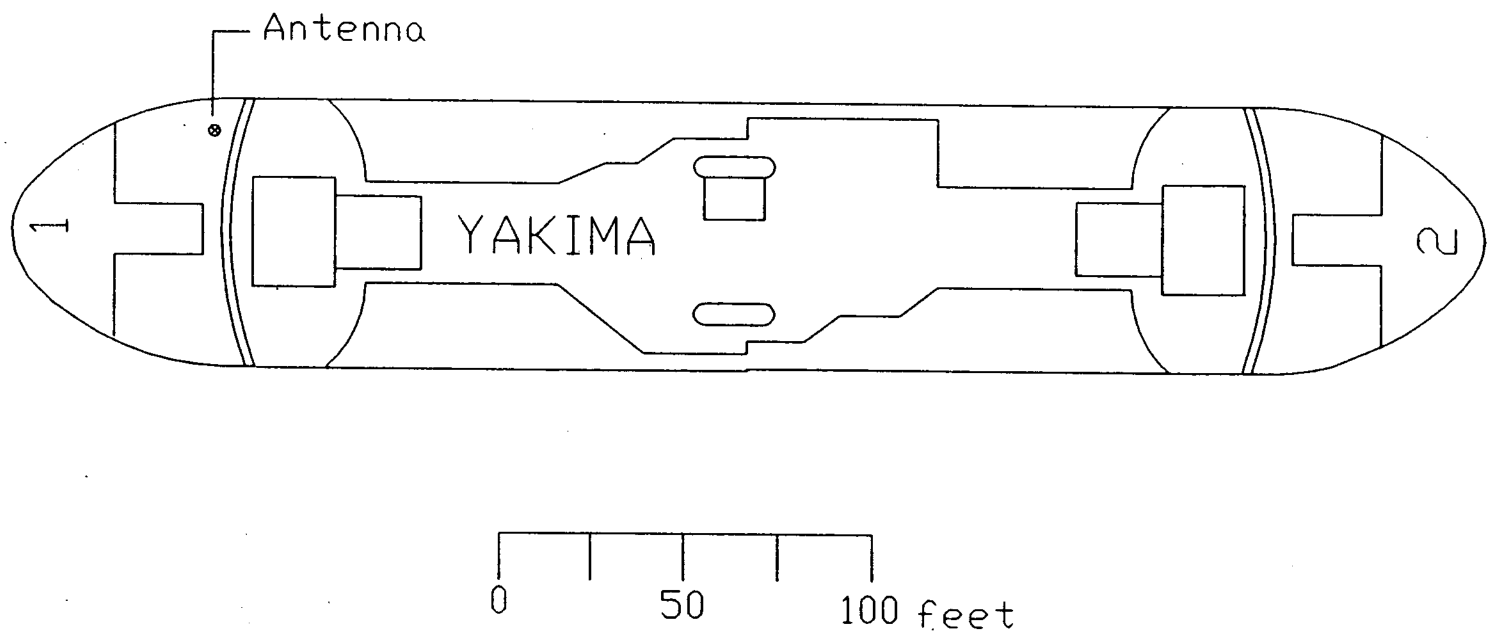


Figure 3.9. Location for GPS Mobile Antenna

```
MEASURED POSITION @ Fri 0:16:25.000 (GPS)      5 SVs, PDOP =  3.3
   Pos: LAT N  47:48.60041   LON W 122:24.37791   Alt  -59.44 m
   Vel:  N   0.00208 min/s    E   0.00566 min/s   Alt   -0.08 m/s
   Clk: bias 199270.5 m  rate -190.523 m/s
SV 20 (ch 3) @ 432985.0000: PR  =     9733.55  DR  = -2039.505  SNR = 16
SV 17 (ch 5) @ 432985.0003: PR  =    85912.82  DR  =  3582.315  SNR = 14
SV 16 (ch 2) @ 432985.0006: PR  =   191943.29  DR  =  -137.691  SNR = 24
SV  3 (ch 1) @ 432985.0007: PR  =   202789.82  DR  =  2401.425  SNR = 19
SV 24 (ch 4) @ 432985.0008: PR  =   252899.47  DR  = -2137.206  SNR = 11
MEASURED POSITION @ Fri 0:16:30.000 (GPS)      5 SVs, PDOP =  3.3
   Pos: LAT N  47:48.61081   LON W 122:24.34969   Alt  -59.96 m
   Vel:  N   0.00207 min/s    E   0.00565 min/s   Alt   -0.14 m/s
   Clk: bias 198317.9 m  rate -190.536 m/s
SV 20 (ch 3) @ 432990.0000: PR  =    11674.46  DR  = -2041.647  SNR = 17
SV 17 (ch 5) @ 432990.0003: PR  =    82503.80  DR  =  3580.527  SNR = 14
SV 16 (ch 2) @ 432990.0006: PR  =   192078.03  DR  =  -141.097  SNR = 24
SV  3 (ch 1) @ 432990.0007: PR  =   200505.57  DR  =  2399.572  SNR = 19
SV 24 (ch 4) @ 432990.0009: PR  =   254931.54  DR  = -2137.525  SNR = 11
MEASURED POSITION @ Fri 0:16:35.000 (GPS)      5 SVs, PDOP =  3.3
   Pos: LAT N  47:48.62116   LON W 122:24.32149   Alt  -60.71 m
   Vel:  N   0.00207 min/s    E   0.00564 min/s   Alt   -0.17 m/s
   Clk: bias 197365.2 m  rate -190.593 m/s
SV 20 (ch 3) @ 432995.0000: PR  =    13618.11  DR  = -2043.413  SNR = 17
SV 17 (ch 5) @ 432995.0003: PR  =    79098.61  DR  =  3579.104  SNR = 14
SV 16 (ch 2) @ 432995.0006: PR  =   192214.53  DR  =  -144.125  SNR = 24
SV  3 (ch 1) @ 432995.0007: PR  =   198223.62  DR  =  2398.133  SNR = 20
SV 24 (ch 4) @ 432995.0009: PR  =   256966.21  DR  = -2137.561  SNR = 11
```

<u>Legend</u>

SV = satellite vehicle
PR = pseudo range
DR = delta range
SNR = signal to noise ratio

Figure 3.10. Typical Output File of GPSLAB

was specified within POSTNAV2, which interpolated the data between the 5 second position updates to provide a position every 1 second. Therefore, when the vessels were at "full ahead," approximately 33 ft/sec, we obtained a position update at approximately every 165 ft. When the vessel was in the final stages of berthing, approximately 5 ft/sec, a position update every 25 ft was available.

2. Elevation mask (10 degrees) — The elevation mask eliminates from the positioning solution any satellite that is below the indicated elevation mask (e.g. an elevation mask of 10 degrees would eliminate any satellite that is below 10 degrees above the horizon). This elevation mask is necessary because satellites that are at low horizontal elevations with respect to the receiver magnify ephemeris errors.

3. PDOP mask (99) — The PDOP mask (or Positioning Dilution of Precision mask) signifies a range of visible satellite geometric configurations, about the receiver that can be used in a positioning solution. A PDOP of 0 is an ideal geometric configuration. As the satellites move around their orbits, the PDOP is constantly changing. As the geometric configuration becomes less advantageous to the positioning solution, the PDOP value increases. Trimble Navigation suggests that a PDOP mask of approximately 99 be used, indicating that once a PDOP of 99 is reached, the receiver will not calculate a position until the PDOP drops back below 99. During this research, PDOP values of 2-8 were regularly observed. However, when only three satellites were available, PDOP values well above 99 were not uncommon.

Configuration settings for GPSLAB, the 4000 RL II and the 4000 DL II are provided here (Appendix C).

To provide data for differentially corrected positions, the reference and mobile units must operate simultaneously. To ensure that reference data were being collected at the same time as the mobile data, GPSLAB was set to continuously collect positioning data from the 4000 RL II at the reference location.

While on board the vessel, the research team collected data primarily during berthing maneuvers. Once the vessel was within approximately 7,000 ft from the landing structure, GPSLAB was programmed to collect positioning data from the 4000 DL II. In addition, the research team recorded all changes in throttle settings for approximately the final 2,000 ft before final berthing (Appendix D). Once the vessel had berthed, GPSLAB was disabled, and data recording for that landing was complete. This procedure was repeated for each recorded landing.

Once data collection was complete, GPSLAB output files (*.GPS) from the remote PC, for both the reference and mobile receivers, were transferred to floppy disks. These disks were then transferred to the post-processing PC that was located at the University of Washington. This computer contained Trimble Navigation's POSTNAV2 software, which locates and matches the corresponding mobile and reference files (*.GPS), and then calculates and applies the necessary correction factors to obtain the differentially corrected positions that have an accuracy of 1 to 3 meters. POSTNAV2 is capable of outputting an ASCII file (*.LST) that contains GPS date and time, Time_TOW, local coordinates, and velocity (Figure 3.11). GPS date and time is referenced to December 31 at 5:00 PM PST as being GPS day #1 & GPS time=00:00:00. For example, January 3rd at 12:00 PM PST would be GPS day #3 & GPS time=19:00:00. Time_TOW refers to the seconds of the GPS week. Sunday at 5:00 PM PST is considered the (0 second) base, with the following Saturday at 4:59:59 PM PST being 604,799 seconds. A local coordinate system was used to simplify the analysis. At both the Edmonds and Kingston terminals, survey monuments located by the Washington State Department of Transportation were used as the base coordinates for each landing

Time_TOW	East(ft)	North(ft)	Up(ft)	East_Vel(ft/s)	North_Vel(ft/s)	Up_Vel(ft/s)
433228	-1338.9	-22.6	24.7	6.29	-2.34	-0.44
433229	-1333.6	-24.8	24.1	6.06	-2.3	-0.46
433230	-1328.2	-27	23.6	5.84	-2.26	-0.48
433231	-1322.8	-29.2	23.1	5.61	-2.23	-0.51
433232	-1317.4	-31.4	22.5	5.38	-2.19	-0.53
433233	-1313.1	-33	22.1	5.17	-2.07	-0.52
433234	-1308.8	-34.6	21.6	4.96	-1.96	-0.5
433235	-1304.4	-36.2	21.2	4.75	-1.84	-0.49
433236	-1300.1	-37.8	20.7	4.54	-1.72	-0.47
433237	-1295.8	-39.4	20.3	4.33	-1.6	-0.45
433238	-1292.5	-40.3	19.9	4.11	-1.47	-0.44
433239	-1289.3	-41.2	19.5	3.89	-1.33	-0.43
433240	-1286.1	-42.2	19.1	3.67	-1.2	-0.42
433241	-1282.8	-43.1	18.7	3.45	-1.06	-0.41
433242	-1279.6	-44	18.3	3.23	-0.93	-0.4
433243	-1277.4	-45	17.4	3.03	-0.94	-0.48
433244	-1275.2	-46	16.6	2.82	-0.95	-0.57
433245	-1273	-47	15.8	2.62	-0.97	-0.65
433246	-1270.8	-48	15	2.42	-0.98	-0.73
433247	-1268.6	-49	14.2	2.21	-0.99	-0.82
433248	-1266.9	-49.6	13.7	2.09	-0.91	-0.76
433249	-1265.3	-50.2	13.1	1.97	-0.84	-0.7
433250	-1263.7	-50.8	12.6	1.85	-0.76	-0.64
433251	-1262.1	-51.4	12.1	1.73	-0.68	-0.58
433252	-1260.5	-52	11.5	1.6	-0.61	-0.53
433253	-1259.5	-52.6	10.8	1.49	-0.61	-0.58
433254	-1258.4	-53.3	10	1.38	-0.61	-0.62
433255	-1257.4	-53.9	9.2	1.27	-0.62	-0.67
433256	-1256.3	-54.5	8.5	1.16	-0.62	-0.72
433257	-1255.3	-55.1	7.7	1.05	-0.62	-0.77
433258	-1254.1	-55.4	6.8	1.07	-0.56	-0.79
433259	-1253	-55.8	5.9	1.09	-0.51	-0.81
433260	-1251.8	-56.1	5.1	1.12	-0.45	-0.83
433261	-1250.6	-56.4	4.2	1.14	-0.39	-0.85
433262	-1249.5	-56.8	3.3	1.16	-0.33	-0.87
433263	-1248.5	-57.2	2.3	1.13	-0.35	-0.9
433264	-1247.5	-57.7	1.3	1.09	-0.38	-0.92
433265	-1246.5	-58.1	0.3	1.06	-0.4	-0.95
433266	-1245.5	-58.6	-0.7	1.02	-0.43	-0.98
433267	-1244.6	-59	-1.7	0.98	-0.45	-1
433268	-1244	-58.9	-2.5	0.89	-0.34	-0.96
433269	-1243.5	-58.8	-3.3	0.8	-0.22	-0.92
433270	-1243	-58.6	-4.1	0.71	-0.1	-0.88
433271	-1242.5	-58.5	-4.9	0.61	0.02	-0.84
433272	-1241.9	-58.3	-5.7	0.52	0.14	-0.8
433273	-1241.7	-58.2	-6.5	0.47	0.15	-0.79
433274	-1241.4	-58	-7.2	0.42	0.16	-0.79
433275	-1241.2	-57.8	-8	0.36	0.16	-0.78

Figure 3.11. Typical Output File of POSTNAV2

structure (Figures 3.12 and 3.13). The latitude, longitude and altitude for each base coordinate was loaded into POSTNAV2. The approach path of the vessel would then be output as an "Easting" and a "Northing," in feet, referenced from the appropriate survey monument as 0.0 ft East and 0.0 ft North.

Within POSTNAV2, output files (*.LST) were named for file management ease. For example, a typical file name would be 709EXY1.LST. The first character represents the month, the second and third represent the day of the month, the fourth signifies the ferry terminal, the fifth and sixth are initials for the ship's master, and the final character represents the landing number of that particular day (Figure 3.14).

For a graphical representation of this study's results, each POSTNAV2 output file (*.LST) was transferred into EXCEL for Windows. With the aid of a macro (Appendix D), EXCEL manipulated the data into an acceptable format (*.WKS) to plot velocity vs. distance from the landing structure. The distance being from the bow of the vessel, not from the antenna location. These (*.WKS) files contained GPS date and time, local coordinates, distance from the landing structure, and total velocity of the vessel (Figure 3.15). Plots of velocity vs. distance from the landing structure for the final 5,000 ft prior to berthing were created for each recorded landing. Plots are provided for Edmonds, Kingston, and the two terminals combined (Figures 3.16, 3.17, and 3.18). Individual landings are provided in Appendix F. A plot of velocity vs. distance from the landing structure for the final 300 ft before berthing was also created for each landing. Plots are provided for Edmonds and Kingston, separately (Figures 3.19 and 3.20) Another figure is also provided showing the plots for Edmonds and Kingston together (Figure 3.21). These plots include the locations of all floating dolphins, pile dolphins, and wing walls. To display the distribution of velocities at different distances from the landing structure, velocity distribution histograms were created. Velocity distributions at 500 ft, 300 ft, 200 ft, 100 ft, and 50 ft were chosen so that they could be applied to any desired landing configuration. Distributions are provided for Edmonds, Kingston, and

Washington State Department of Transportation

REPORT OF SURVEY MARK

EDMONDS

TODAY'S DATE		STAMPED IDENTIFICATION
01-10-89	T 27 R 3E S 24	EDMONDS

COUNTY	NEAREST CITY OR TOWN	STATE ROUTE	MILE POST
SNOHOMISH	EDMONDS	104	24.5

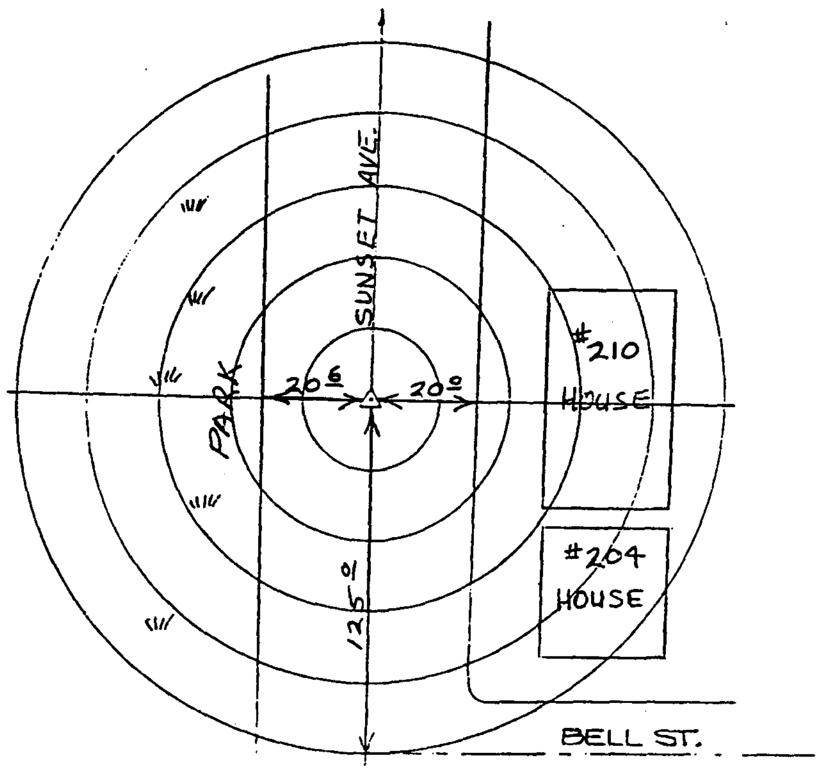
DESCRIPTION OF SURVEY MARK THE STATION IS LOCATED IN THE CITY OF EDMONDS 0.1 MI. NORTHEAST OF THE WA. STATE FERRY TERMINAL. THE MARK IS A WSDOT BRASS DISK SET IN A CONCRETE MONUMENT UNDER A CASE AND COVER IN THE CENTERLINE OF SUNSET AVE. DIRECTLY WEST OF THE HOUSE AT 210 SUNSET AVE. IT IS 125 .0 FT. NORTH OF THE INTERSECTION WITH BELL ST. 20.0 FT. WEST OF THE EAST CURB LINE AND 20.6 FT. EAST OF THE WEST CURB LINE.

ORGANIZATION ESTABLISHING	DATE ESTABLISHED
WSDOT	1989
NAME(S) OF INDIVIDUAL(S) RELOCATING GEOGRAPHIC SERVICES	DOT DISTRICT 1

HAS SURVEY MARK BEEN LOCATED BY GLOBAL POSITIONING SYSTEM? [x] YES [ ] NO

IF SO, NAD "83"		WASHINGTON STATE GRID SYSTEM	
LATITUDE	LONGITUDE	N	E
47 48 48.79309	122 22 50.76469	Y :91617.4256	X 384119.5481

ZONE [x] NORTH [ ] SOUTH [x] PRIME MARK [ ] AZIMUTH POINT [ ] BM ELE.______



LOCATION DRAWING
SCALE 1/2" = 10 FT

DOT FORM 321-042 2/87

Figure 3.12. Survey Monument at Edmonds (Base Coordinate) (courtesy of WSDOT)

Washington State Department of Transportation

REPORT OF SURVEY MARK

KINGSTON

TODAY'S DATE		STAMPED IDENTIFICATION
10-31-39	T 27N R 2E S25	KINGSTON

COUNTY	NEAREST CITY OR TOWN	STATE ROUTE	MILE POST
KITSAP	KINGSTON	SR104	24.4

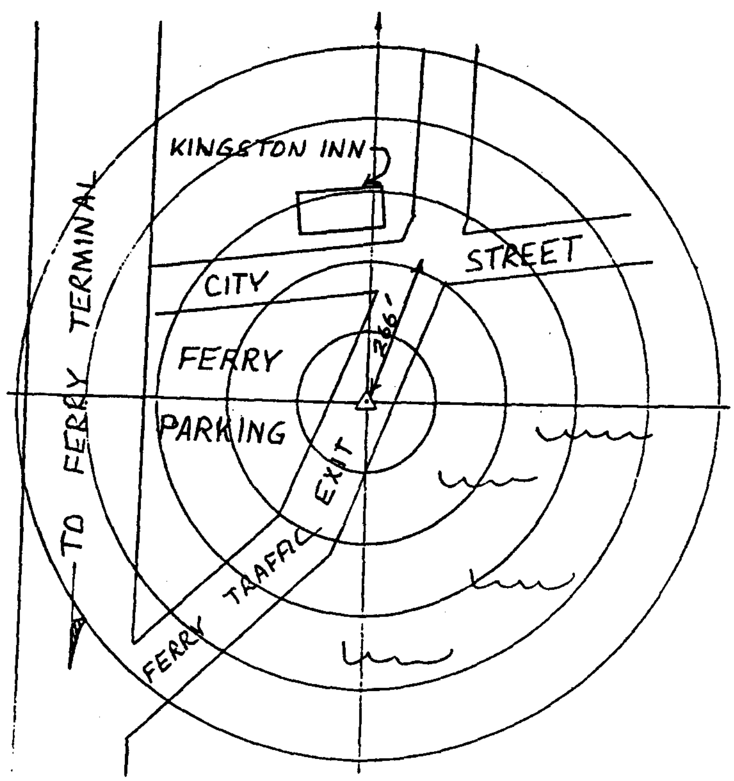
DESCRIPTION OF SURVEY MARK STATION IS LOCATED WITHIN THE TOWN OF KINGSTON. THE MARK IS SET IN A ROUND CONCRETE MONUMENT UNDER A STANDARD WSDOT MONUMENT CASE AND COVER IN THE SHOULDER NORTH OF THE EXIT LANE FOR FERRY TRAFFIC. IT IS 266 FEET SOUTHEAST OF THE INTERSECTION OF FERRY EXIT AND CITY STREET NEAR THE "KINGSTON INN."

ORGANIZATION ESTABLISHING	DATE ESTABLISHED
WSDOT	1989
NAME(S) OF INDIVIDUAL(S) RELOCATING GEOGRAPHIC SERVICES	DOT DISTRICT 3

HAS SURVEY MARK BEEN LOCATED BY GLOBAL POSITIONING SYSTEM? [x] YES [ ] NO

IF SO, NAD'83'		WASHINGTON STATE GRID SYSTEM	
LATITUDE	LONGITUDE	N	E
47 47' 48.64888"	122 29' 42.99615	Y 89939.1806 M	X 375505.6777 M

ZONE [x] NORTH [ ] SOUTH | [x] PRIME MARK [ ] AZIMUTH POINT | [ ] BM ELE.__________



LOCATION DRAWING
SCALE 1/2" = 10 FT

DOT FORM 321-042 2/87

Figure 3.13. Survey Monument at Kingston (Base Coordinate) (courtesy of WSDOT)

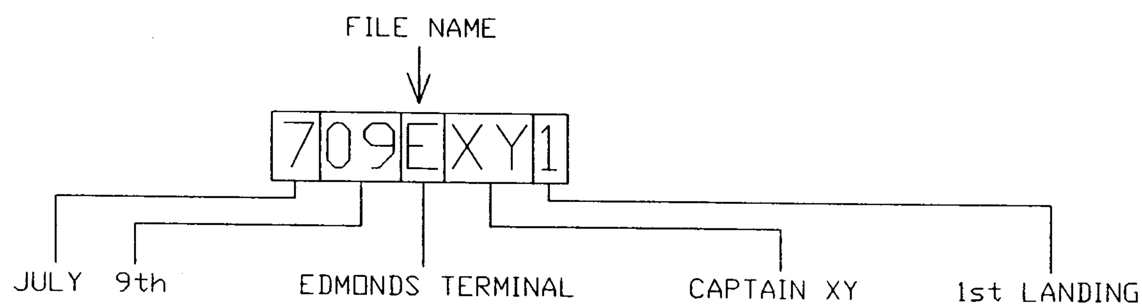


Figure 3.14. **File Structure of POSTNAV2 Output Files**

Time_TOW	East(ft)	North(ft)	Distance	Velocity
433228	-1339	-23	104	6.7
433229	-1334	-25	98	6.5
433230	-1328	-27	93	6.3
433231	-1323	-29	87	6
433232	-1317	-31	81	5.8
433233	-1313	-33	76	5.6
433234	-1309	-35	72	5.3
433235	-1304	-36	67	5.1
433236	-1300	-38	63	4.9
433237	-1296	-39	58	4.6
433238	-1293	-40	55	4.4
433239	-1289	-41	51	4.1
433240	-1286	-42	48	3.9
433241	-1283	-43	44	3.6
433242	-1280	-44	41	3.4
433243	-1277	-45	39	3.2
433244	-1275	-46	36	3
433245	-1273	-47	34	2.8
433246	-1271	-48	32	2.6
433247	-1269	-49	29	2.4
433248	-1267	-50	27	2.3
433249	-1265	-50	26	2.1
433250	-1264	-51	24	2
433251	-1262	-51	22	1.9
433252	-1261	-52	21	1.7
433253	-1260	-53	19	1.6
433254	-1258	-53	18	1.5
433255	-1257	-54	17	1.4
433256	-1256	-55	16	1.3
433257	-1255	-55	15	1.2
433258	-1254	-55	14	1.2
433259	-1253	-56	12	1.2
433260	-1252	-56	11	1.2
433261	-1251	-56	10	1.2
433262	-1250	-57	9	1.2
433263	-1249	-57	8	1.2
433264	-1248	-58	7	1.2
433265	-1247	-58	6	1.1
433266	-1246	-59	5	1.1
433267	-1245	-59	4	1.1
433268	-1244	-59	4	1
433269	-1244	-59	3	0.8
433270	-1243	-59	3	0.7
433271	-1243	-59	2	0.6
433272	-1242	-58	2	0.5
433273	-1242	-58	1	0.5
433274	-1241	-58	1	0.4
433275	-1241	-58	1	0.4

Figure 3.15. Excel Formatted Spreadsheet

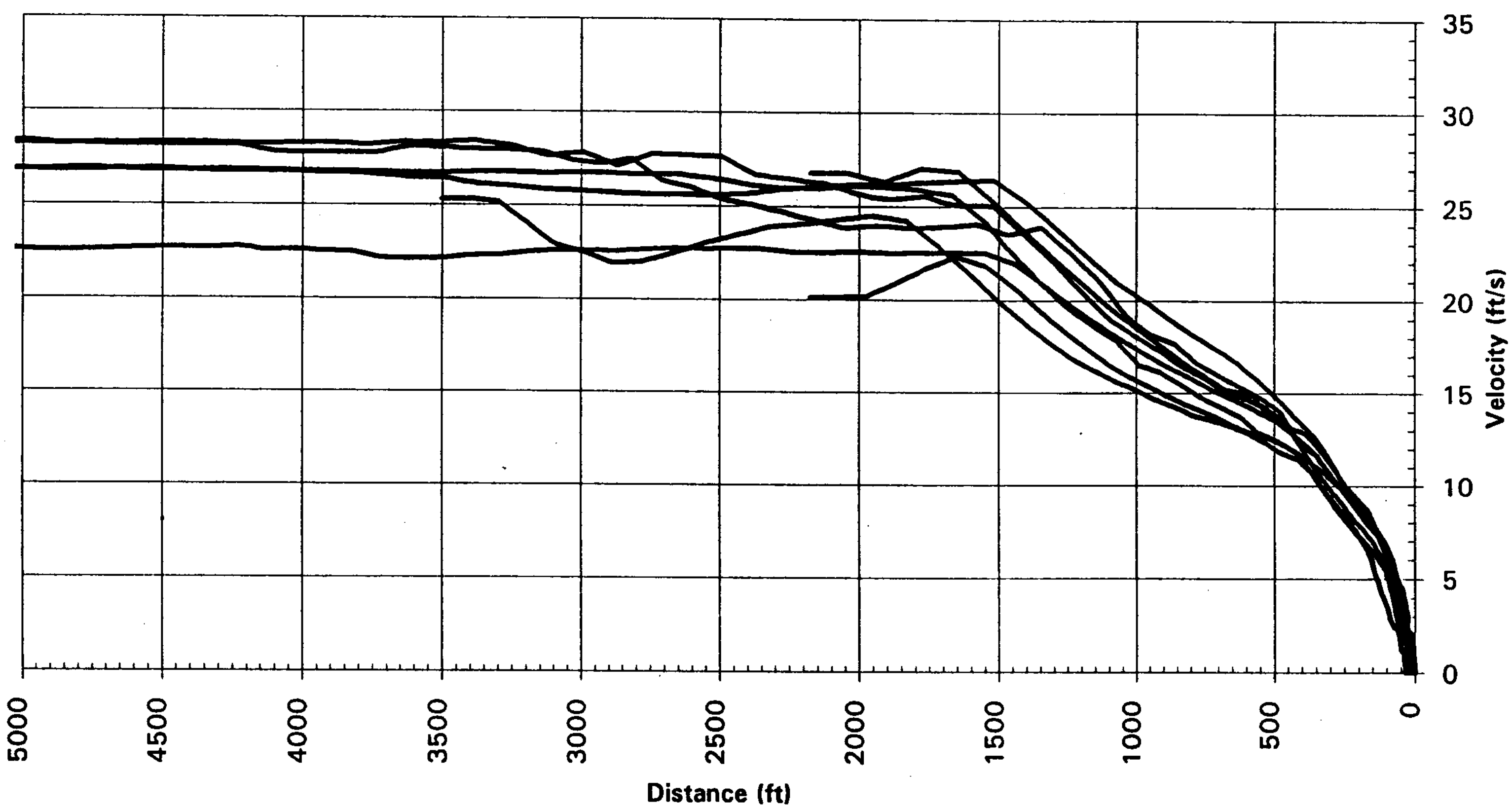


Figure 3.16. Velocity vs. Distance from Edmonds Landing Structure (5,000 ft.)

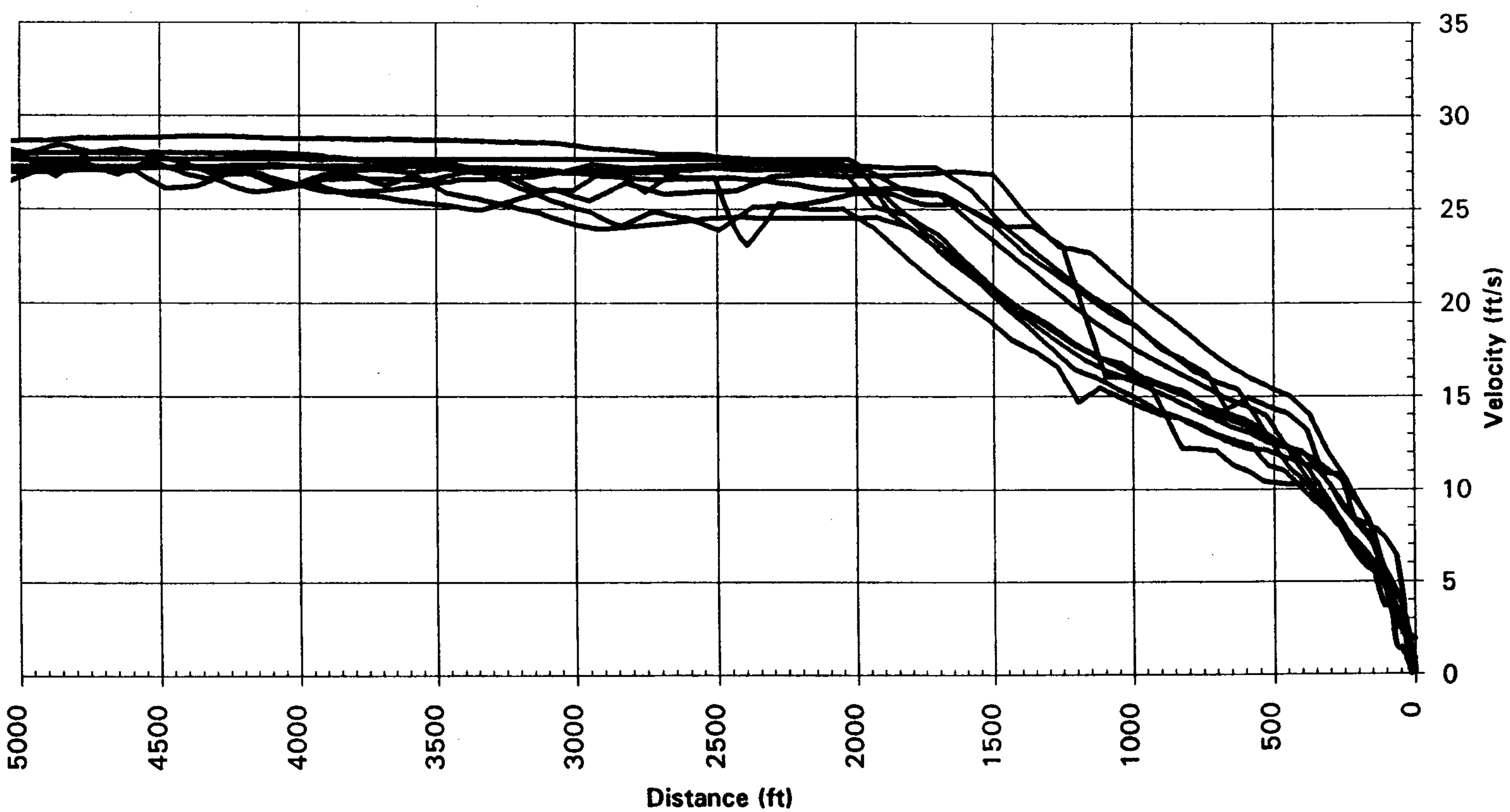


Figure 3.17. Velocity vs. Distance from Kingston Landing Structure (5,000 ft.)

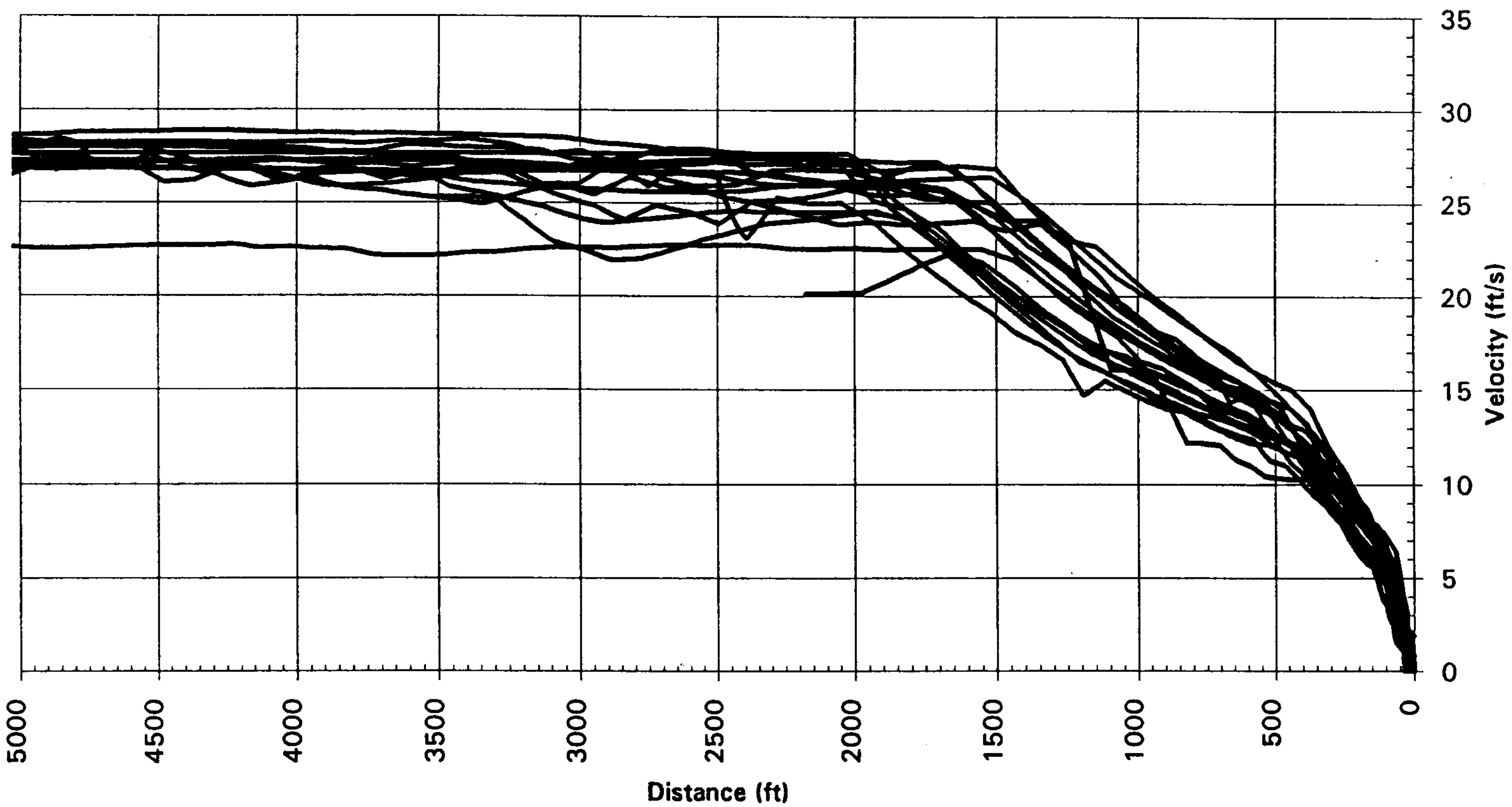


Figure 3.18. Velocity vs. Distance from Landing Structures (5,000 ft.)

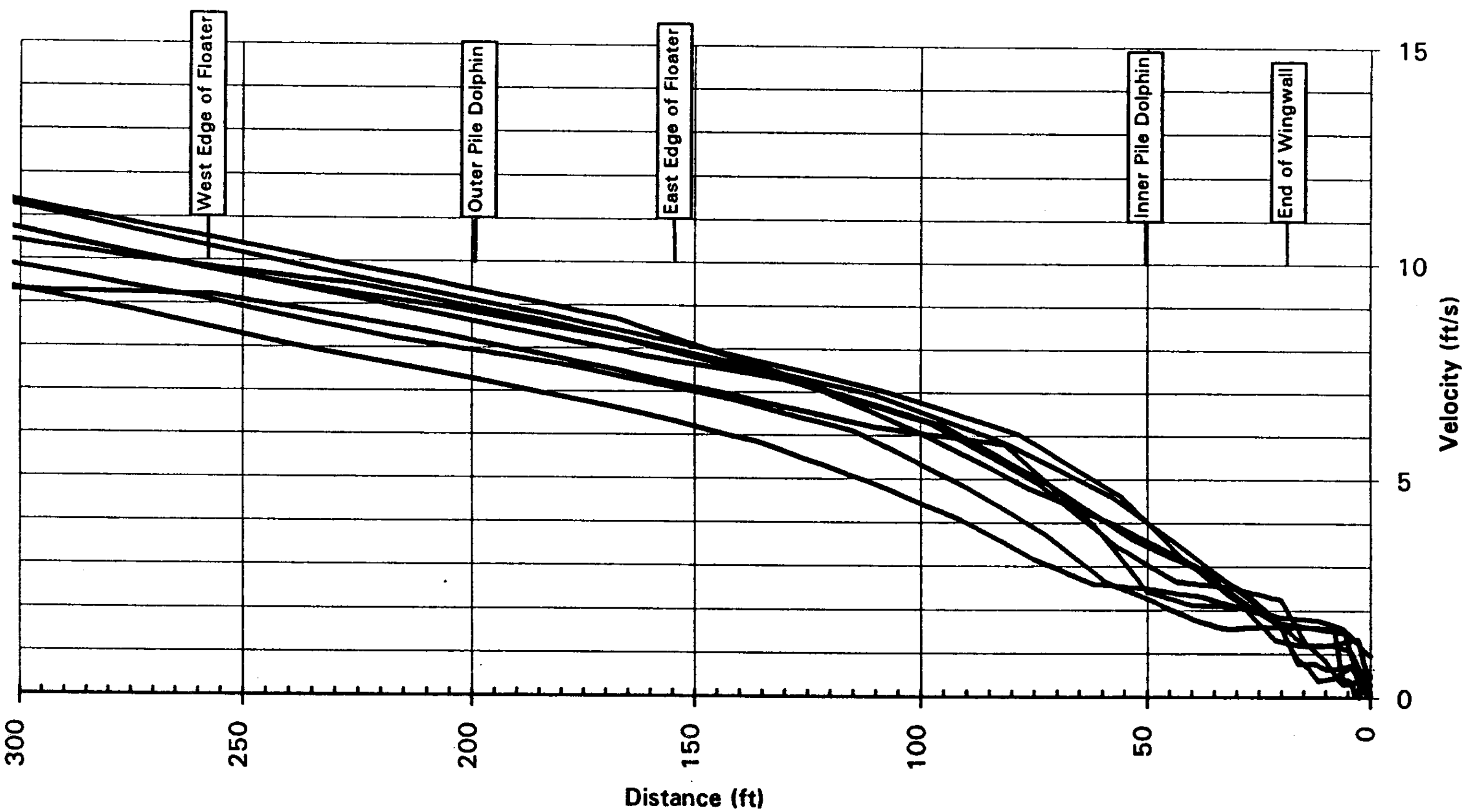


Figure 3.19. Velocity vs. Distance from Edmonds Landing Structure (300 ft.)

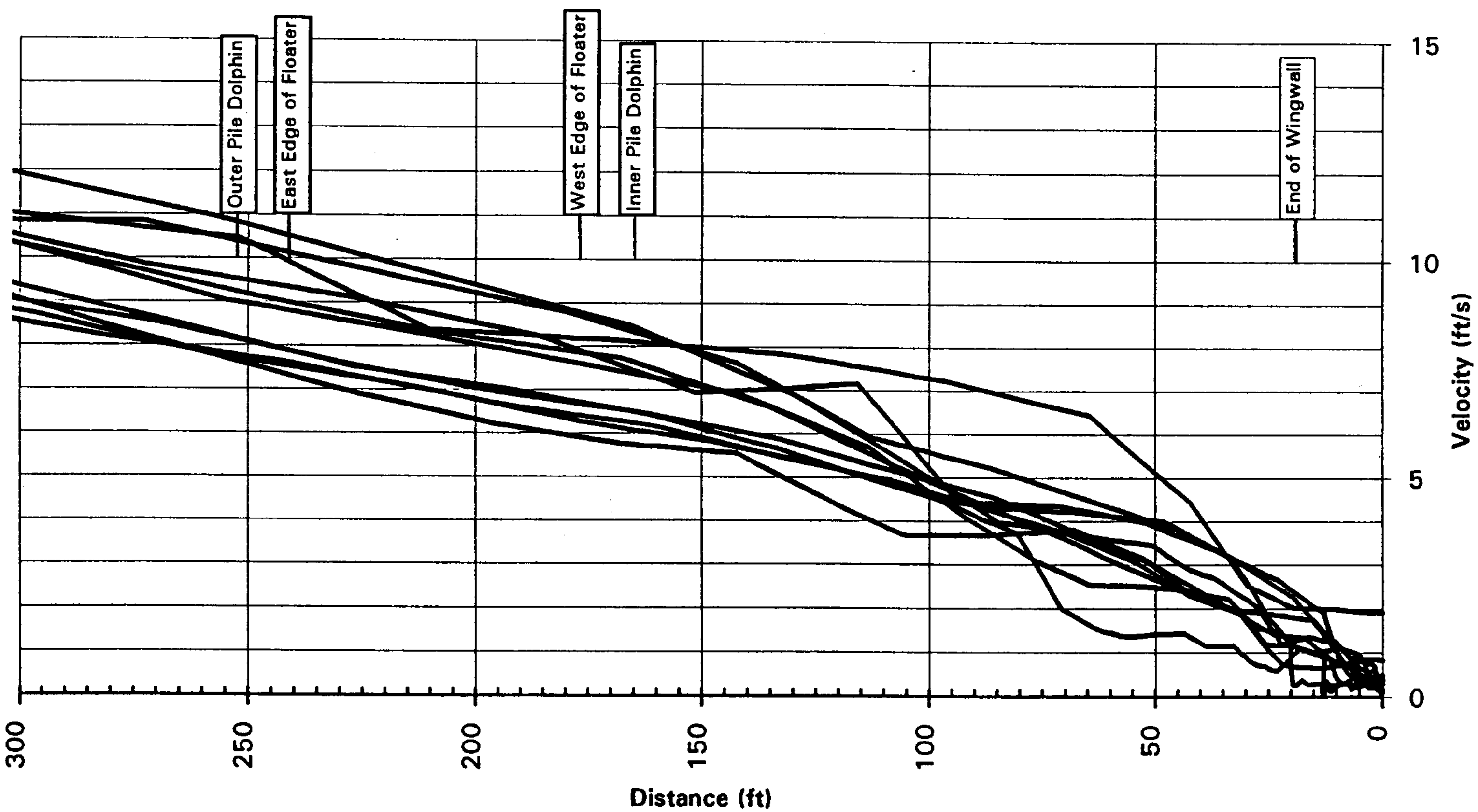


Figure 3.20. Velocity vs. Distance from Kingston Landing Structure (300 ft.)

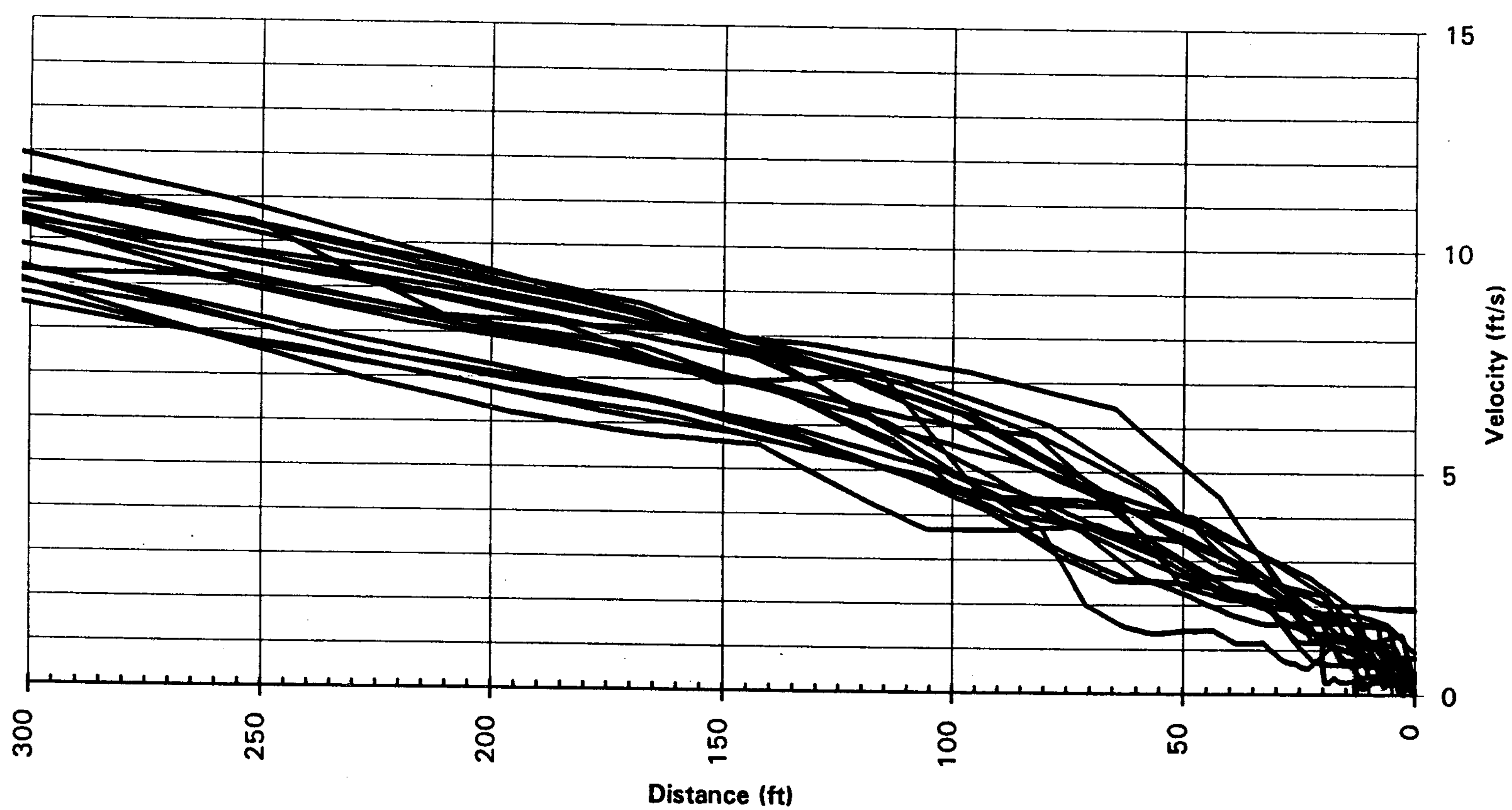


Figure 3.21. Velocity vs. Distance from Landing Structures (300 ft.)

the two terminals combined (Figures 3.22, 3.23, and 3.24). For each landing the research team recorded, throttle settings and velocity vs. GPS time was plotted. Velocity was plotted against GPS time since throttle settings were referenced to the 4000 DL II's GPS clock. Vertical arrows represent the instant a throttle setting was changed (Figures 3.25 and 3.26). Additionally, each landings throttle settings were analyzed to develop plots of throttle setting vs. time from the landing structure (Figures 3.27, 3.28, and 3.29). The EXCEL macro then converted the data into an Easting, Northing format (*.CSV) (Figure 3.30). These *.CSV files had to then be transferred to a text editor to insert a row that contained the command "PLINE," and then converted to a (*.SCR) file extension. These steps were necessary for AUTOCAD to plot the vessel's approach path. These (*.SCR) files were transferred into AUTOCAD so the vessel's approach path could be plotted (Figures 3.31 and 3.32). This procedure was repeated for each recorded landing (see Appendix F).

A mean approach path for Edmonds and Kingston was calculated by obtaining coordinates x/y for which each approach path crossed a circle at a given radius from the landing structure (e.g., 5,000 ft). For each radius, the crossing points were then analyzed to obtain a mean coordinate (Mean $X = X_i/n$, Mean $Y = Y_i/n$). This procedure was repeated for radii of 5,000 ft, 4,000 ft, 3,000 ft, 2,000 ft, 1,000 ft, and 500 ft. For each radius, each landing approach's coordinates were compared to that same distance interval's mean coordinate. The results were displayed in positioning distribution histograms from the mean approach path for distances of 5,000 ft, 4,000 ft, 3,000 ft, 2,000 ft, 1,000 ft, and 500 ft from the landing structure (Figures 3.33 and 3.34).

To determine the effects of current on vessel approach path's, the researchers referenced *Capt'n Jack's Tide and Current Almanac* to obtain tide and current information for each recorded landing. They were able to obtain tidal current speed and tidal direction at a point 2.7 miles west-southwest of the Edmonds terminal (Table 3.1). (5) This information was graphically represented, as well, within AUTOCAD

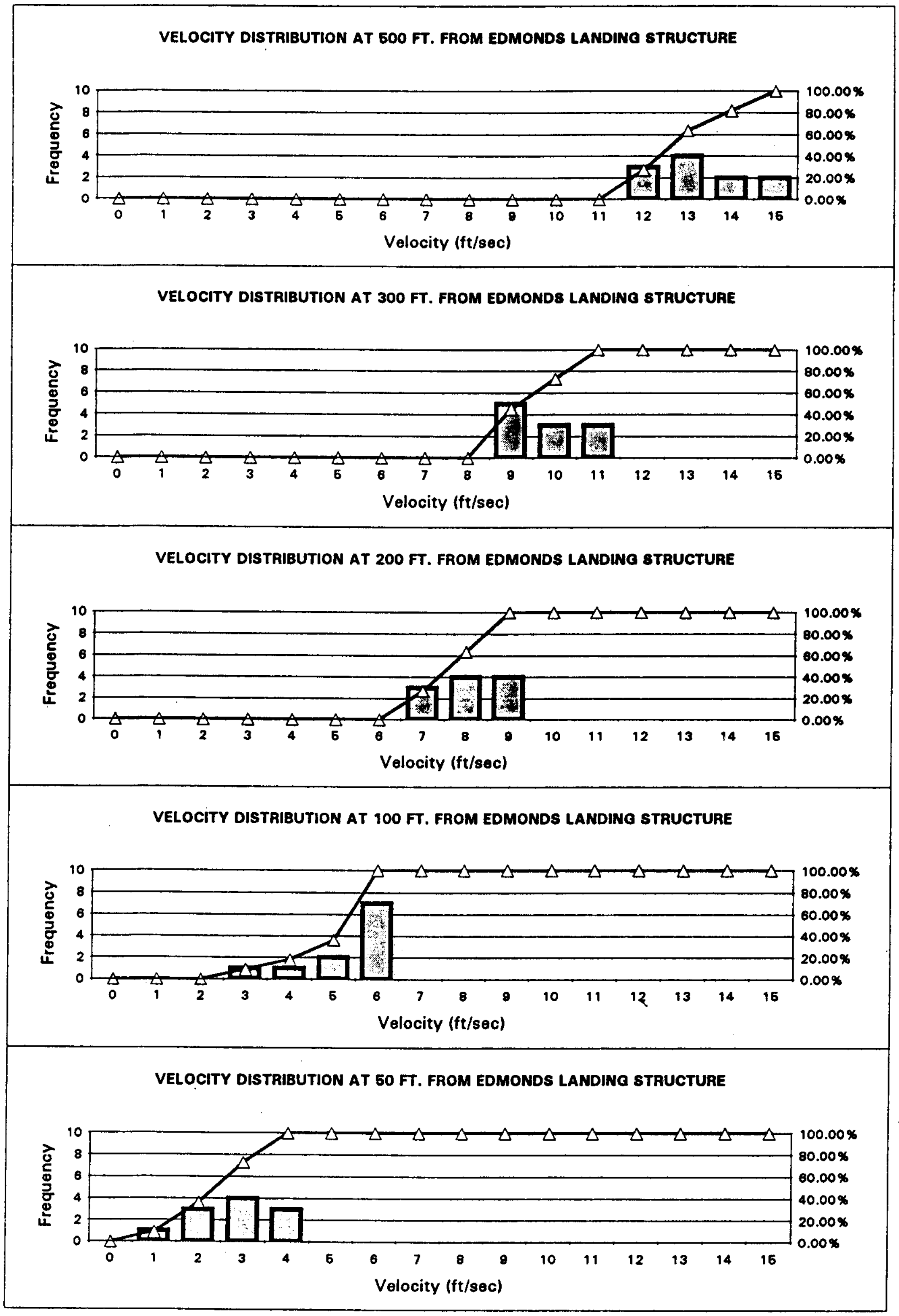


Figure 3.22. Velocity Distribution Histograms at Edmonds Terminal

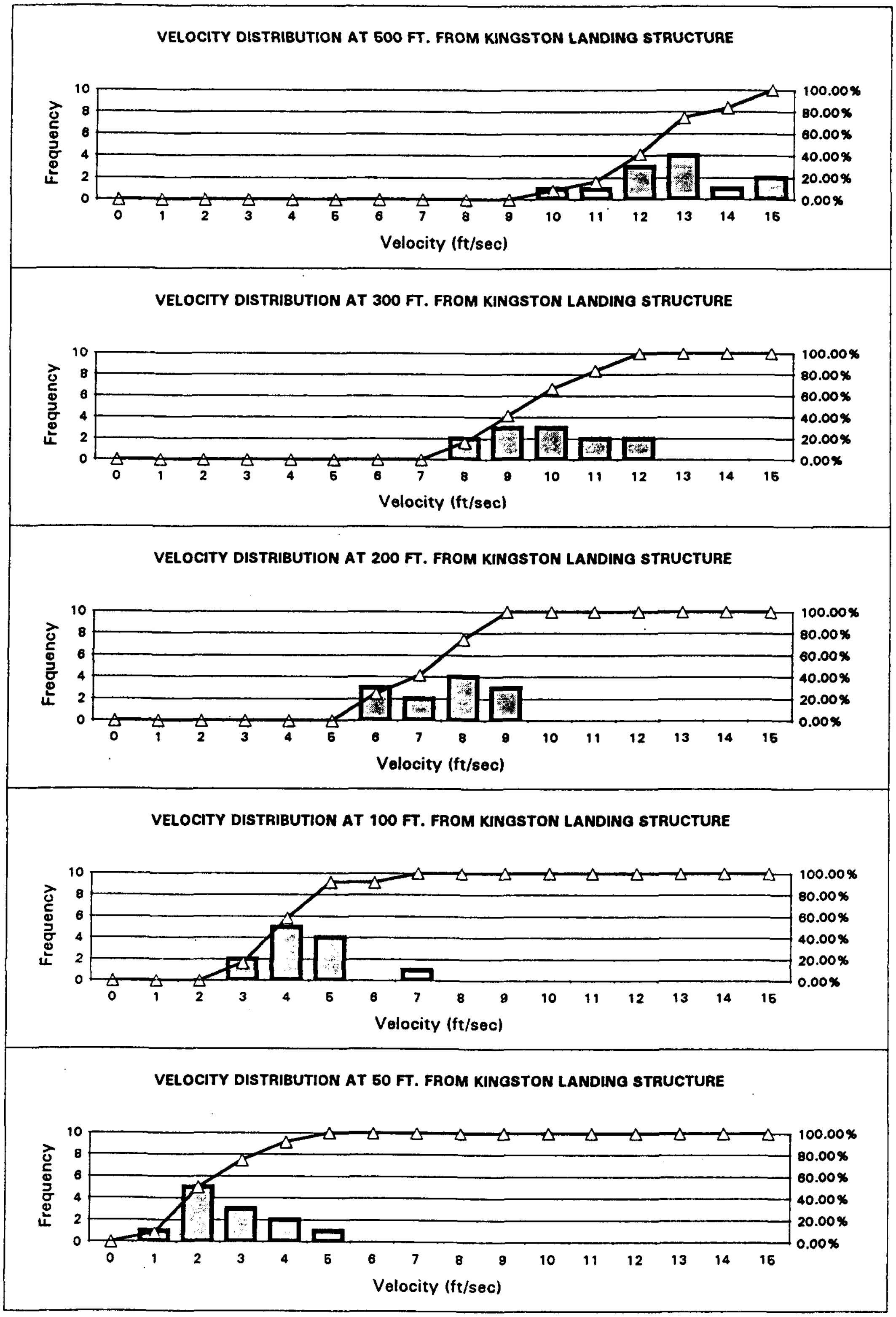


Figure 3.23. Velocity Distribution Histograms at Kingston Terminal

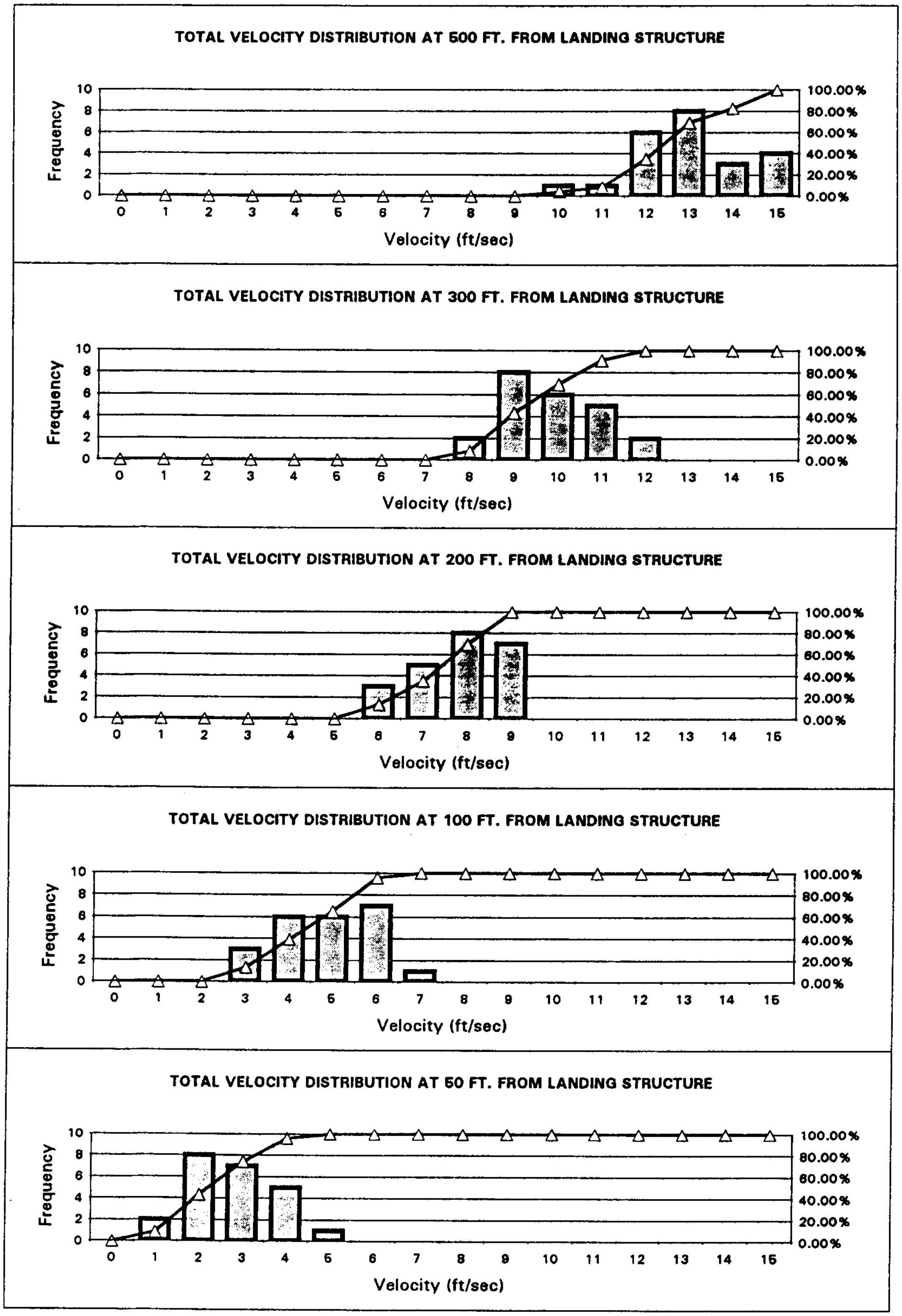


Figure 3.24 . Total Velocity Distribution Histograms

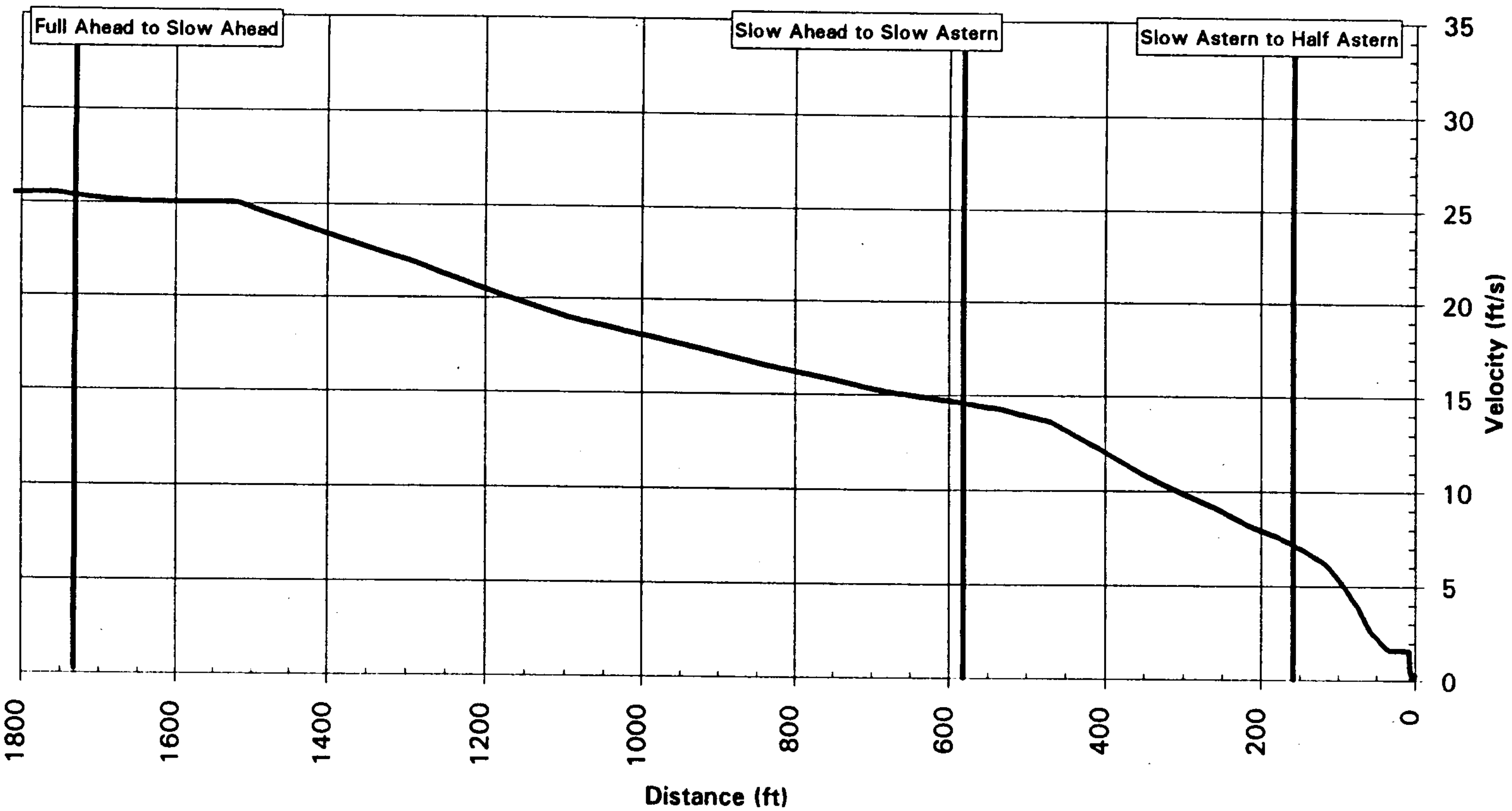


Figure 3.25. Adjustments to Throttle Settings for Edmonds Landing — 720EXX2

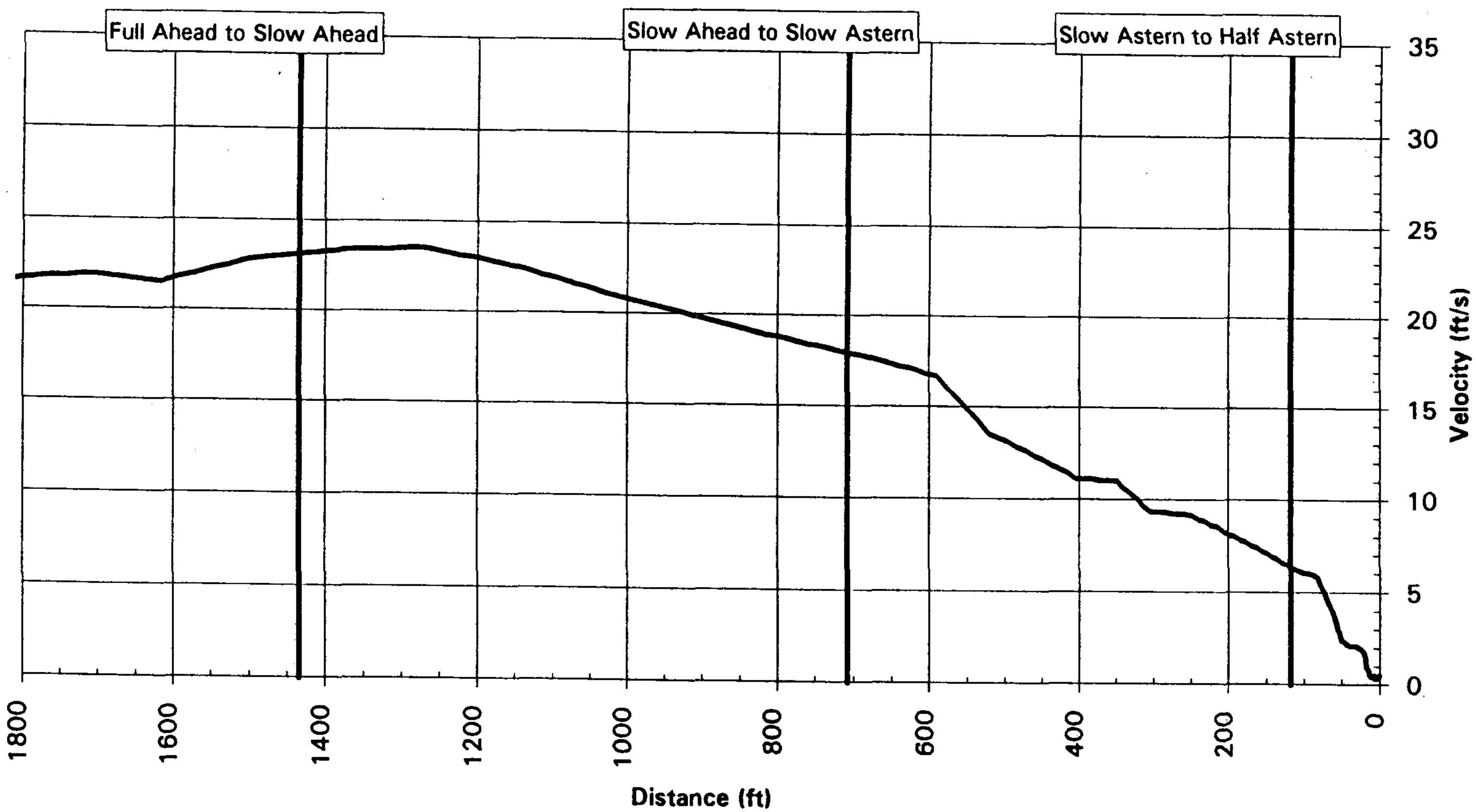


Figure 3.26. Adjustments to Throttle Settings for Edmonds Landing — 720EYY3

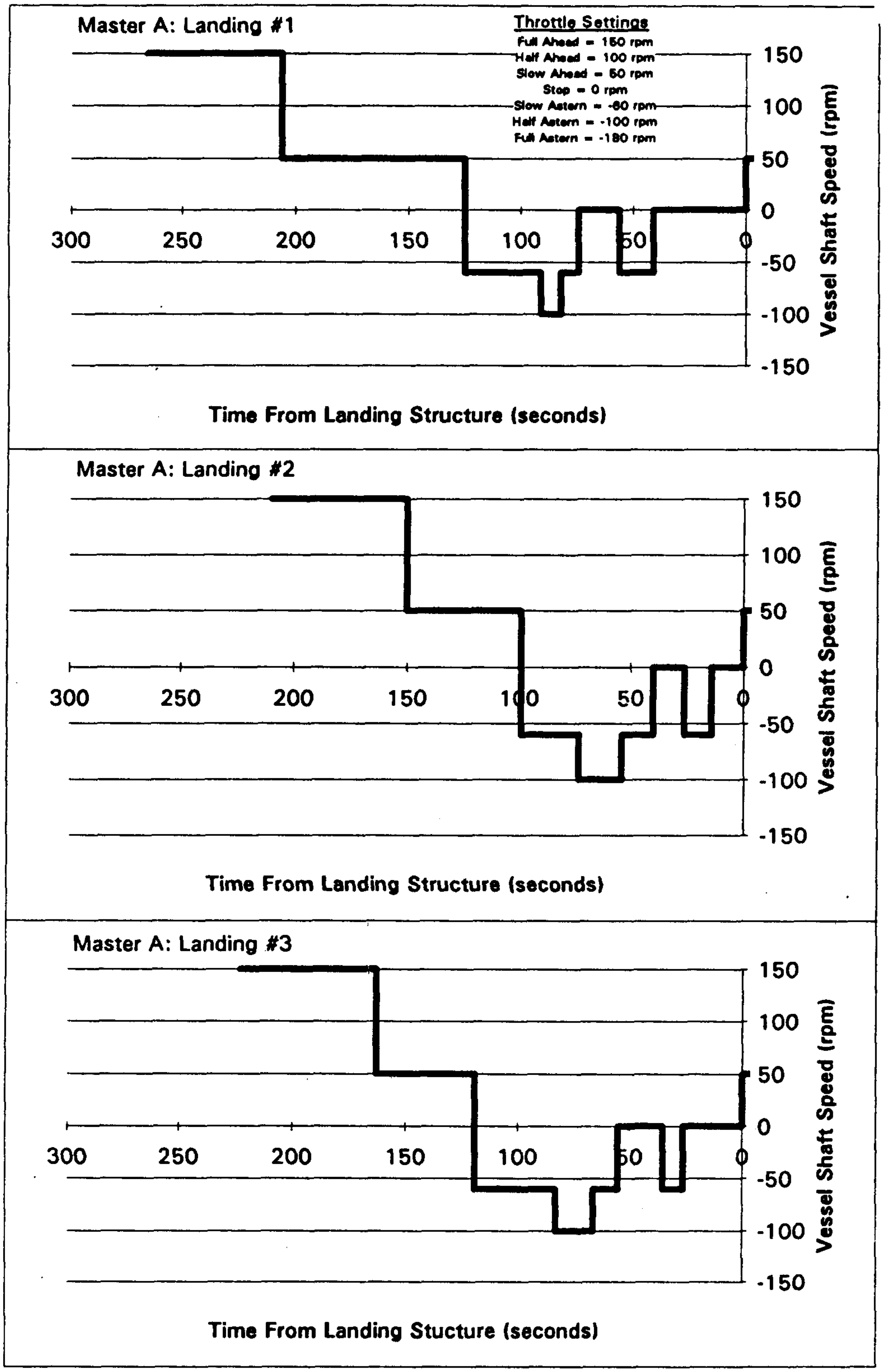


Figure 3.27. Consistent Throttle Settings vs. Time from Landing Structure for Master A

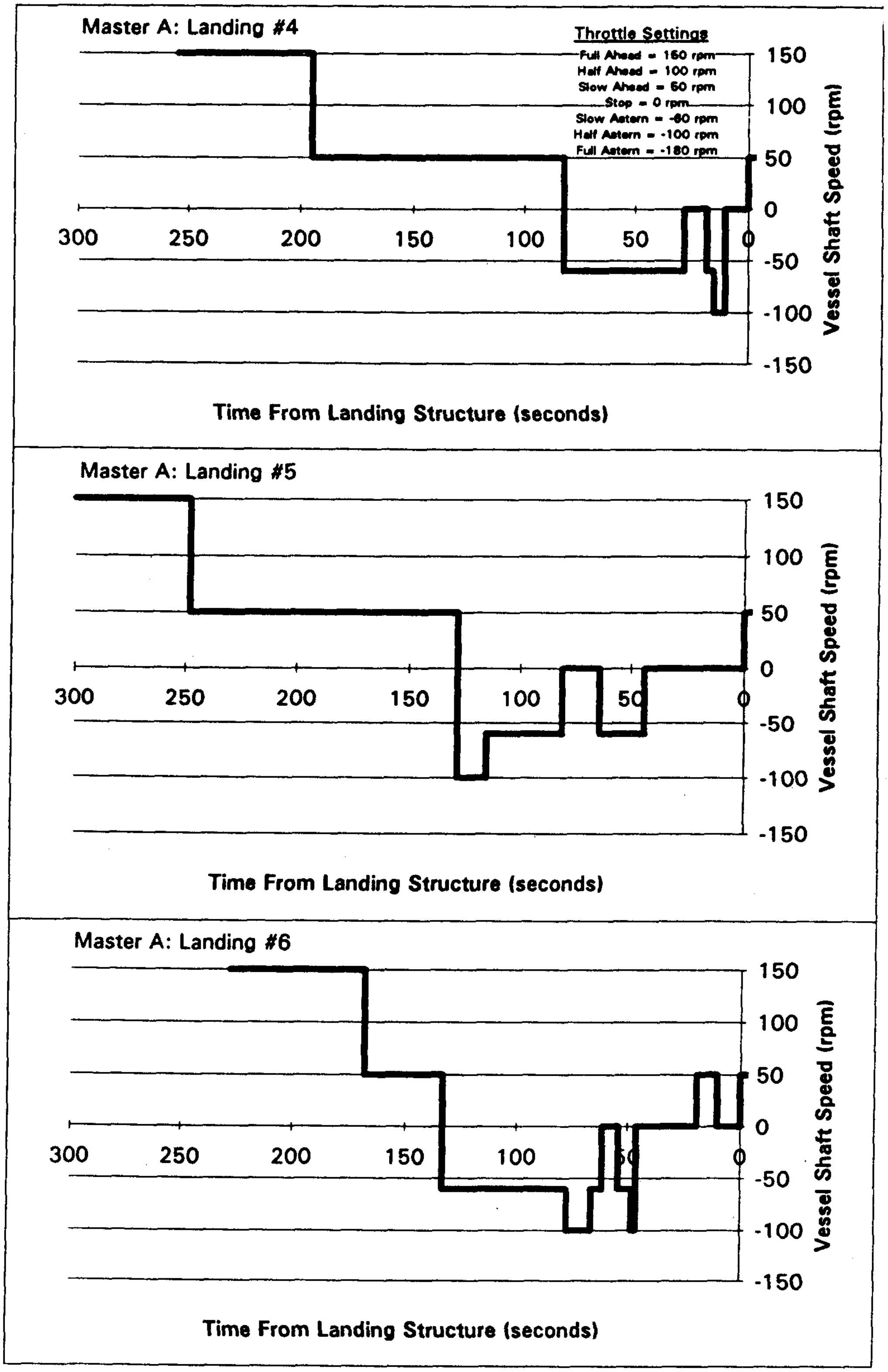


Figure 3.28 . Inconsistent Throttle Settings vs. Time from Landing Structure for Master A

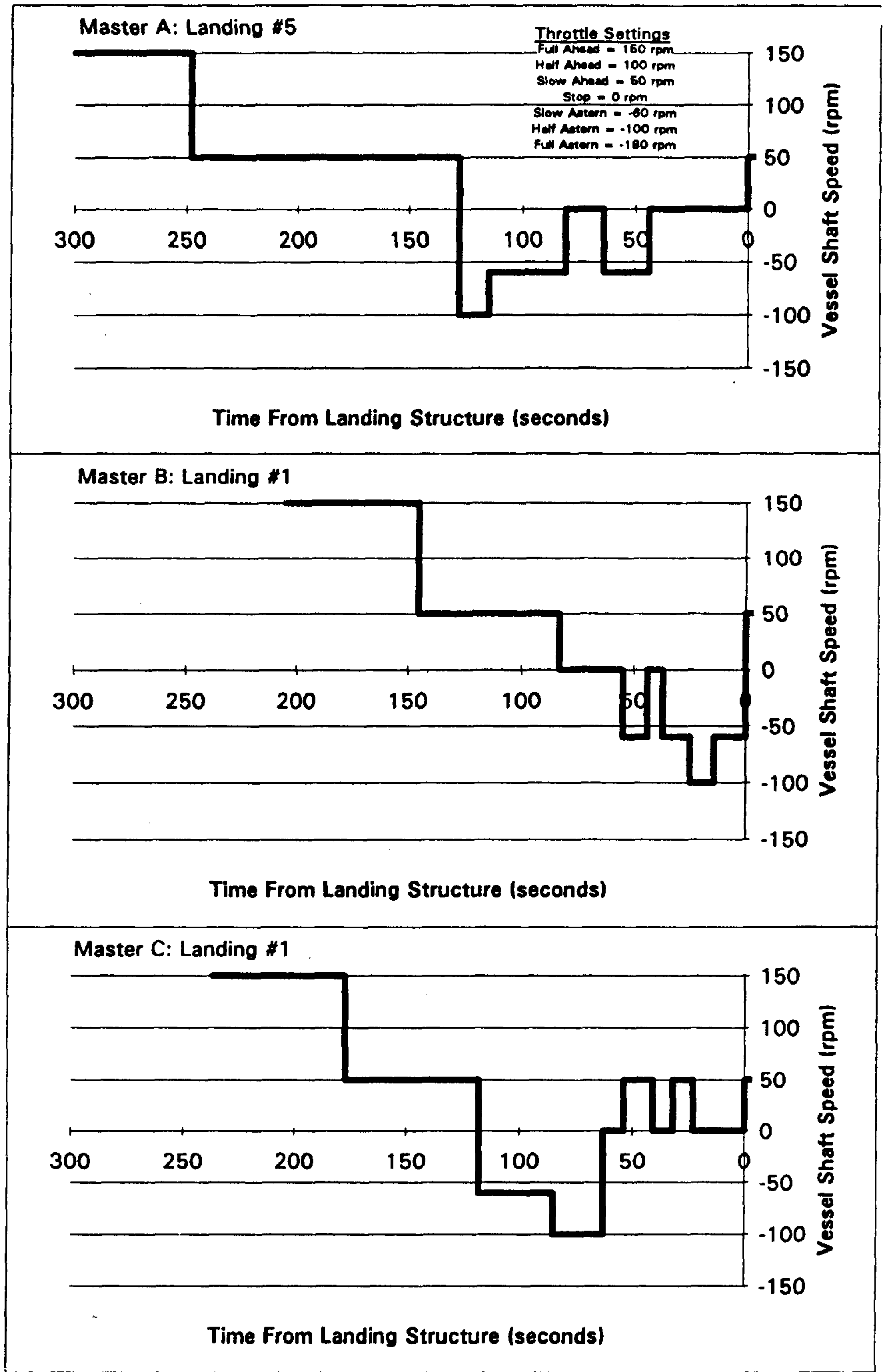


Figure 3.29. Comparison of Throttle Settings vs. Time from Landing Structure for Masters A, B, and C

EASTING	NORTHING
-9702	-3008
-9676	-2999
-9650	-2990
-9624	-2981
-9599	-2972
-9573	-2963
-9547	-2955
-9521	-2946
-9495	-2937
-9469	-2928
-9444	-2919
-9418	-2910
-9392	-2901
-9366	-2892
-9340	-2883
-9314	-2874
-9289	-2865
-9263	-2856
-9237	-2847
-9211	-2838
-9185	-2829
-9159	-2821
-9134	-2812
-9108	-2803
-9082	-2794
-9056	-2785
-9030	-2776
-9004	-2767
-8979	-2758
-8953	-2749
-8927	-2740
-8901	-2731
-8875	-2722
-8849	-2713
-8823	-2704
-8798	-2695
-8772	-2687
-8746	-2678
-8720	-2669
-8694	-2660
-8668	-2651
-8643	-2642
-8617	-2633
-8591	-2624
-8565	-2615
-8539	-2606
-8514	-2596

Figure 3.30. Excel Converted File (*.CSV)

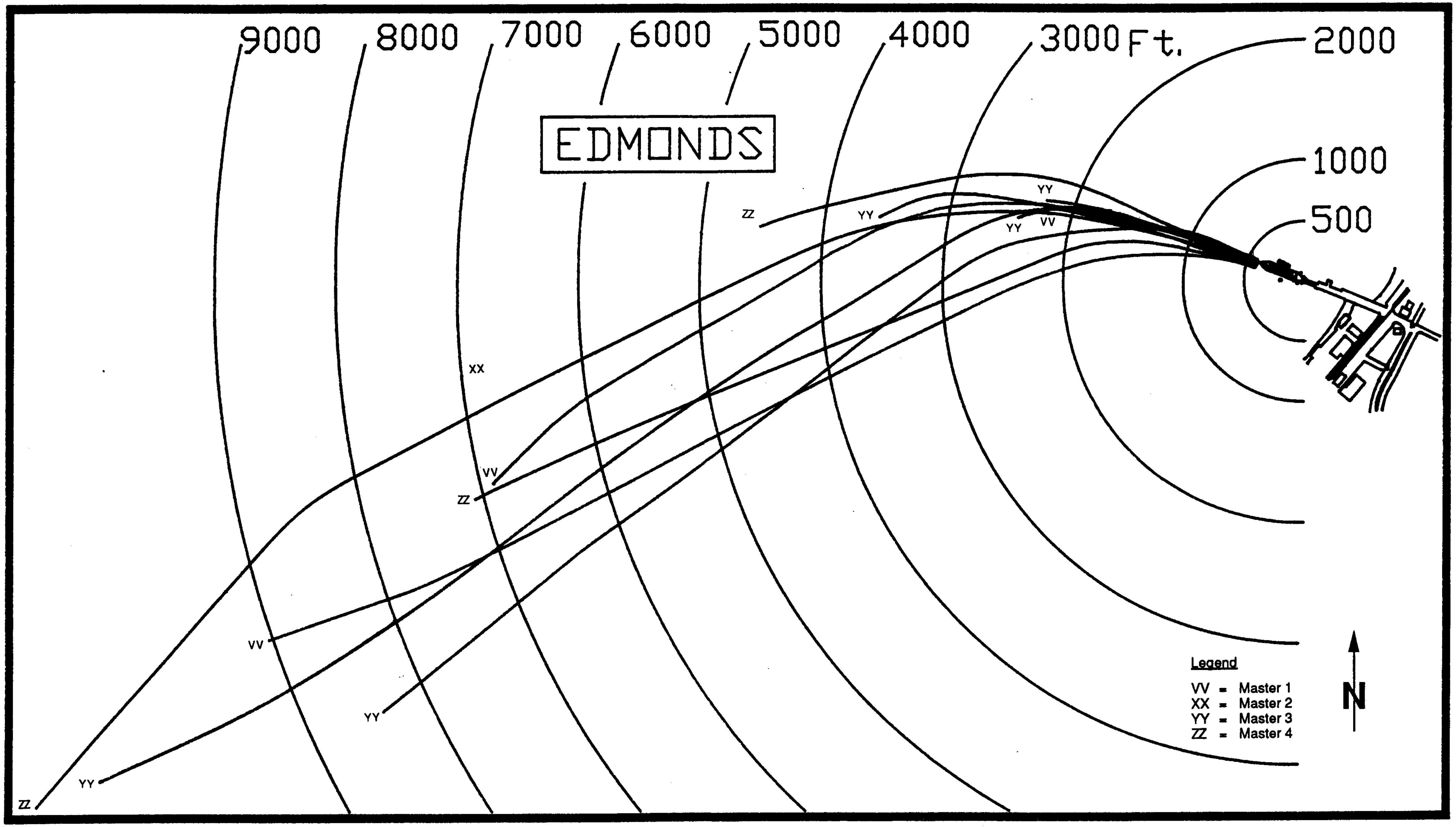


Figure 3.31. Landing Approaches at Edmonds

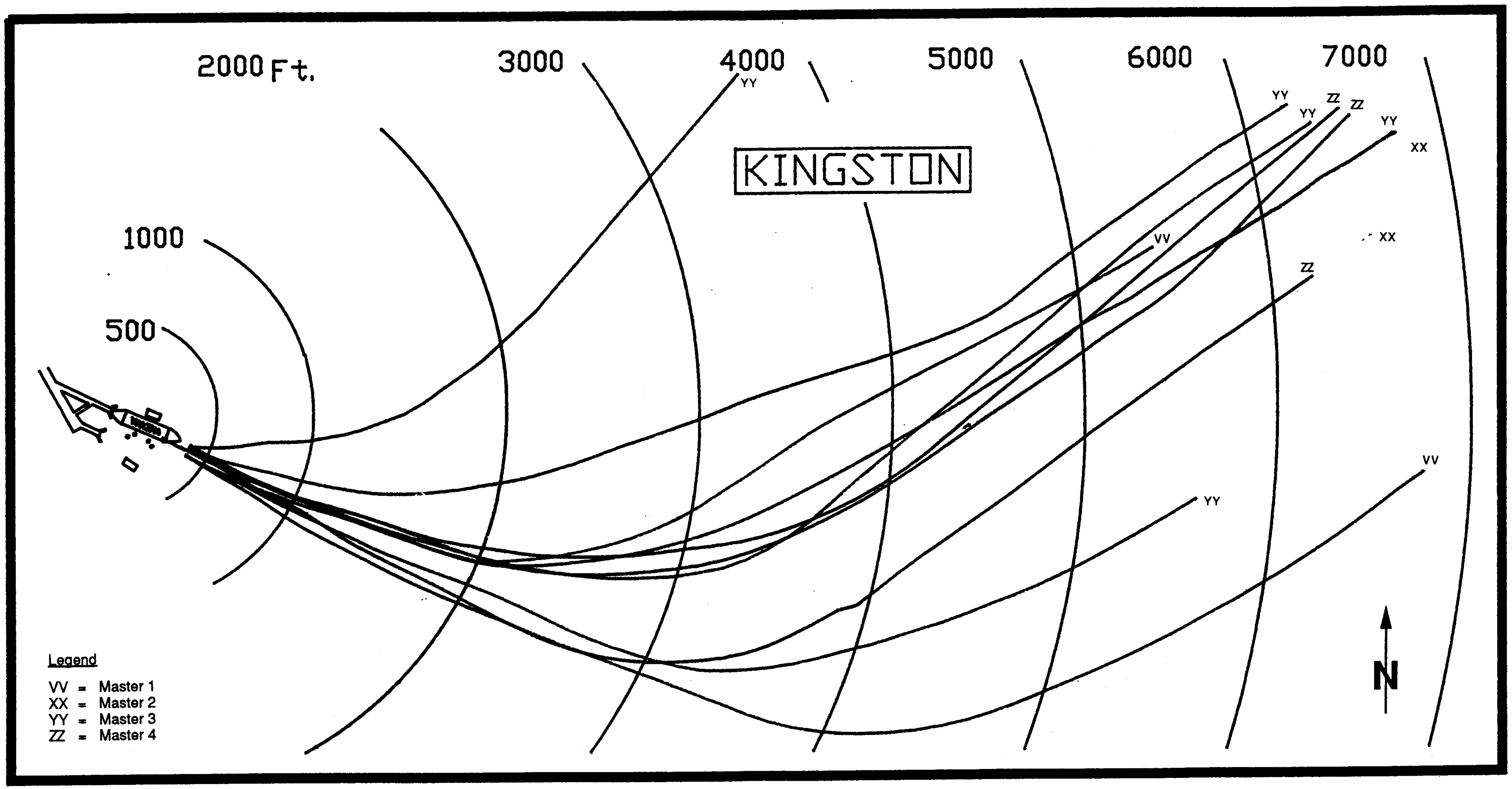


Figure 3.32. Landing Approaches at Kingston

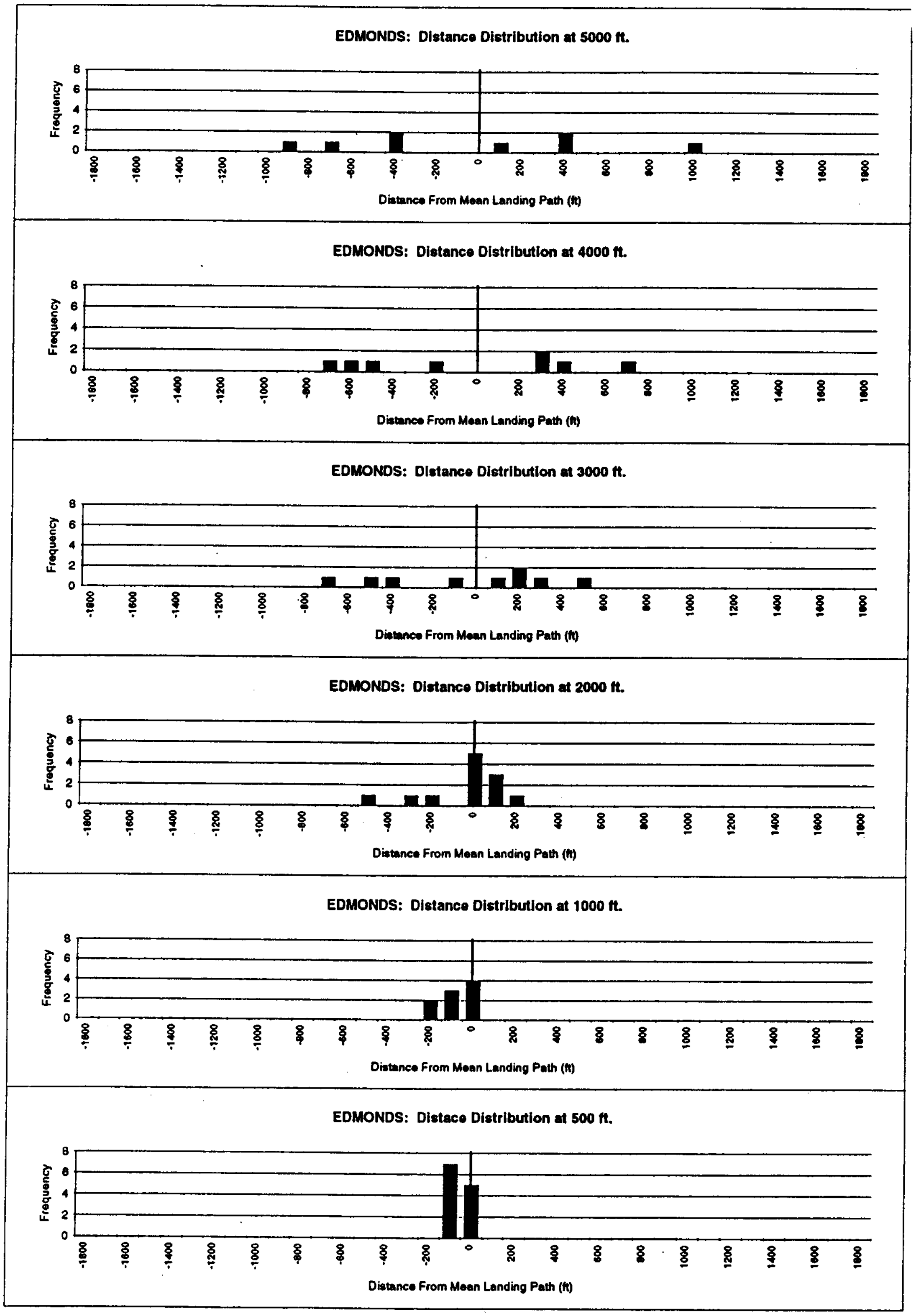


Figure 3.33. Distance Distribution Histograms at Edmonds

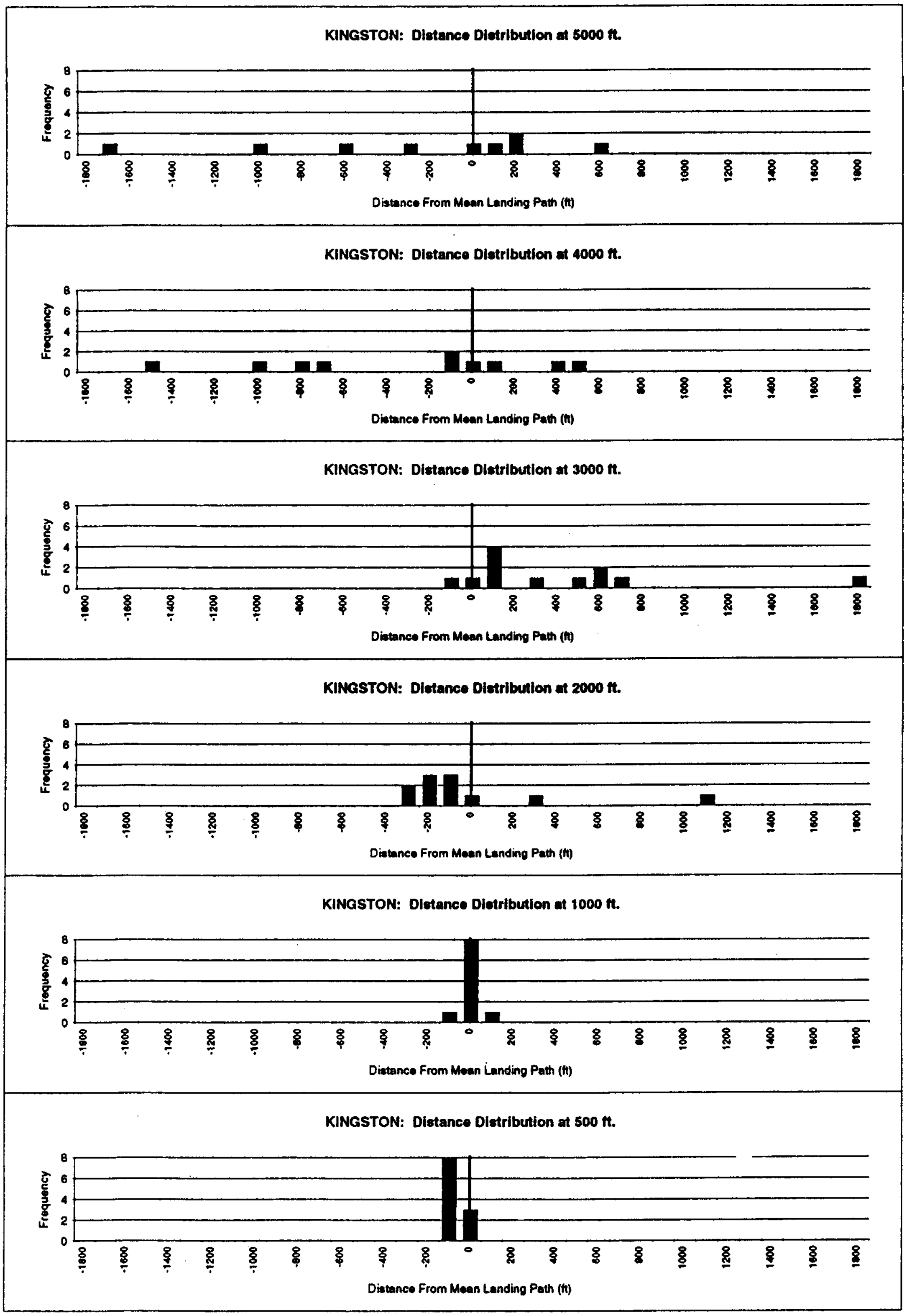


Figure 3.34. Distance Distribution Histograms at Kingston

Table 3.1. Tidal Current Speed and Tidal Direction

RUN	TIME	TIDAL CURRENT SPEED	TIDAL DIRECTION
709EJE3	15:42	0.04 KNOTS	EBB
709EJE2	14:16	0.14 KNOTS	FLOOD
709EJE4	17:13	0.20 KNOTS	EBB
712EPM2	11:25	0.18 KNOTS	EBB
712ERE6	17:21	0.10 KNOTS	FLOOD
720EJB2	11:17	0.21 KNOTS	EBB
720ERE3	12:33	0.37 KNOTS	EBB
720ERE5	15:33	0.21 KNOTS	EBB
723EPM3	12:50	0.02 KNOTS	FLOOD
723EPM5	15:42	0.19 KNOTS	EBB
723ERE2	9:54	0.12 KNOTS	FLOOD
709KJE2	15:02	0.07 KNOTS	FLOOD
709KJE3	16:28	0.11 KNOTS	EBB
709KRE1	10:30	0.26 KNOTS	FLOOD
712KRE5	15:11	0.25 KNOTS	FLOOD
712KRE6	16:37	0.16 KNOTS	FLOOD
717KPM1	11:54	0.52 KNOTS	EBB
718KJB2	11:55	0.49 KNOTS	EBB
720KJB3	11:51	0.35 KNOTS	EBB
720KRE4	13:16	0.36 KNOTS	EBB
723KPM4	13:10	0.02 KNOTS	EBB
723KPM6	17:16	0.10 KNOTS	EBB
723KRE3	11:56	0.10 KNOTS	FLOOD

(Figures 3.35 and 3.36). Each recorded landing was color-coded according to tidal direction (e.g., red = flood (south), blue = ebb (north)).

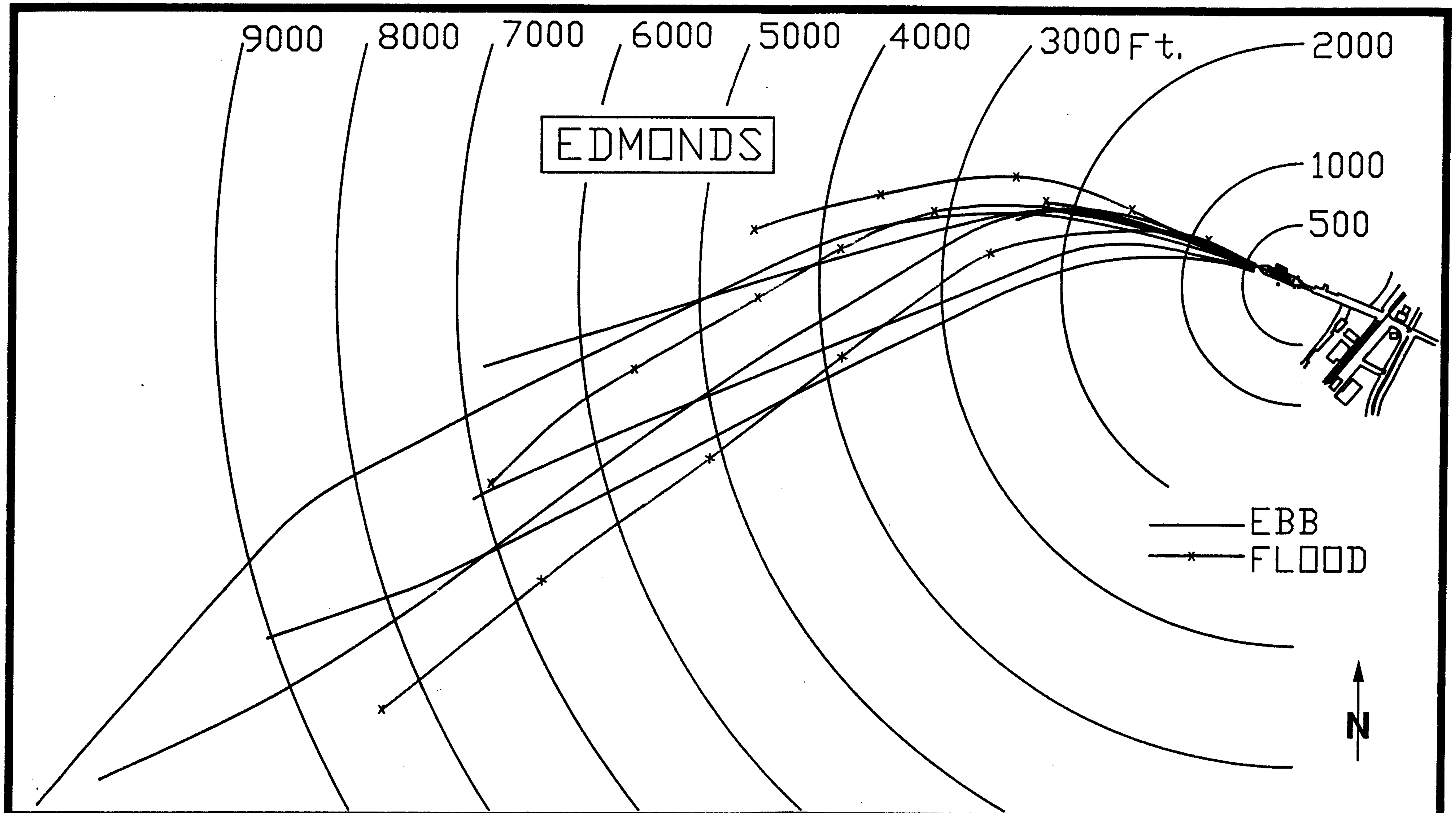


Figure 3.35. Current Effects at Edmonds

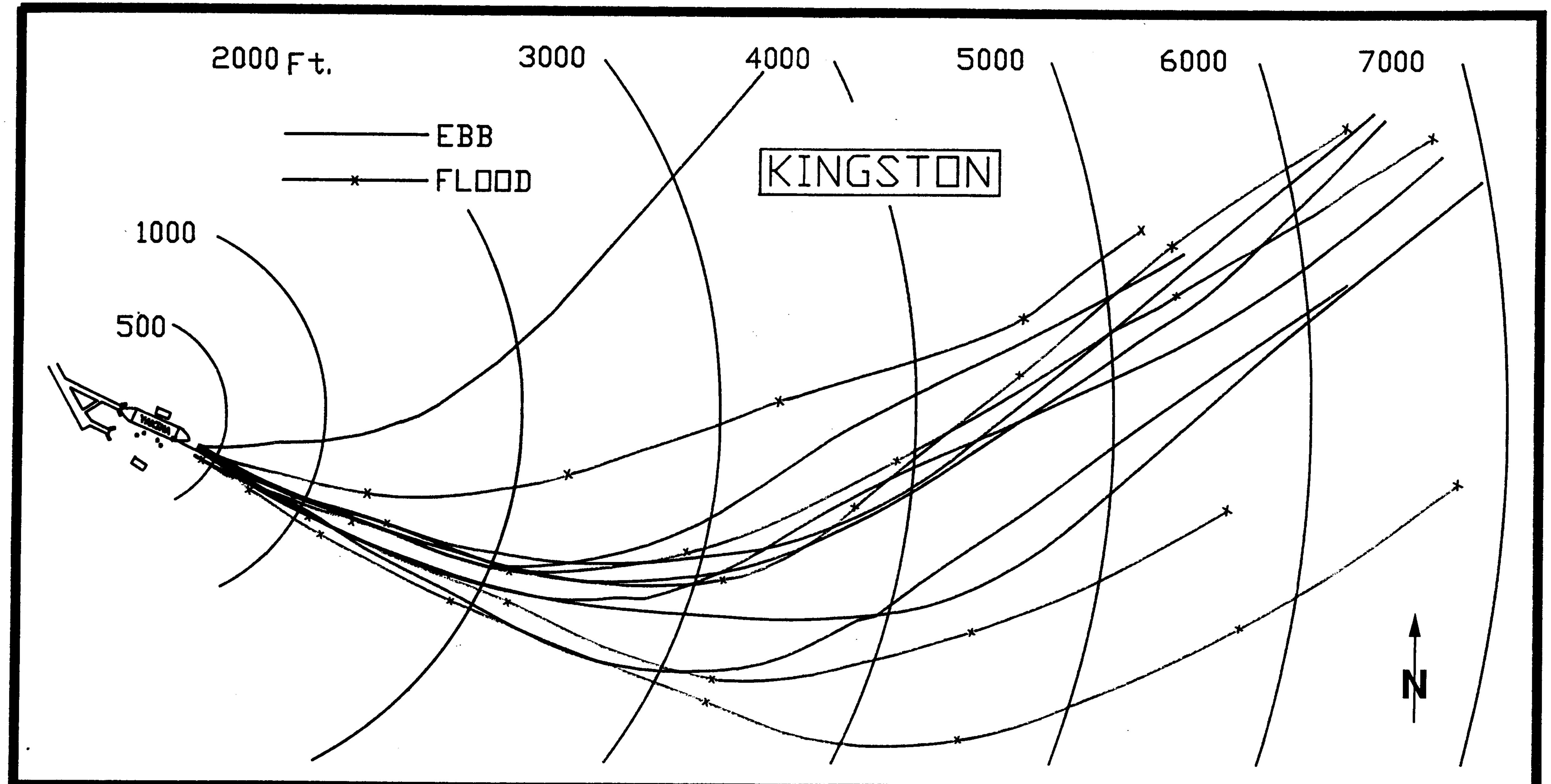


Figure 3.36. Current Effects at Kingston

CHAPTER 4

FINDINGS: RESULTS OF GPS TRACKING METHOD

It should now be obvious that GPS is capable of providing efficient and accurate positioning information. As outlined in the previous chapter, in the GPS Tracking Methodology section, the data from GPS can be manipulated into many forms. The following list outlines the specific topics that will discussed in more detail:

- velocity vs. distance plots (5000 ft)
- velocity vs. distance plots including throttle settings
- throttle setting vs. time from landing structure
- velocity vs. distance plots (300 ft)
- velocity distribution histograms
- AUTOCAD approach paths
- AUTOCAD approach paths showing current effects
- distance distribution histograms

Velocity vs. distance from the landing structure for the final 5,000 ft prior to berthing was analyzed (Figure 3.18). The results indicated that there is a consistent berthing velocity pattern. The vessels cross the sound at 26 to 29 ft/sec. It is interesting to note that the GPS data did not reveal any vessel speeds greater than the rated maximum. At a distance of approximately 1,500 ft from the landing structure, the vessel uniformly decreases velocity until it is approximately 500 ft from the landing structure, at which time the vessel's velocity is 10 to 15 ft/sec. This deceleration is maintained until the vessel's velocity is 6 to 8 ft/sec at 150 ft. At this point, the vessel's power is once again altered to uniformly decrease its velocity so that when it reaches the landing structure, the velocity is less than 0.5 ft/sec. This pattern can be further verified by the velocity vs. distance plots, which include the vessel's location at the time of a throttle setting (Figures 3.25 and 3.26). These figures indicate that vessels travel at "full ahead" until they are approximately 1,500 to 1,700 ft from the landing structure, at which point they decrease their power to "slow ahead." A delay of approximately 200 ft or 7 seconds is apparent until the vessel reacts to this throttle change. This delay is the time needed for the ship's master to telegraph the engine room, for the engineer to make the throttle adjustments, and for the engine and drive train to respond. The throttle setting is again changed from "slow ahead" to "slow astern" at approximately 600 to 700 ft. A delay of approximately 100 ft, or 7 seconds, is visible at this slower velocity. An additional adjustment from "slow astern" to "half astern" is made at roughly 150 ft from the landing structure. At this slower velocity, a delay of only 50 ft, or 7 seconds, is apparent. Once the vessel has reached the landing structure, a throttle setting of "slow ahead" is chosen to hold the vessel in position between the wing walls. These results confirm the results of Ishii. (6) The data from eight recorded landings from 1,000 ft from the landing structure are very similar to our data (Figure A.1 in Appendix A).

The plots of throttle setting vs. time from the landing structure were further analyzed. Figure 3.27 indicates that Master A followed the same sequence of throttle setting adjustments for three landing approaches. For example, full ahead _ slow ahead _ slow astern _ half astern _ slow astern _ stop _ slow astern _ stop _ slow ahead. However, every landing by Master A did not follow this sequence consistently (Figure 3.28). In addition, a comparison among Master A, Master B, and Master C revealed no set sequence of throttle setting adjustments among the ship masters for the duration of the landing approach (Figure 3.29). On the other hand, all masters appeared to have established a pattern for the first five throttle settings. This pattern was full ahead _ slow ahead _slow astern _half astern _ slow astern. Of the 13 recorded landings that contained throttle settings, 10 followed this pattern. Individual landings can be seen in Appendix G.

The plots of velocity vs. distance from the landing structure for the final 300 ft indicate very consistent velocities during final berthing maneuvers (Figure 3.21). These plots indicate berthing velocities of approximately 0.5 ft/sec, which correspond to the results of PIANC (7) and Jahren and Jones. (8)

Some recorded landings indicate apparent fluctuations in the vessel's velocity as it approached the landing structure (Figure 4.1). It is likely that the velocities did not actually fluctuate, but were caused by errors in satellite positioning data. As described earlier, three satellites can cause high values of PDOP. Since, at the time of this study, there were only 19 satellites available, the probability of having at least four visible satellites was poor. The distortions in the velocity vs. distance plots can be attributed to time periods of high PDOP values. In addition, Trimble Navigation verified that these distortions could have been caused by short tracking times. A Trimble representative stated that each time the receiver is activated it takes approximately 5 minutes to "settle down" and accurately track. Because the project's tracking sessions usually lasted only 5 to 8 minutes, this "settle down" period also contributed to the distorted results.

From figures 3.18 and 3.21 the velocity distribution histograms were created (Figure 3.24). The histograms clearly depict that the vessels uniformly decrease their velocity until berthed at the landing structure. Relative cumulative frequencies for each velocity distribution were calculated. 95th, 90th, 75th, 50th, 25th, 10th, and 5th percentiles are provided (Table 4.1). The histograms indicate that the approach velocities are within ± 2.5 ft/sec of one another.

The AUTOCAD plots (Figures 3.31 and 3.32) revealed that vessels take a wide variety of paths when the vessel is more than 1000 ft from the landing structure. It is apparent that the vessel is committed once it is within the final 500 ft from the landing structure. At 500 ft from the landing structure, all the vessels' paths were within 90 ft of each other. As a comparison, at 5,000 ft from the landing structure, the vessels' paths varied as much as 2,250 ft from one another. The research team, through discussions with the captains, found that each individual landing is highly dependent on many factors. These factors include marine traffic (such as fishing boats and cargo ships), wind, current,

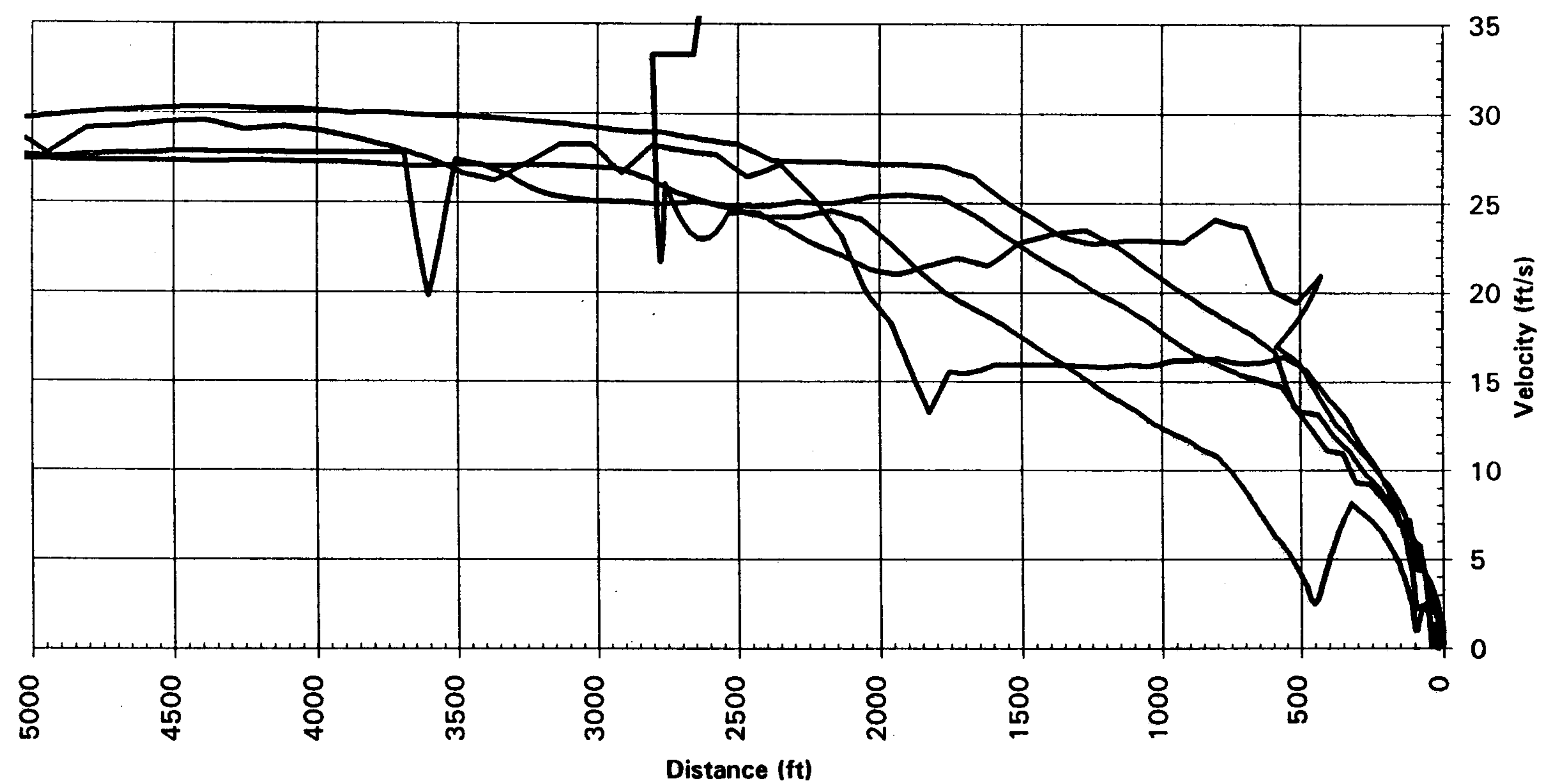


Figure 4.1. Velocity vs. Distance from Landing Structure — Distorted Data

Table 4.1. Relative Cumulative Frequencies of Velocities

500 FEET FROM LANDING STRUCTURE

95th Percentile	8.89 knots	15.00 ft/sec
90th Percentile	8.59 knots	14.50 ft/sec
75th Percentile	8.06 knots	13.60 ft/sec
50th Percentile	7.41 knots	12.50 ft/sec
25th Percentile	6.87 knots	11.60 ft/sec
10th Percentile	6.58 knots	11.10 ft/sec
5th Percentile	5.92 knots	10.00 ft/sec

300 FEET FROM LANDING STRUCTURE

95th Percentile	6.81 knots	11.50 ft/sec
90th Percentile	6.52 knots	11.00 ft/sec
75th Percentile	6.16 knots	10.40 ft/sec
50th Percentile	5.57 knots	9.40 ft/sec
25th Percentile	5.04 knots	8.50 ft/sec
10th Percentile	4.74 knots	8.00 ft/sec
5th Percentile	4.44 knots	7.50 ft/sec

200 FEET FROM LANDING STRUCTURE

95th Percentile	5.27 knots	8.90 ft/sec
90th Percentile	5.10 knots	8.60 ft/sec
75th Percentile	4.86 knots	8.20 ft/sec
50th Percentile	4.44 knots	7.50 ft/sec
25th Percentile	3.85 knots	6.50 ft/sec
10th Percentile	3.38 knots	5.70 ft/sec
5th Percentile	3.14 knots	5.30 ft/sec

100 FEET FROM LANDING STRUCTURE

95th Percentile	3.55 knots	6.00 ft/sec
90th Percentile	3.32 knots	5.60 ft/sec
75th Percentile	3.20 knots	5.40 ft/sec
50th Percentile	2.67 knots	4.50 ft/sec
25th Percentile	2.07 knots	3.50 ft/sec
10th Percentile	1.78 knots	3.00 ft/sec
5th Percentile	1.42 knots	2.40 ft/sec

50 FEET FROM LANDING STRUCTURE

95th Percentile	2.37 knots	4.00 ft/sec
90th Percentile	2.13 knots	3.60 ft/sec
75th Percentile	1.84 knots	3.10 ft/sec
50th Percentile	1.24 knots	2.10 ft/sec
25th Percentile	0.83 knots	1.40 ft/sec
10th Percentile	0.59 knots	1.00 ft/sec
5th Percentile	0.24 knots	0.40 ft/sec

and even the individual captain's techniques. The various tracks shown on the AUTOCAD plots (Figures 3.31 and 3.32) represent different ship masters. For example, VV represents master #1, XX represents master #2, etc. These plots clearly show that the same captain does not follow identical approach paths or perform identical berthing maneuvers for each landing. As discussed previously, many factors can influence the approach taken by the individual masters.

Each previously mentioned AUTOCAD plot was transformed to display the influence of tidal direction on vessel landing approaches (Figures 3.35 and 3.36). These plots indicate that current did not influence the approach paths into Edmonds or Kingston. However, as shown in Table 3.1, the tidal current speeds were very low (0.26 knots flood to 0.52 knots ebb). Various ship masters commented that currents were influential at other landing facilities where tidal current speeds were greater.

These velocity plots were further analyzed to develop distance distribution histograms. These distance distributions show the vessel's position distribution from the mean path at distances of 5,000 ft, 4,000 ft, 3,000 ft, 2,000 ft, 1,000 ft, and 500 ft (Figures 3.33 and 3.34). These distributions clearly verify that no consistent approach pattern has been established. Furthermore, a pattern cannot be established because of the the number of factors that influence the approaches, as was discussed previously.

In comparison to the video tracking methods reviewed in Chapter 2, GPS is a more precise and accurate method of tracking a vessel. However, the accuracy of GPS is highly dependent upon the number of satellites in view. As discussed earlier, four satellites must be visible to obtain a three-dimensional (3-D) position. If the elevation is known it is possible to obtain a two-dimensional (2-D) position solution with only three satellites. Because a vessel's elevation changes little (except for slow changes during the tide cycle), it is theoretically possible to track a vessel with only three satellites by using the last known elevation to obtain the solution. To set the 4000 RL II and the 4000 DL II in a positioning mode of LAT/LON/HEIGHT (3D mode) or LAT/LON/USING FIXED

HEIGHT (2D mode). The 3D mode will calculate a latitude, longitude, and elevation at a specified sync interval. On the other hand, in the 2-D mode, the latitude and longitude will be calculated, but the last recorded altitude would be output. The receivers would remain in the 3-D mode whenever four or more satellites were available. The receivers would automatically switch to a 2-D positioning mode when only three satellites were available and use the last calculated elevation in its solution. This may appear to be acceptable; however, when only three satellites are available, the odds of them being in a geometric configuration that provides an acceptable DOP value is highly unlikely. This was the cause of the distorted data the researchers obtained, which was previously discussed. The researchers recommend that Trimble Navigation's SATVIZ software be utilized as a pre-mission planning package. This software can "look into the future" and let the research team know when the best visibility periods will be.

The GPS tracking method provided more accurate results concerning the approximate approach velocities and positions of the ferries. This method was advantageous in that is was very easy to operate, and it was efficient, post analysis did not require large amounts of time, and the results were accurate to within approximately 1 to 3 meters. No velocities that exceeded the vessel's capabilities or unreasonable vessel approaches were detected. Disadvantages of this method included the high initial equipment costs and the time investment required to establish a working system.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

The development of vessel tracking methods provides tools with which to record vessel approaches. The results of these records provide information that can assist in the proper design of landing structures and safe operation of vessels during berthing. The following sections summarize the operational conclusions, case study conclusions, and recommendations of this study:

OPERATIONAL CONCLUSIONS

- Vessel approach paths can be estimated with the remote video method. With synchronized portable video cameras located at two separate coordinates, the vessel's location can be referenced to the locations of known landmarks from each camera location. Post analysis of each camera's recordings provides approximate vessel locations within ± 200 ft.
- Vessel approach paths can also be estimated with the radar image method. A portable video camera can be used to record the position of the ferry on the radar screen in the pilot house. The results of these images provide approximate vessel locations within ± 200 ft.
- The results indicating the vessel locations, obtained from the remote video method and the radar image method, can be further analyzed to obtain velocities. Plots of velocity vs. distance from the landing structure can then be developed. These may be used for the development of safe vessel berthing velocities.
- GPS tracking methods can be utilized to track the vessel's path. This method is capable of determining vessel locations every 1 second to within ± 10 ft, as well as the vessel's velocity at that same instant.

- Plots of velocity vs. distance from the landing structure can be developed from the GPS tracking method. These plots may be used to develop velocity distribution histograms, which can aid in the development of safe vessel berthing velocities.
- Recordings of throttle settings can be taken while the GPS tracking method is used. These are useful when they are laid over plots of velocity vs. distance from the landing structure. The results indicate the distance required between the time the throttle setting is ordered from the ship's master until the vessel velocity actually responds. Additionally, plots of throttle setting vs.time from the landing structure can be developed to establish throttle setting patterns among individuals or groups of ship masters.
- AUTOCAD can be used to graphically represent the approach paths of vessels. It can provide a comparison of the approaches taken by different ship's masters, as well as adjustments made for marine traffic and currents.
- Distance distribution histograms can be created from the results of the AUTOCAD plots. These are useful in establishing a consistent approach path to be used as a design criterion for landing structures.

CASE STUDY CONCLUSIONS

- Plots of velocity vs. distance from the landing structure indicated that there was an approach velocity pattern. This pattern indicated that WSF vessels crossed the Puget Sound at 26 ft/sec. to 29 ft/sec. At a distance of approximately 1,500 ft from the landing structure, the vessels uniformly decreased velocity until, at approximately 500 ft, the vessels' velocity was 10 ft/sec. to 15 ft/sec. This deceleration was maintained until the vessels' velocity was 6 ft/sec. to 8 ft/sec. at 150 ft. At this point, the vessels' power was once again altered to uniformly decrease the vessels' velocity so that when the vessels reached the landing structure, the velocity is less than 0.5 ft/sec. In the area of the outer landing aids (250 ft from the dock), the vessels are traveling at 7 ft/sec. to 11 ft/sec.

- Throttle setting vs. time from the landing structure plots indicated that all masters had established a pattern for the first five throttle settings before final berthing. This pattern was full ahead _ slow ahead _ slow astern _ half astern _ slow astern.
- AUTOCAD plots indicating WSF vessel approach paths suggested that no common approach pattern existed when the vessels were more than 1000 ft from the landing structure. However, the vessels were committed once they were within the final 500 ft of the landing structure. At 500 ft, all the vessels' paths were within 90 ft of each other, while at 5,000 ft the vessels' paths varied as much as 2,250 ft from one another.
- Current did not influence the landing approaches into the Edmonds and Kingston terminals. However, the reference tidal current speeds were very low (0.26 knots flood to 0.52 knots ebb). Various ship masters commented that currents were influential at other landing facilities where tidal current speeds were greater.

RECOMMENDATIONS

- This study included only 24 landings, which was not a sufficient sample for obtaining accurate statistical information. Therefore, the equipment should be used to capture additional landings to produce a larger sample of berthing events.
- The research team instrumented the mobile PC with an anemometer capable of calculating wind speed and direction, and a digital compass. At the time of publication, this research team was unable to analyze the effects of wind on the berthing maneuvers of the vessels at the Edmonds and Kingston terminals. It became apparent through discussions with several masters that wind and current effects were the factors that most influenced the approach velocities and positions of the ferries. Subsequent research should be performed, at various terminals, to analyze the effects of wind and current on the final berthing maneuvers of the vessels.

- The vessel tracking system should be developed so it can be used as a regular part of the ferry landing design process. It will increase understanding of how vessels use landing aids and will provide more information on vessel approach velocities and approach paths.
- Based on the observations of this study, WSDOT should design its outer landing aids for approach velocities of at least 12 ft/sec. with a small angle of attack. PIANC suggests that 15 degrees is an appropriate value for the approach angle.

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APPENDIX A

LITERATURE REVIEW

APPENDIX A

LITERATURE REVIEW

Selecting the proper speeds and approach angles is critically important to the development of design criteria for vessel landing facilities. Little research has been done to develop suitable design criteria for end loading ferries. The limited research that has been done has been based on the kinetic energy model, in which landing structures must absorb the kinetic energy associated with the vessel's berthing velocity. The kinetic energy (KE) is calculated by the following equation (1, 2, 3):

$$KE = 1/2\,(w/g)CV^2$$

where

where	w	=	weight of vessel
	V	=	approach velocity
	g	=	acceleration of gravity, and
	C	=	a coefficient that accounts for the vessel's approach angle, the eccentricity of impact, and various hydrodynamic effects.

Design criteria for berthing energy have also been developed through observations of fender deflections during berthing events. (3) Researchers equipped berthing fenders with deflection measuring devices and estimated the berthing energy by calculating the energy vs. deflection relationship for the fender. On the basis of the observation of approximately 5000 berthing events, probability distribution functions were created in which a design energy that had a predetermined probability of exceedance could be chosen.

In selecting the design approach velocity for catastrophic berthing events, Ishii observed eight landing maneuvers on videotape. (4) The ferry's distance from the landing and its speed were estimated by scaling the video image against objects of known dimensions. The results of the observations are shown in Figure A.1. The design criteria were developed for a hypothetical accident in which a vessel loses propulsion and drifts

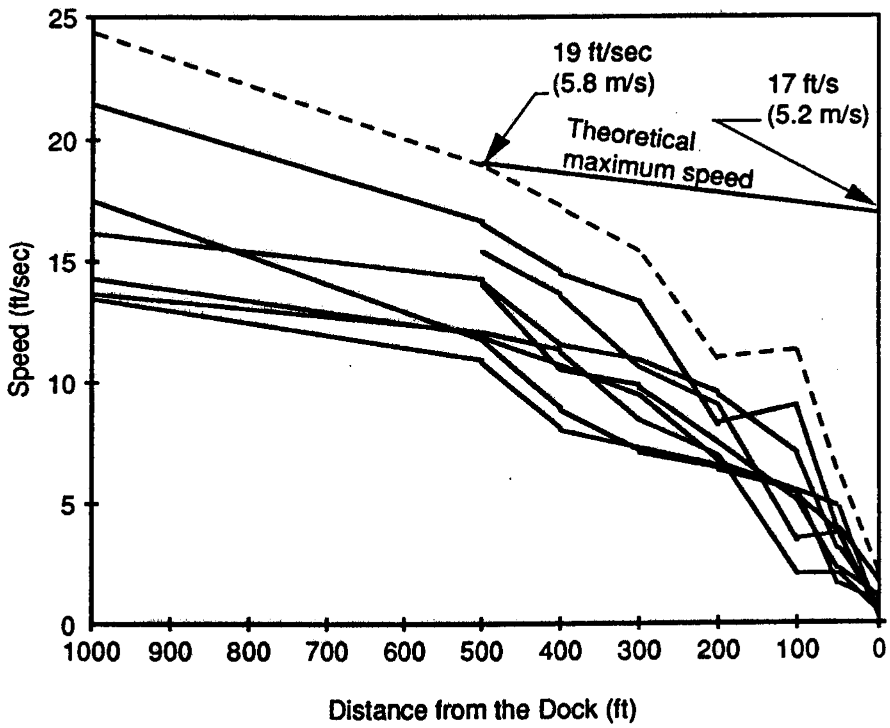

Figure A.1. Speed vs. Distance (4)

into a berth without power. The theoretical maximum speed at the landing structure was found to be 17 ft/sec. This estimate was developed by assuming that the maximum speed at a distance of 500 ft from the berth was 19 ft/sec (Figure A.1). Calculations indicated that 2 ft/sec of velocity would be lost in the remaining 500 ft. Ishii proposed conceptual innovative designs that could safely absorb the energies associated with a catastrophic berthing. One example would absorb energy by dragging concrete anchors on the bottom of the harbor. These anchors would be placed 500 ft from the berth and would be engaged in emergency situations with the release of a hook from the vessel.

Pankchik and Ladegaard included a computer simulation of vessel approaches as an important part of the procedure for designing a new landing facility at Helsingør, Denmark. (5) These computer simulations were not useable for our research for the following reasons. First, the required hardware and software is only available at a limited number of locations (e.g., Danish Hydraulics Institute, Kingspoint, New York and Waterways Experiment Station, Vicksburg, Ms.); and second, the effort required to tailor the simulation to one of WSF's locations is beyond the scope of the project. Pankchik and Ladegaard revealed berthing velocities of 6.5 ft/sec (2 m/s) at 360 ft (111 m) from the landing structure, 3.2 ft/sec (1 m/s) at 182 ft (55 m) from the landing structure, and 1.6 ft/sec (0.5 m/s) prior to the final berthing.

Jahren and Jones recorded over 1,500 berthing events on video tape to develop design criteria for wing walls for berthing events in which the damage incurred is repairable. (6) The vessel's velocity for the final 5 to 15 feet was obtained, as well as wing wall deflections at the time of vessel impact. Jahren and Jones obtained a mean landing speed of 0.58 ft/sec and a 95th percentile landing speed of 0.91 ft/sec (Figure A.2). The approach velocity and deflection measurements were also analyzed to calculate a berthing coefficient, C, of 0.6 (Figure A.3). Because observations were only made near the wing walls, this study provided no information on the relation of the final

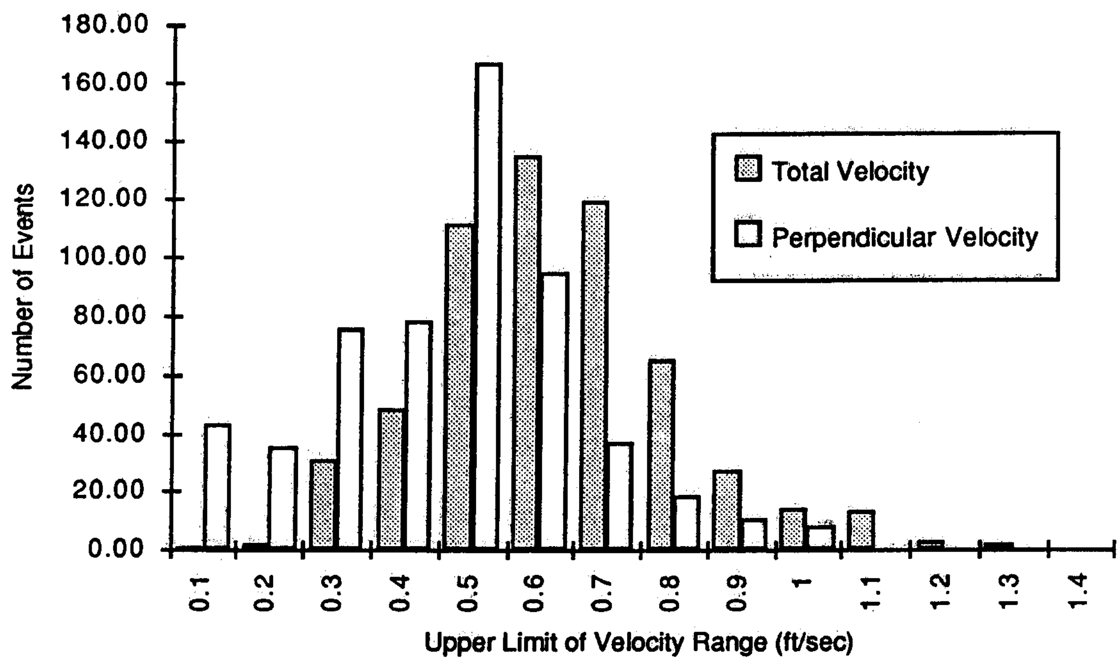

Figure A.2. Velocity Distribution for 568 Berthing Events (6)

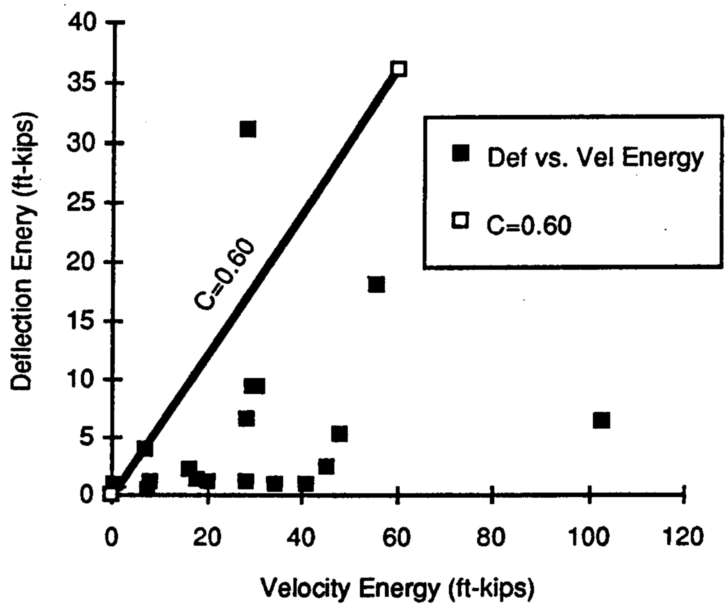

Figure A.3. Deflection Energy vs. Velocity Energy (6) approach to the rest of the berthing maneuver. In addition, no information was provided for the design of other landing aids, such as dolphins.

For this project, the researchers chose GPS to track the vessel's location. This method has been widely used in tracking vehicle and vessel locations in the transportation industry. For example, Webb and Hewlett utilized GPS to track ships in real time. Differential GPS, with mobile receivers installed on two vessels, was used to confirm that proposed channel widths were adequate for two-way traffic in the Houston Ship Channel. (7) This was done by tracking two ships as they passed to find the minimum required channel width.

Burlington Northern Railroad (BN), in an effort to control traffic on its rail system, is considering a proposal to implement a GPS-based Advanced Railroad Electronics System (ARES). With ARES, differentially corrected GPS data on location and speed of all BN trains are fed into a command and control system via digital communications. There, a computerized tactical traffic planner determines the best plan for operating the system. Most of BN's network is single track, which produces the situation in which two trains must pass each other at sidetracks. The tactical planner issues commands to adjust the trains' speeds and routes so that the trains can meet at sidetracks without delay and maintain relatively high fuel efficiency. (8)

A survey of the literature revealed that approach velocity is crucial to the development of design criteria for ferry landing structures. In addition, past research indicated that GPS is a proven tracking method. Our research will expand on the research done by Jahren and Jones by implementing GPS to track vessel approaches beginning at approximately 5,000 ft from the landing structure.

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APPENDIX B

SOFTWARE NARRATIVES

GPSLAB Narrative for use on an IBM PC

Starting from the C:\> **dir**
Turn on the: 12V Voltage Regulator
4000 DL GPS Unit
C:**gpslab** and Enter (about 3 times)

CHOOSE AN ITEM
F2: Configure Control
F3: Set Masks
F1: Elevation mask (should be at 7 degrees)
F2: DOP mask (should be at 10)
(can be changed based on accuracy desired)
F4: Set Modes
F1: Set Sync (should be at 5 seconds)

TO RECORD AND STOP
F1: Data Selection
F4: Store Data
(Screen should begin to flip and show satellites)
F4: Stop Recording
(F4 must be pressed to stop recording, it will continue to record if Esc is used to close out of GPSLAB)
ESC: Until Quit
(It is possible now to check if the run was good)

FILE NAME AND TIME
At the bottom of the screen the file name will be listed as follows:
C: 194-0001.GPS (194th GPS day at the first second of recording)

TO CHECK IF THE DATA IS GOOD
Go into gpslab
C:\gps\gpslab>**gpslab**
Data File record list
Go to File
Change first 3 entries to "selected"
Choose File - you may have to toggle the screen down to find your file
Get completely out of File using the Esc key
C:\gps\gpslab>**type *filename*.lst**
Use CTRL S - to stop the file and see if it shows:
MEASURED POSITION @ DATE - - - - - - - - - -
POSITION -
- -
- -
Use CTRL C - to stop the file from running

POSTNAV2

From C:\ type "postnav"↵

Choose ***Configure*** from pull down menu

Choose ***Run***

- ***Run ID*** - input file name
- ***File Type*** - GPS (default)
- ***Filter Options*** - Filter/Smooth (default)
- ***Info Reference***
  1. Specify Directory
  2. Specify File Name
  3. Input Position

     Latitude - N 047°39'09.6277"
     Longitude - W 122°18'17.9054"
     Altitude - 66.113 meters
- ***Info Mobile***
  1. Specify Directory
  2. Specify File Name
  3. Mobile Dynamics - Medium
  4. Altitude Hold Mode - On (default)
  5. Altitude - Last Good (default)
- ***Info Output***
  1. Output File (.SSF)- No
  2. Audit File (.AUD) - No
  3. ASCII Output File (.LST) - Yes
  4. ASCII Residual File (.RES) - No
  5. Coordinate System - ENU

     EDMONDS
     Latitude - N 047°48'48.7931"
     Longitude - W 122°22'50.7647"
     Altitude - 30 meters

     KINGSTON
     Latitude - N 047°47'48.6489"
     Longitude - W 122°29'42.9962"
     Altitude - 25 meters
  6. Units - Feet

- ***Timing*** - (default)
- ***SV Selection*** - (default)

Choose ***Process*** from pull down menu

Choose ***Quit*** from pull down menu

Data is now in C:\GPS\POSTNAV\Filename.LST

APPENDIX C

SOFTWARE CONFIGURATIONS

"GPSLAB" CONFIGURATION SETTINGS

DATA COLLECTION AND STORAGE

DATA COLLECTION MAIN MENU

F1 - DATA SELECTION

F1 - COLLECT RANGE/RANGE RATES	[ON]
F2 - COLLECT POSTION DATA	[ON]
F3 - COLLECT NAV DATA UPDATES	[ON]
F4 - STORE COLLECTED DATA	[OFF]
F6 - REQUEST ACTIVITY REPORT	[OFF]
F7 - REQUEST REFERENCE POSITION	[OFF]
F8 - REQUEST IONO/CLOCK PARAMETERS	[OFF]

F2 - CONFIGURATION CONTROL

F1 - SET SAT TRACK SELECTION

F1 - MANUAL SELECTION	[OFF]
F2 - ALL IN VIEW MODE	[ON]
F3 - BEST CONSTELLATION	[OFF]
F6 - AUTO MODE	[OFF]
F8 - LIST SAT POSTITON	[OFF]

F2 - SET AVERAGING TIME

CURRENT SV AVERAGE TIME 0.3 SECONDS

F3 - SET MASKS

F1 - SET ELEVATION MASKS
CURRENT ELEVATION MASK 7 DEGREES
F2 - SET DOP MASKS
CURRENT DOP MASK 99.0
F6 - SET HEALTH OVERRIDE
"DO NOT ALTER"

F4 - SET MODES

F1 - SET SYNC
CURRENT SYNC TIME 5.0 SECONDS

F2 - DOPPLER AIDING SELECTED	[ON]
F6 - FIXED HEIGHT ENABLED	[OFF]
F7 - FIXED FREQUENCY ENABLED	[OFF]

F6 - SET REFERENCE POSITION

CURRENT LAT, LON, ALT [N 000, E 000, 000]

F7 - SET OFFSET POSITION

CURRENT OFFSET [N 000, E 000, 000]

APPENDIX D

RECORDED THROTTLE SETTINGS

7/12/92

FERRY-THROTTLE

NAME		ERIC SHIMIZU								
DATE		7/12/92								
FERRY ROUTE		EDMONDS — KINSTON								
				AHEAD				ASTERN		
CAPTAIN	RUN #	GPS TIME	FULL	1/2	SLOW	STOP	FULL	1/2	SLOW	NOTES/COMMENTS
	EZZ2	16 39 35		X						
	↓	16 : 41 : 43	X							ENGINE @ 120 TURNS FOR FULL
		16 48 28	~~[illegible]~~	X						90 ( ) ½
		16 51 48	214		X					50 ( ) SLOW
		16 53 39	103			X				
		16 53 54	88		X					
		16 : 54 16	~~[illegible]~~ 66						X	
		16 54 34	~~[illegible]~~ 48					X		
		16 54 50	~~[illegible]~~ 32			X				
		16 55 : 00	~~[illegible]~~ 22						X	
		16 55 22	0 0		X					
	EZZ3	18 33 00	155		X					
	↓	18 : 34 : 08	87						X	
		18 : 34 : 35	60					X		
		18 34 52	43						X	
		18 34 59	36			X				
		18 35 : 09	26						X	
		18 35 20	15			X				
		18 35 35	0		X					
	EZZ4	20 : 07 : 52								ENGINES @ 140 TURNS FOR FULL
	↓	20 : 08 : 20	205							20R
		20 08 50	145		X					5R
		20 09 52	83						X	
		20 : 10 : 20	55					X		35R
		20 : 10 : 31	44						X	
		20 10 38	37			X				
		20 10 50	25						X	
		20 : 11 : 01	14			X				
		20 : 11 : 15	0		X					

12
60
39
111 44
22
66
32
60
60
49
200

Full - Astern = 120
Half - " =
Slow - =

7/20/92 (MON)

FERRY-THROTTLE

NAME										
DATE										
FERRY ROUTE										
				AHEAD				ASTERN		
CAPTAIN	RUN #	GPS TIME	FULL	1/2	SLOW	STOP	FULL	1/2	SLOW	NOTES/COMMENTS
	720EXX1	16:43:29			X					0.2 nm away
		16:44:38							X	
		16:45:11						X		
		16:45:22				X				.1 nm away
		16:45:42			X					
		16:45:55				X				
		16:46:04			X					
		16:46:13				X				
		16:46:36			X					
		: :								
	720EXX2	19: :	X	→	→	→				.5nm captain [illegible]
		19:12:30			X					16 mph → 12 [illegible]
		19:13:31						- →	X	
		19:14:12						X		
		19:14:21							X	
		19:14:25				X				3 clicks
		19:14:55							X	
		19:15:02				X				
		19:15:08			X					
		19:15:22			X					
		: :								
	720EYY3	19:39:50			X					.125nm away
		19:40:25							X	
		19:41:21						X		
		19:41:32							X	
		19:41:37				X				
		19:41:44							X	
		19:41:50						X		
		19:41:52				X				
		19:42:19			X					
		19:42:28				X				
		19:42:38			X					
		: :								
	720EYY4	21:03:19	X							.847nm away
		21:0[illegible]:00	X							captain takes over @ .461 nm away
		21:06:23			X					
		21:07:07							X	.04 nm away
		21:07:43						X		
		21:08:00							X	
		21:09:11				X				
		21:09:31							X	
		21:09:40				X				
		21:09:06			X					
		: :								
		: :								
		: :								

APPENDIX E

EXCEL MACRO FOR CONVERTING RAW DATA TO SPREADSHEET FORMAT

EDMONDS (a)

```
=OPEN?()
=SELECT("C1")
=EDIT.DELETE(1)
=SELECT("C4,C7","R1C7")
=CLEAR(1)
=SELECT("R1C4")
=FORMULA("Distance")
=SELECT("R1C7")
=FORMULA("Velocity")
=SELECT("R2C2")
=SELECT.END(4)
=COPY()
=SELECT("R1C10")
=PASTE()
=SELECT("R1C3")
=SELECT.END(4)
=COPY()
=SELECT("R1C11")
=PASTE()
=SELECT("R2C4")
=FORMULA("=SQRT((RC[-2]-R1C10)^2+(RC[-1]-R1C11)^2)")
=COPY()
=SELECT("R2C3")
=SELECT.END(4)
=SELECT("RC[1]:R3C4","R3C4")
=PASTE()
=SELECT("R2C7")
=FORMULA("=SQRT(RC[-2]^2+RC[-1]^2)")
=COPY()
=SELECT("R2C6")
=SELECT.END(4)
=SELECT("RC[1]:R3C7","R3C7")
=PASTE()
=SELECT("C4")
=COPY()
=SELECT("C8")
=PASTE.SPECIAL(3,1,FALSE,FALSE)
=SELECT("C7")
=COPY()
=SELECT("C9")
=PASTE.SPECIAL(3,1,FALSE,FALSE)
=SELECT("C10:C11")
=EDIT.DELETE(1)
=SELECT("C4:C7")
=EDIT.DELETE(1)
=SELECT("C2:C4")
=FORMAT.NUMBER("0")
=SELECT("C5")
```

```
=FORMAT.NUMBER("0.0")
MYDOC=MID(GET.DOCUMENT(1),1,7)
=SAVE.AS("C:\CHART1\"&MYDOC&".WKS")
=SELECT("C4,C5","R1C5")
=NEW(2,3)
=WINDOW.MAXIMIZE()
=ATTACH.TEXT(1)
=FORMAT.FONT(0,1,FALSE,"MS Sans Serif",12,TRUE,FALSE,FALSE,FALSE)
=FORMULA("=""VELOCITY VS. DISTANCE FROM EDMONDS LANDING STRUCTURE""")
=ATTACH.TEXT(2)
=FORMAT.FONT(0,1,FALSE,"MS Sans Serif",10,TRUE,FALSE,FALSE,FALSE)
=FORMULA("=""Velocity (ft/s)""")
=ATTACH.TEXT(3)
=FORMAT.FONT(0,1,FALSE,"MS Sans Serif",10,TRUE,FALSE,FALSE,FALSE)
=FORMULA("=""Distance (ft)""")
=SELECT("Axis 2")
=PATTERNS(1,1,1,1,3,2,4)
=SCALE(TRUE,5000,500,50,TRUE,FALSE,TRUE,FALSE)
=SELECT("Axis 1")
=PATTERNS(1,1,1,1,3,2,4)
=SCALE(TRUE,35,5,1,TRUE,FALSE,FALSE,FALSE)
=SELECT("Axis 2")
=PATTERNS(1,1,1,1,3,2,4)
=FORMAT.TEXT(,,2)
=SELECT("S1")
=PATTERNS(0,1,1,3,2,1,1,3,FALSE)
=SELECT("AXIS 1")
=GRIDLINES(TRUE,FALSE,TRUE,FALSE)
=PAGE.SETUP("",MYDOC,0.75,0.75,1,1,3,FALSE,FALSE,2,1,100,1)
=SAVE.AS("C:\CHART1\"&MYDOC&".XLC")
=PRINT(1,1,)
=SELECT("Axis 2")
=PATTERNS(0,1,1,4,3,2,4)
=SCALE(TRUE,300,50,5,TRUE,FALSE,TRUE,FALSE)
=PATTERNS(0,1,1,2,3,2,4)
=SELECT("Axis 1")
=PATTERNS(1,1,1,1,3,2,4)
=SCALE(TRUE,15,5,1,TRUE,FALSE,FALSE,FALSE)
=ADD.ARROW()
=FORMAT.SIZE(341.25,-172.5)
=FORMAT.MOVE(402.25,202.75)
=FORMAT.SIZE(0,-147.75)
=PATTERNS(0,1,1,4,2,1,1)
=ADD.ARROW()
=FORMAT.SIZE(297,-172.5)
=FORMAT.MOVE(358,203.5)
=FORMAT.SIZE(0,-148.5)
=FORMAT.MOVE(358.75,203.5)
=PATTERNS(0,1,1,4,2,1,1)
```

```
=ADD.ARROW()
=FORMAT.SIZE(157.5,-172.5)
=FORMAT.MOVE(218.5,203.5)
=FORMAT.SIZE(0,-148.5)
=PATTERNS(0,1,1,4,2,1,1)
=ADD.ARROW()
=FORMAT.SIZE(109.5,-171)
=FORMAT.MOVE(170.5,202.75)
=FORMAT.SIZE(0,-146.25)
=SELECT("Plot")
=SELECT("Arrow 4")
=PATTERNS(0,1,1,4,2,1,1)
=ADD.ARROW()
=FORMAT.SIZE(20.25,-171)
=FORMAT.MOVE(81.25,202.75)
=FORMAT.SIZE(0,-146.25)
=PATTERNS(0,1,1,4,2,1,1)
=FORMULA("=""Text""")
=FORMULA("=""End of Wingwall""")
=FORMAT.TEXT(2,2,2,FALSE,TRUE)
=FORMAT.FONT(0,1,FALSE,"MS Sans Serif",8,FALSE,FALSE,FALSE,FALSE)
=PATTERNS(0,1,1,1,FALSE,1,1,1,2,FALSE)
=FORMAT.FONT(0,3,FALSE,"MS Sans Serif",8,FALSE,FALSE,FALSE,FALSE)
=FORMAT.MOVE(385.75,139)
=FORMULA("=""Text""")
=FORMULA("=""End of Wingwall""")
=SELECT("Plot")
=FORMULA("=""Text""")
=FORMULA("=""Inner Pile Dolphin""")
=FORMAT.TEXT(2,2,2,FALSE,TRUE)
=FORMAT.FONT(0,1,FALSE,"MS Sans Serif",8,FALSE,FALSE,FALSE,FALSE)
=PATTERNS(0,1,1,1,FALSE,1,1,1,2,FALSE)
=FORMAT.FONT(0,3,FALSE,"MS Sans Serif",8,FALSE,FALSE,FALSE,FALSE)
=FORMAT.MOVE(341.5,135.25)
=SELECT("Plot")
=FORMULA("=""Text""")
=FORMULA("=""East Edge of Floater""")
=FORMAT.TEXT(2,2,2,FALSE,TRUE)
=FORMAT.FONT(0,1,FALSE,"MS Sans Serif",8,FALSE,FALSE,FALSE,FALSE)
=PATTERNS(0,1,1,1,FALSE,1,1,1,2,FALSE)
=FORMAT.FONT(0,3,FALSE,"MS Sans Serif",8,FALSE,FALSE,FALSE,FALSE)
=FORMAT.MOVE(221.5,124.75)
=SELECT("Plot")
=FORMULA("=""Text""")
=FORMULA("=""Outer Pile Dolphin""")
=FORMAT.TEXT(2,2,2,FALSE,TRUE)
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APPENDIX F

SUMMARY OF INDIVIDUAL LANDINGS

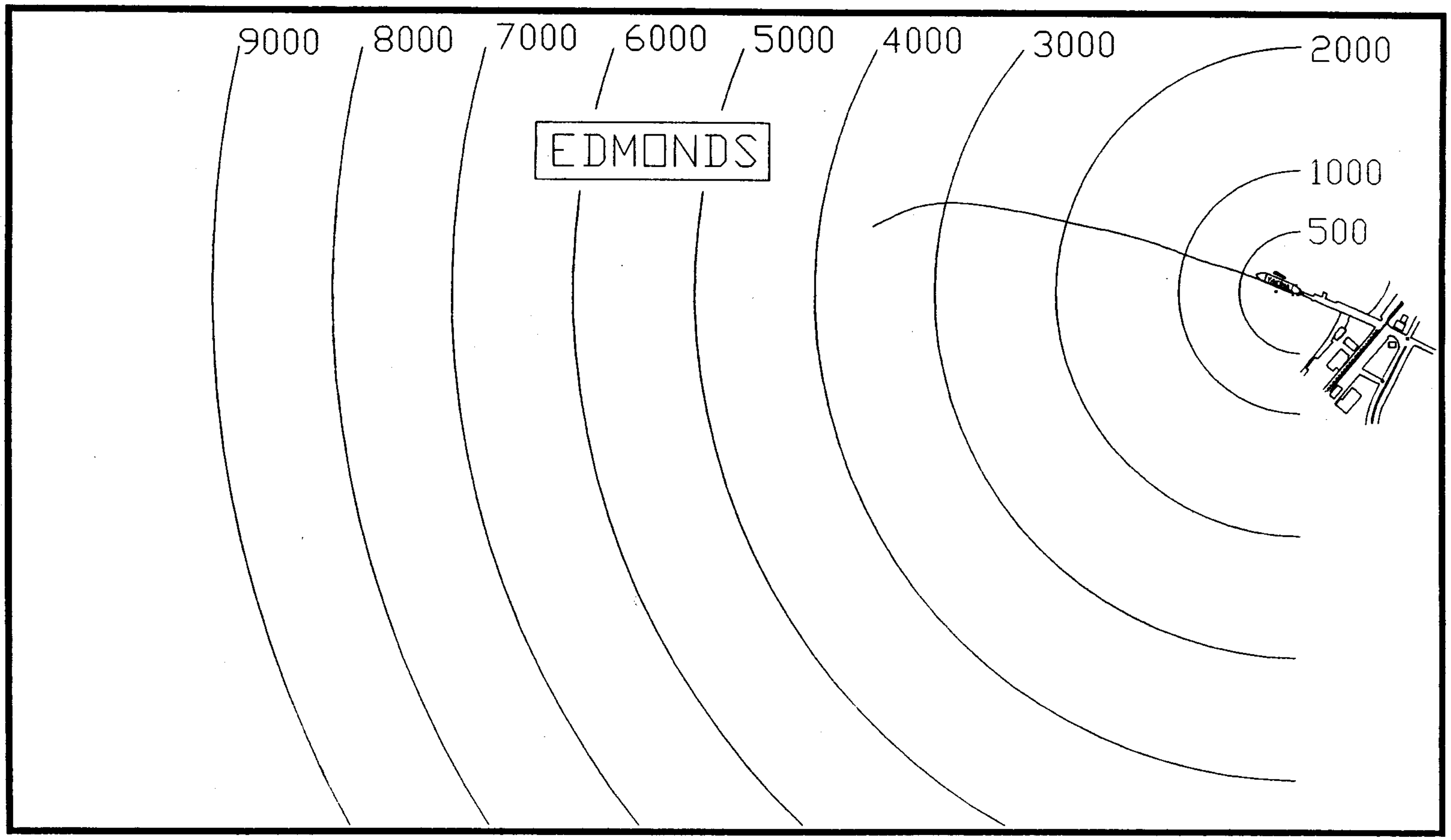

Figure E-1. Final Berthing Approach — 630EYY1

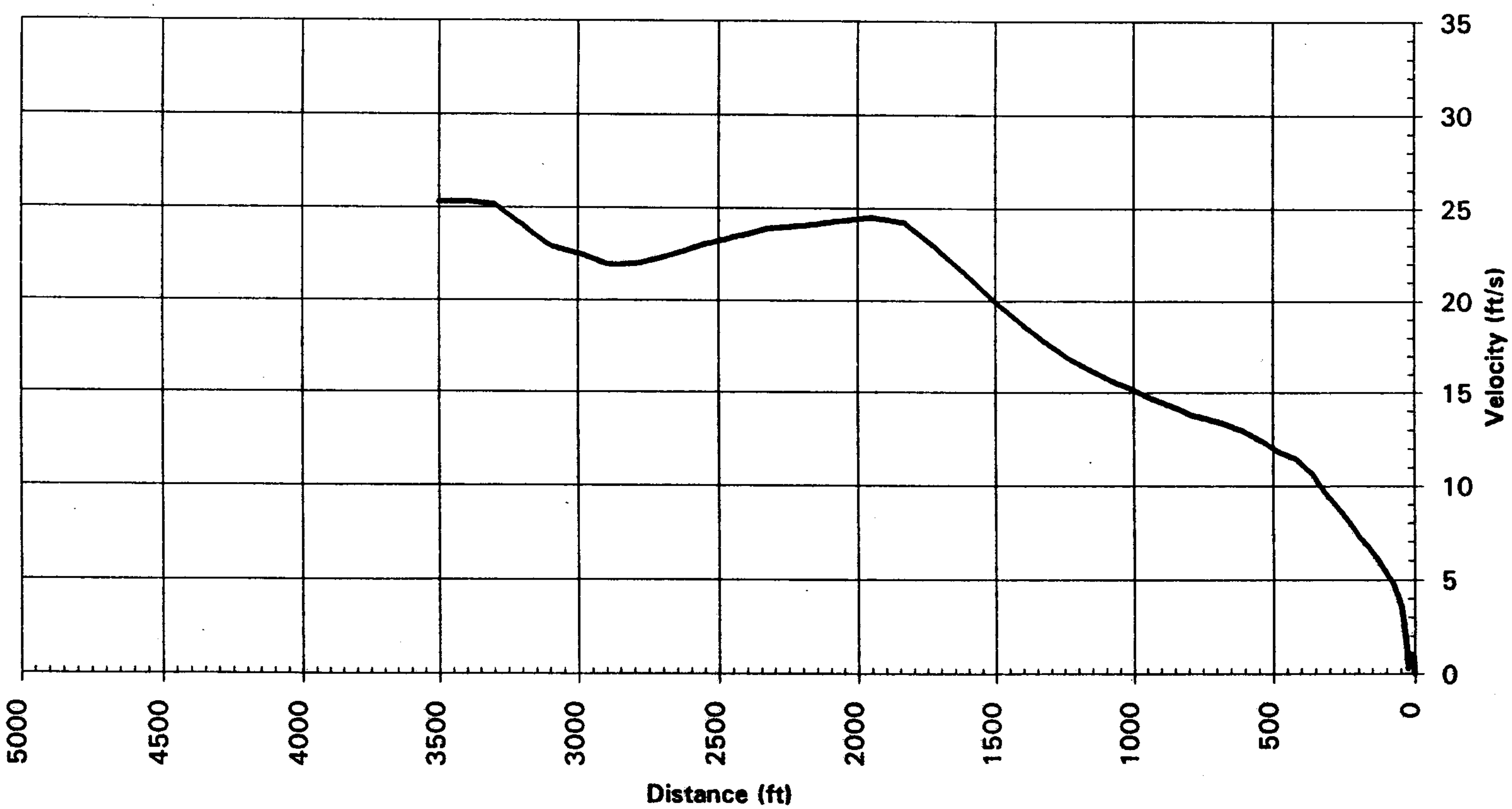

Figure E-2. Velocity vs. Distance from Edmonds Landing Structure (5,000 ft.) — 630EYY1

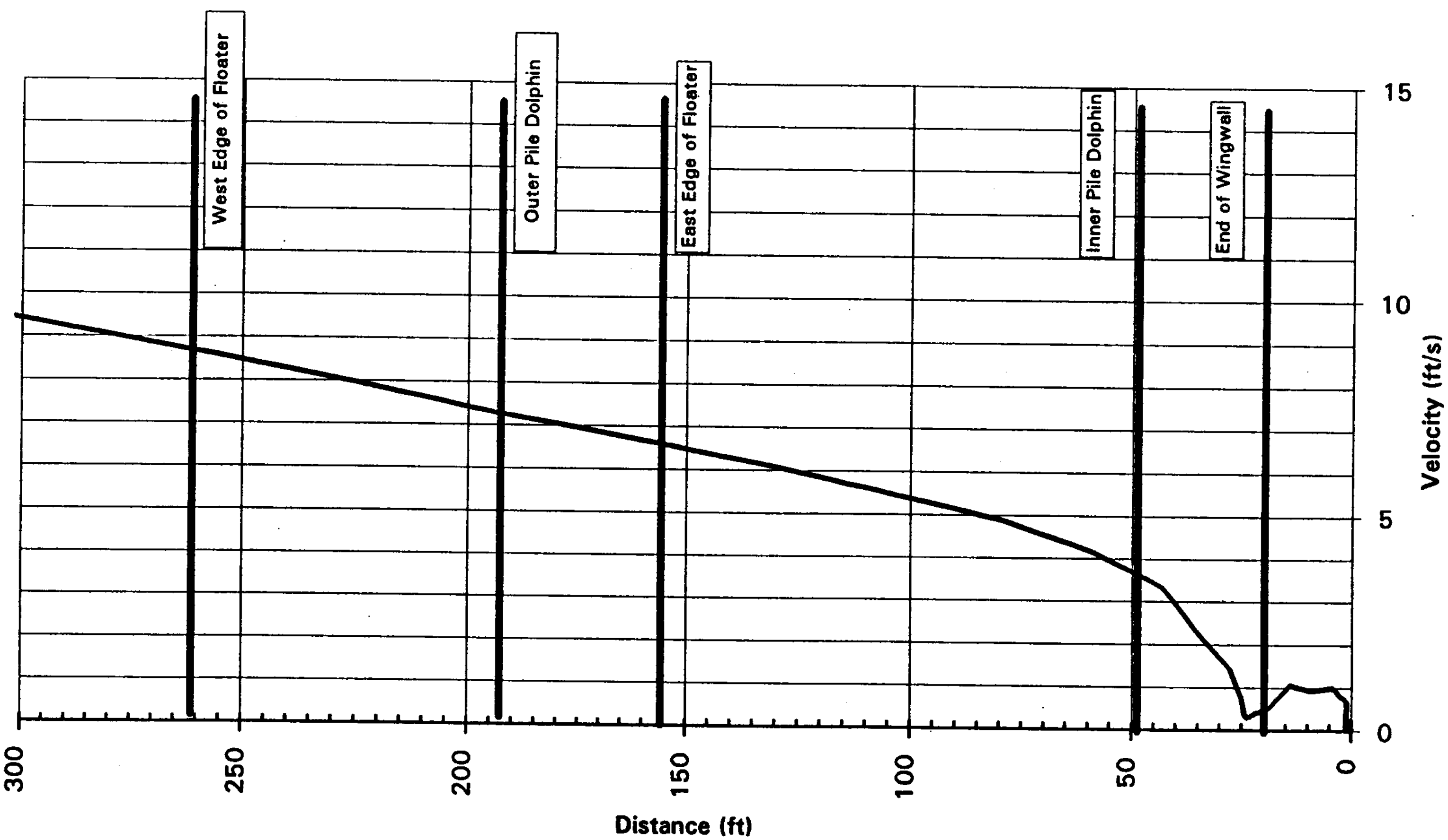

Figure E-3. Velocity vs. Distance from Edmonds Landing Structure (300 ft.) — 630EYY1

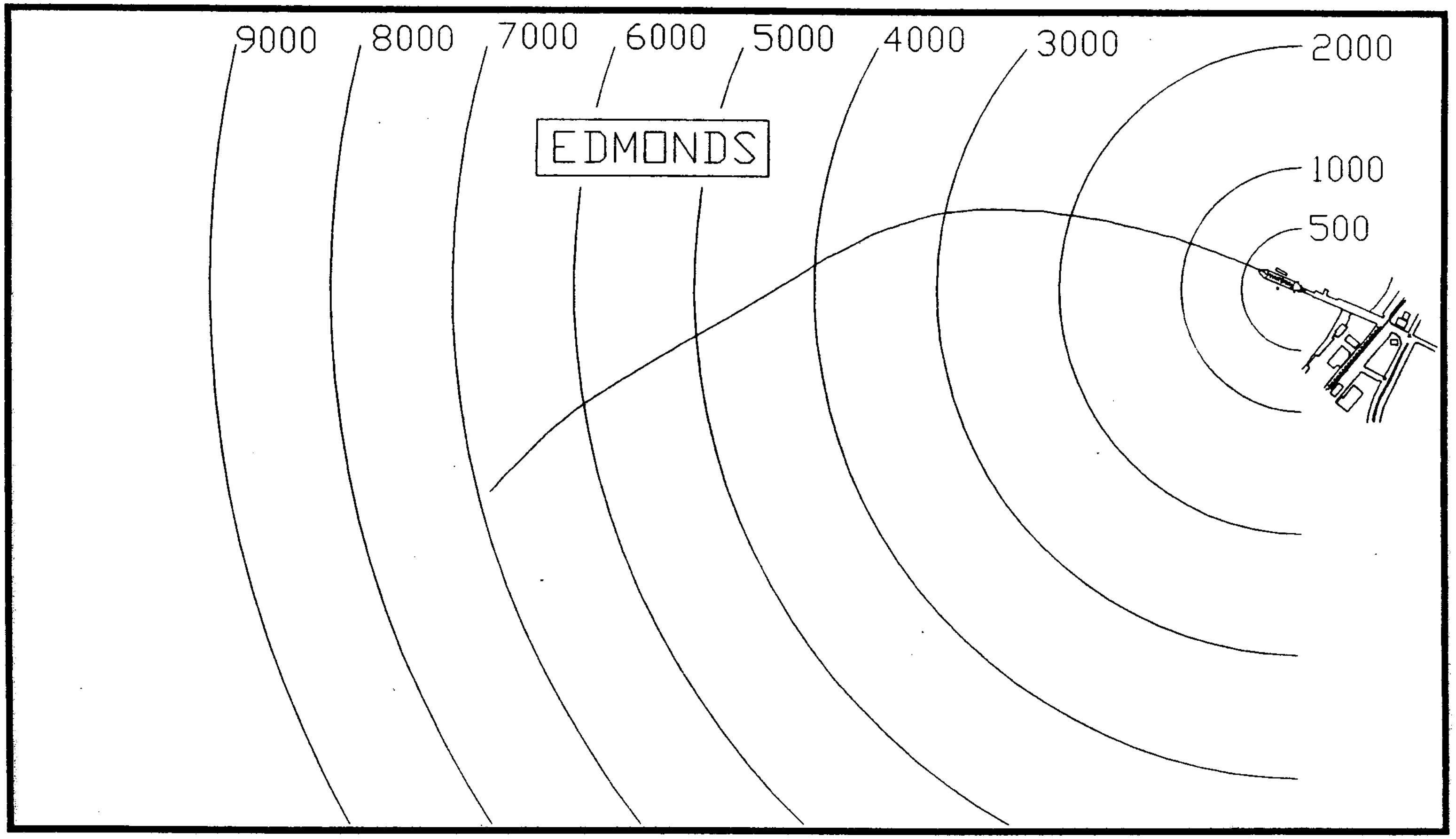

Figure E-4. Final Berthing Approach — 709EVV2

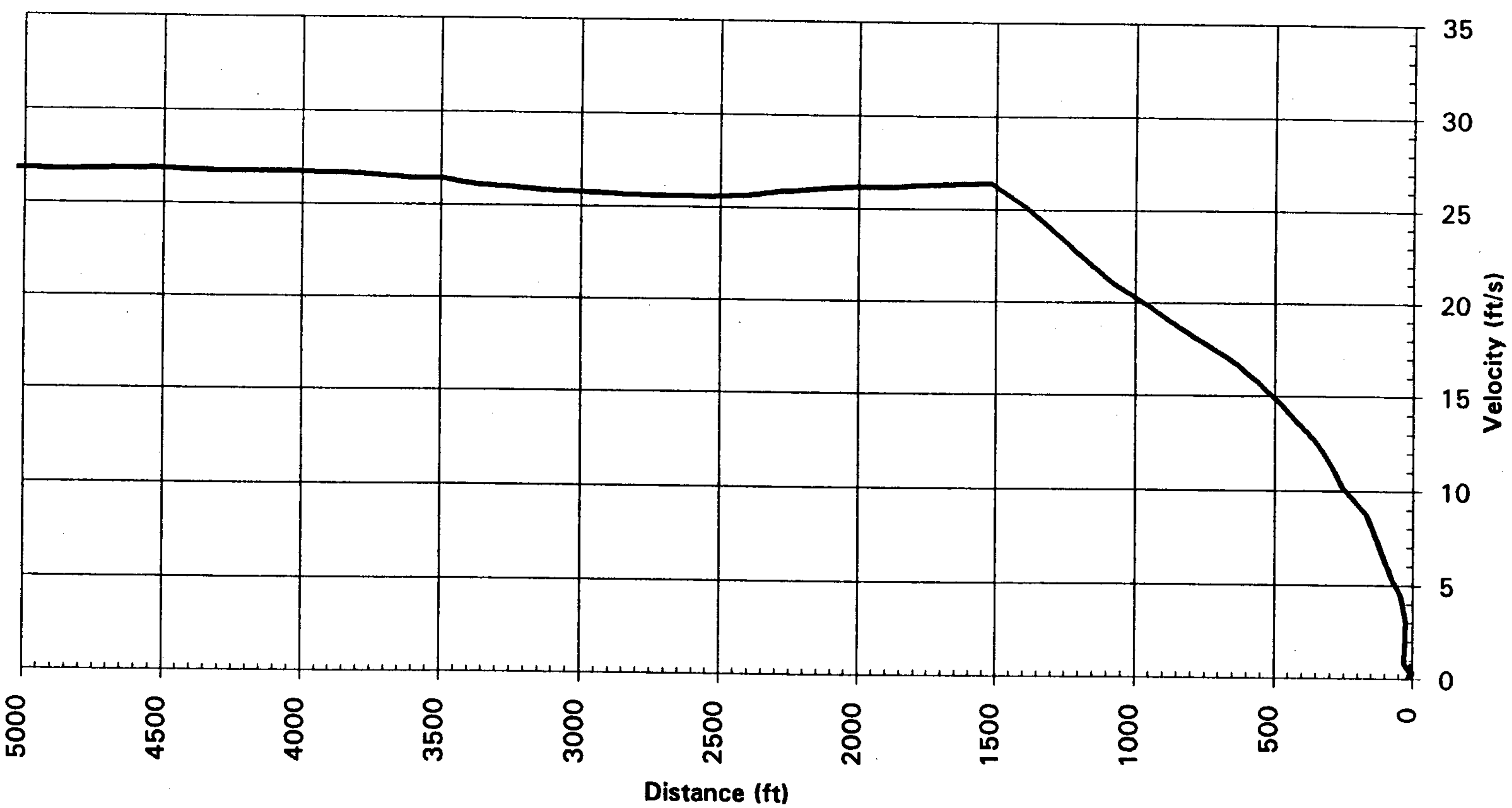

Figure E-5. Velocity vs. Distance from Edmonds Landing Structure (5,000 ft.) — 709EVV2

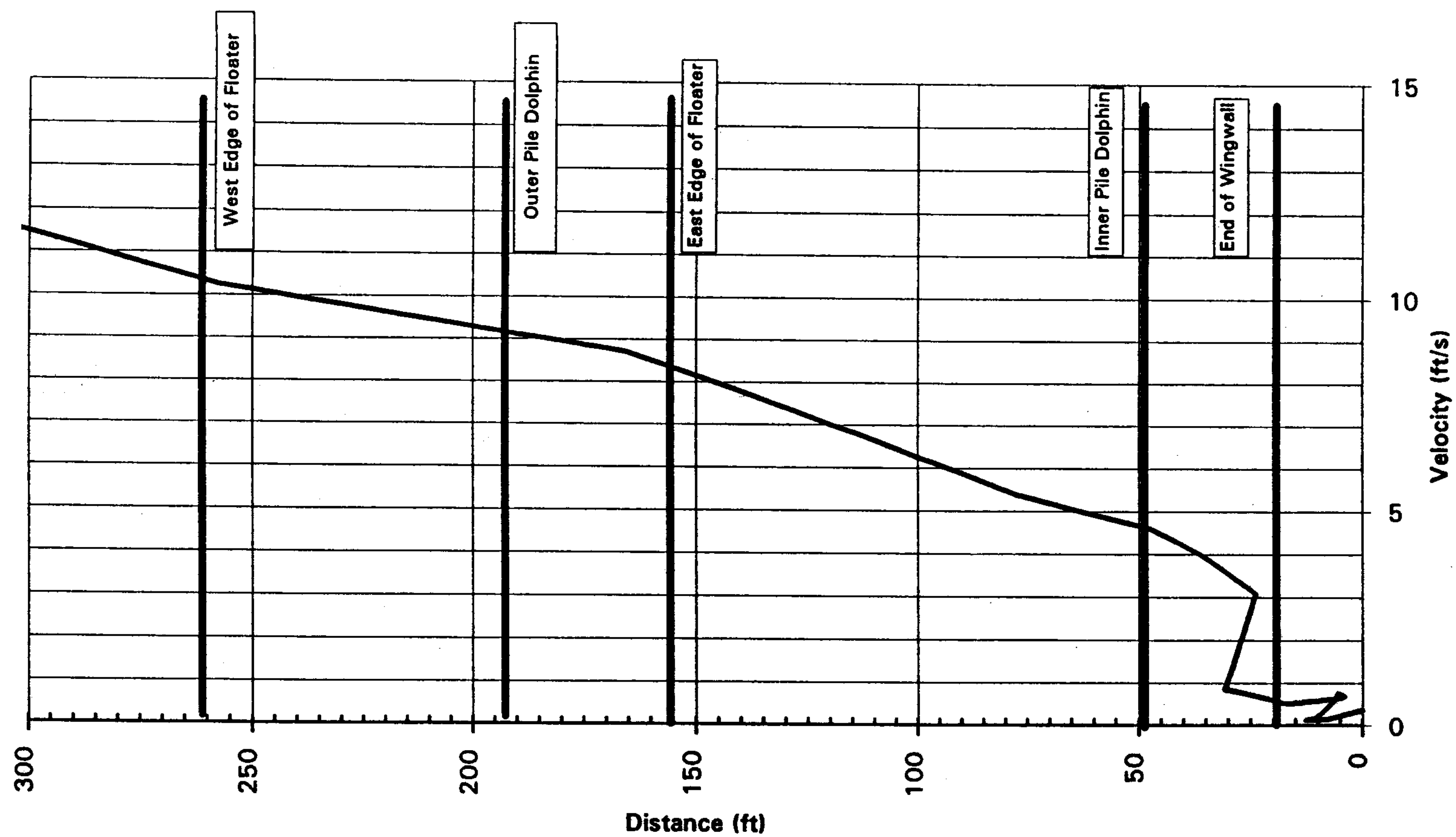

Figure E-6. Velocity vs. Distance from Edmonds Landing Structure (300 ft.) — 709EVV2

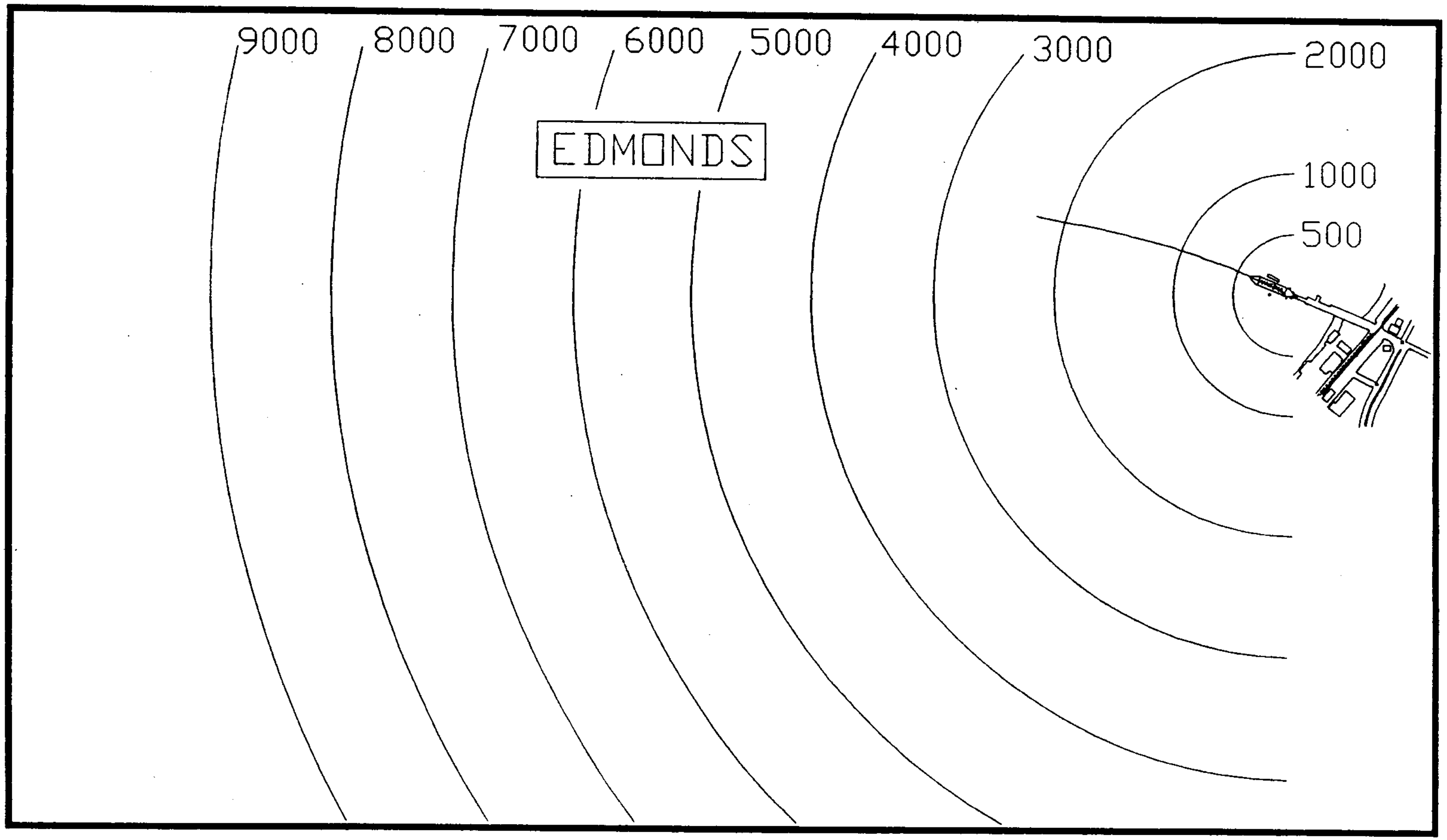

Figure E-7. Final Berthing Approach — 709VV3

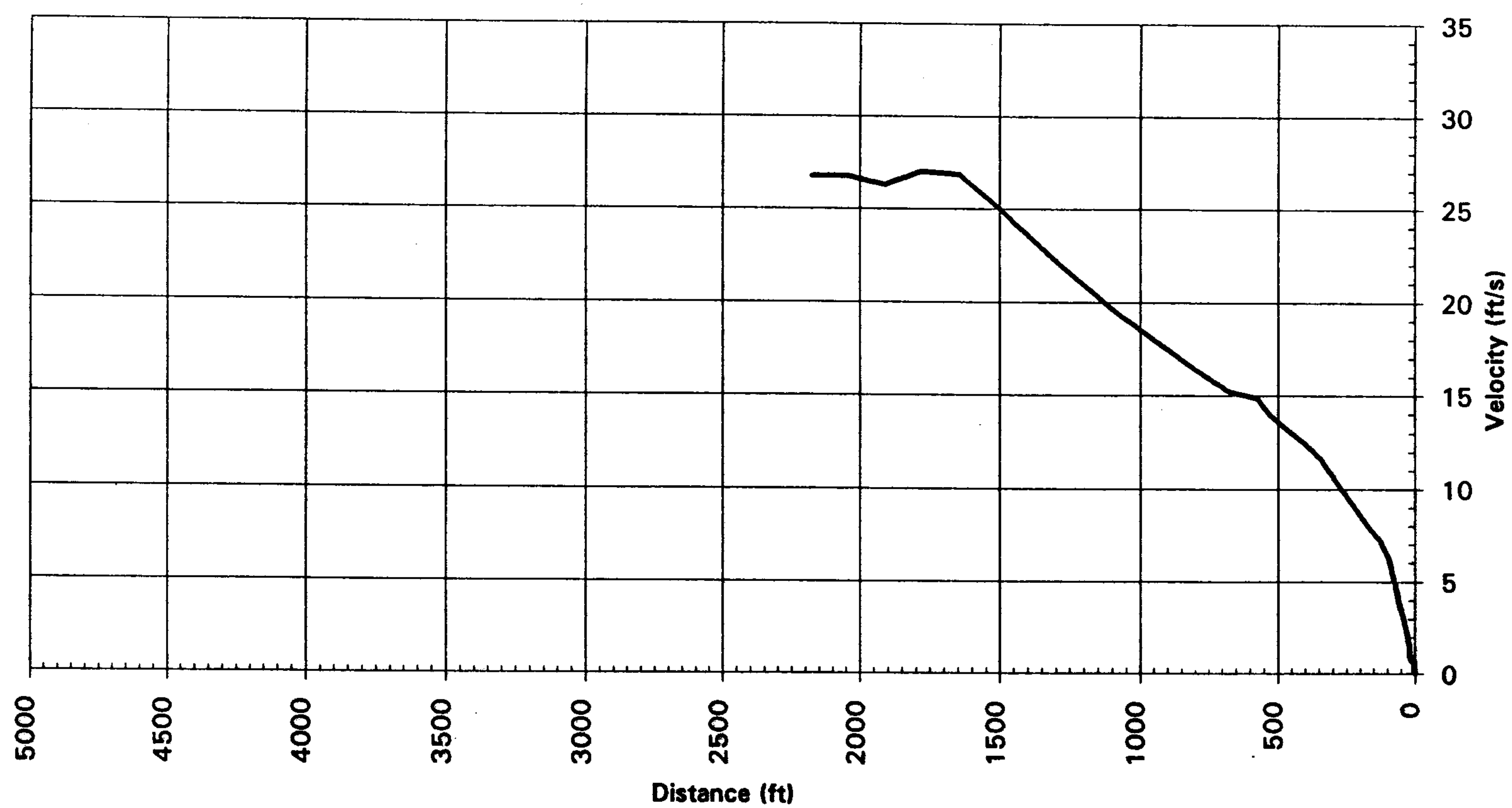

Figure E-8. Velocity vs. Distance from Edmonds Landing Structure (5,000 ft.) — 709EVV3

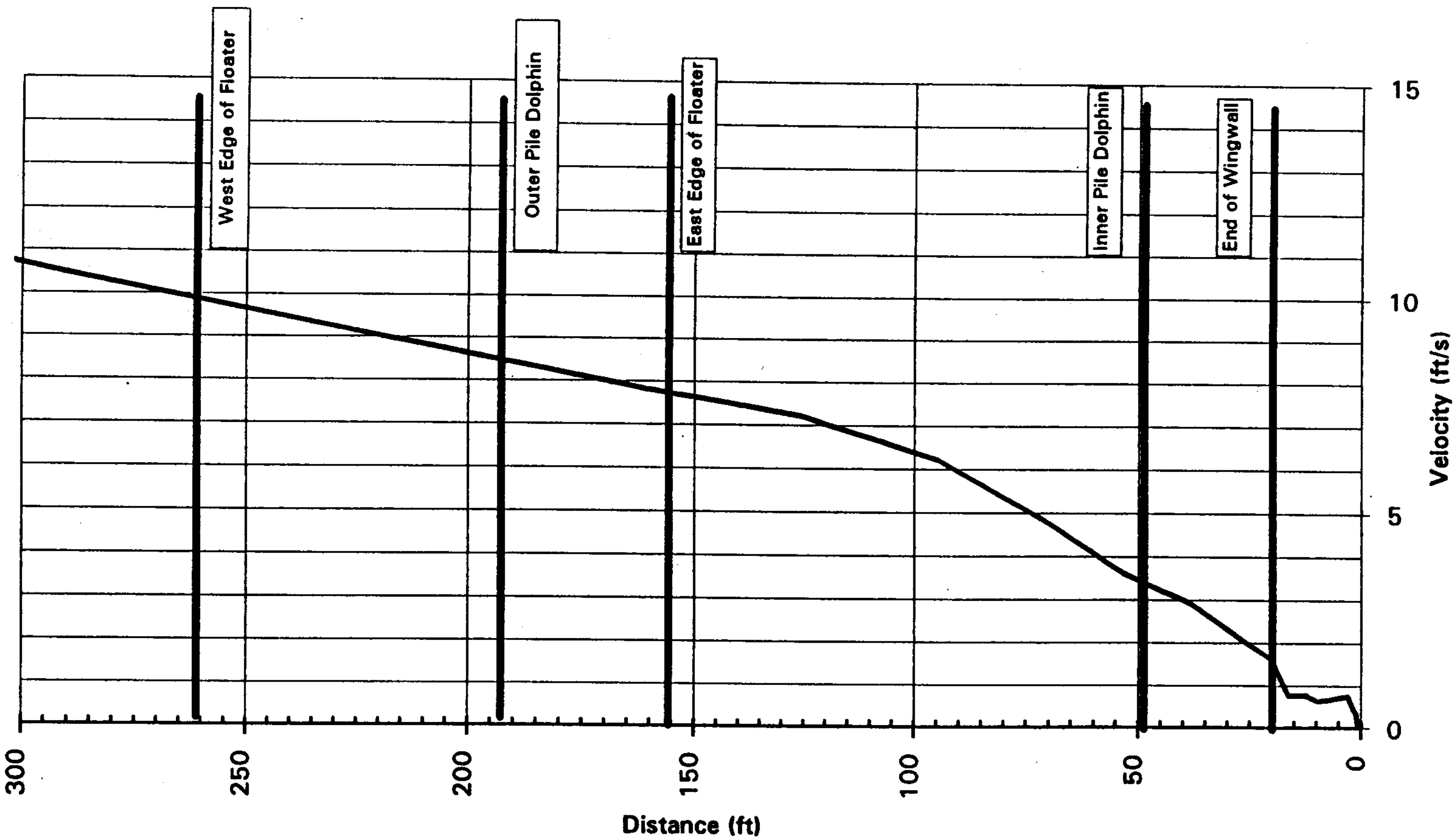

Figure E-9. Velocity vs. Distance from Edmonds Landing Structure (300 ft.) — 709EVV3

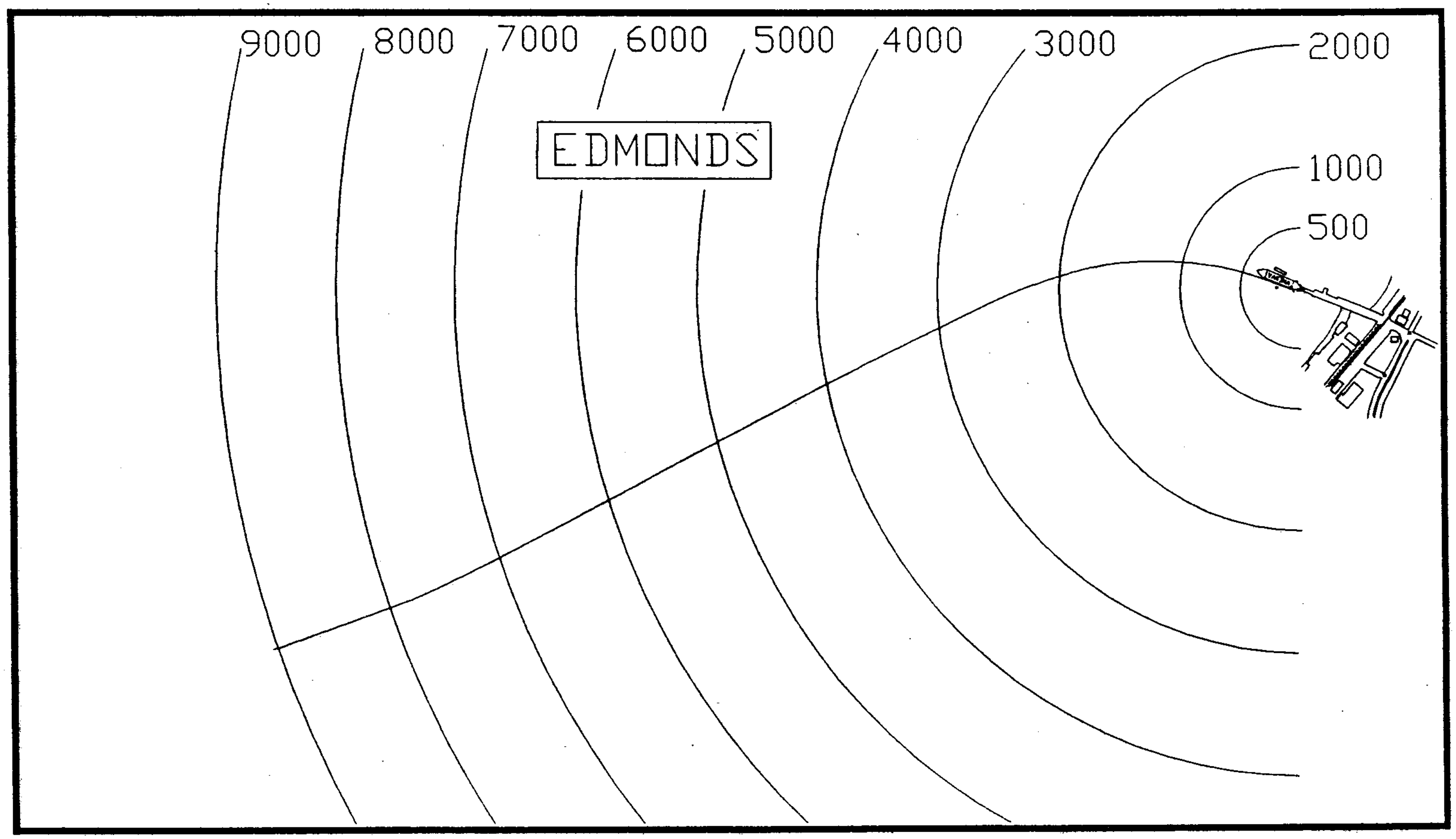

Figure E-10. Final Berthing Approach — 709EVV4

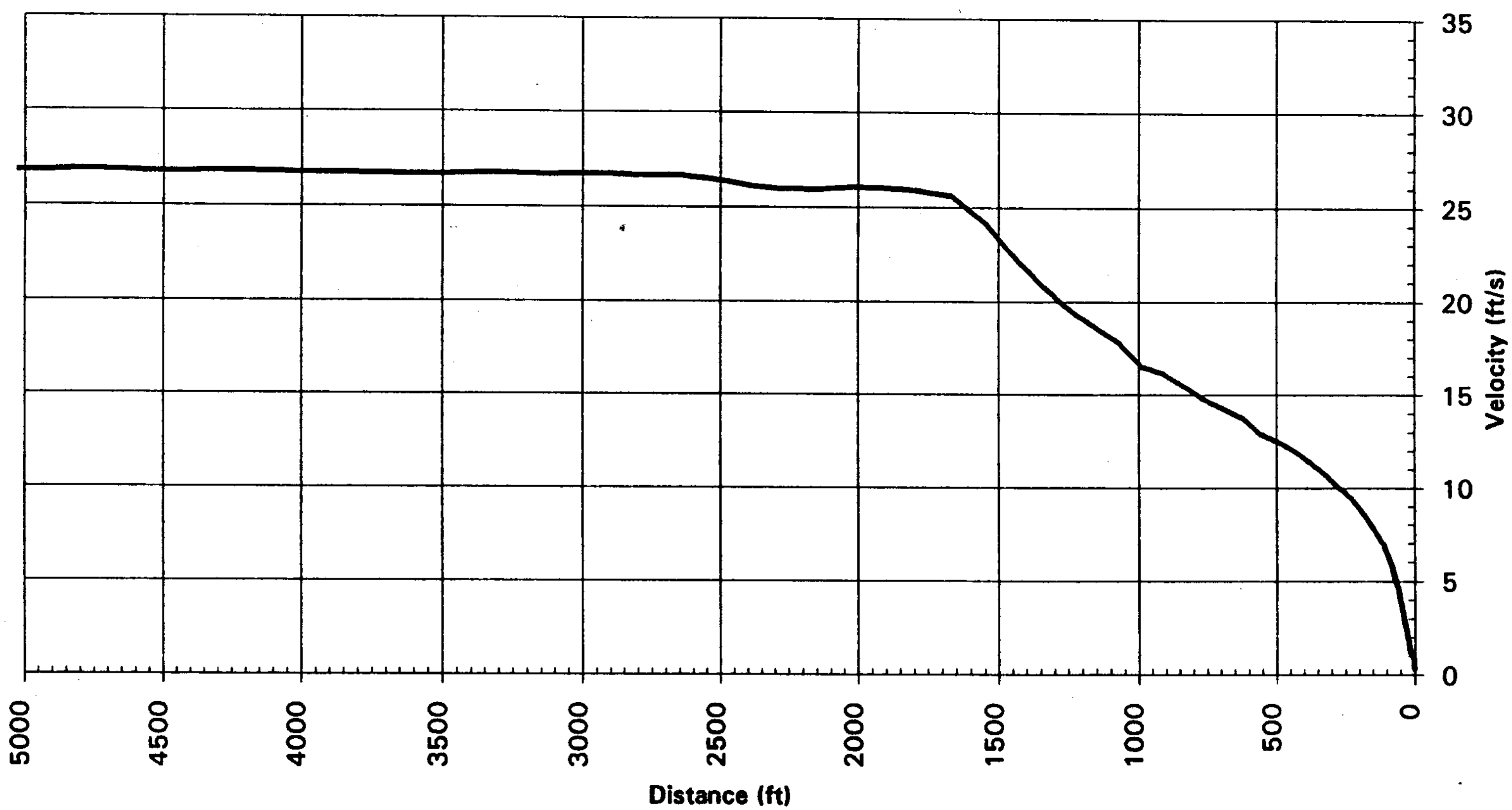

Figure E-11. Velocity vs. Distance from Edmonds Landing Structure (5,000 ft.) — 709EVV4

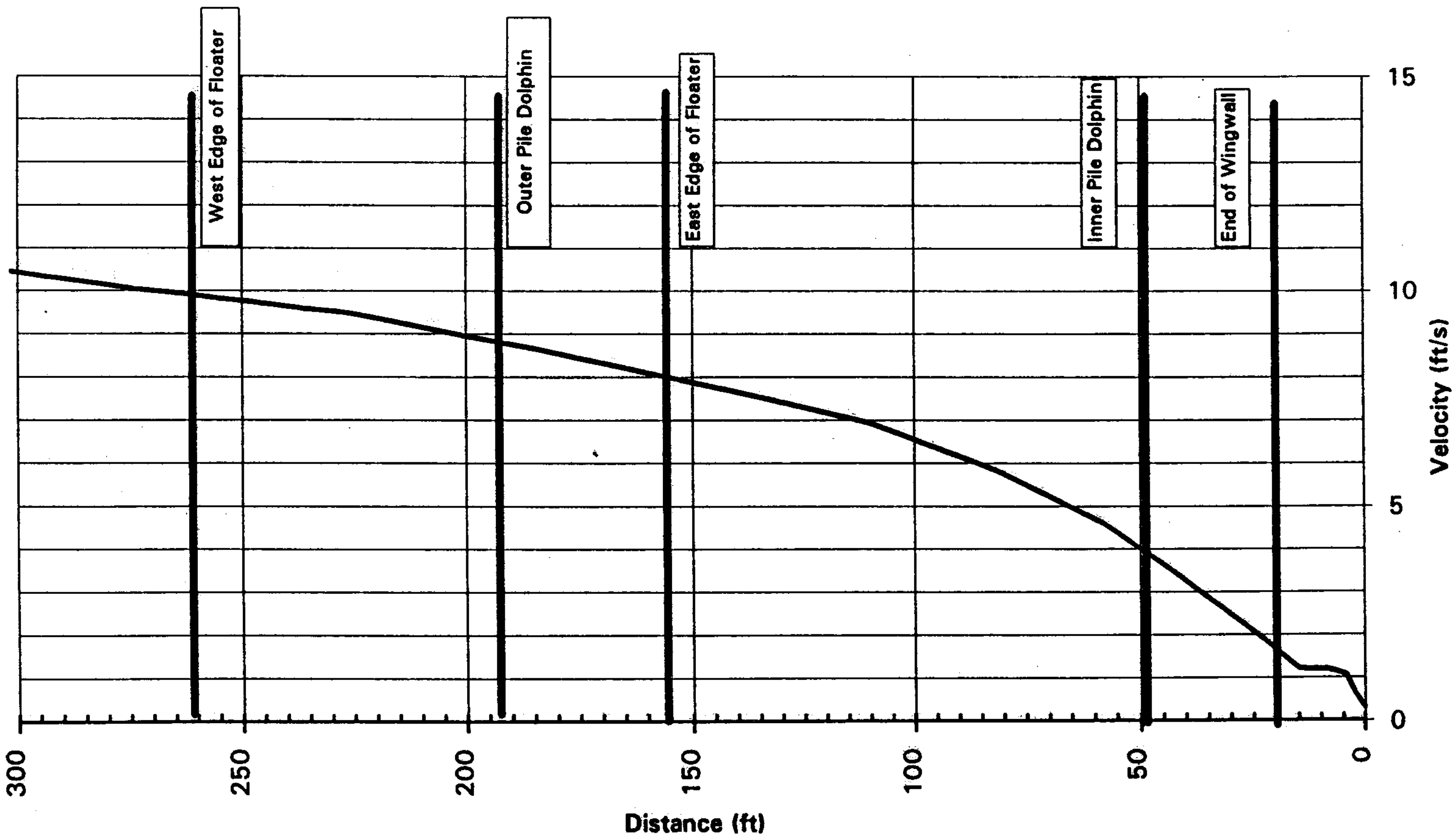

Figure E-12. Velocity vs. Distance from Edmonds Landing Structure (300 ft.) — 709EVV4

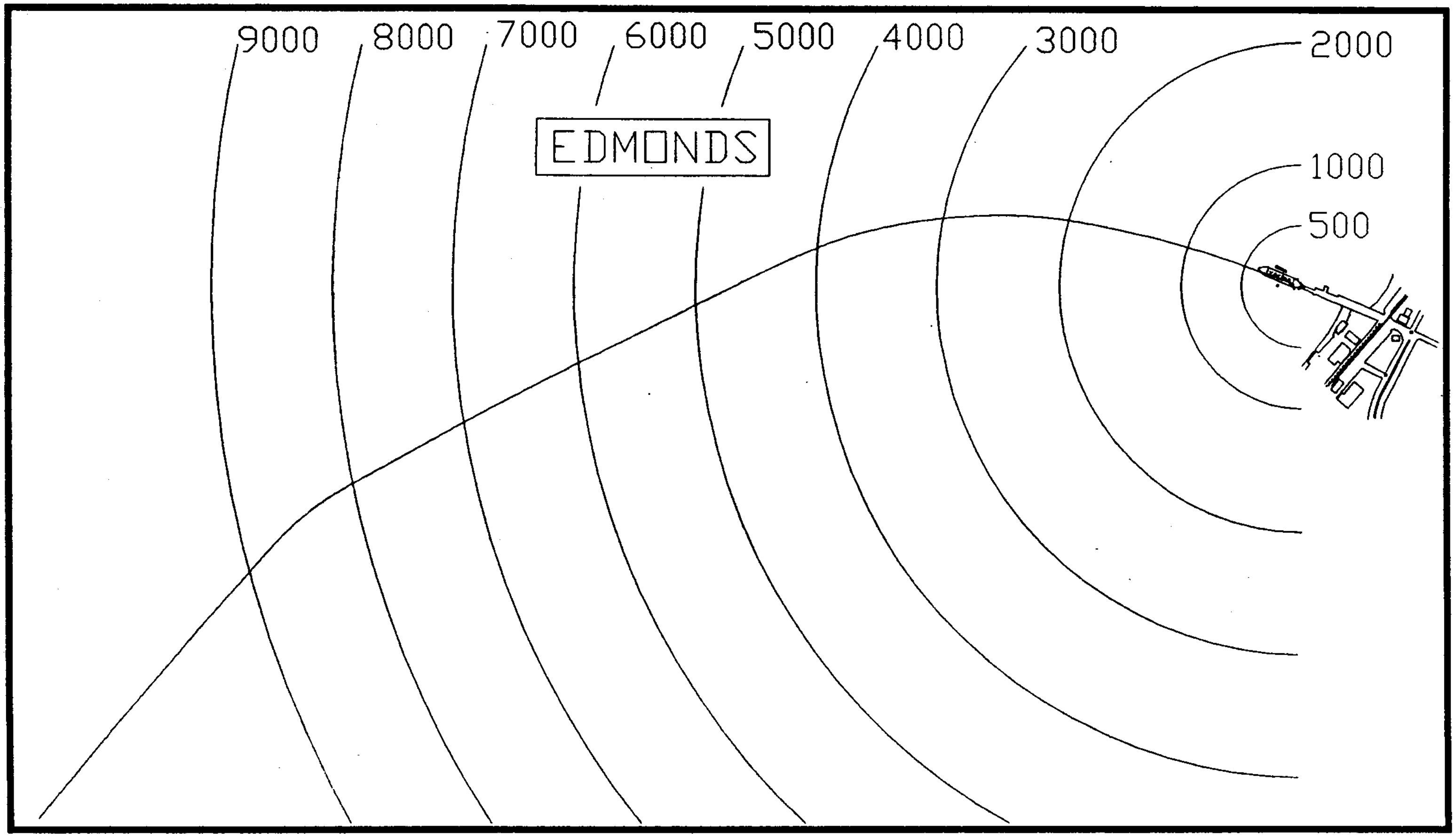

Figure E-13. Final Berthing Approach — 712EZZ2

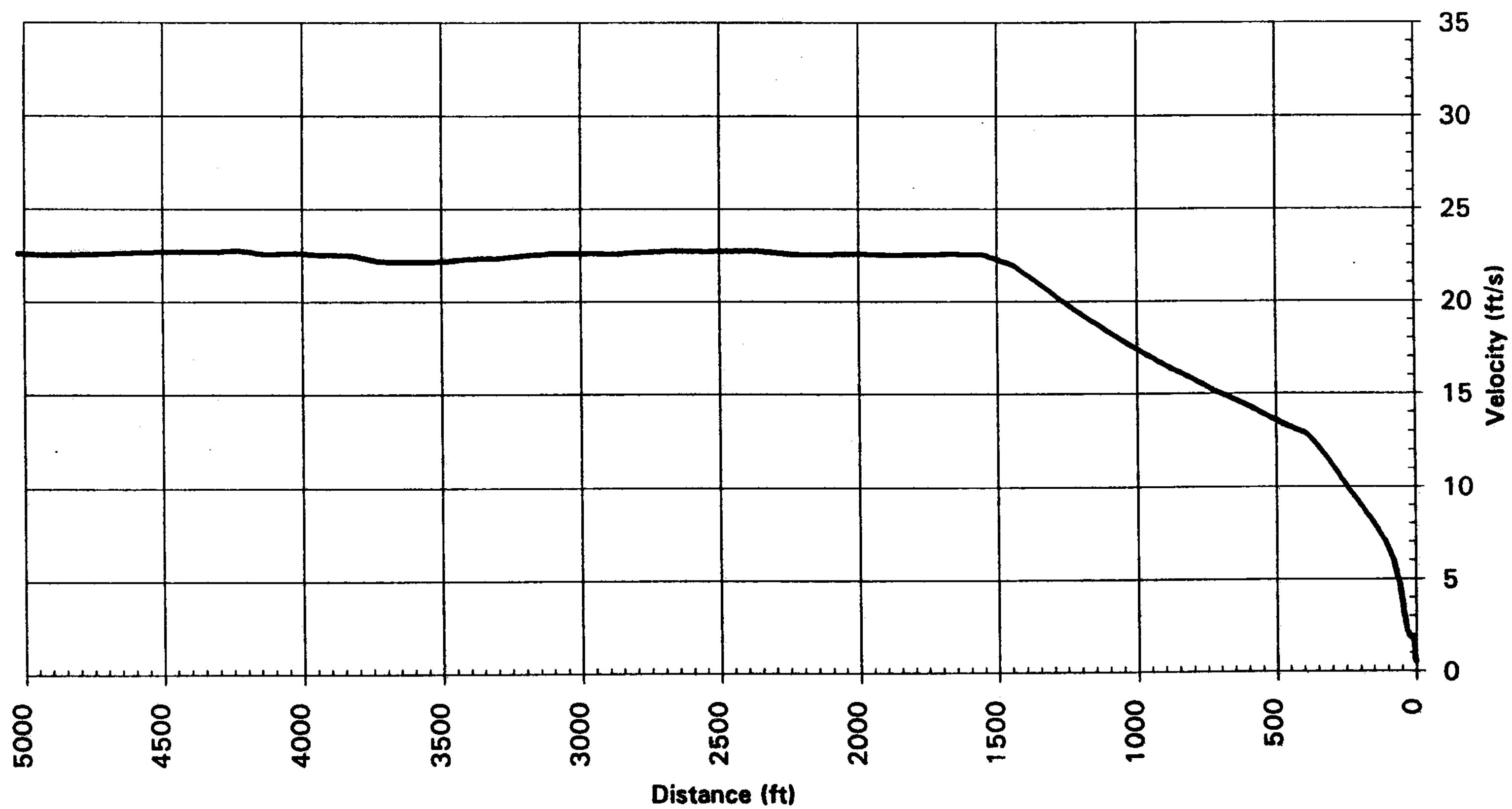

Figure E-14. Velocity vs. Distance from Edmonds Landing Structure (5,000 ft.) — 712EZZ2

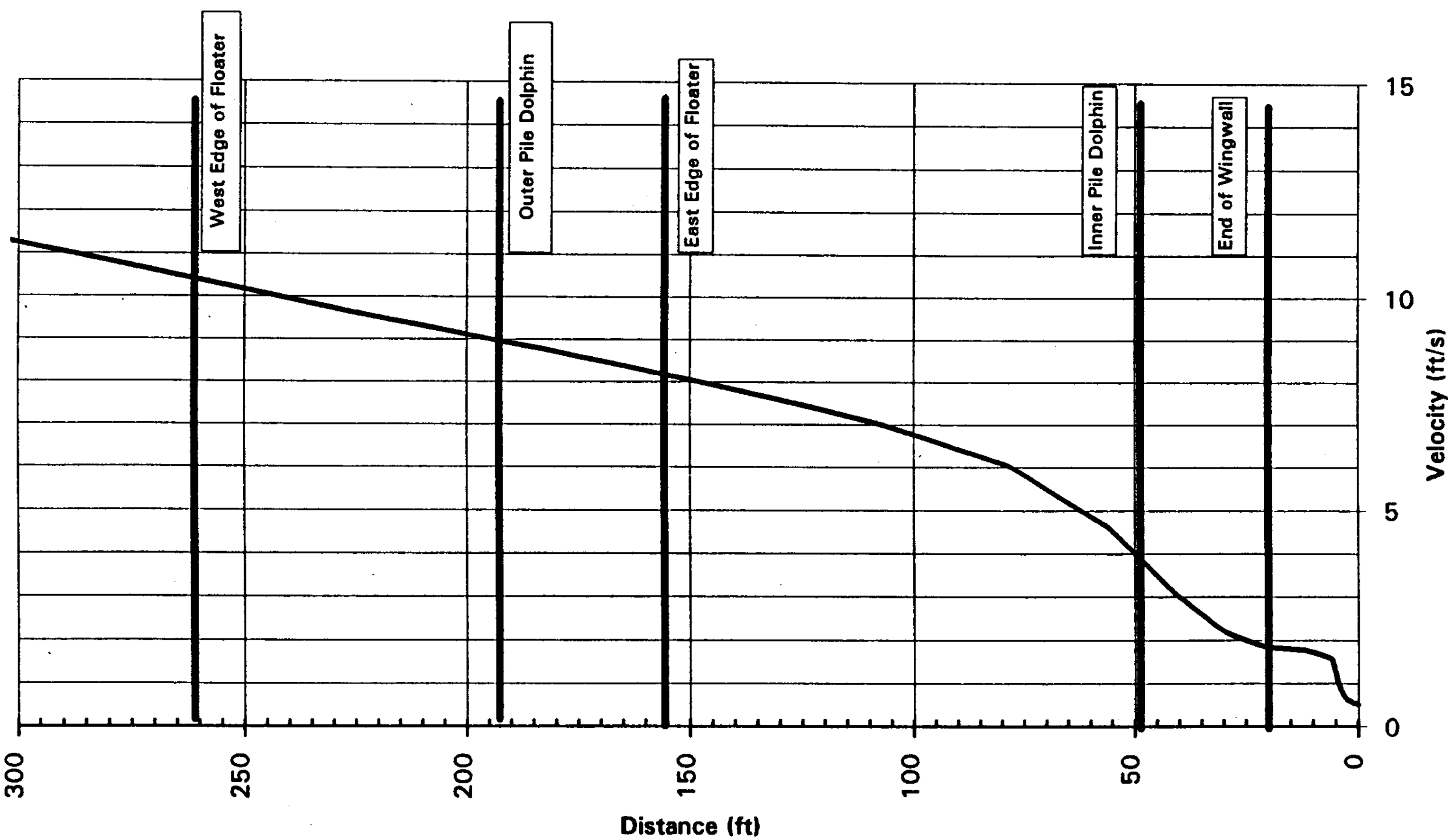

Figure E-15. Velocity vs. Distance from Edmonds Landing Structure (300 ft.) — 712EZZ2

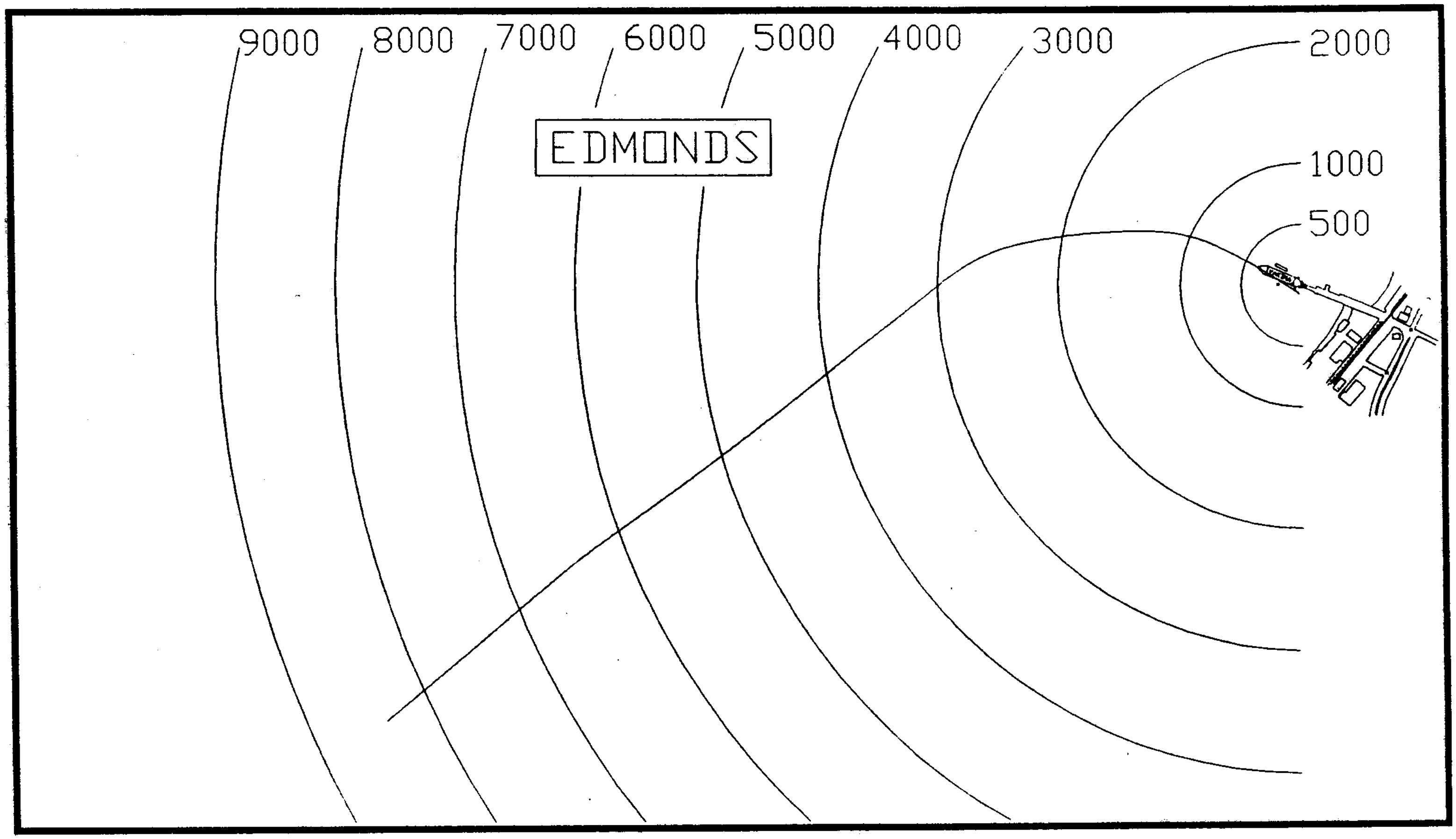

Figure E-16. Final Berthing Approach — 712EYY6

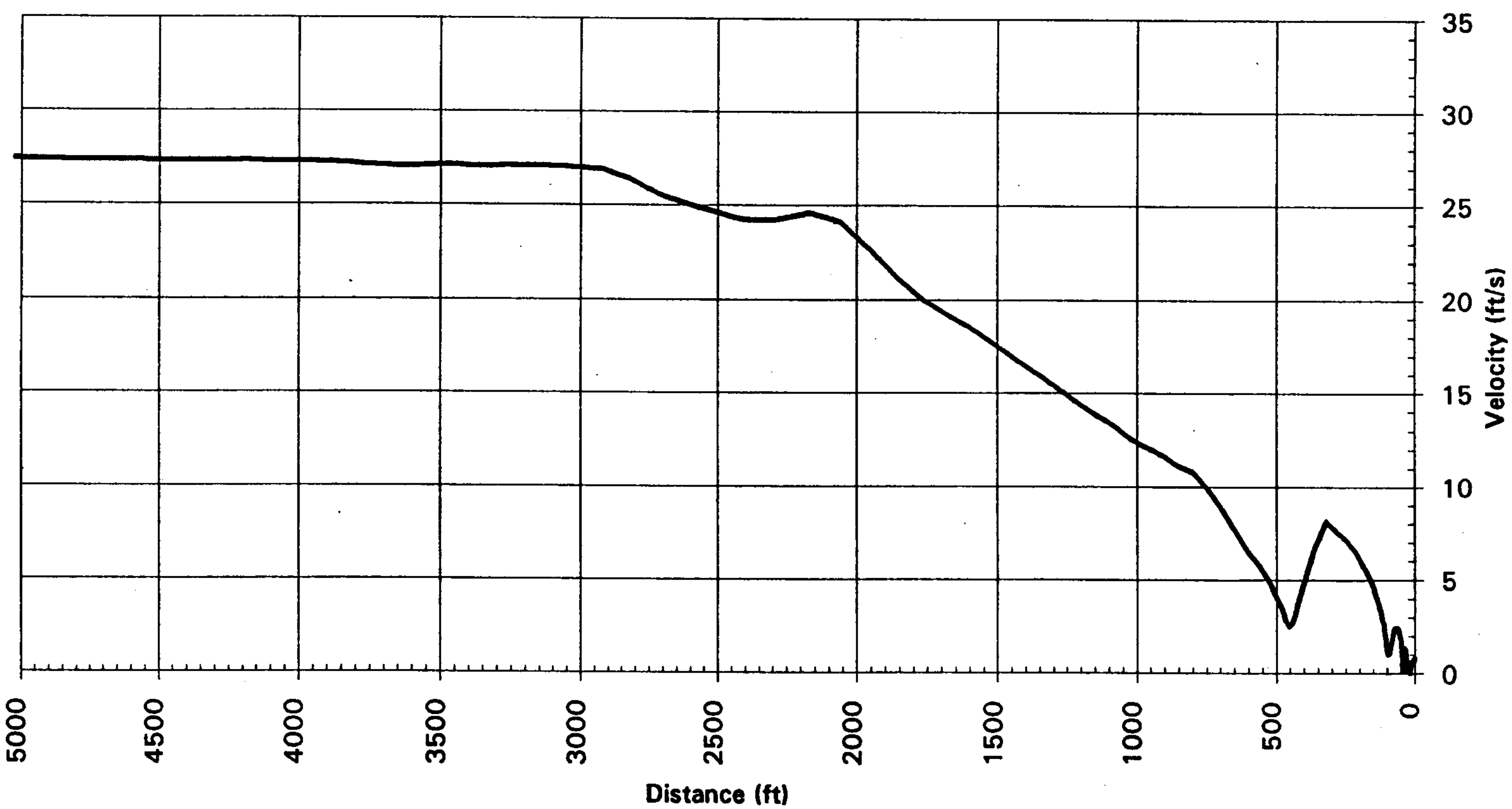

Figure E-17. Velocity vs. Distance from Edmonds Landing Structure (5,000 ft.) — 712EYY6

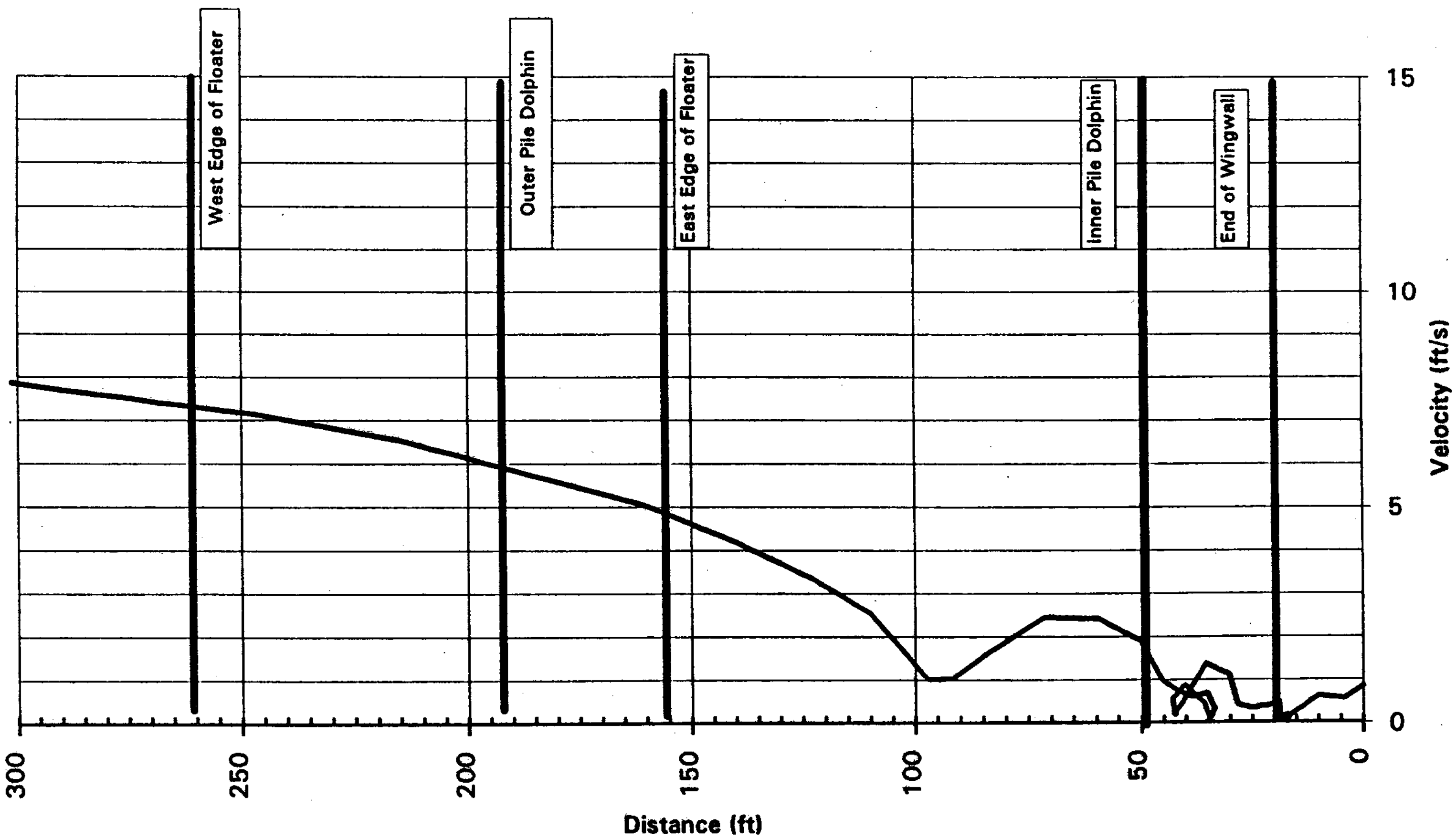

Figure E-18. Velocity vs. Distance from Edmonds Landing Structure (300 ft.) — 712EYY6

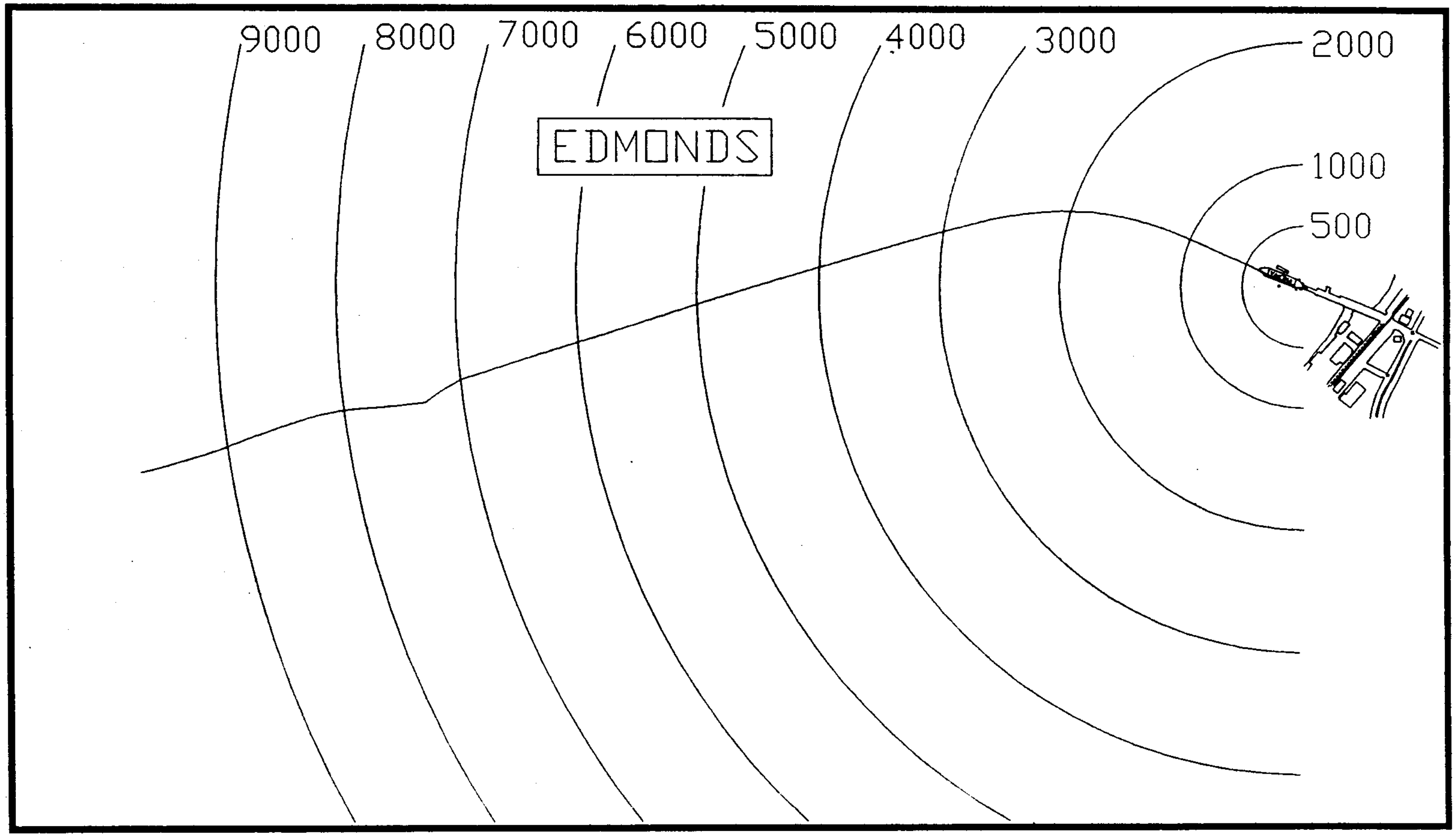

Figure E-19. Final Berthing Approach — 720EXX2

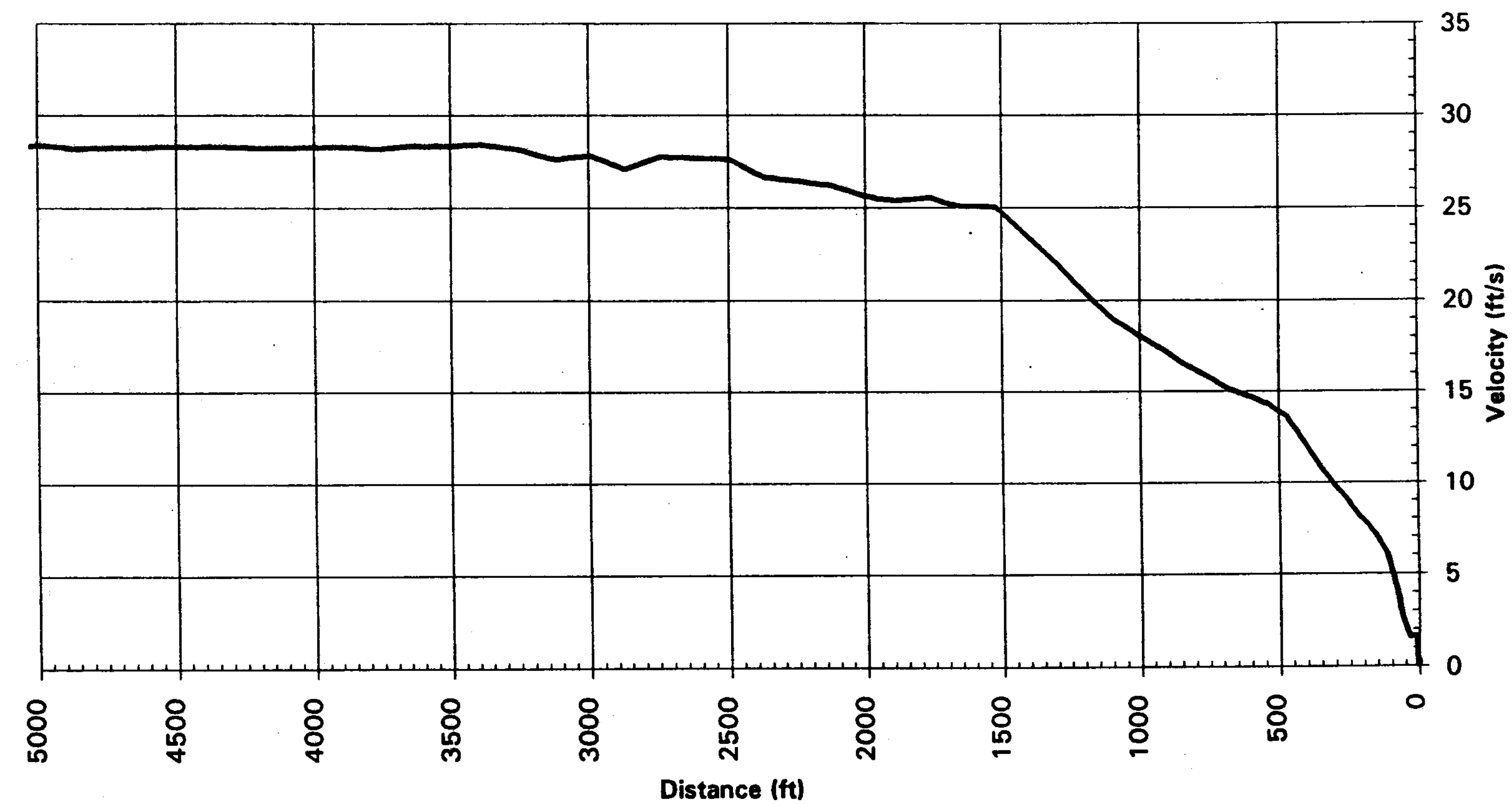

Figure E-20. Velocity vs. Distance from Edmonds Landing Structure (5,000 ft.) — 720EXX2

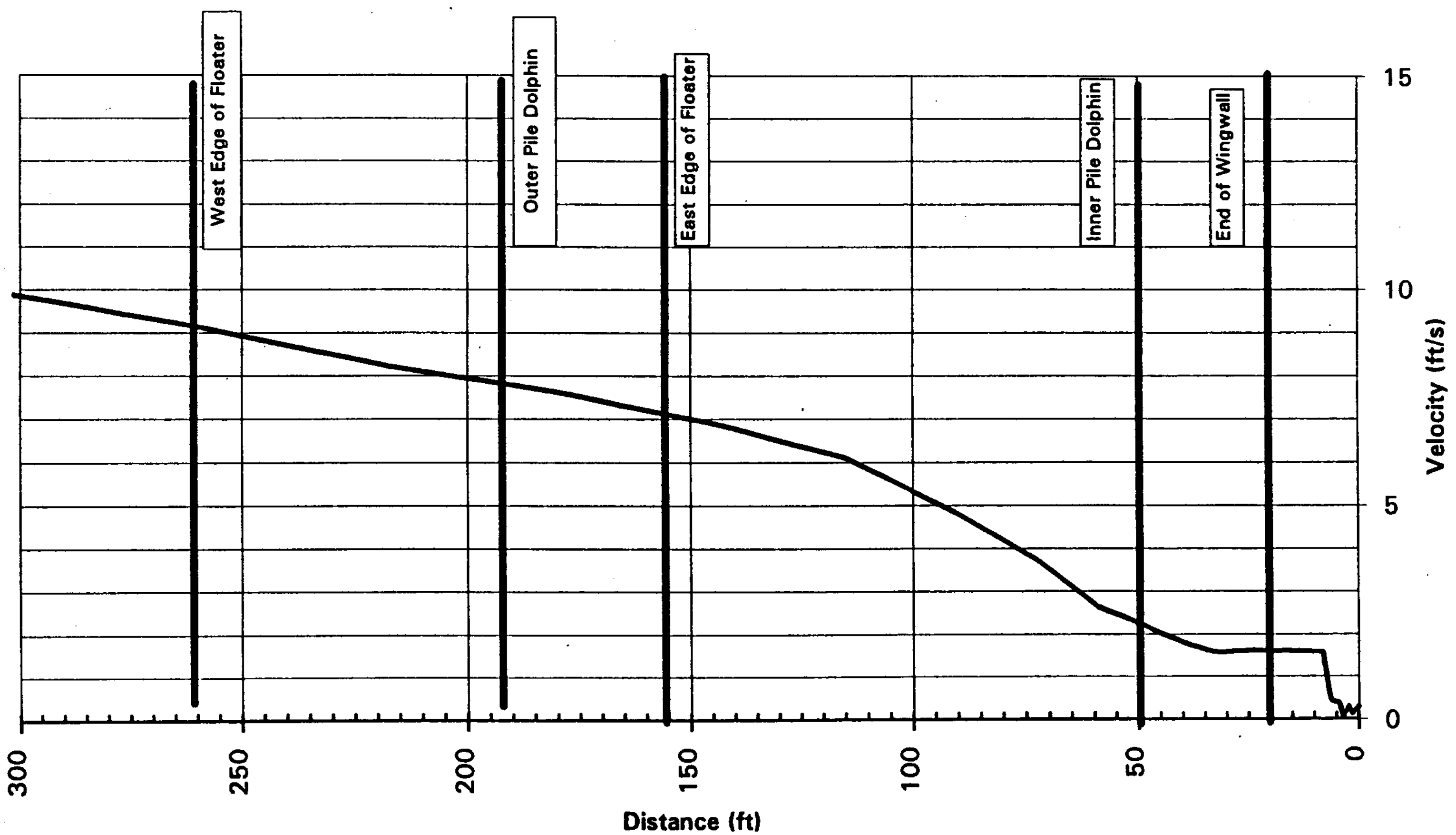

Figure E-21. Velocity vs. Distance from Edmonds Landing Structure (300 ft.) — 720EXX2

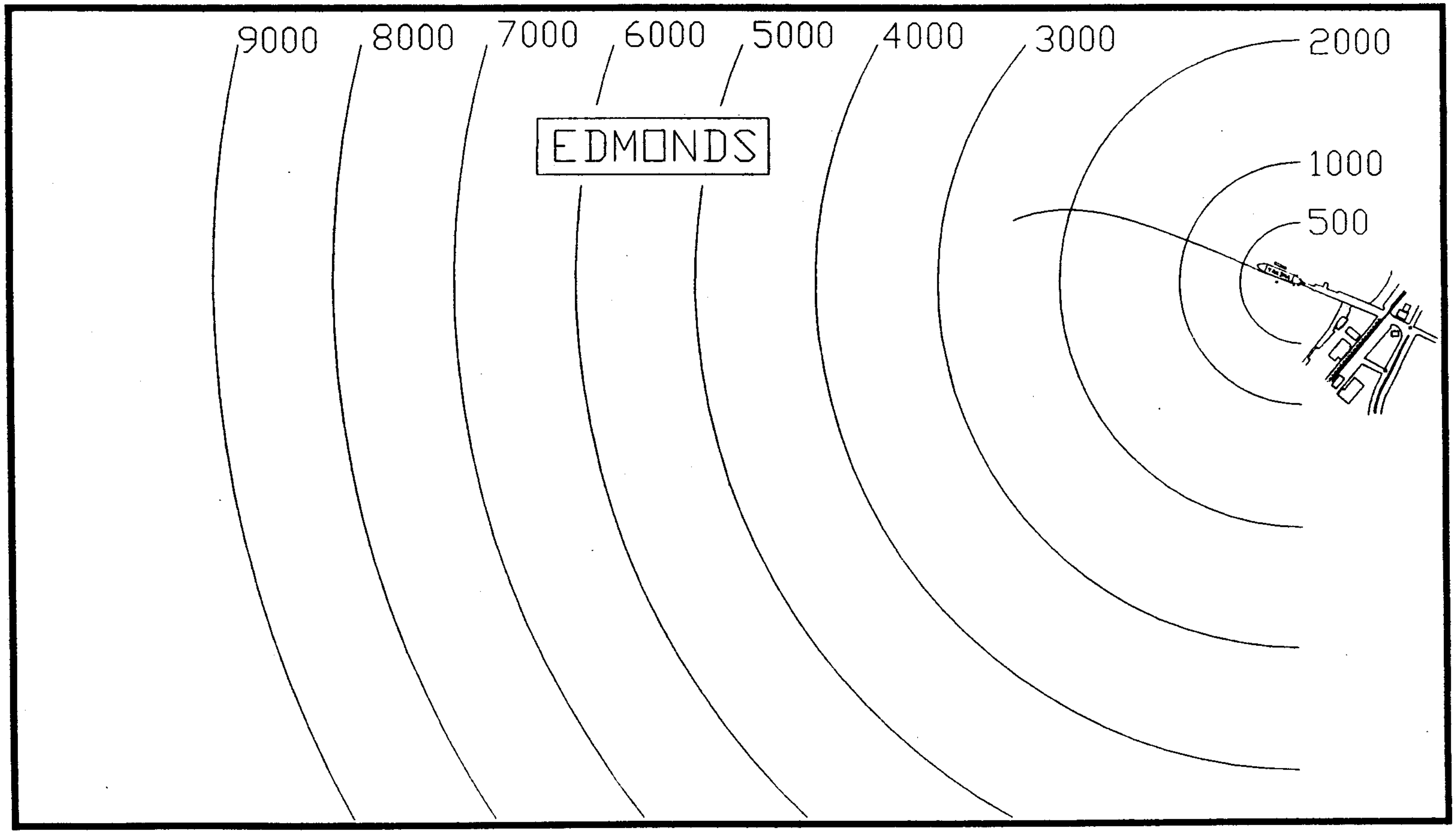

Figure E-22. Final Berthing Approach — 720EYY3

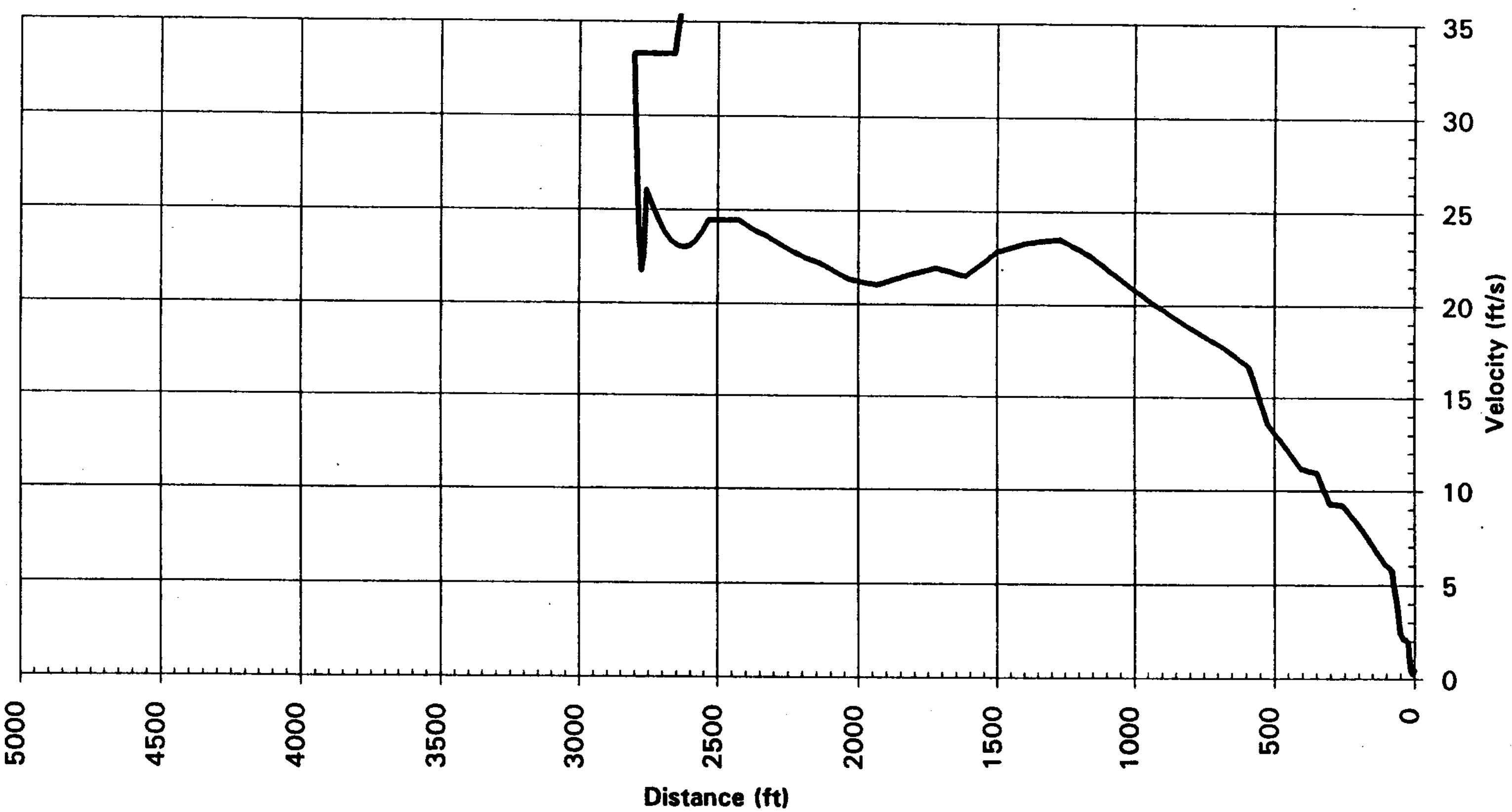

Figure E-23. Velocity vs. Distance from Edmonds Landing Structure (5,000 ft.) — 720EYY3

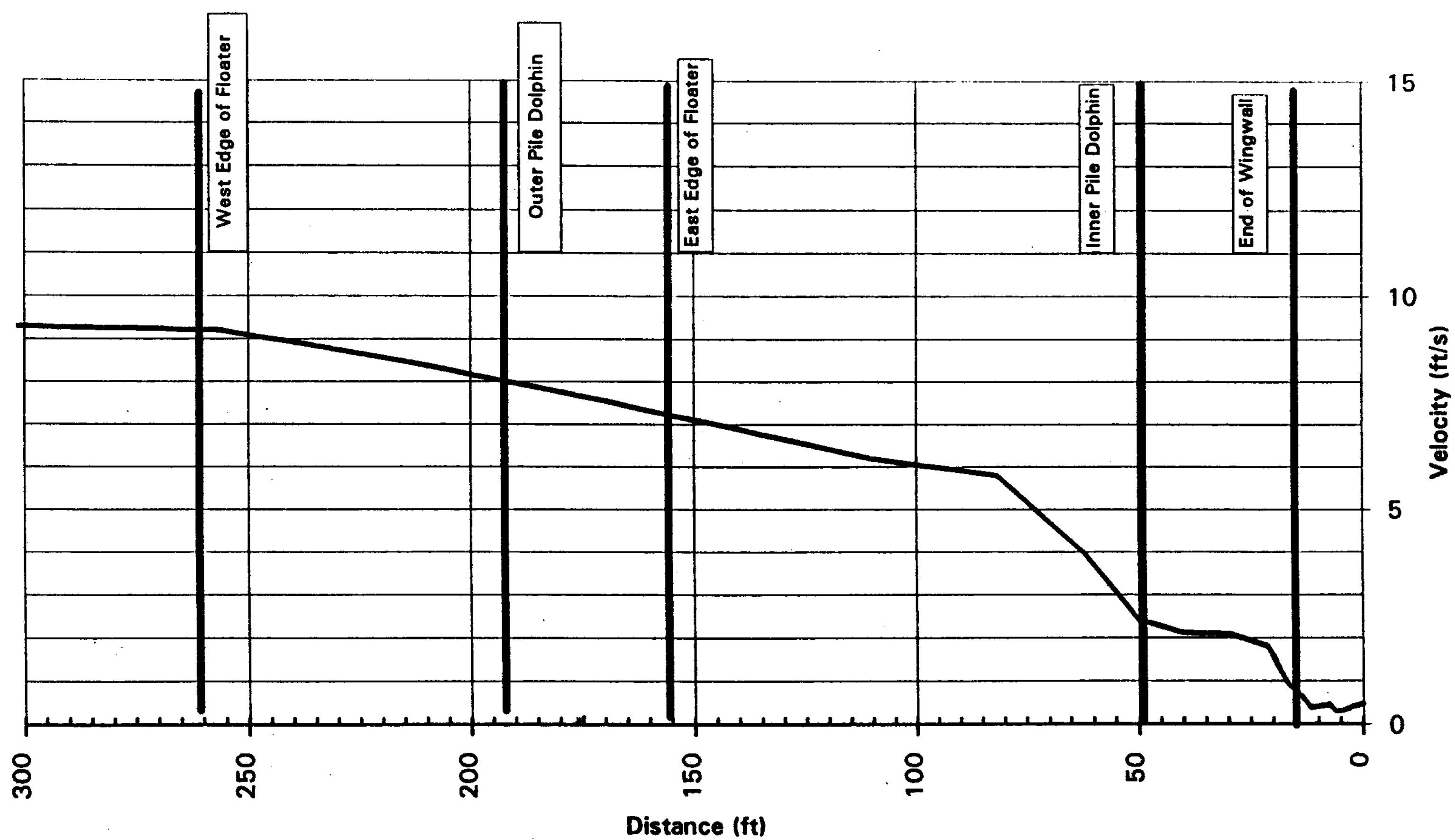

Figure E-24. Velocity vs. Distance from Edmonds Landing Structure (300 ft.) — 720EYY3

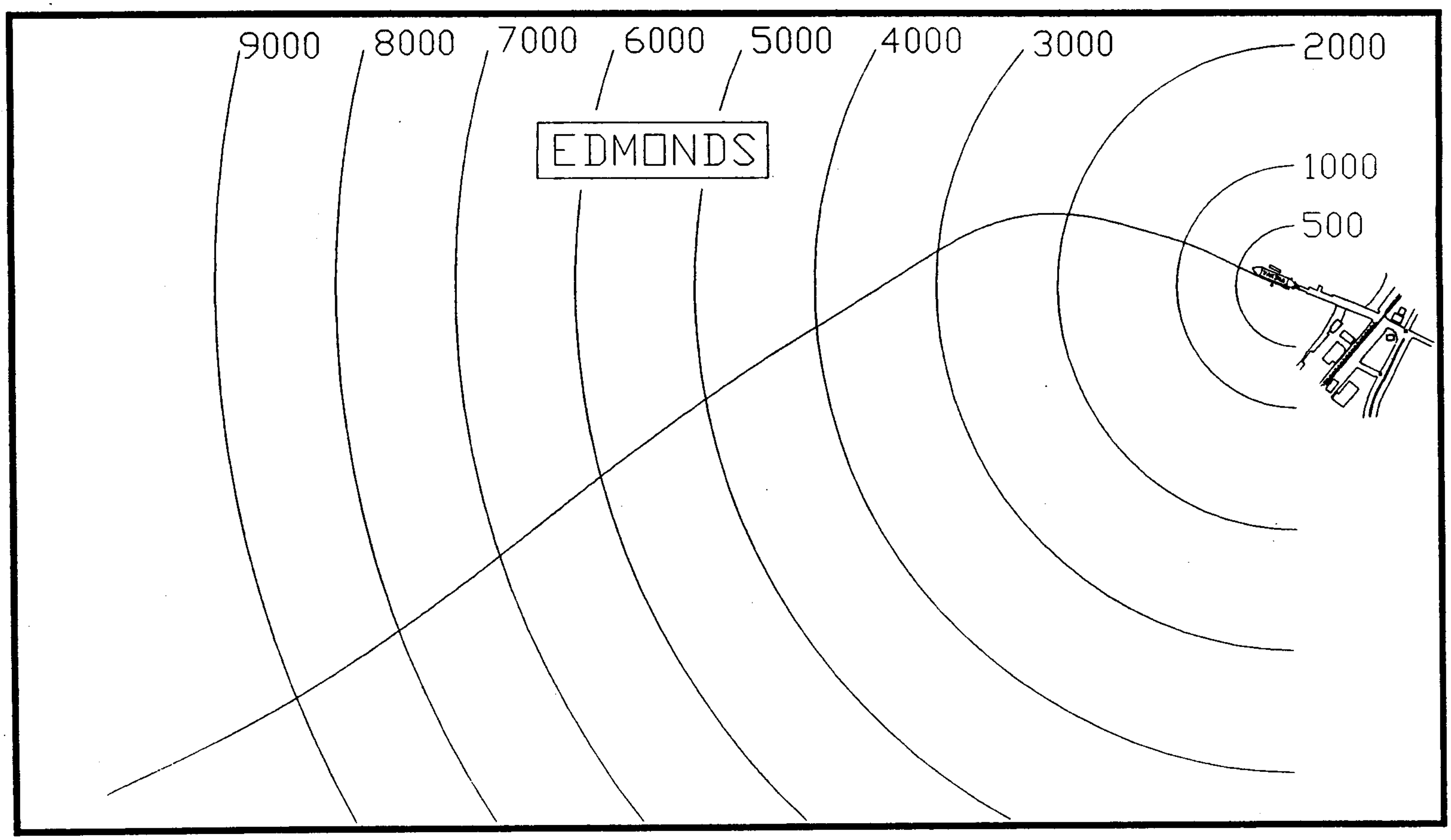

Figure E-25. Final Berthing Approach — 720EYY5

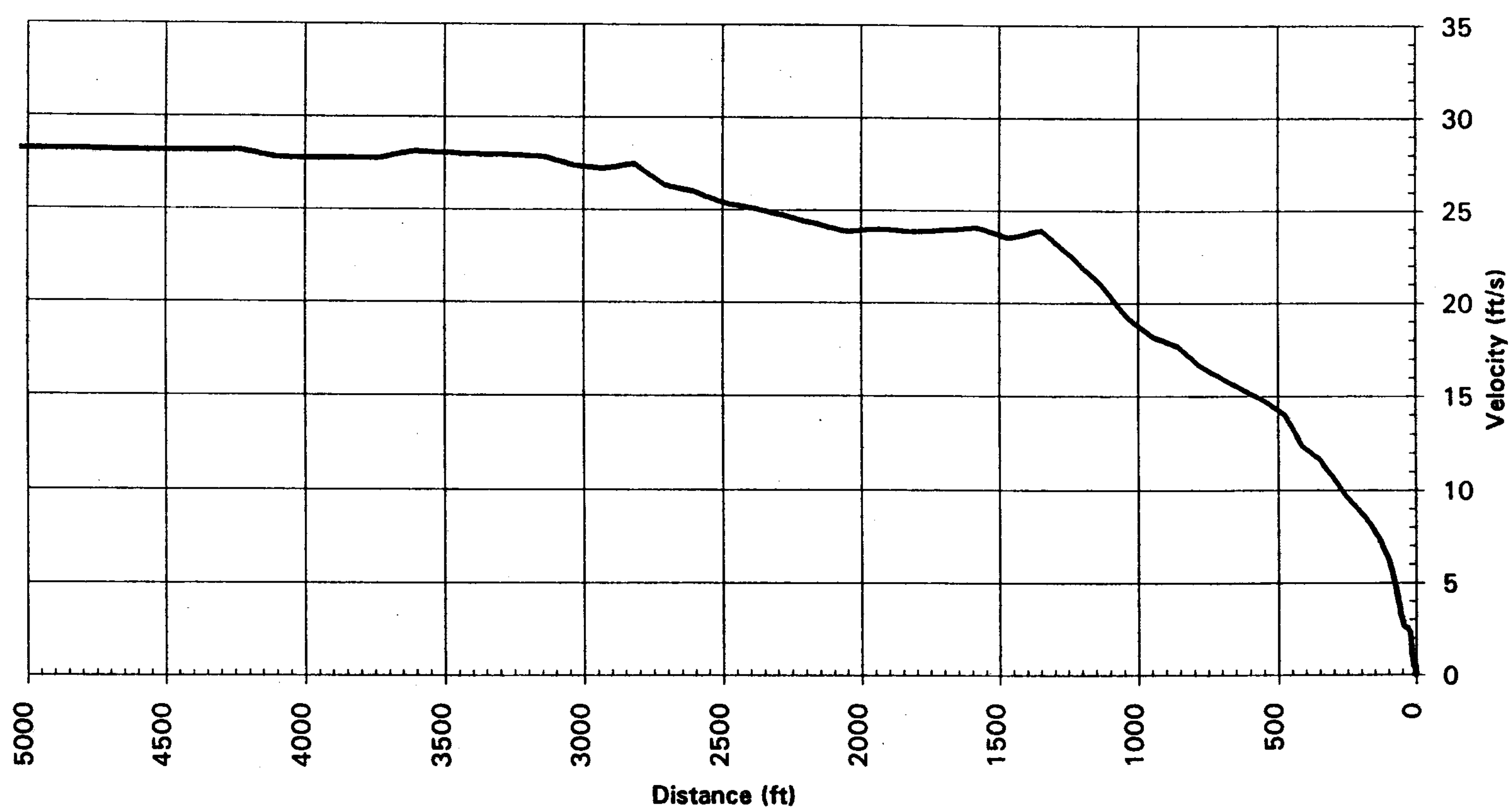

Figure E-26. Velocity vs. Distance from Edmonds Landing Structure (5,000 ft.) — 720EYY5

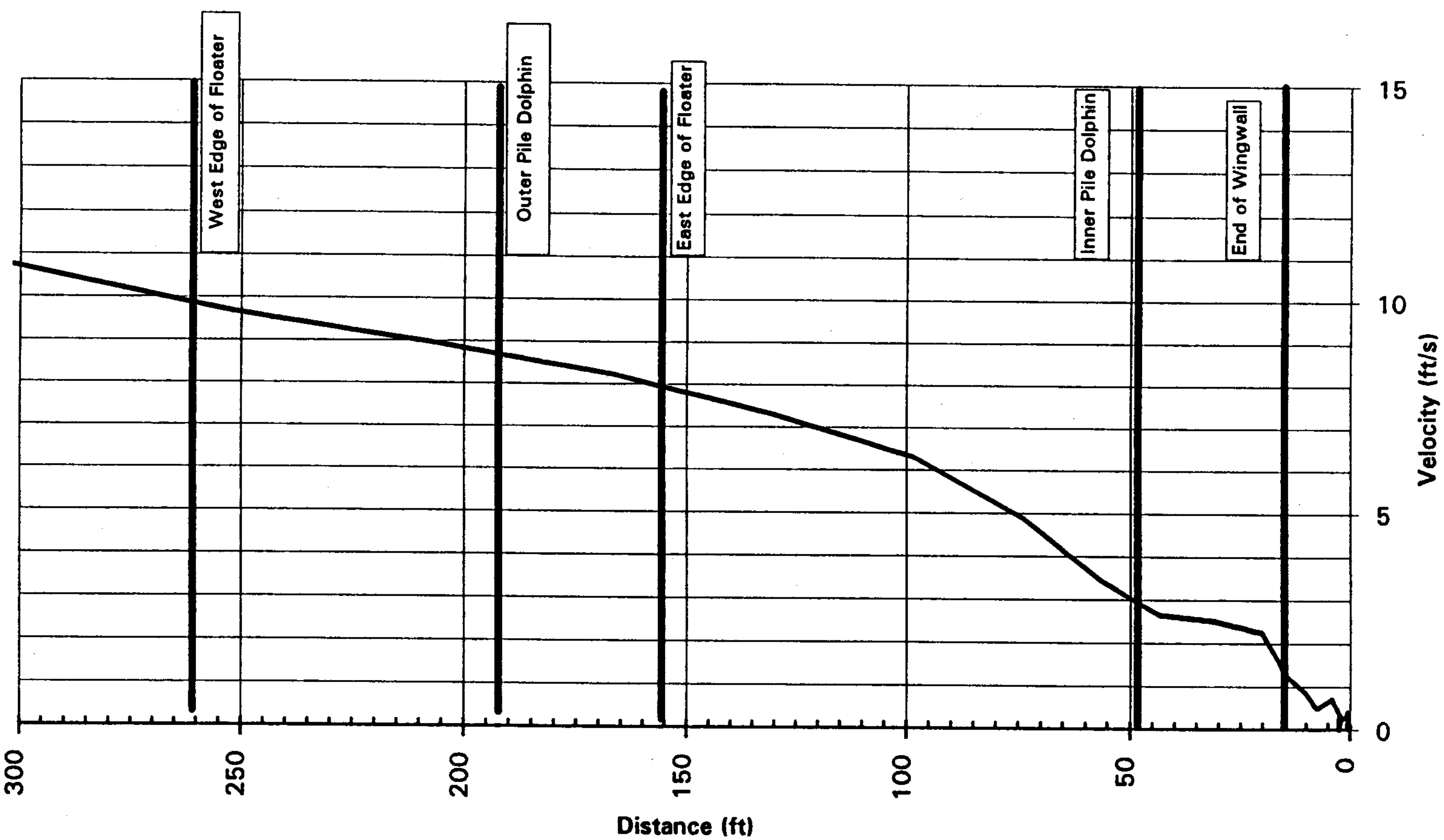

Figure E-27. Velocity vs. Distance from Edmonds Landing Structure (300 ft.) — 720EYY5

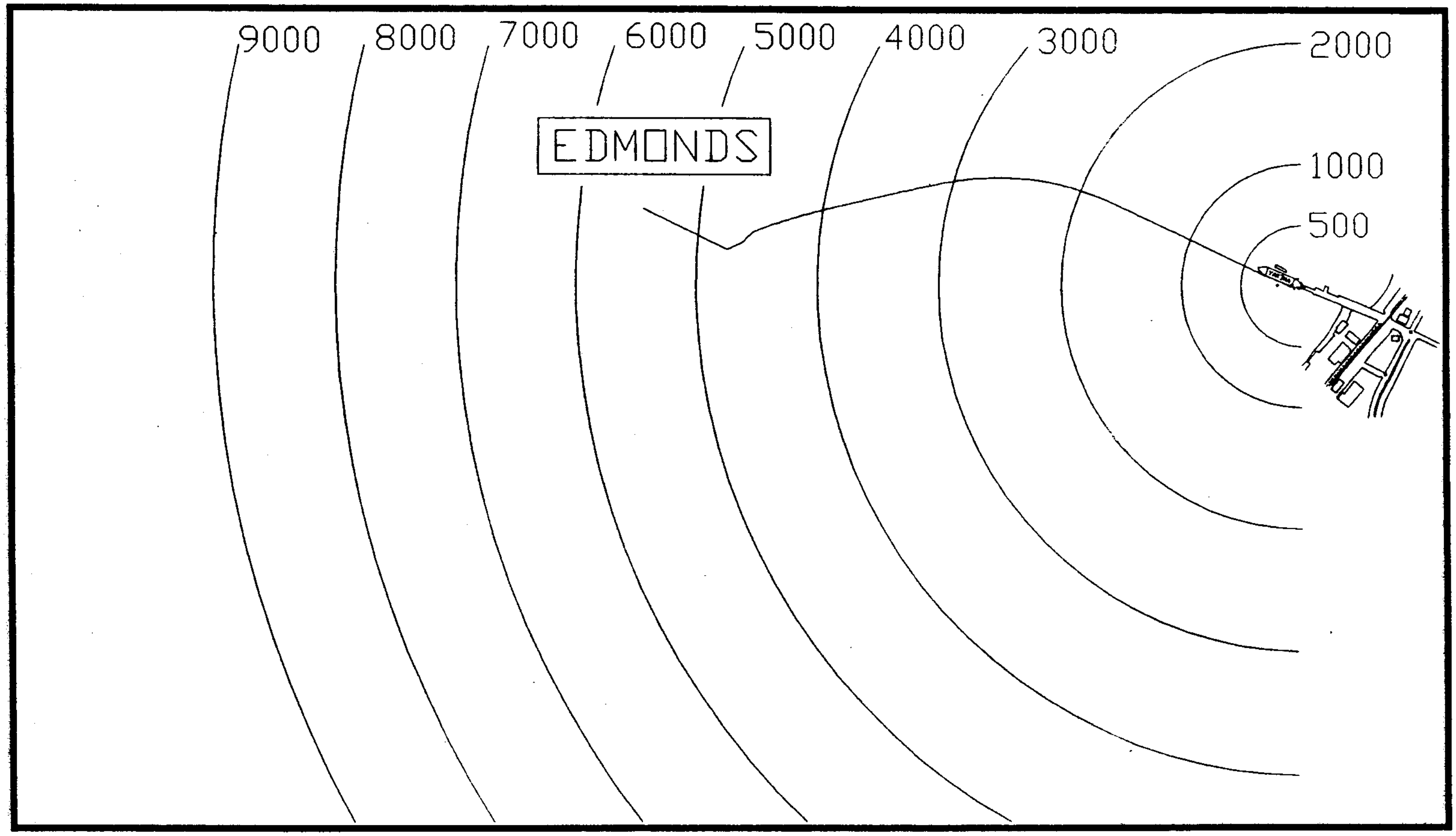

Figure E-28. Final Berthing Approach — 723EZZ3

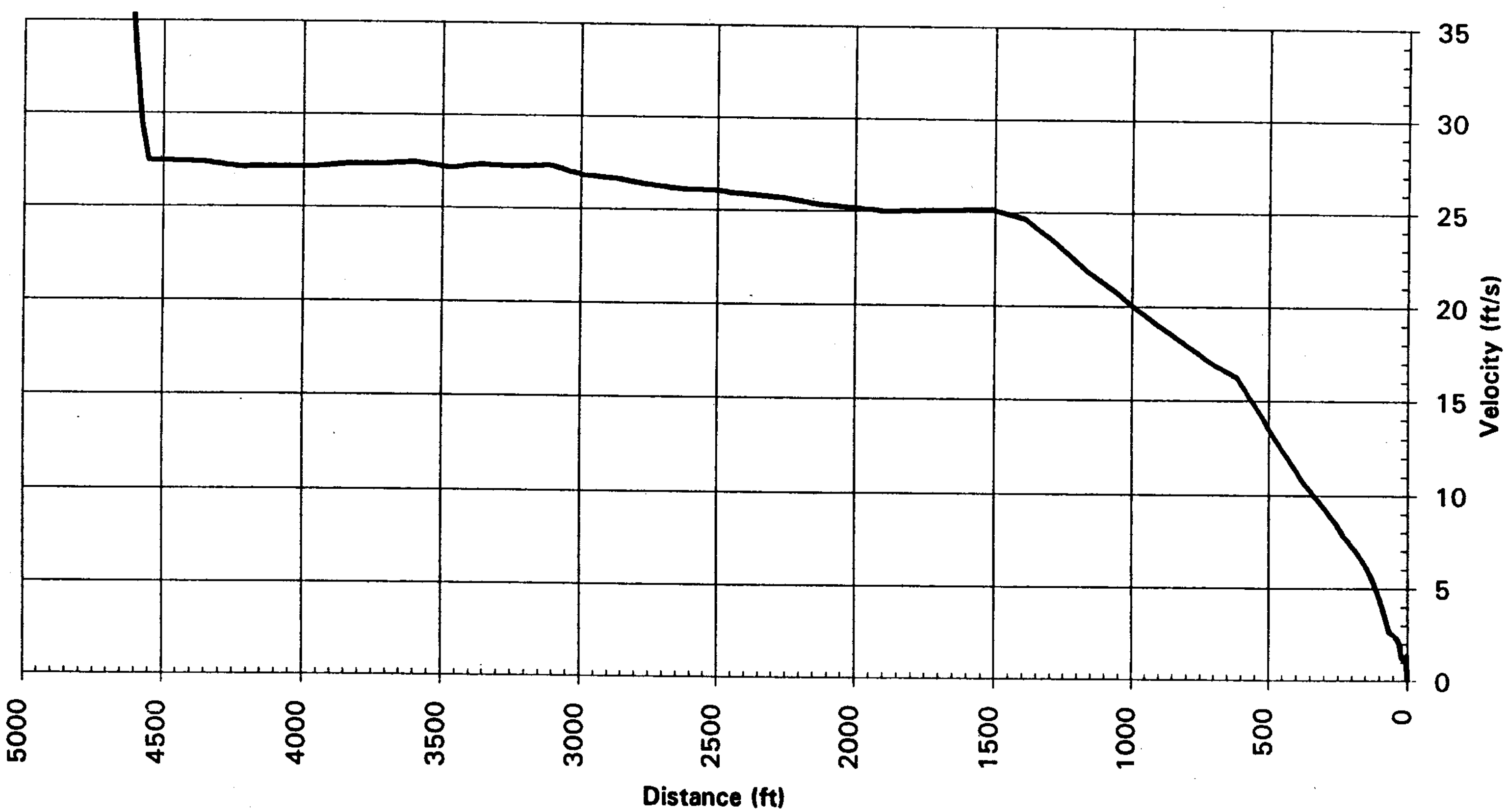

Figure E-29. Velocity vs. Distance from Edmonds Landing Structure (5,000 ft.) — 723EZZ3

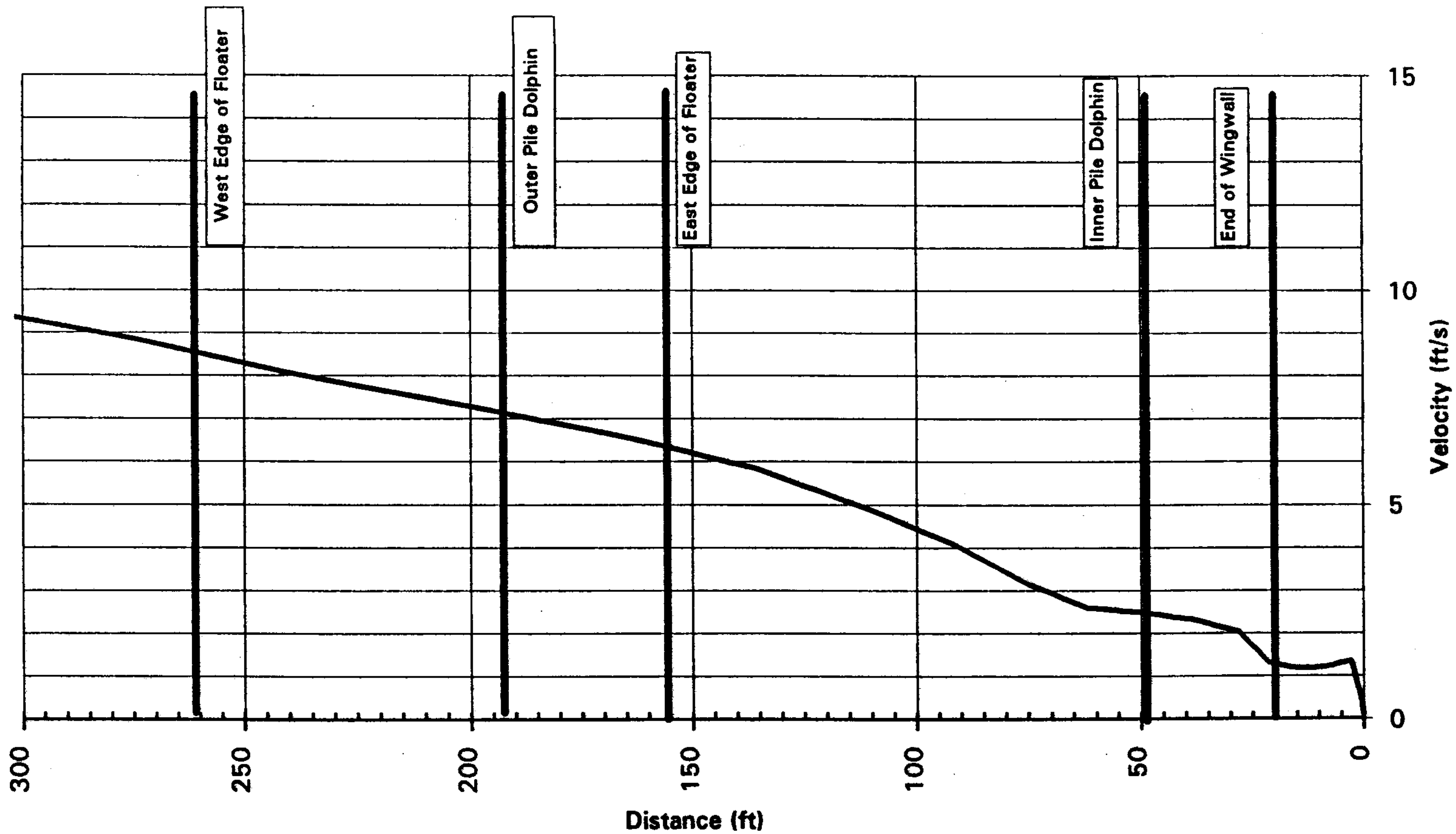

Figure E-30. Velocity vs. Distance from Edmonds Landing Structure (300 ft.) — 723EZZ3

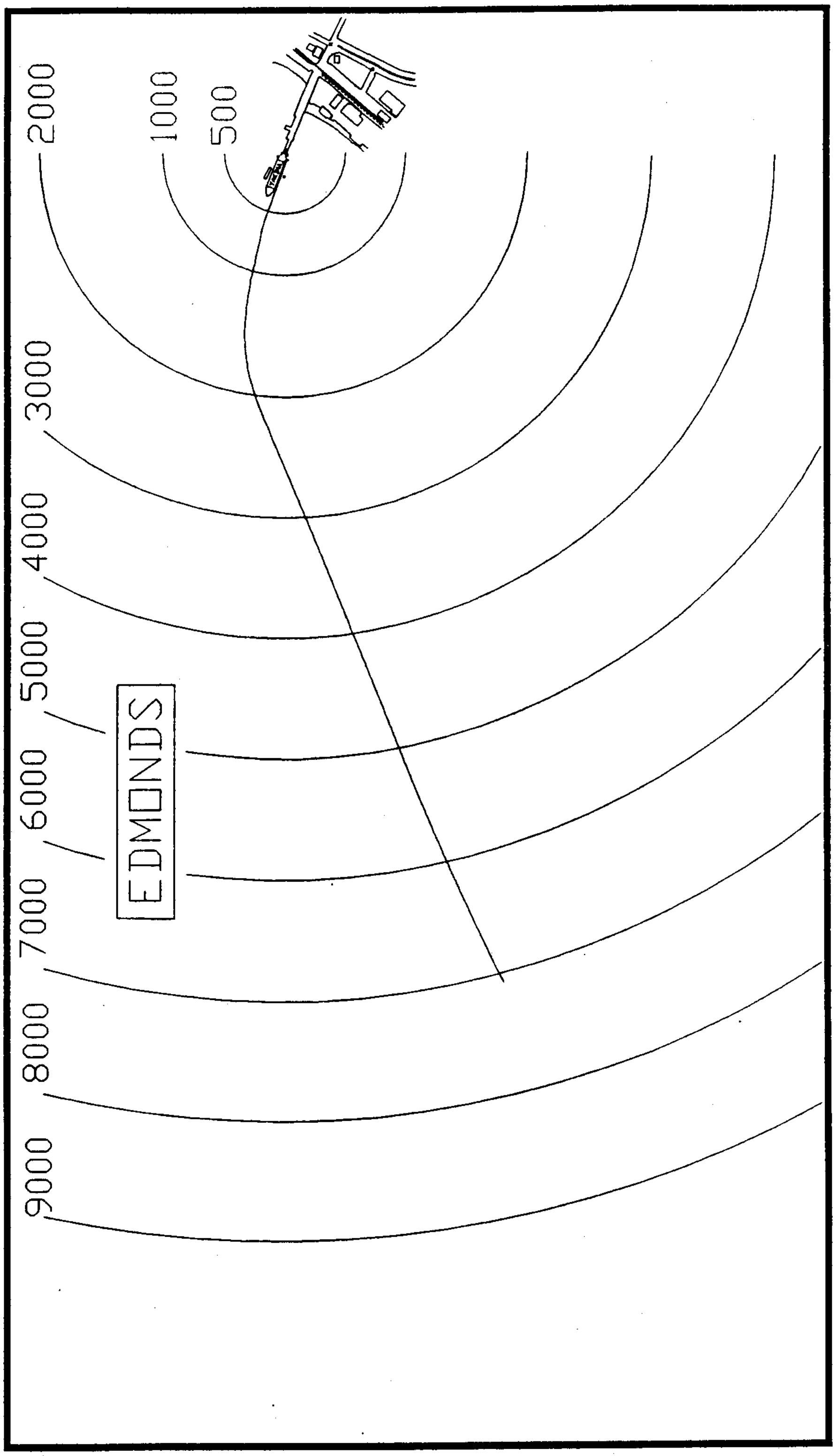

Figure E-31. Final Berthing Approach — 723EZZ5

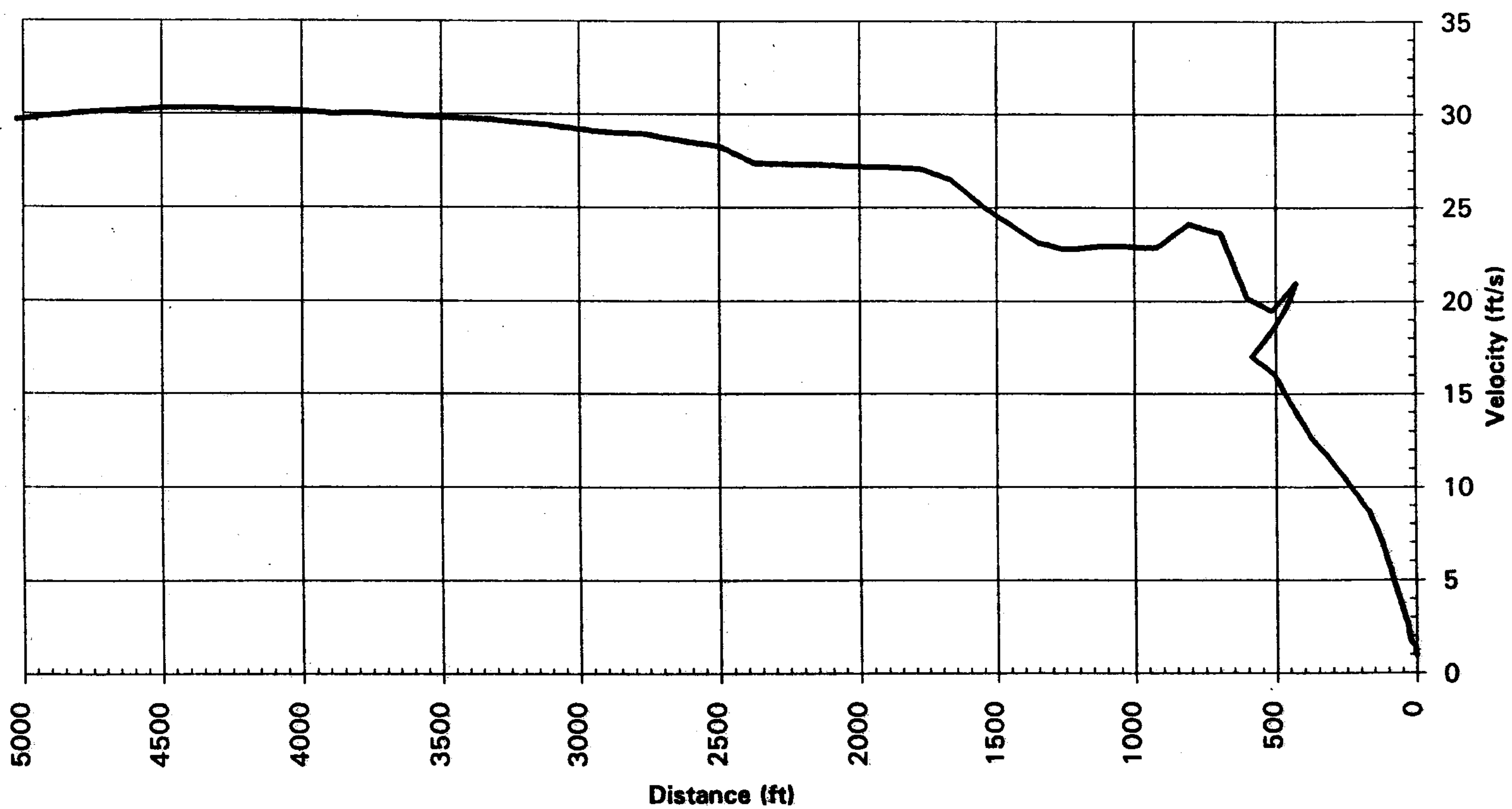

Figure E-32. Velocity vs. Distance from Edmonds Landing Structure (5,000 ft.) — 723EZZ5

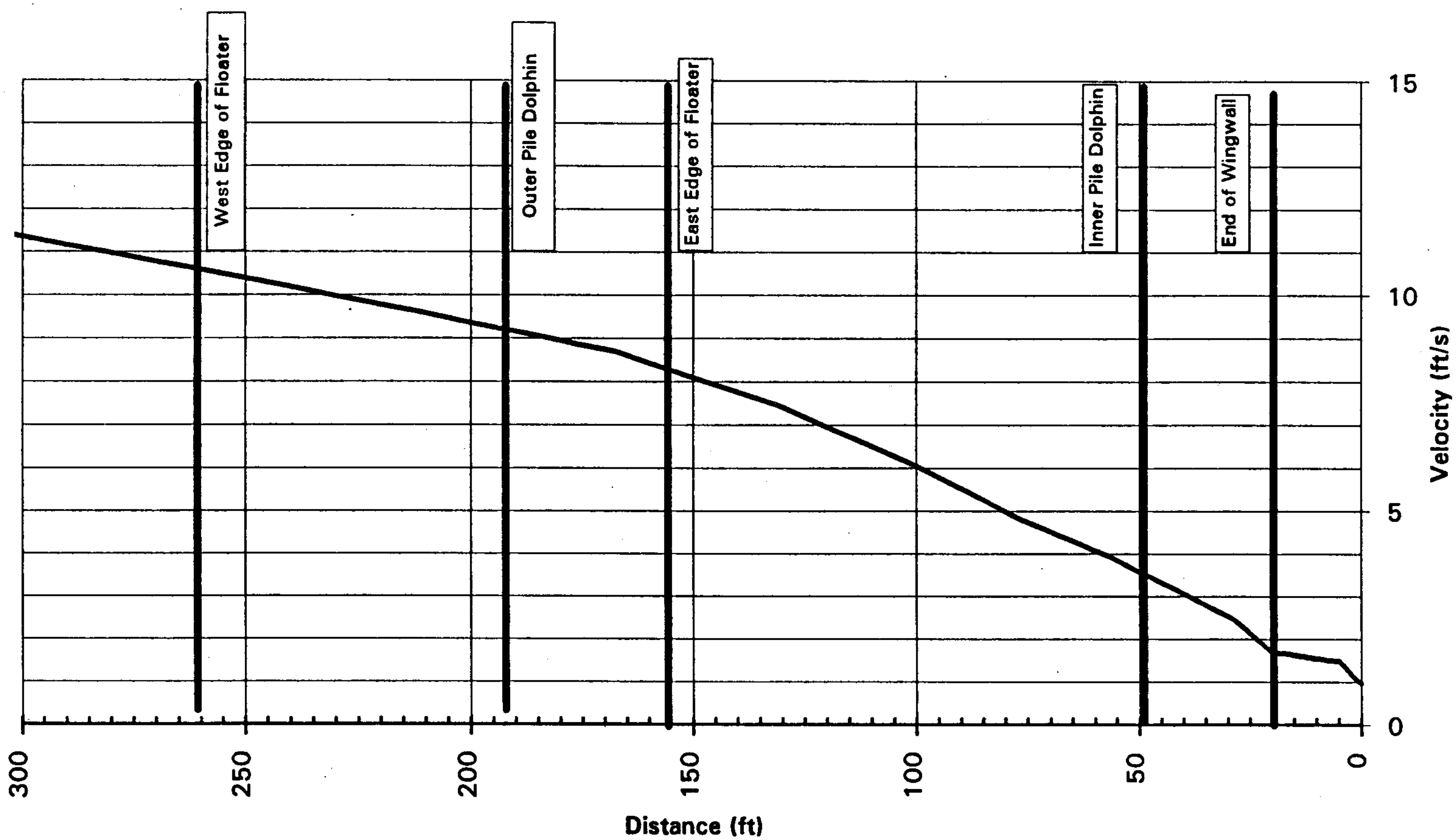

Figure E-33. Velocity vs. Distance from Edmonds Landing Structure (300 ft.) — 723EZZ5

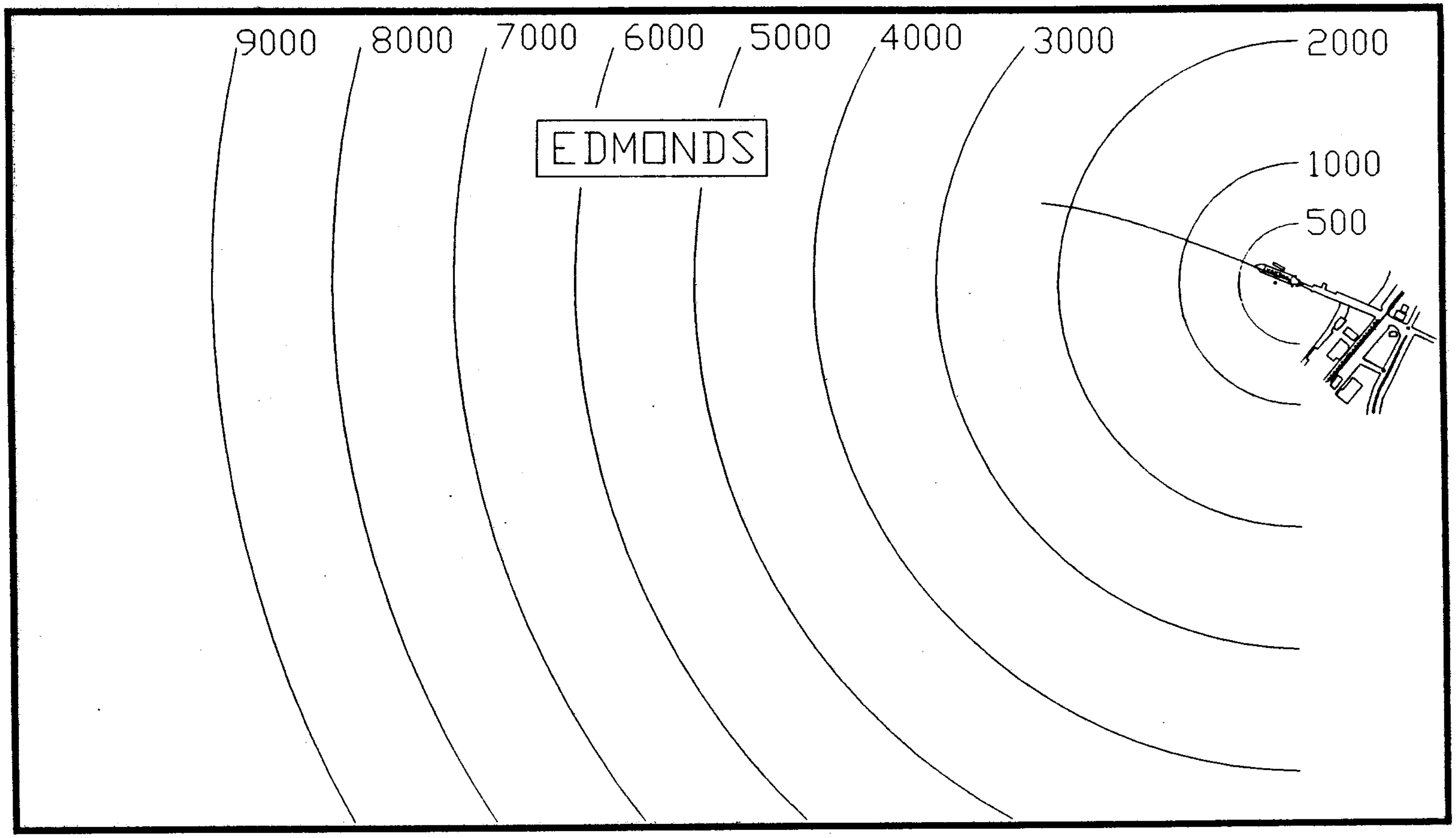

Figure E-34. Final Berthing Approach — 723EYY2

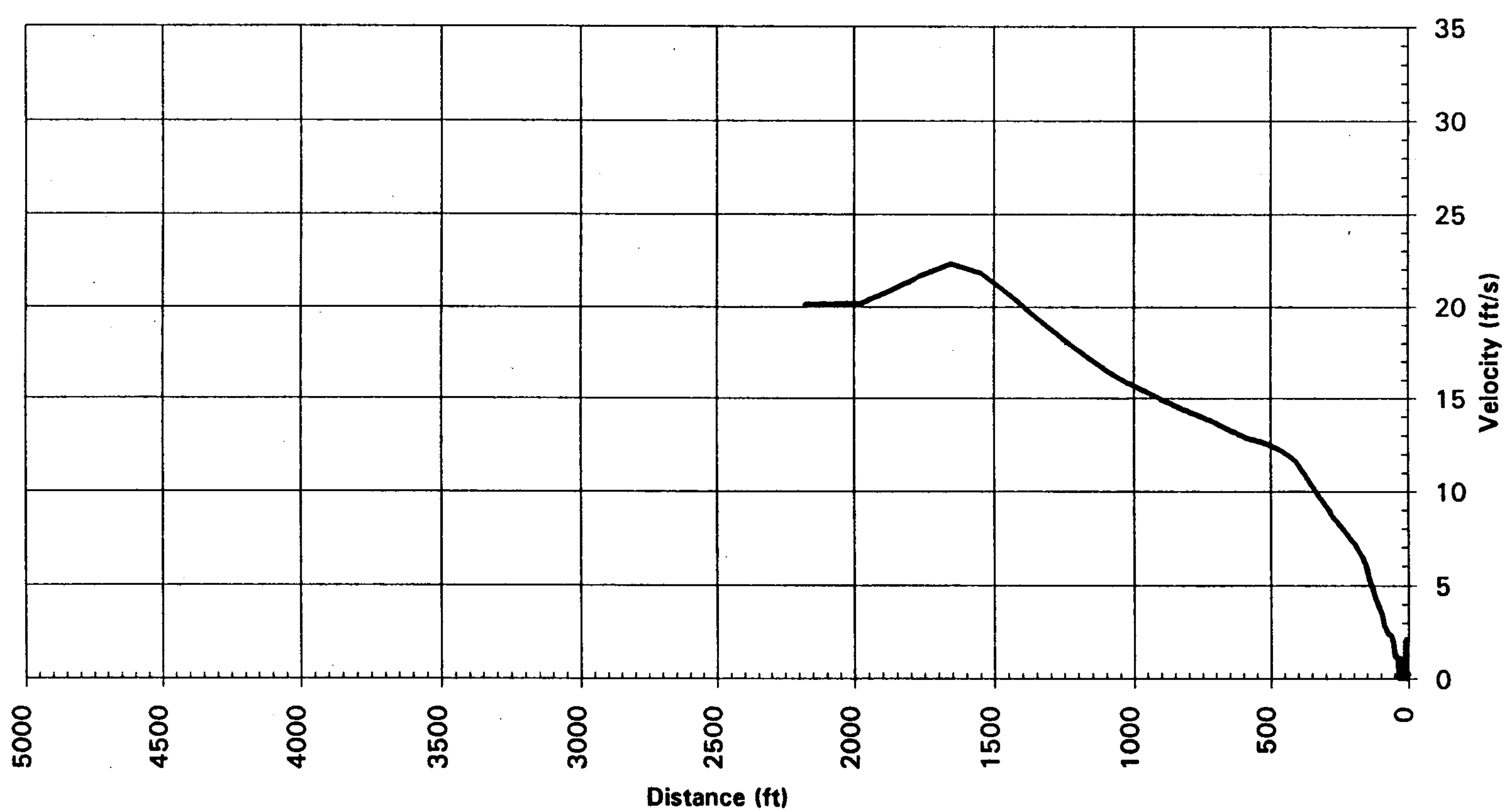

Figure E-35. Velocity vs. Distance from Edmonds Landing Structure (5,000 ft.) — 723EYY2

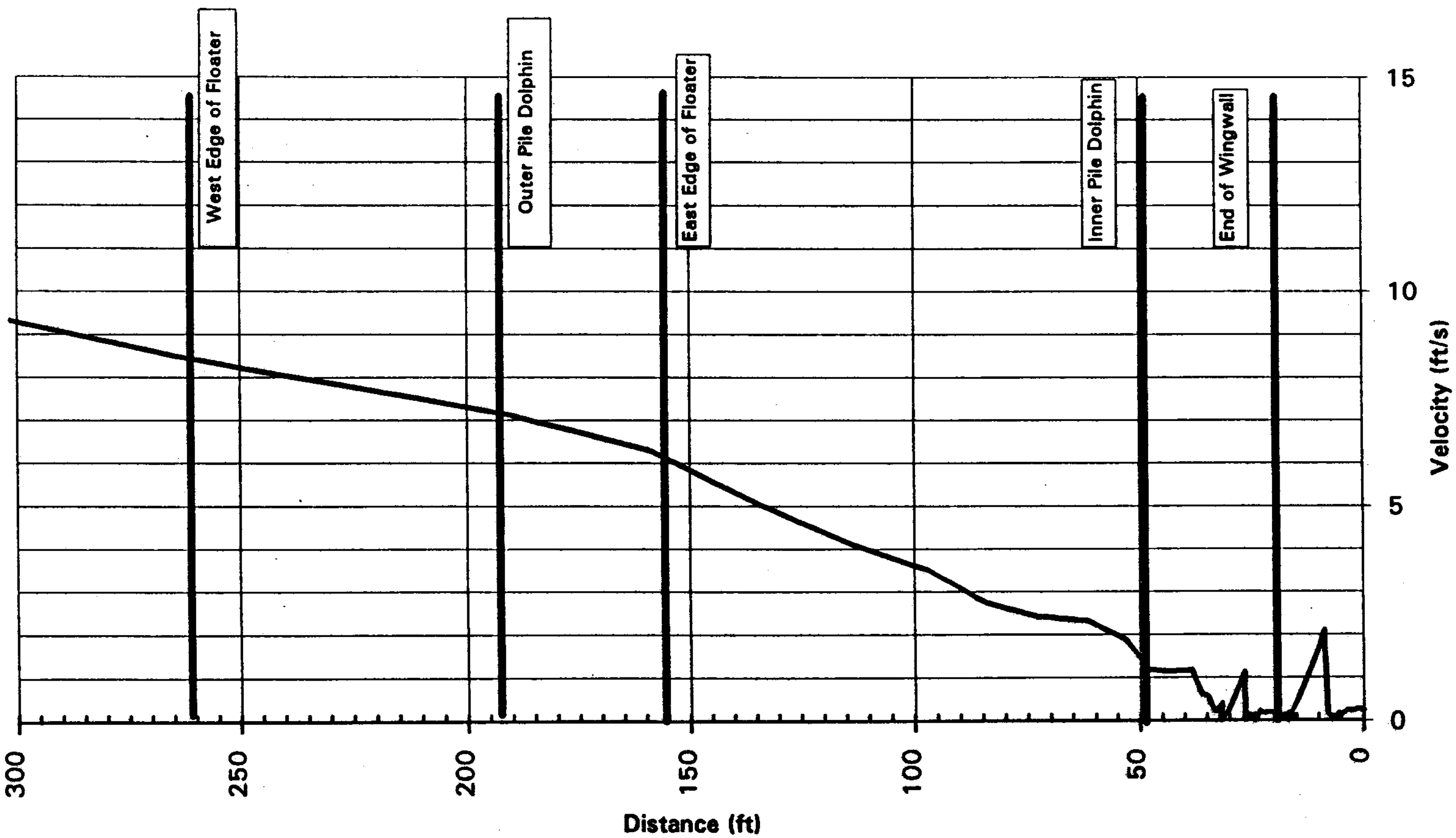

Figure E-36. Velocity vs. Distance from Edmonds Landing Structure (300 ft.) — 723EYY2

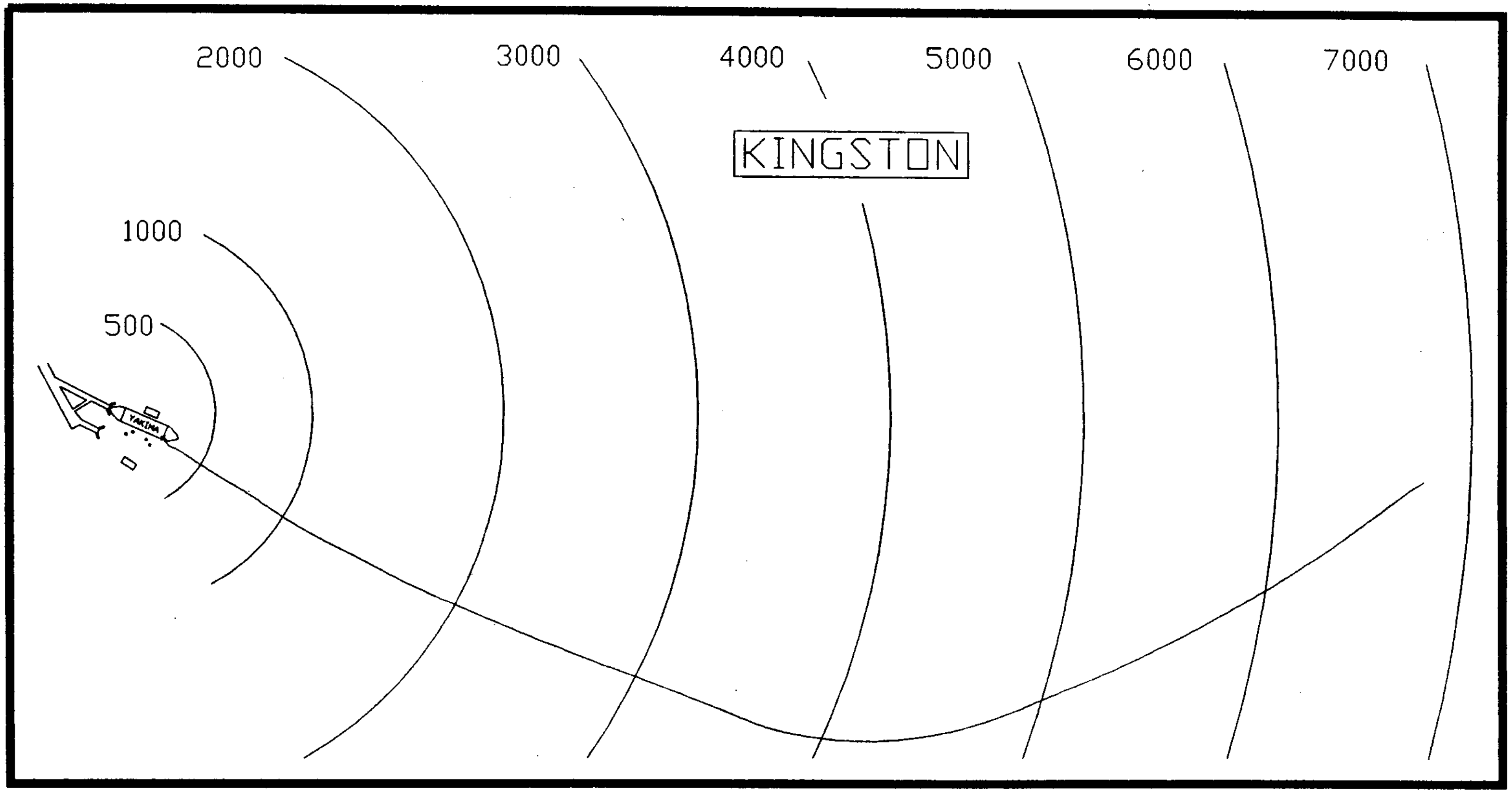

Figure E-37. Final Berthing Approach — 709KVV2

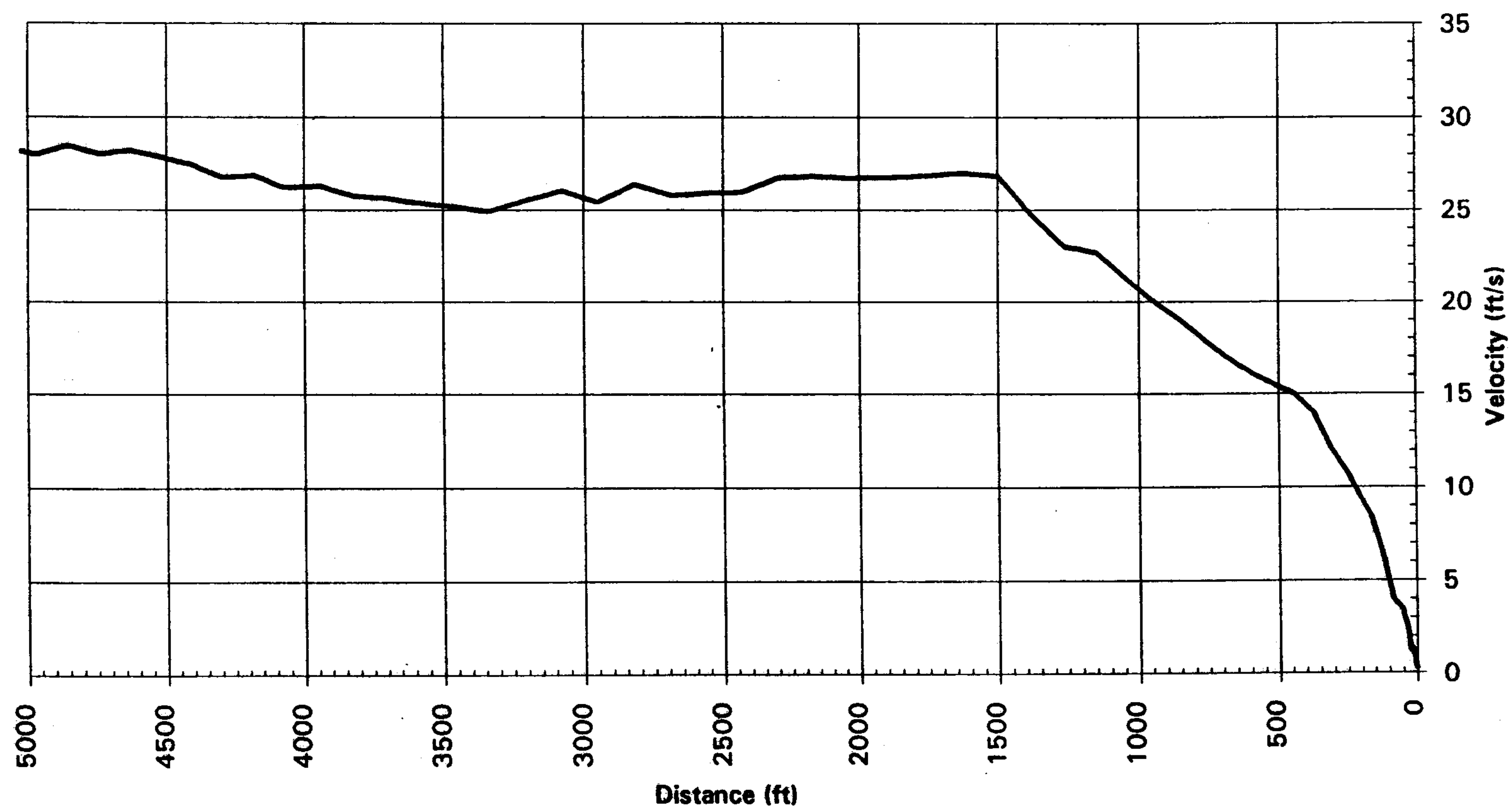

Figure E-38. Velocity vs. Distance from Kingston Landing Structure (5,000 ft.) — 709KVV2

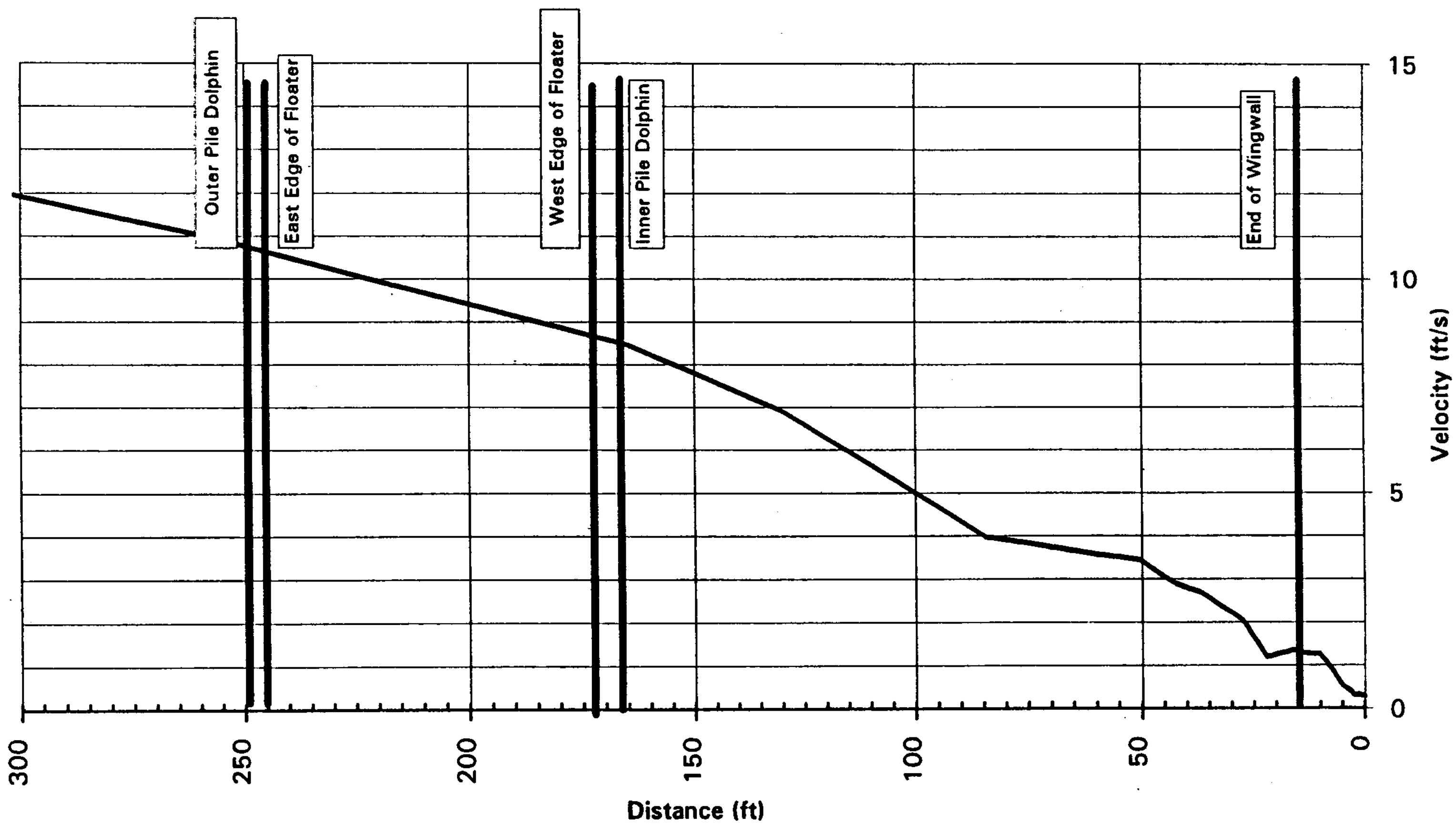

Figure E-39. Velocity vs. Distance from Kingston Landing Structure (300 ft.) — 709KVV2

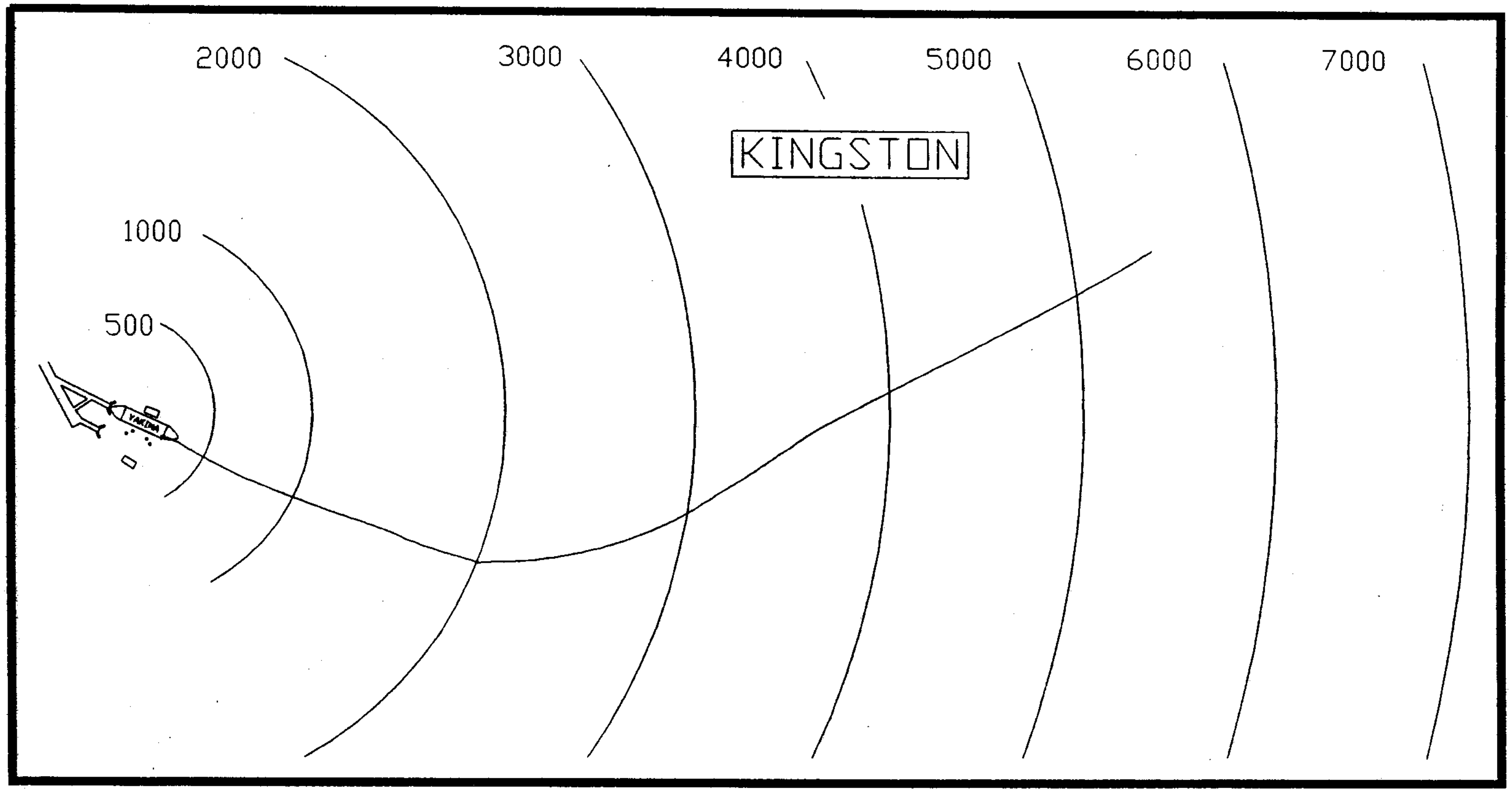

Figure E-40. Final Berthing Approach — 709KVV3

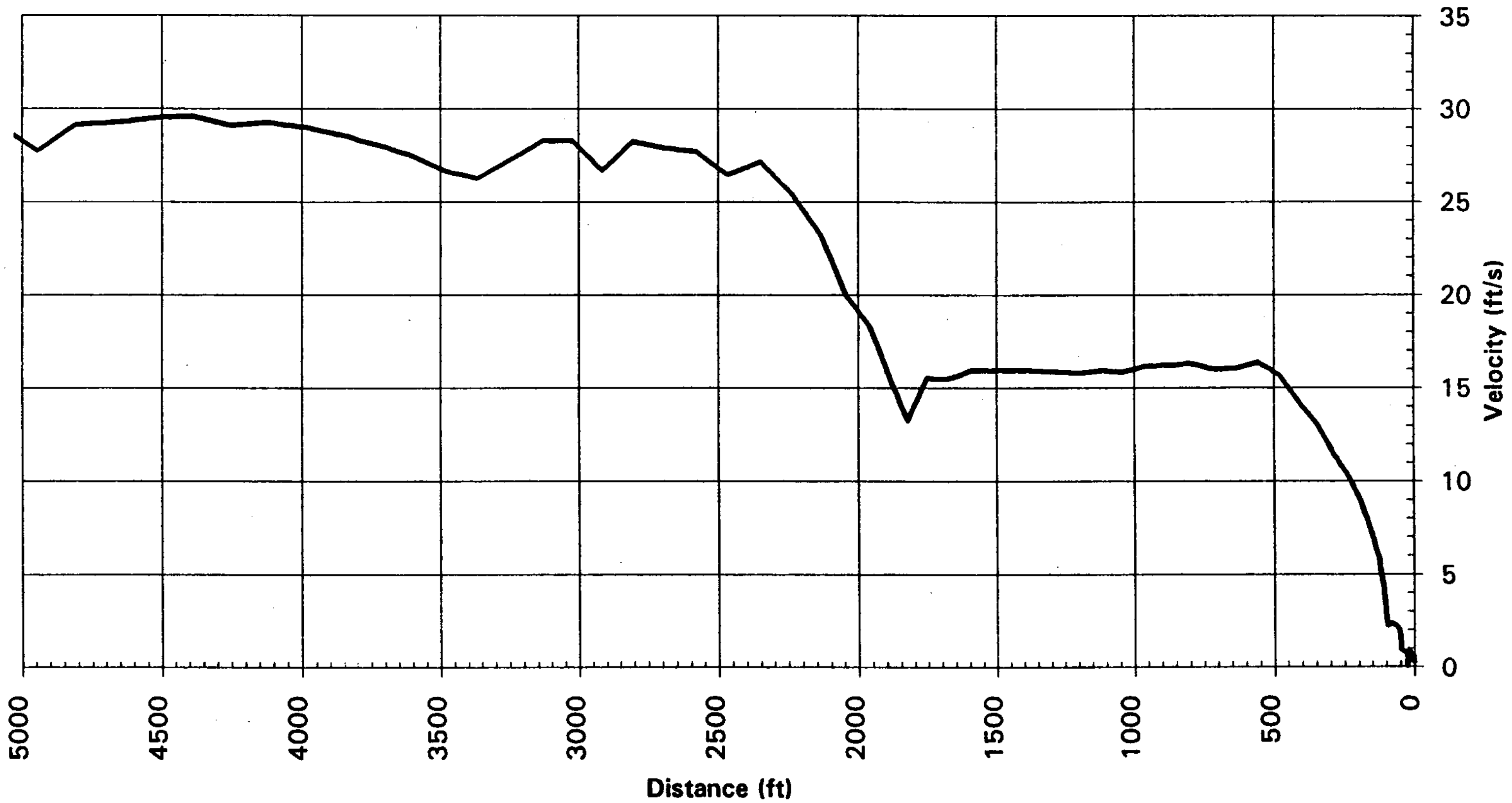

Figure E-41. Velocity vs. Distance from Kingston Landing Structure (5,000 ft.) — 709KVV3

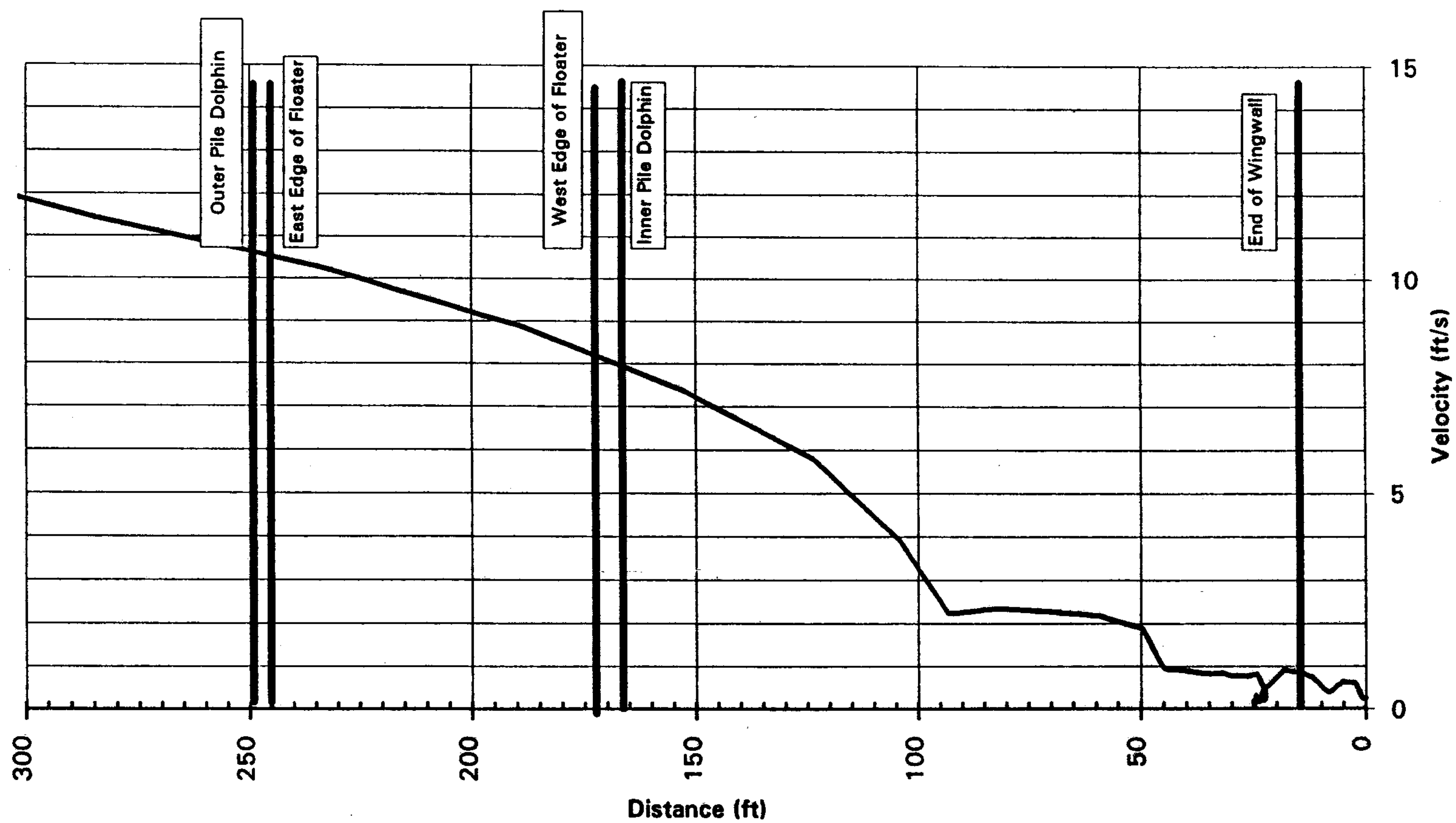

Figure E-42. Velocity vs. Distance from Kingston Landing Structure (300 ft.) — 709KVV3

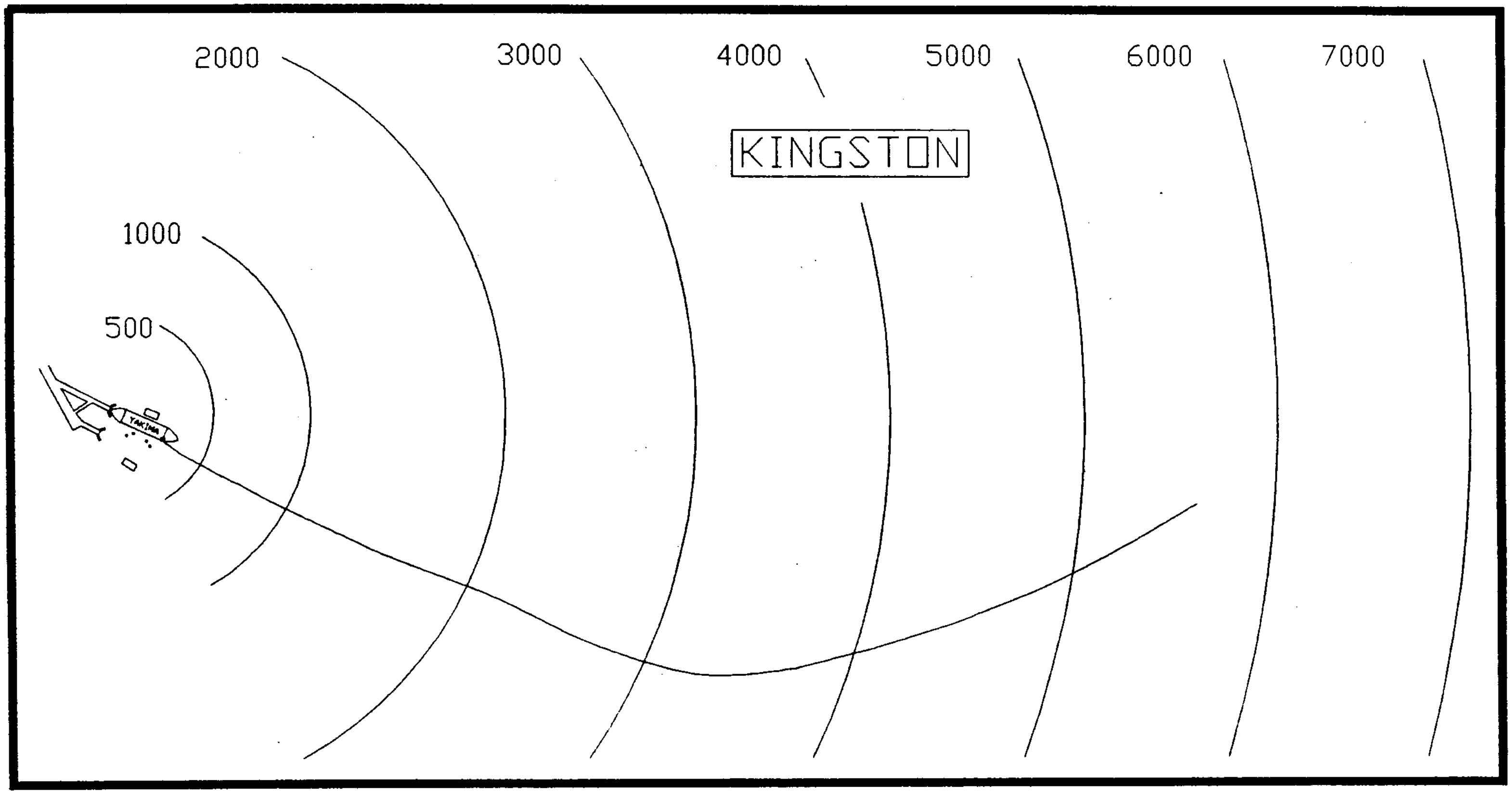

Figure E-43. Final Berthing Approach — 709KYY1

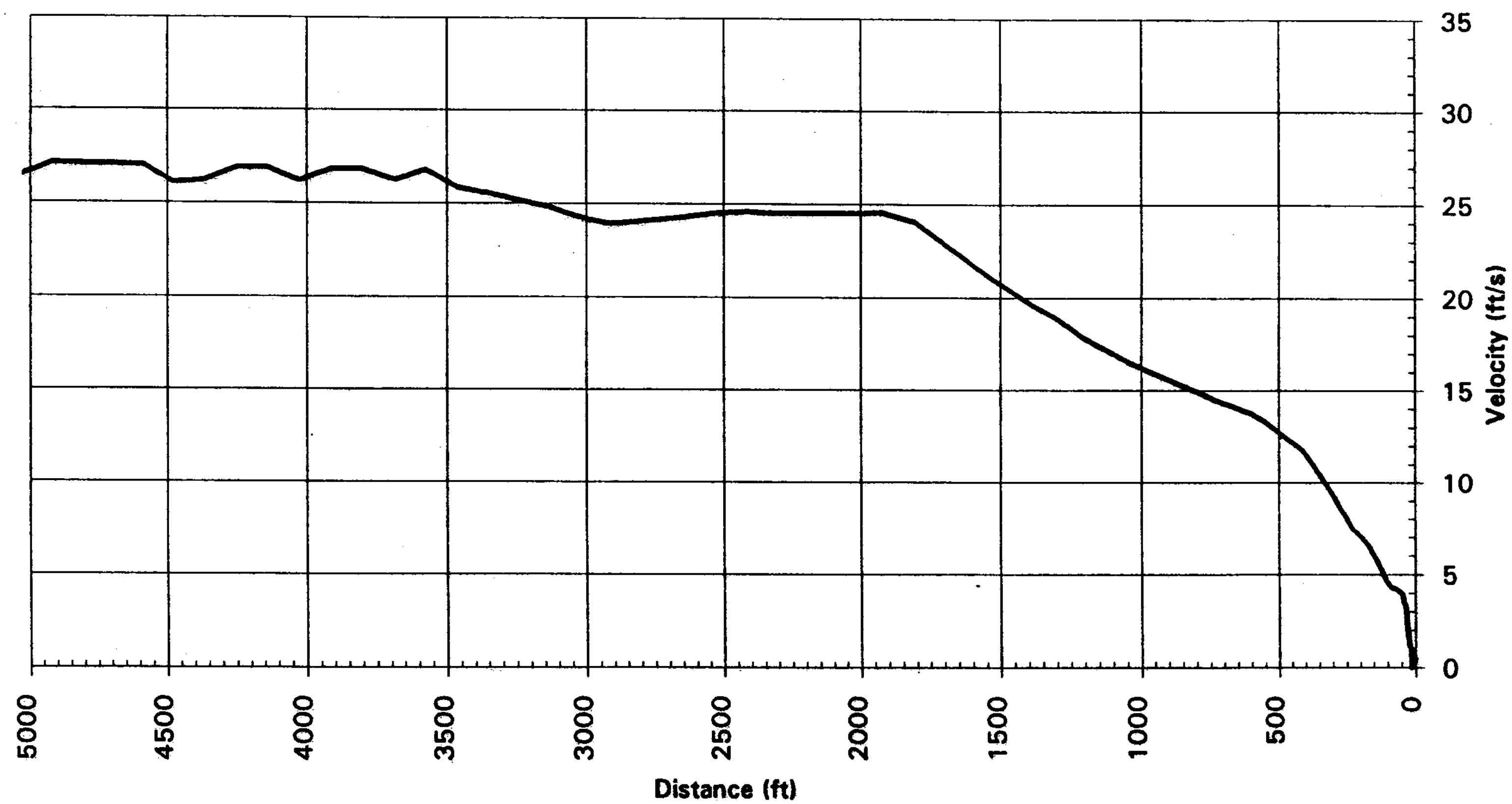

Figure E-44. Velocity vs. Distance from Kingston Landing Structure (5,000 ft.) — 709KYY1

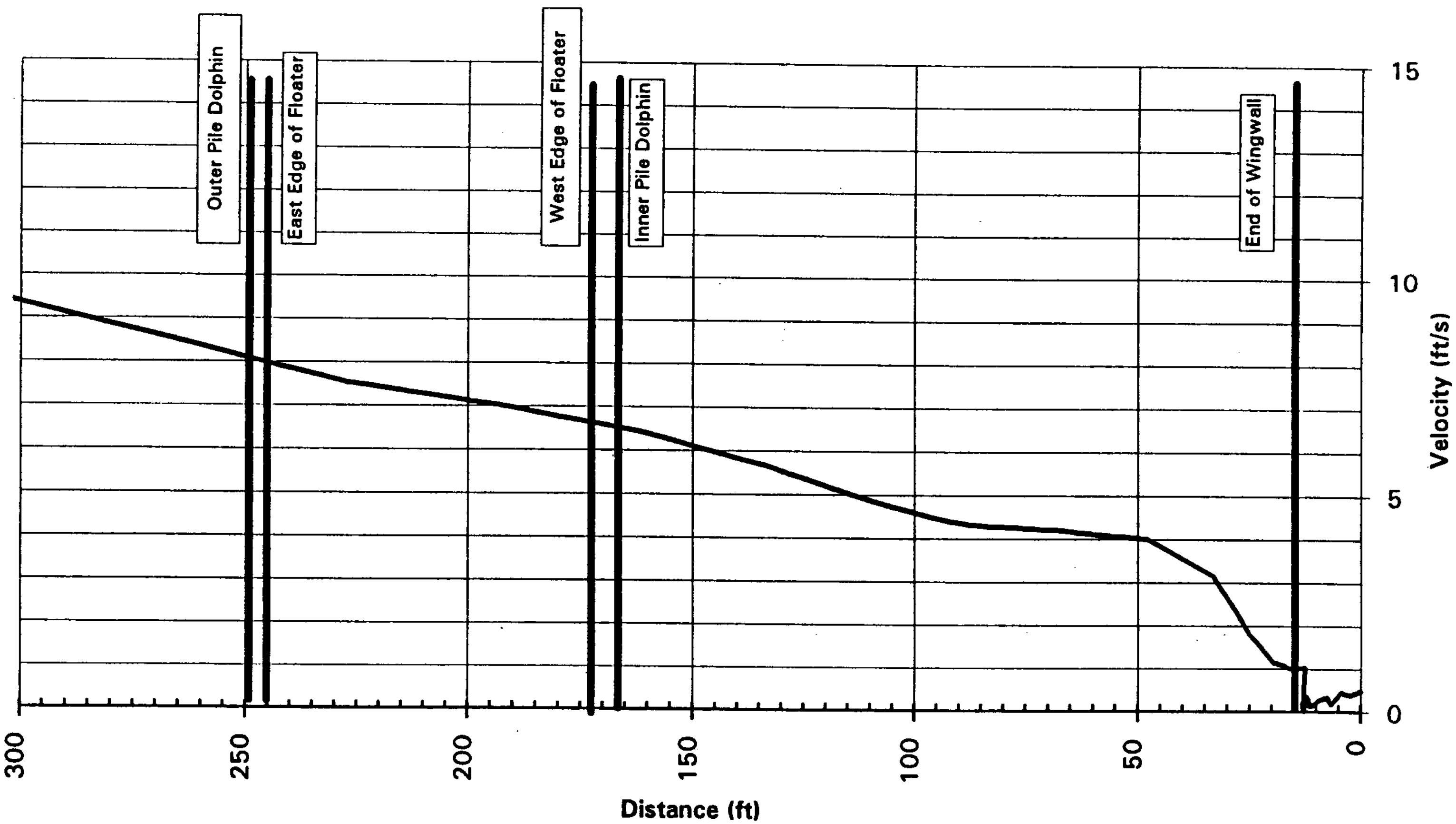

Figure E-45. Velocity vs. Distance from Kingston Landing Structure (300 ft.) — 709KYY1

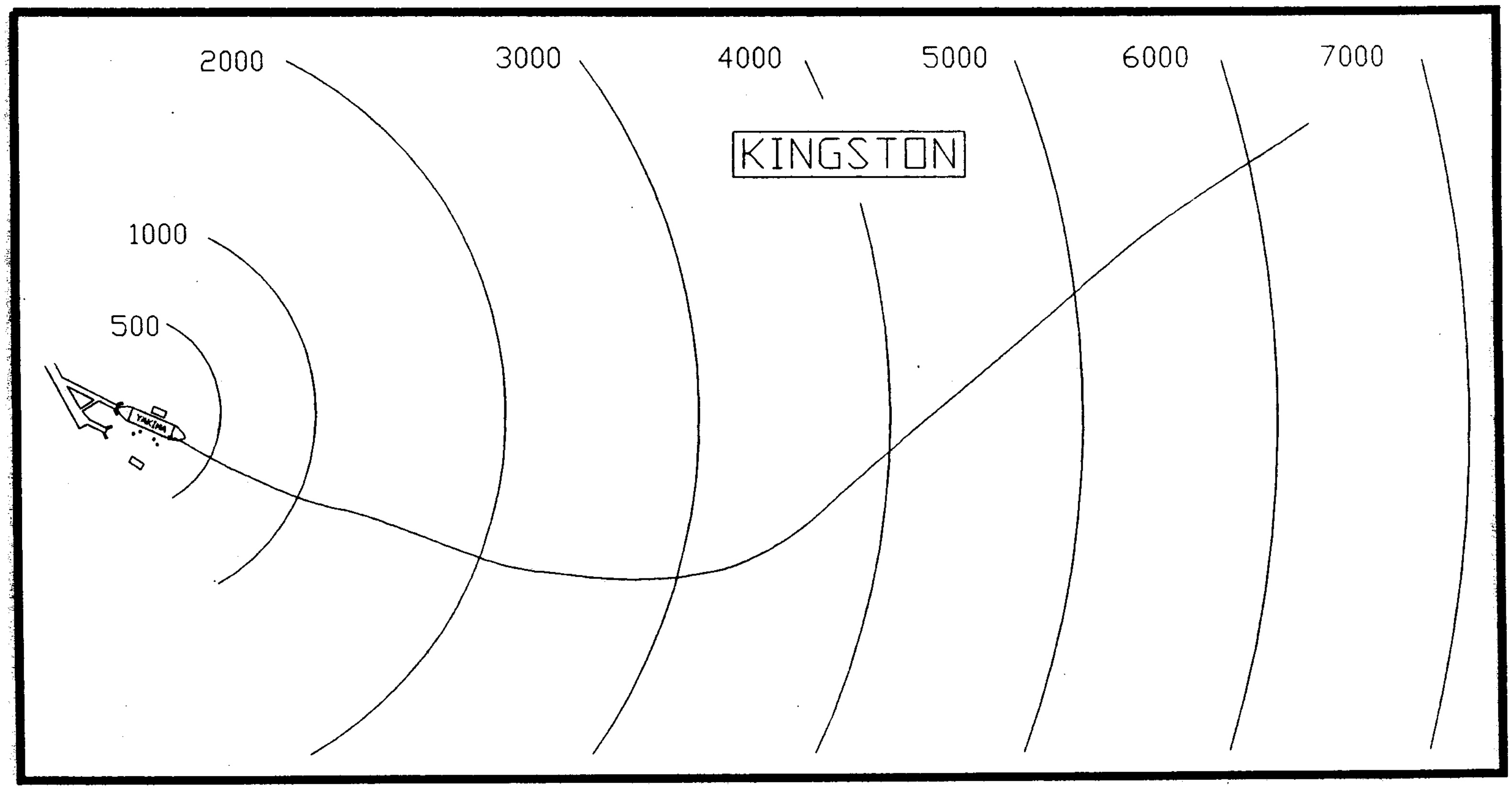

Figure E-46. Final Berthing Approach — 709KYY5

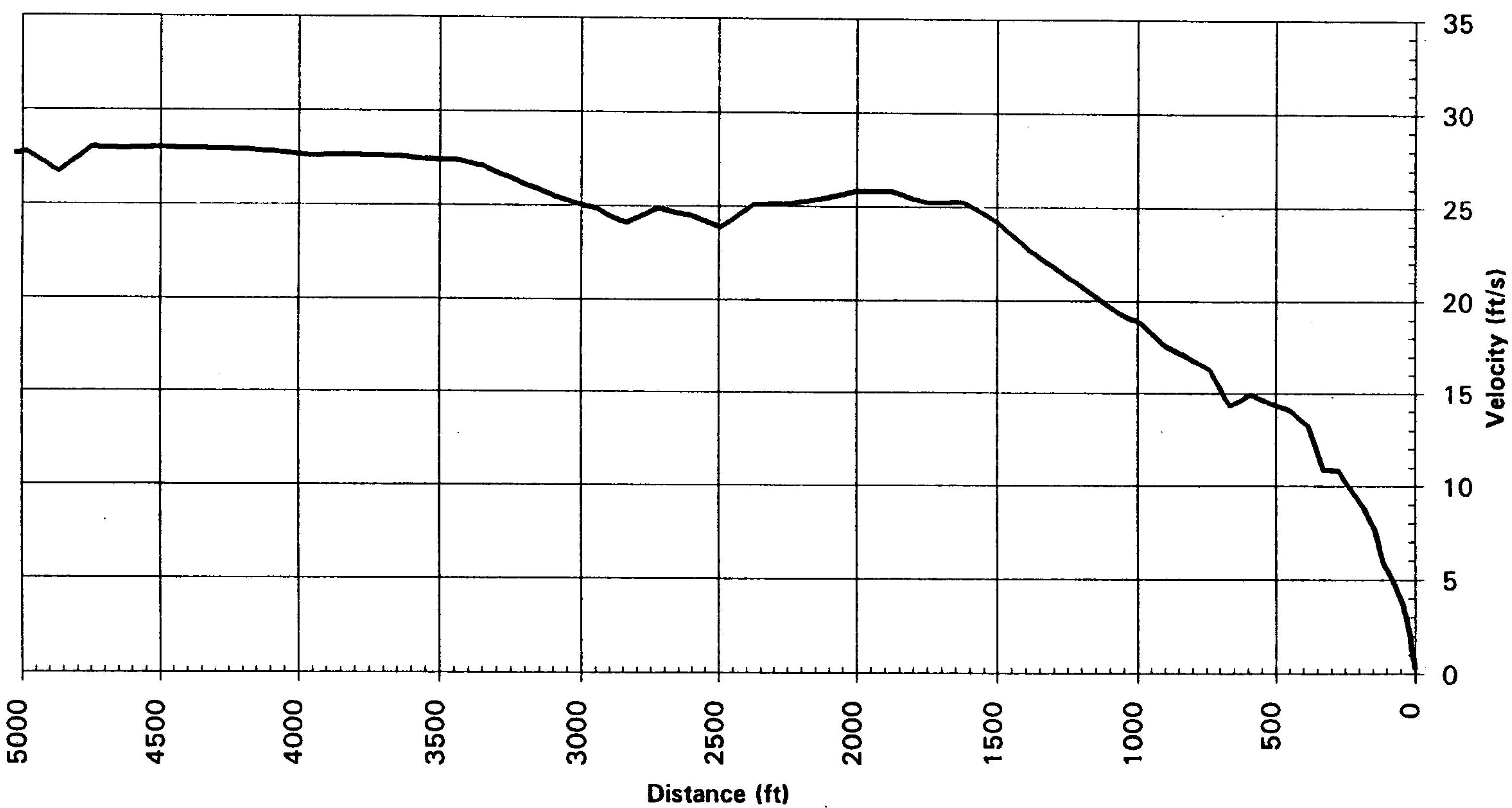

Figure E-47. Velocity vs. Distance from Kingston Landing Structure (5,000 ft.) — 709KYY5

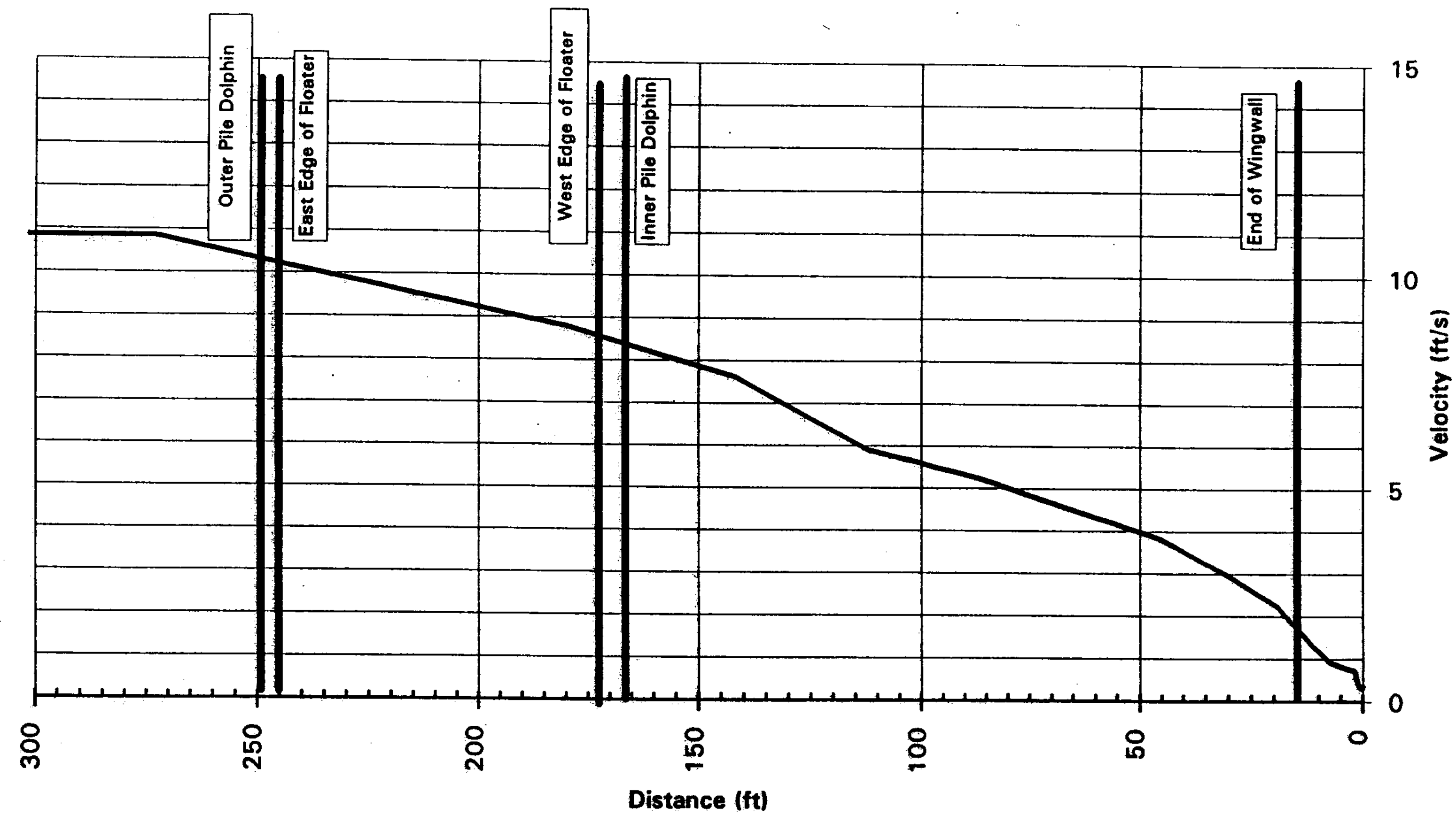

Figure E-48. Velocity vs. Distance from Kingston Landing Structure (300 ft.) — 709KYY5

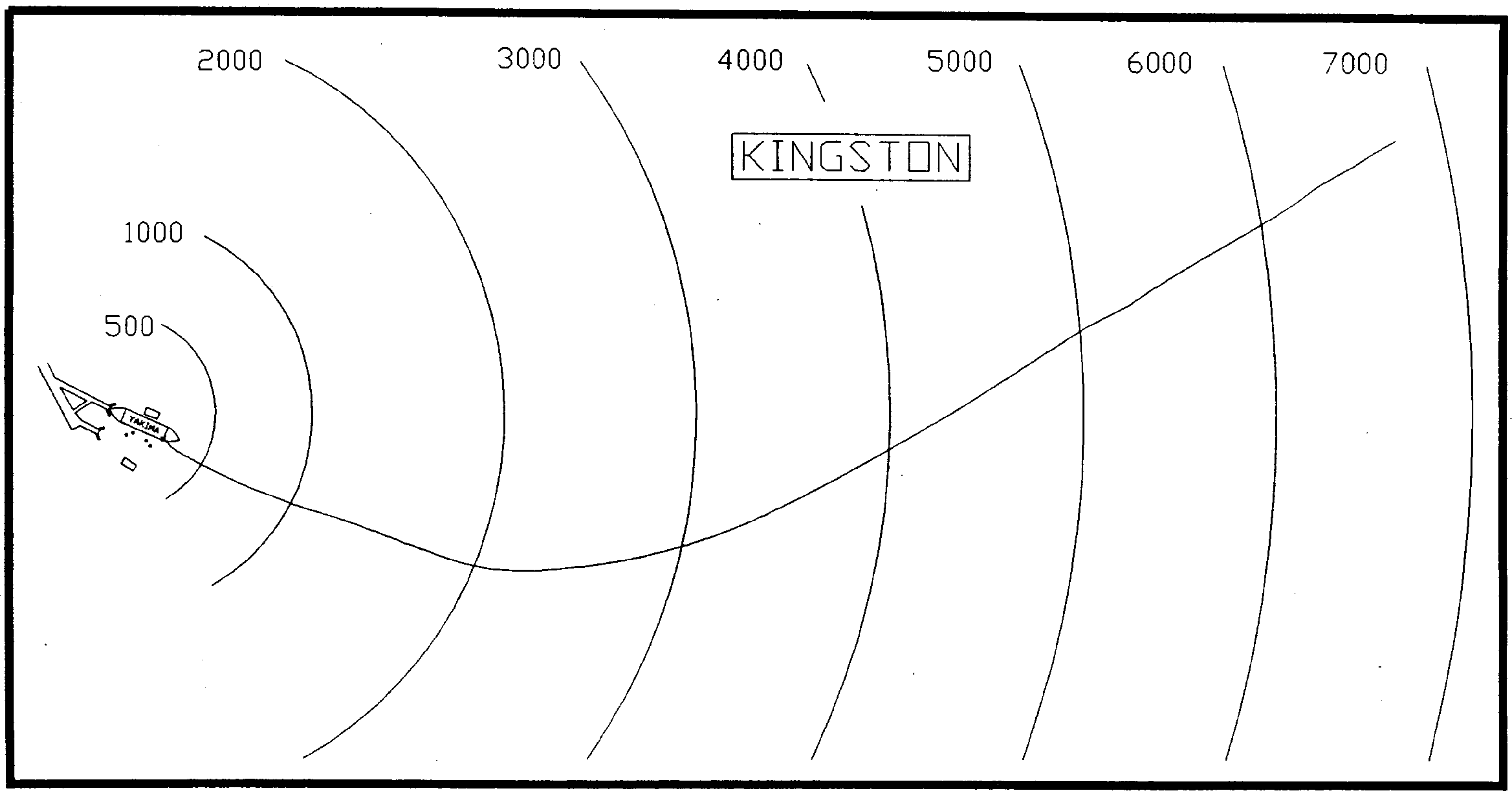

Figure E-49. Final Berthing Approach — 712KYY6

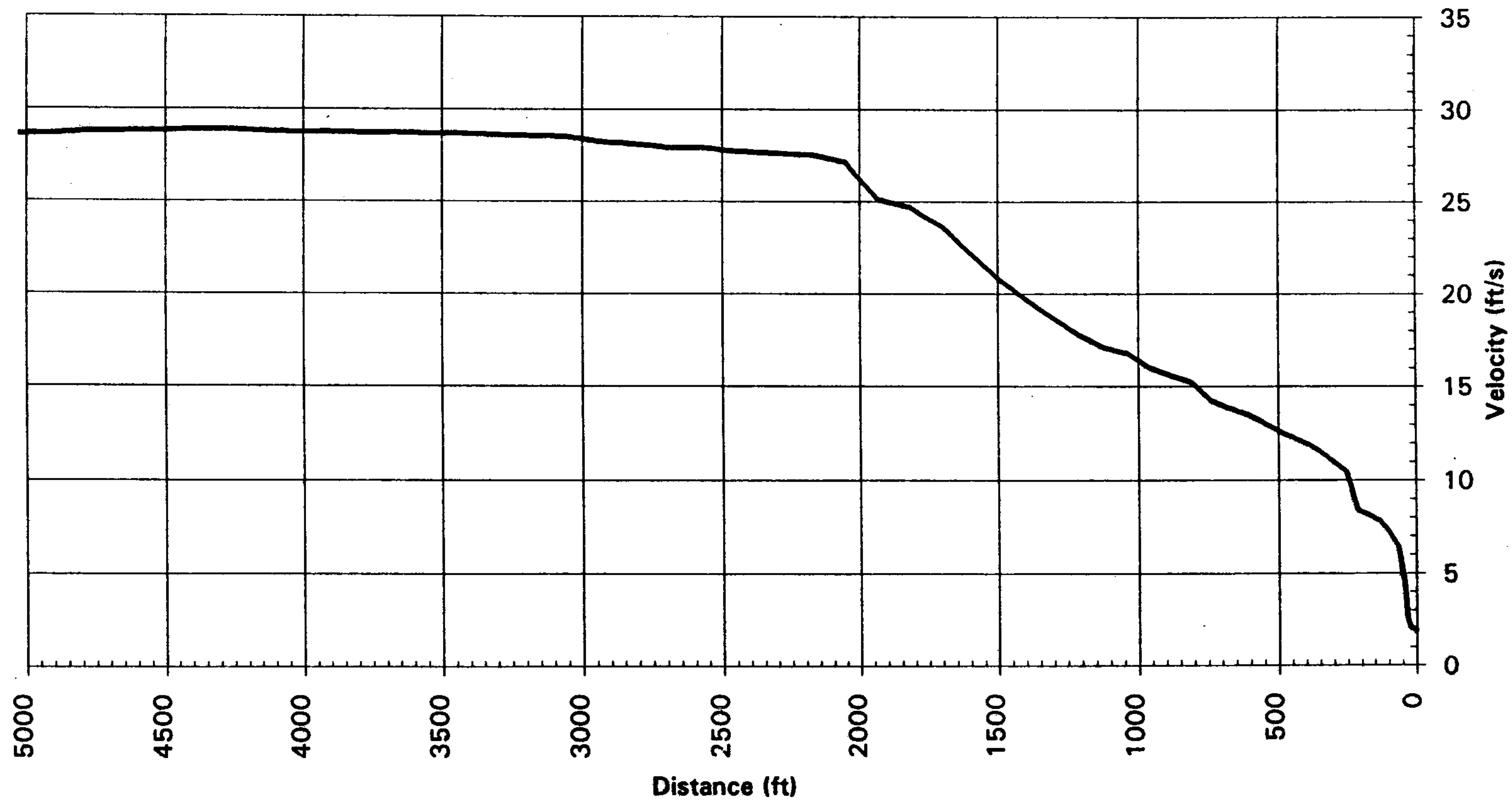

Figure E-50. Velocity vs. Distance from Kingston Landing Structure (5,000 ft.) — 712KYY6

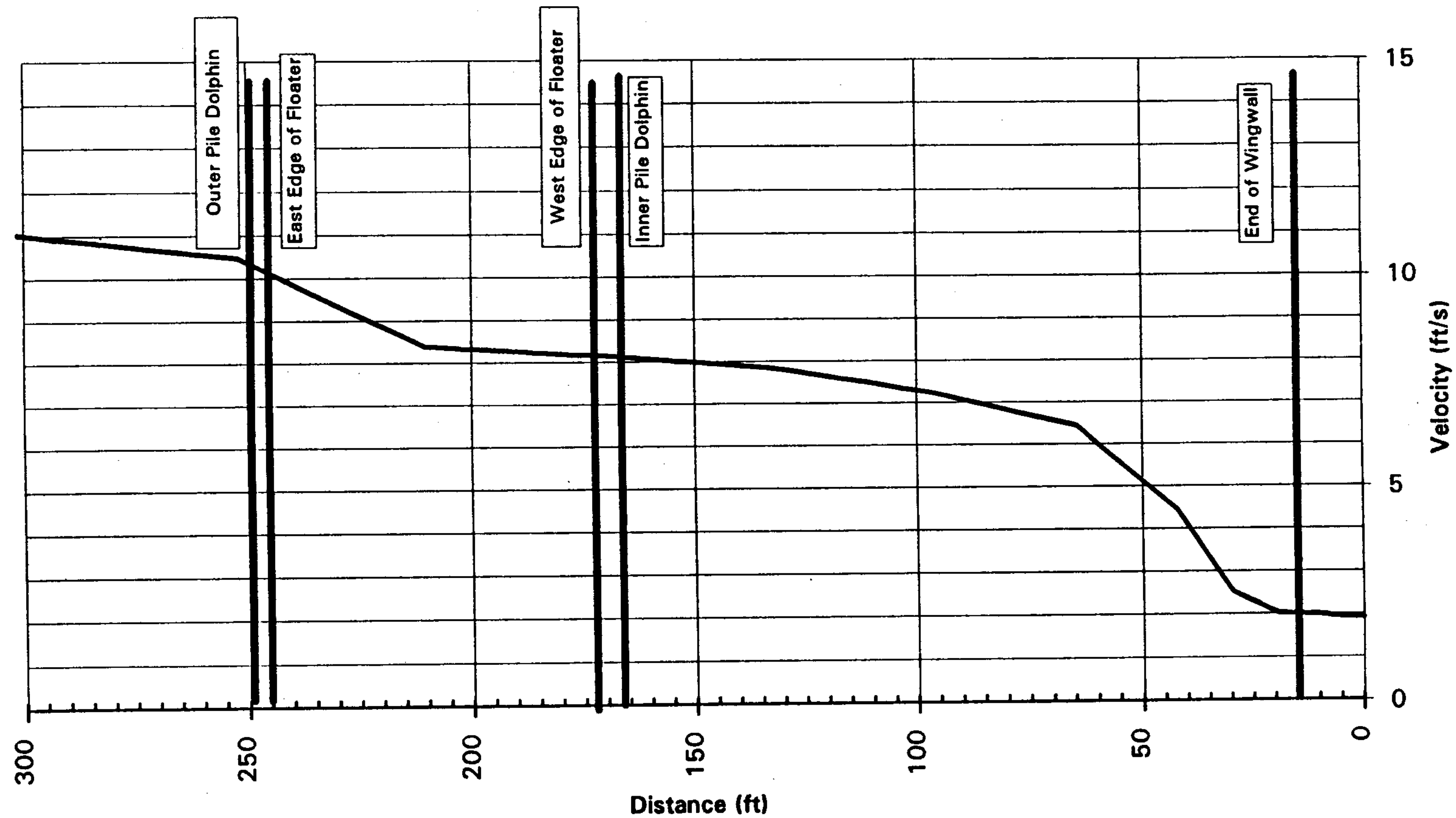

Figure E-51. Velocity vs. Distance from Kingston Landing Structure (300 ft.) — 712KYY6

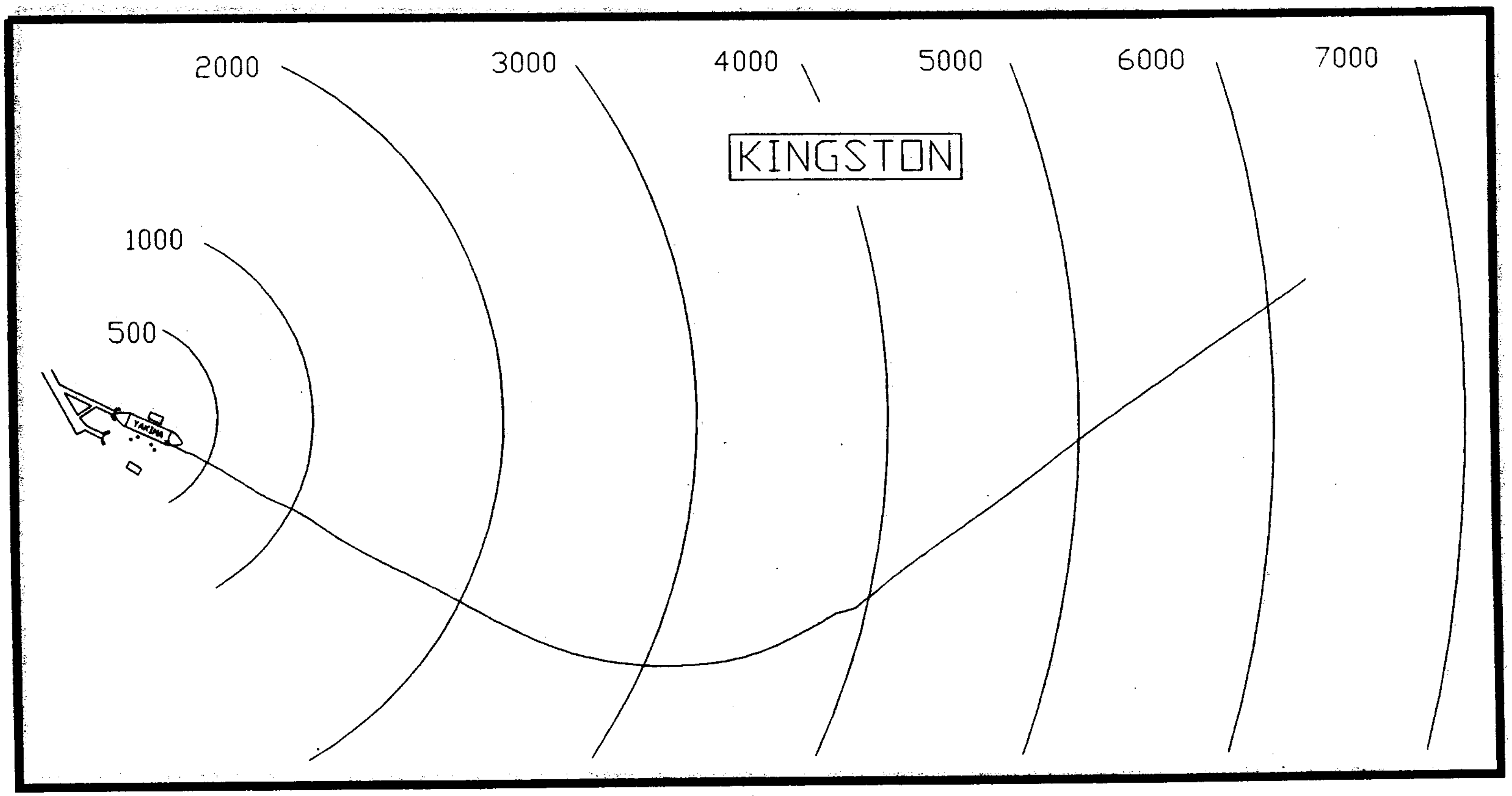

Figure E-52. Final Berthing Approach — 717KZZ1

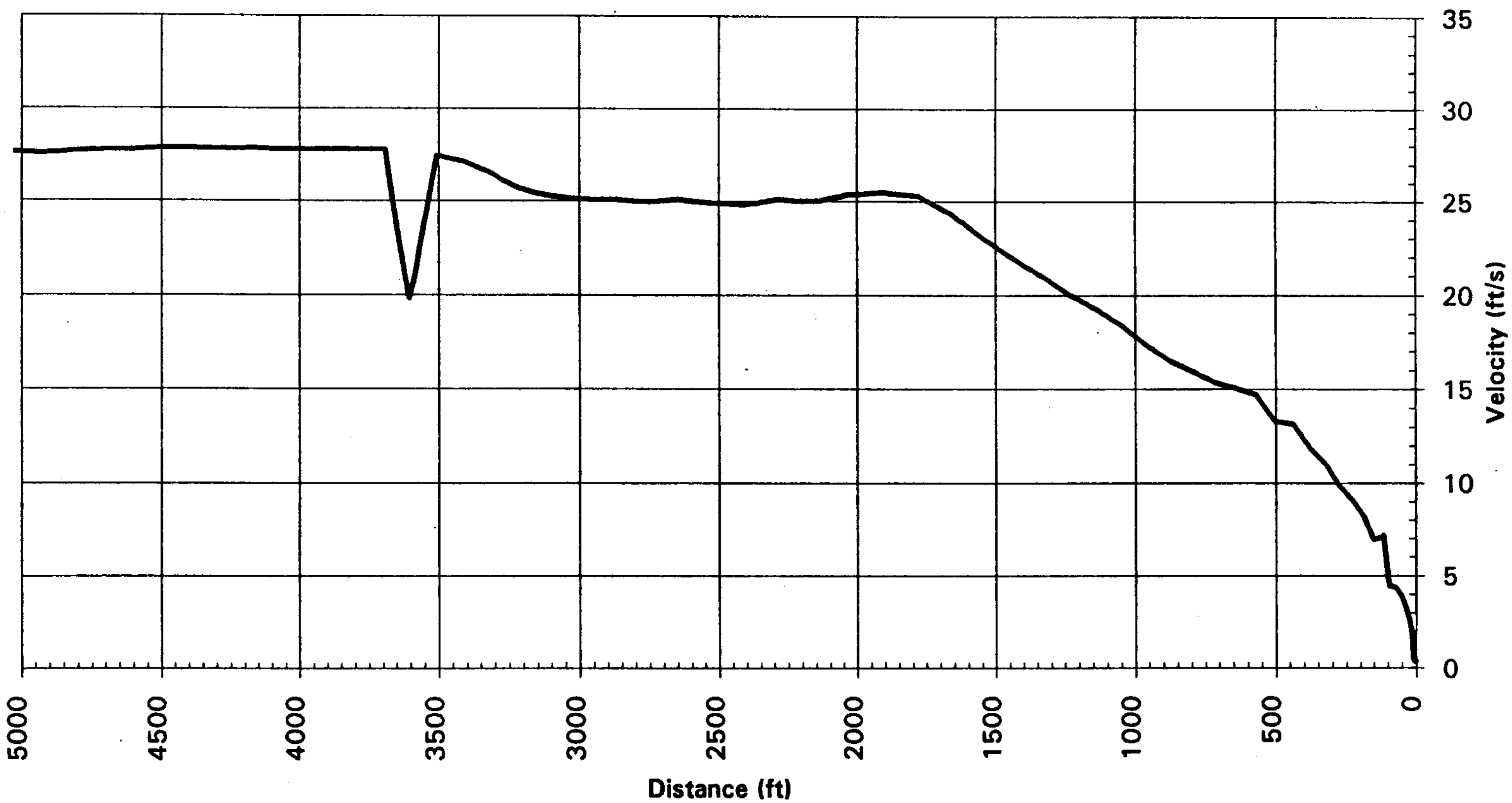

Figure E-53. Velocity vs. Distance from Kingston Landing Structure (5,000 ft.) — 717KZZ1

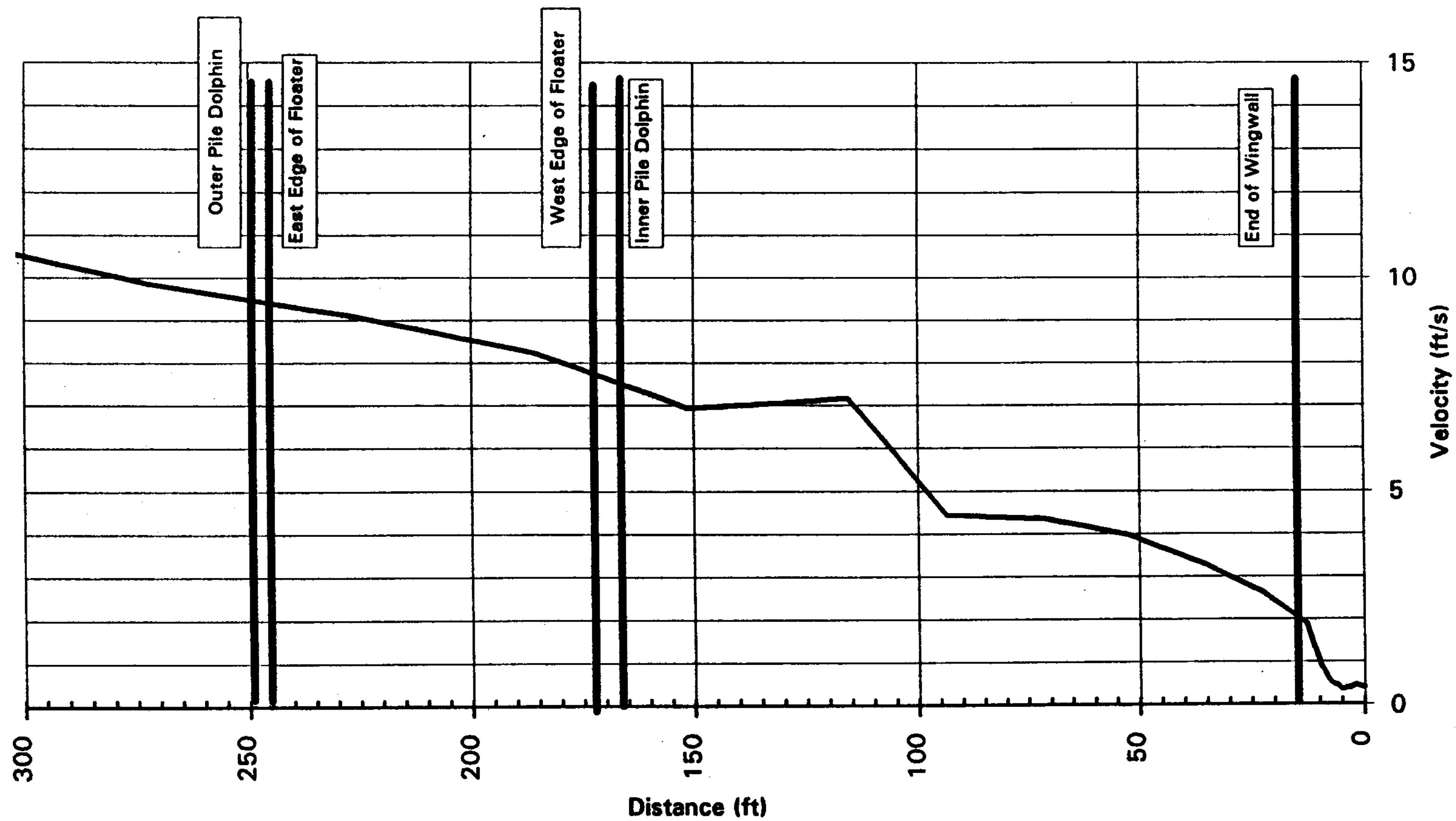

Figure E-54. Velocity vs. Distance from Kingston Landing Structure (300 ft.) — 717KZZ1

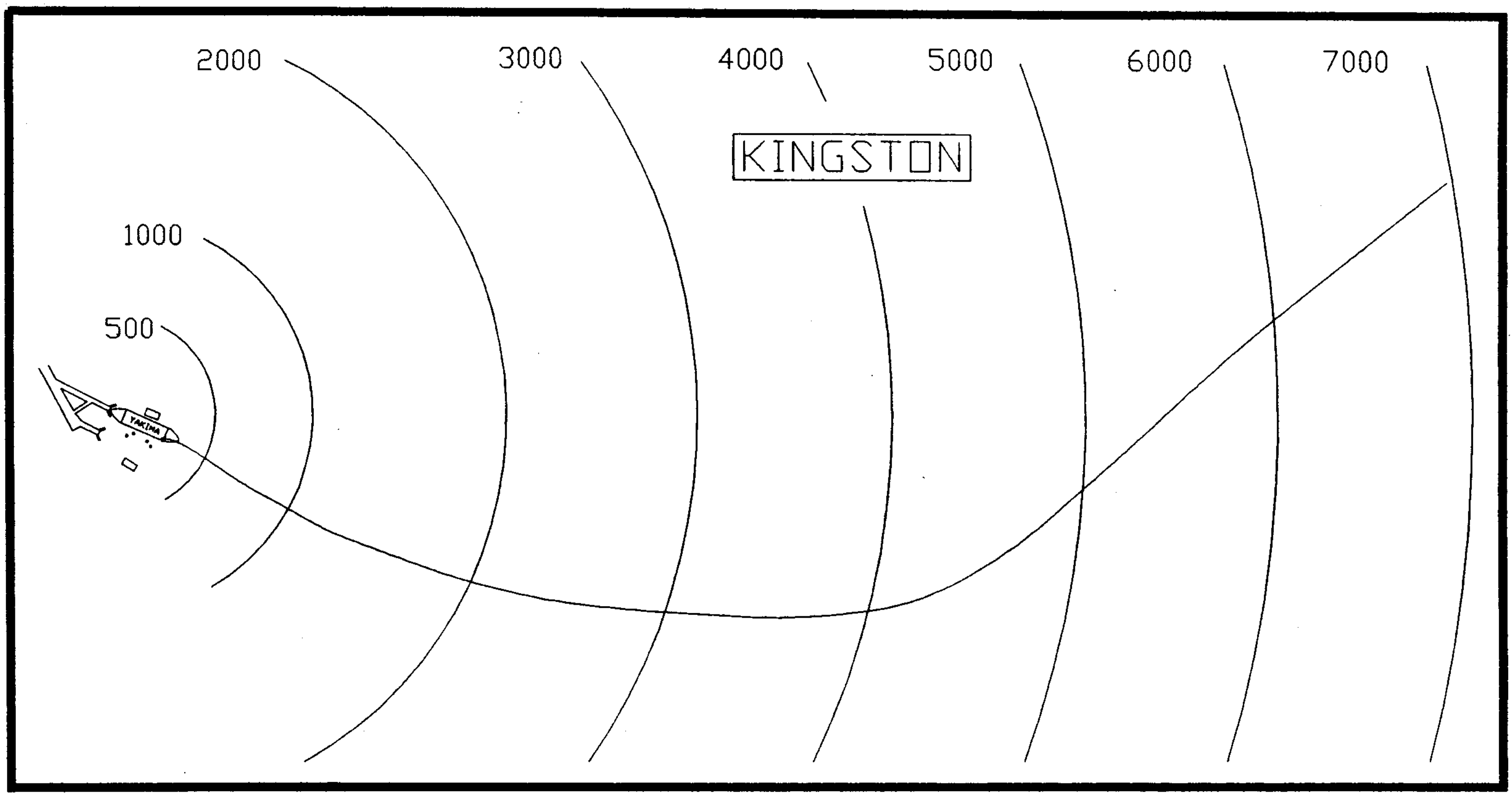

Figure E-55. Final Berthing Approach — 718KXX2

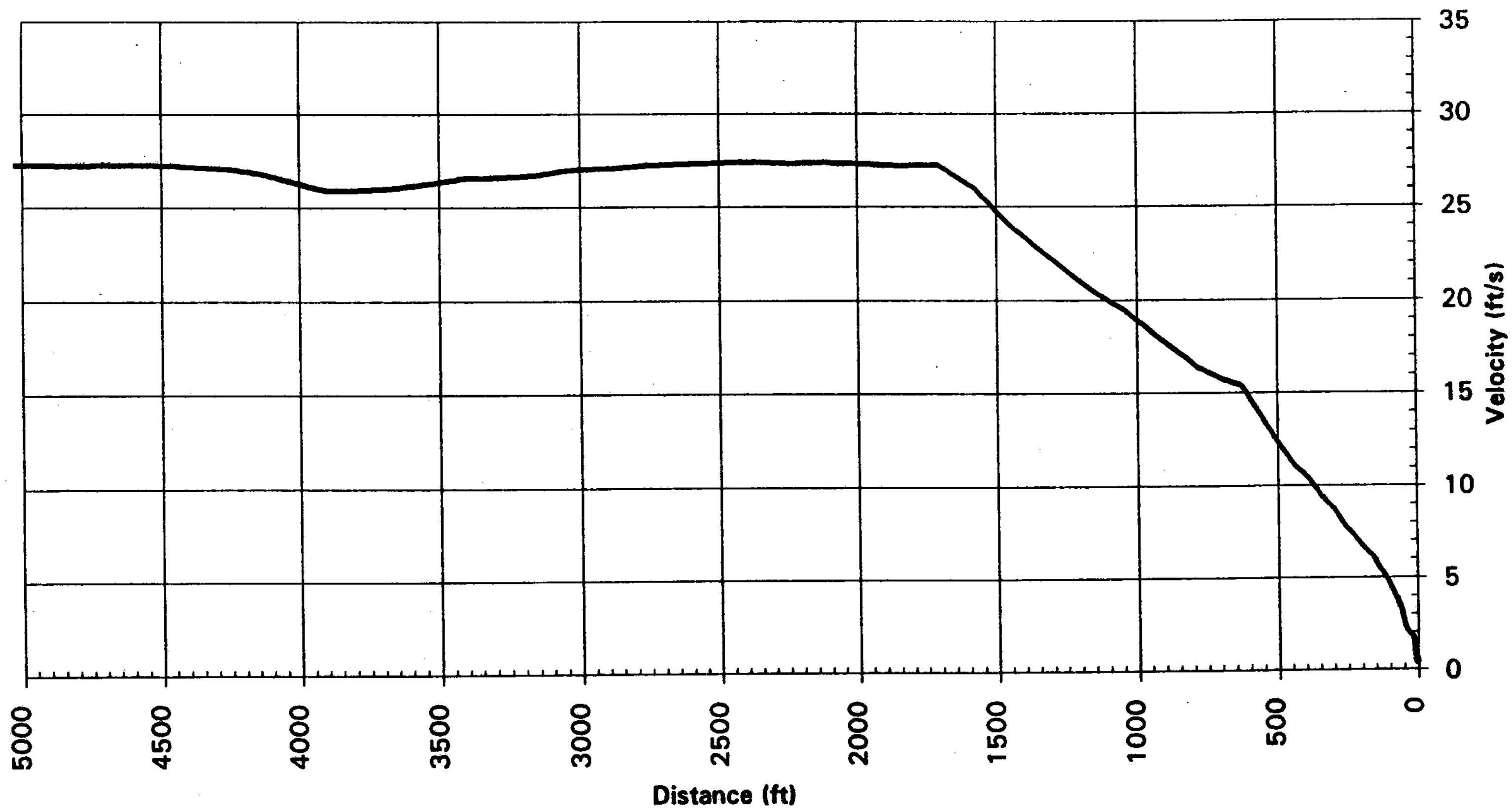

Figure E-56. Velocity vs. Distance from Kingston Landing Structure (5,000 ft.) — 718KXX2

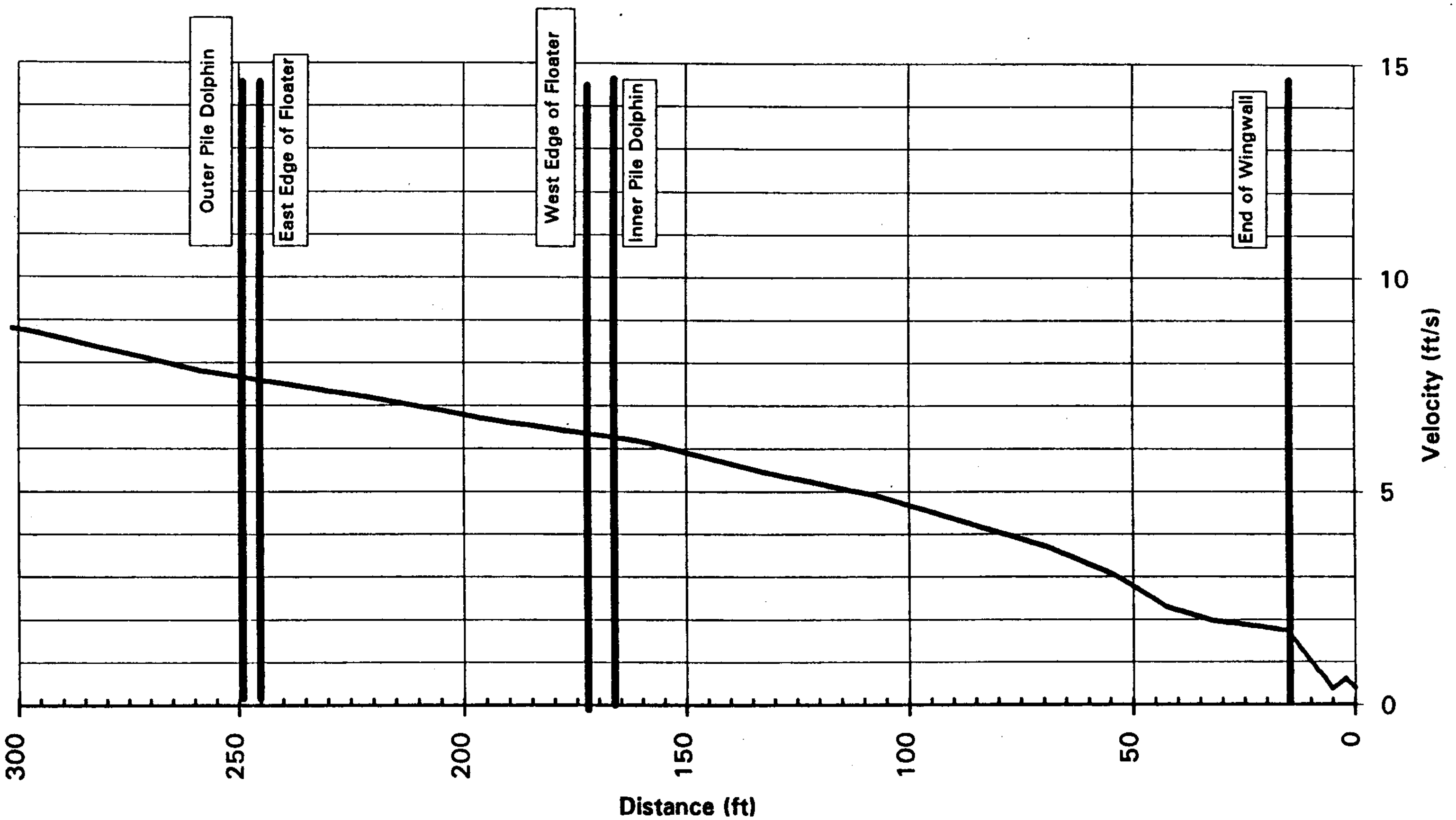

Figure E-57. Velocity vs. Distance from Kingston Landing Structure (300 ft.) — 718KXX2

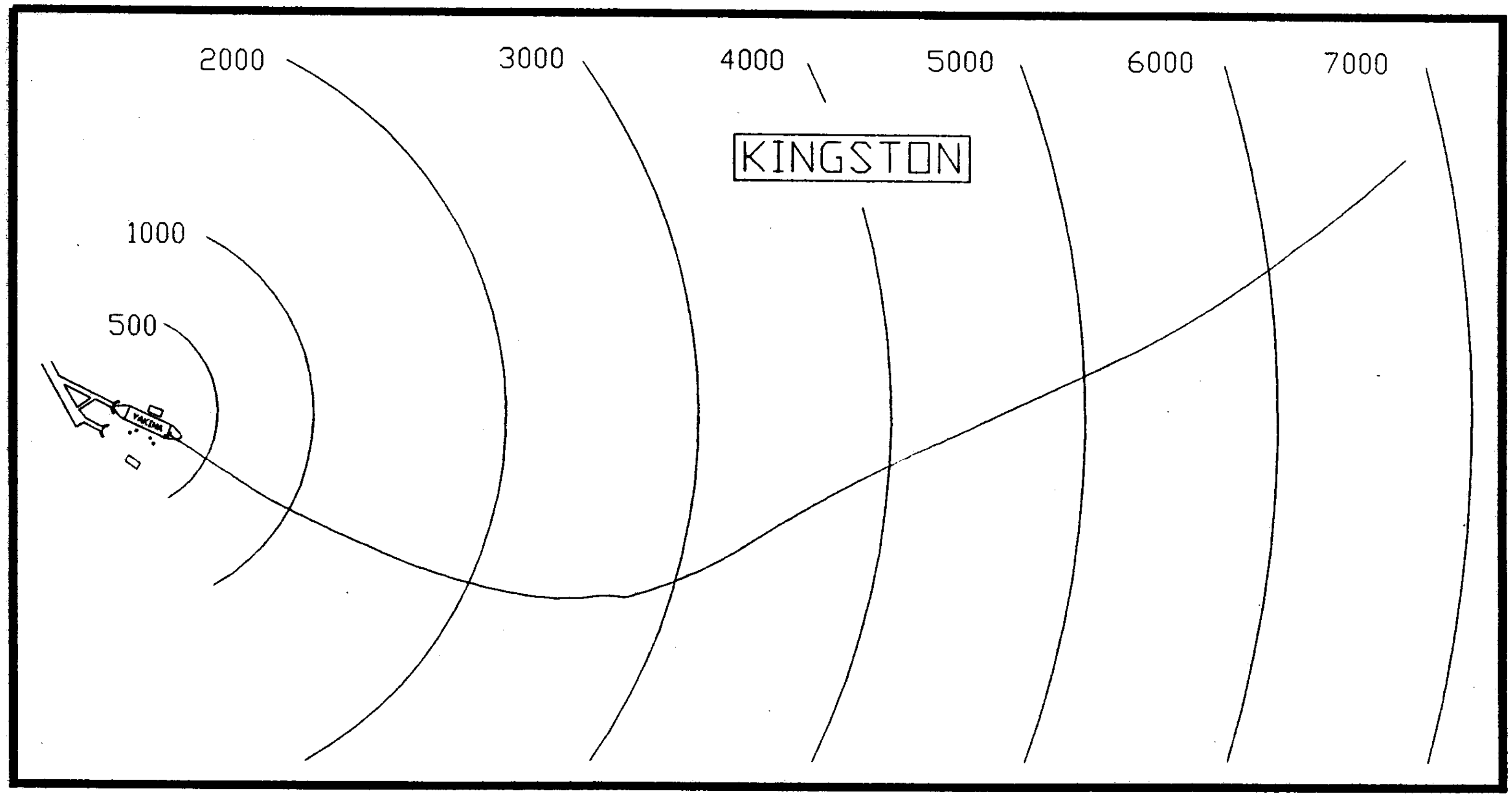

Figure E-58. Final Berthing Approach — 720KXX3

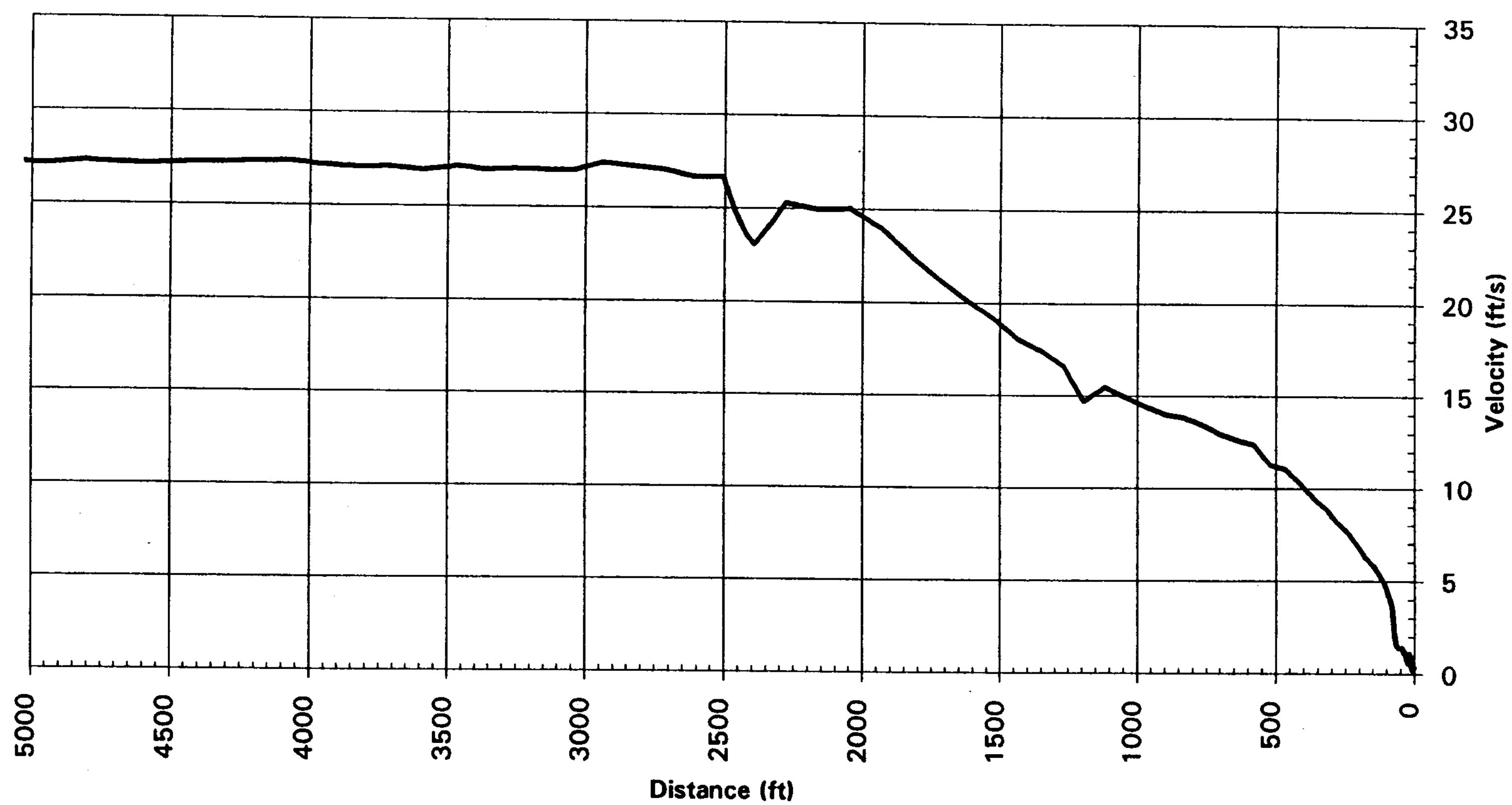

Figure E-59. Velocity vs. Distance from Kingston Landing Structure (5,000 ft.) — 720KXX3

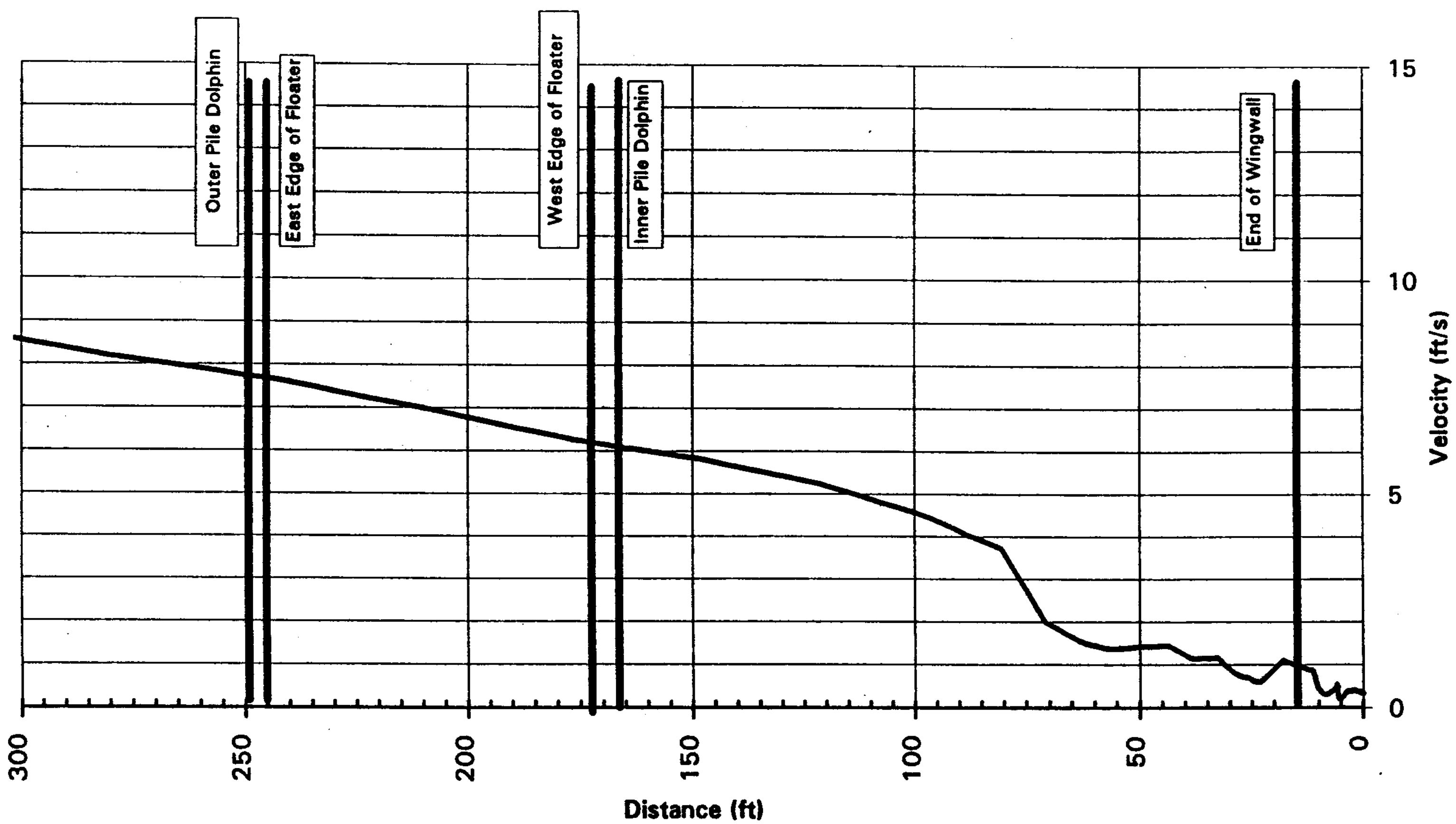

Figure E-60. Velocity vs. Distance from Kingston Landing Structure (300 ft.) — 720KXX3

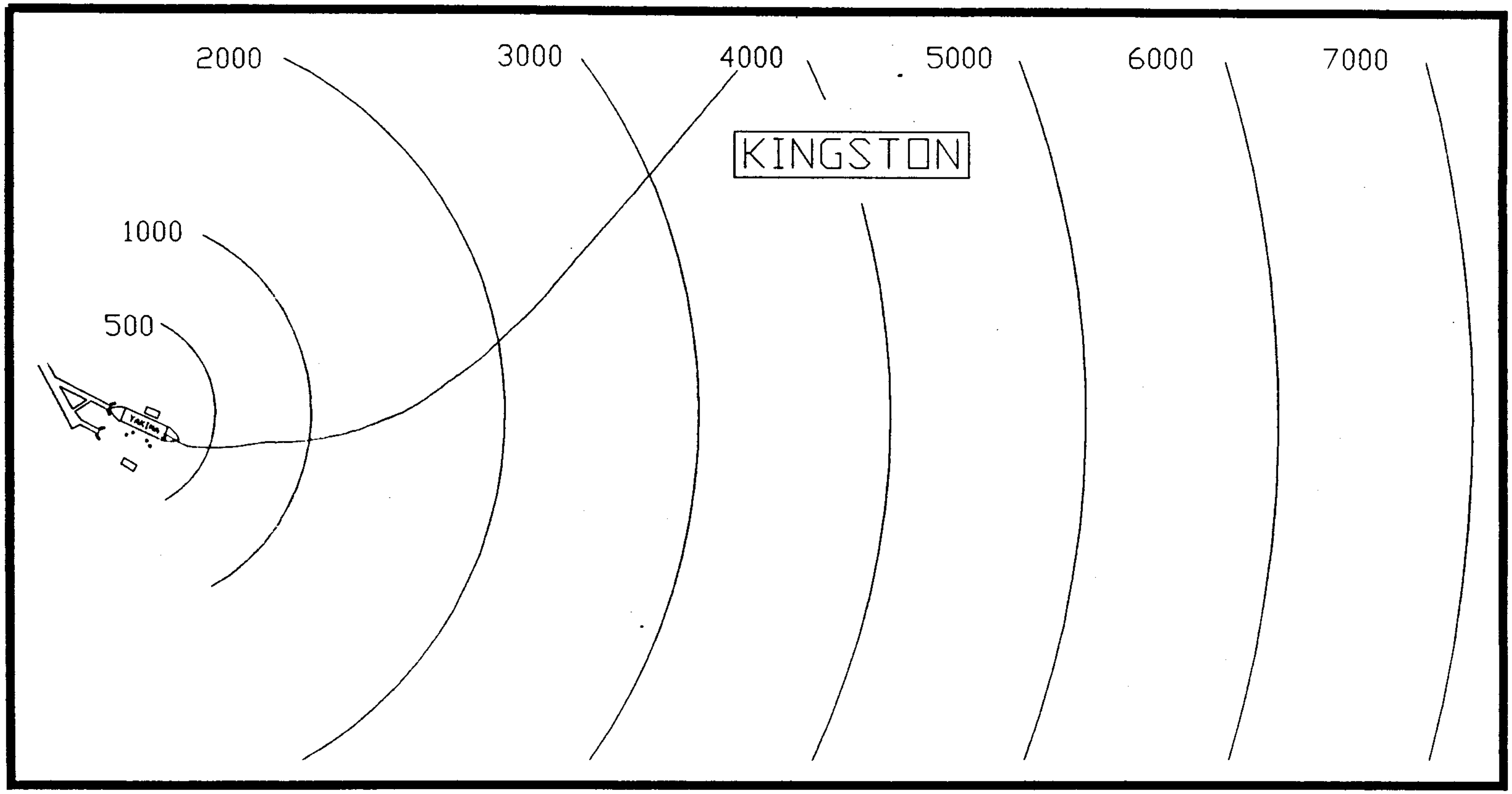

Figure E-61. Final Berthing Approach — 720KYY4

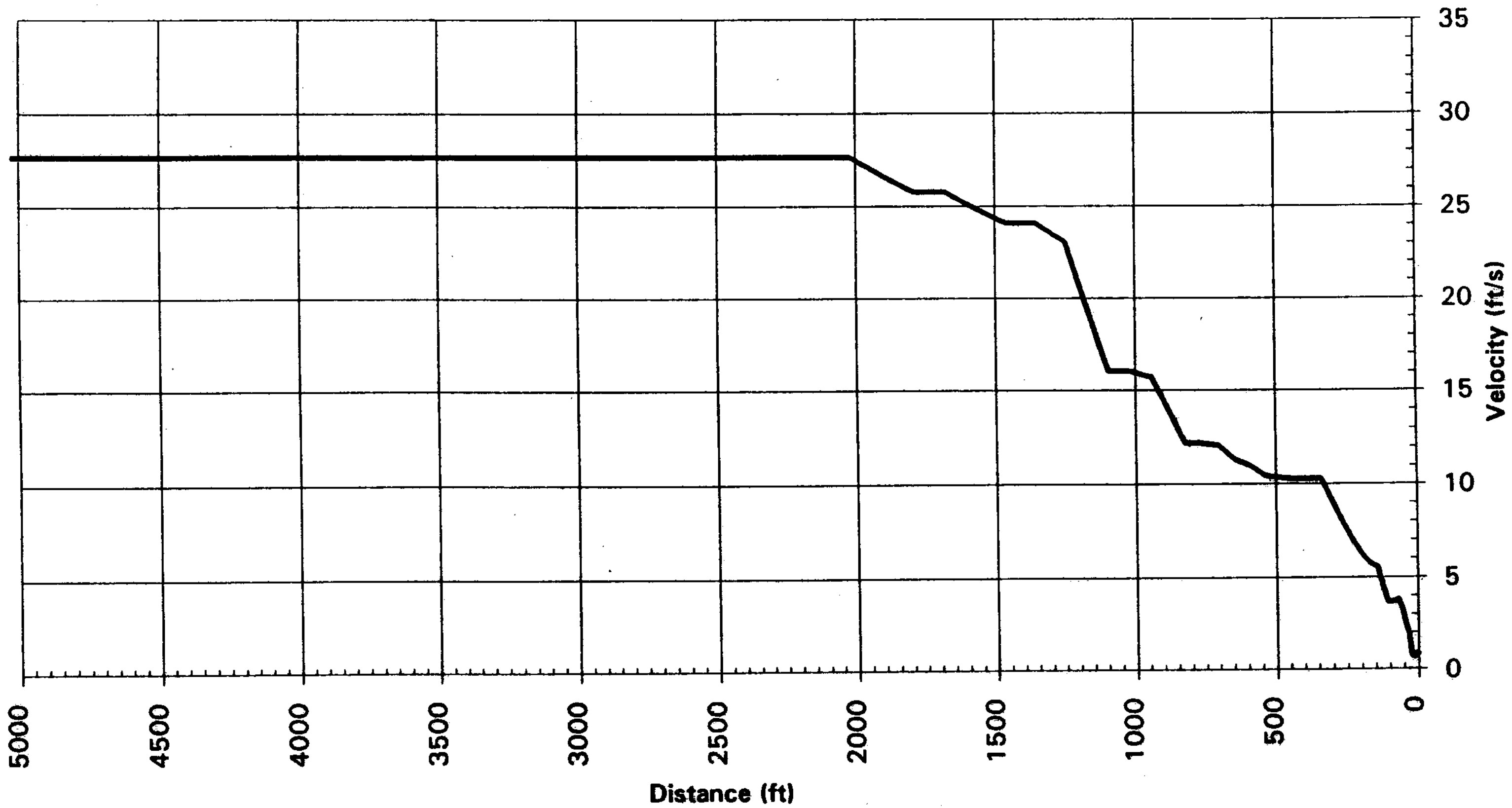

Figure E-62. Velocity vs. Distance from Kingston Landing Structure (5,000 ft.) — 720KYY4

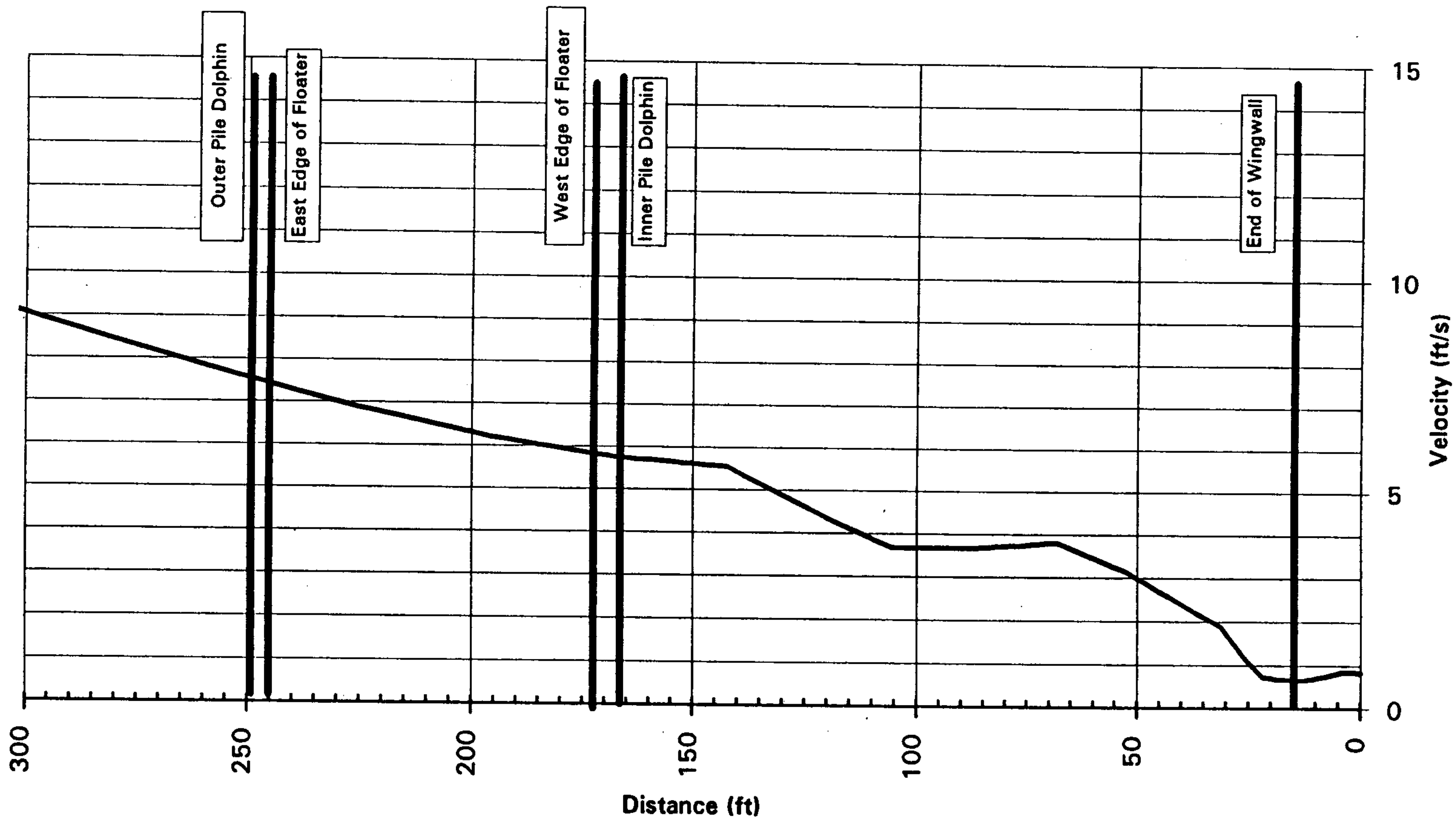

Figure E-63. Velocity vs. Distance from Kingston Landing Structure (300 ft.) — 720KYY4

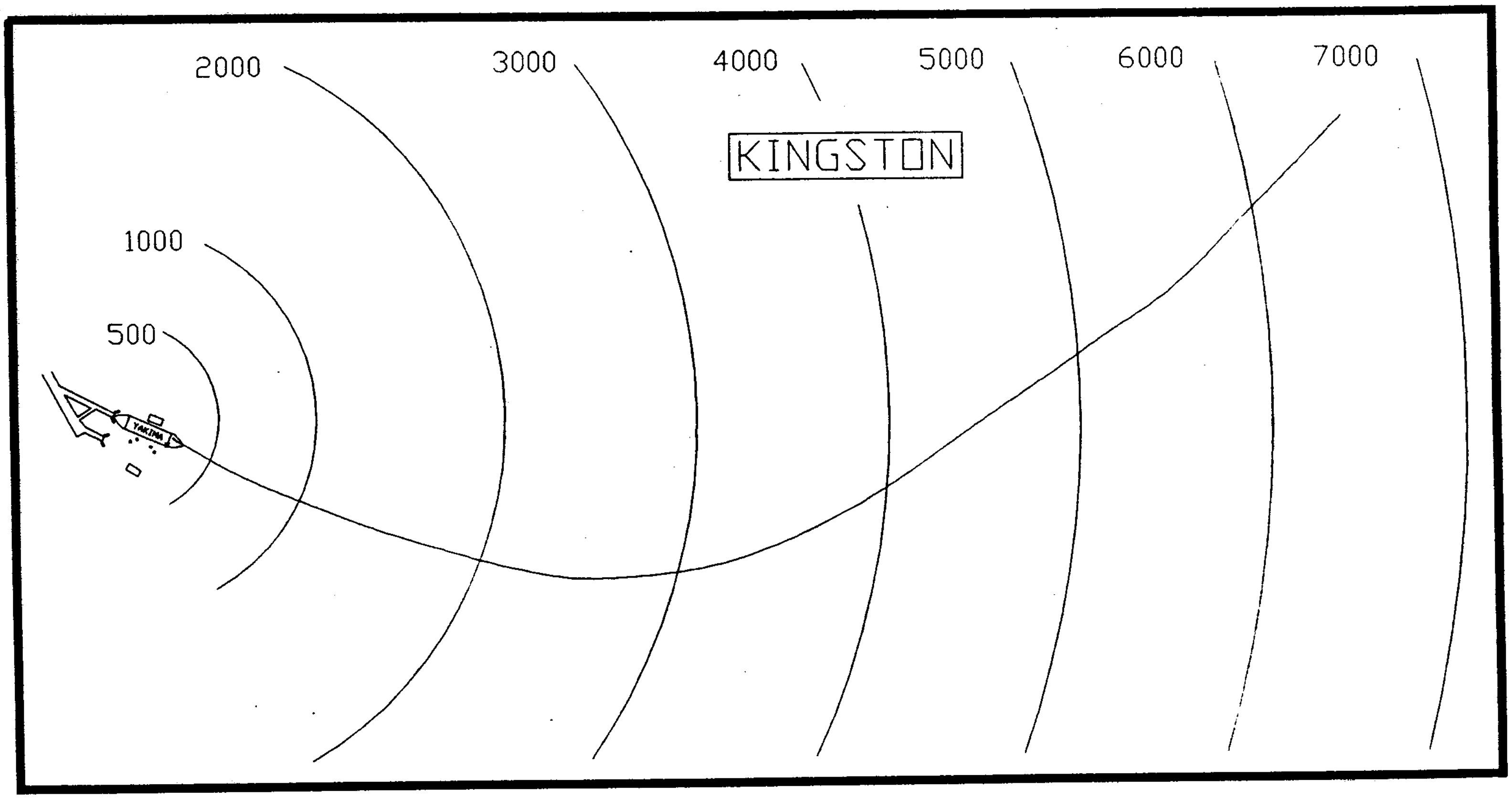

Figure E-64. Final Berthing Approach — 723KZZ4

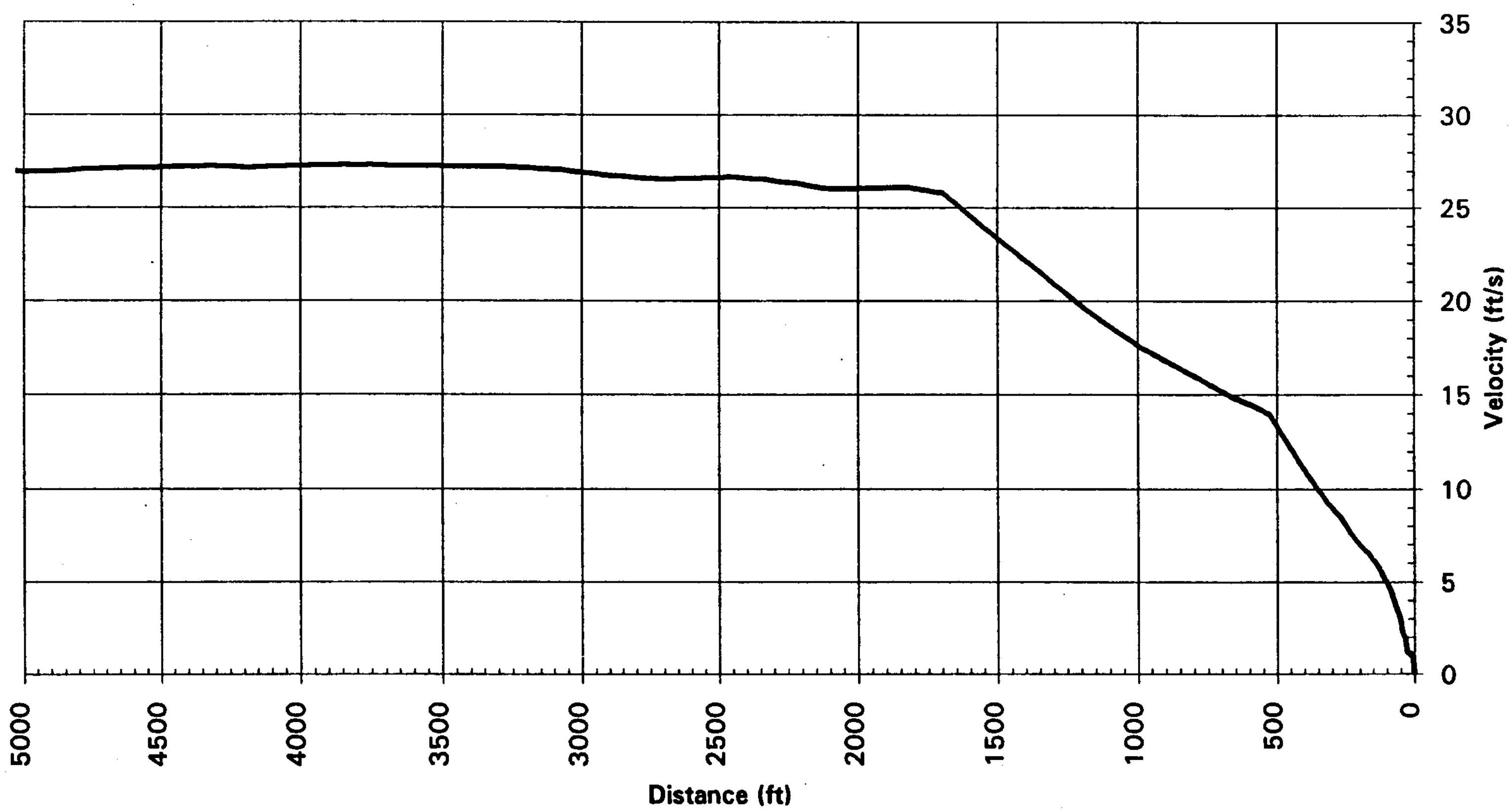

Figure E-65. Velocity vs. Distance from Kingston Landing Structure (5,000 ft.) — 723KZZ4

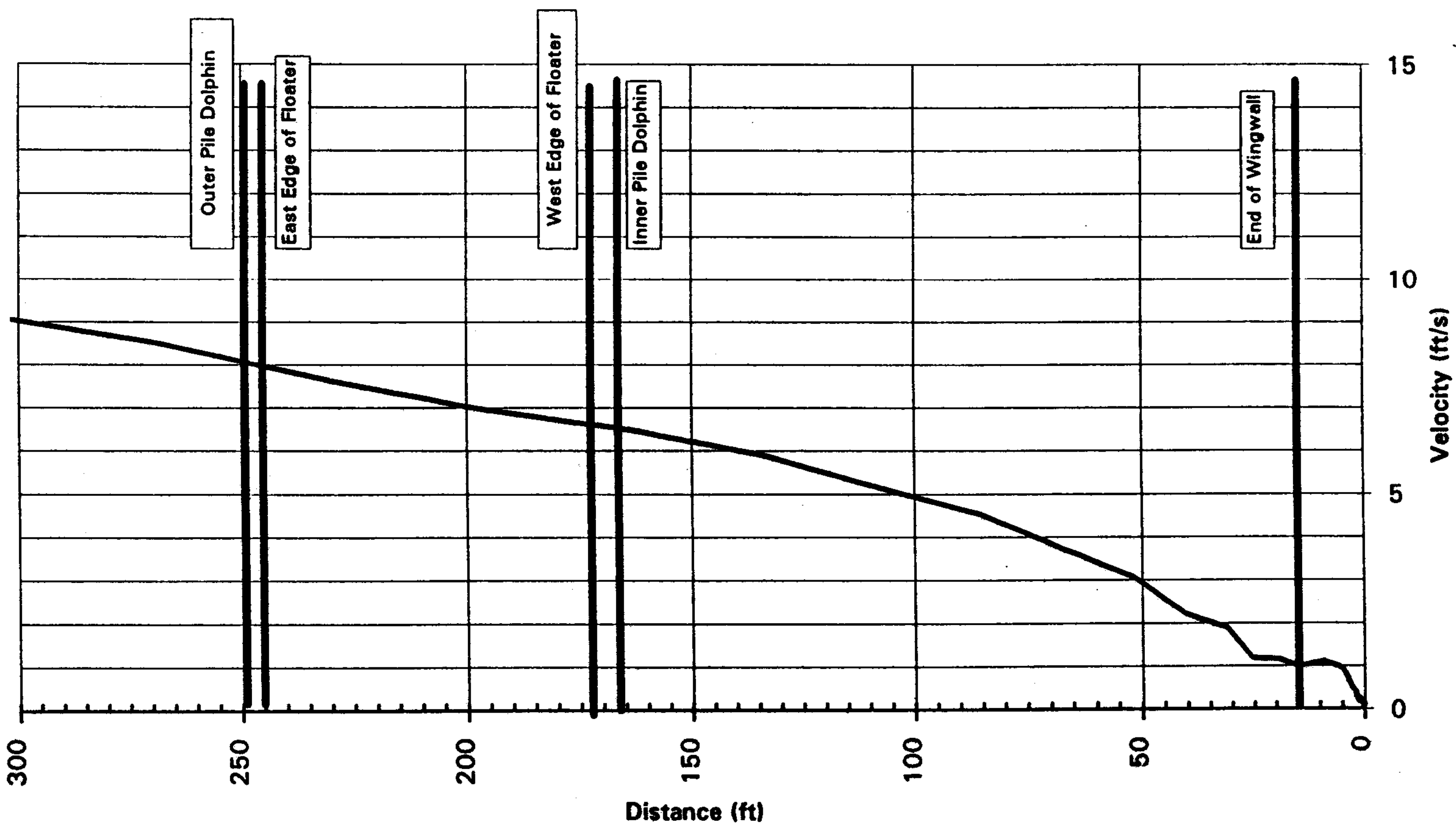

Figure E-66. Velocity vs. Distance from Kingston Landing Structure (300 ft.) — 723KZZA

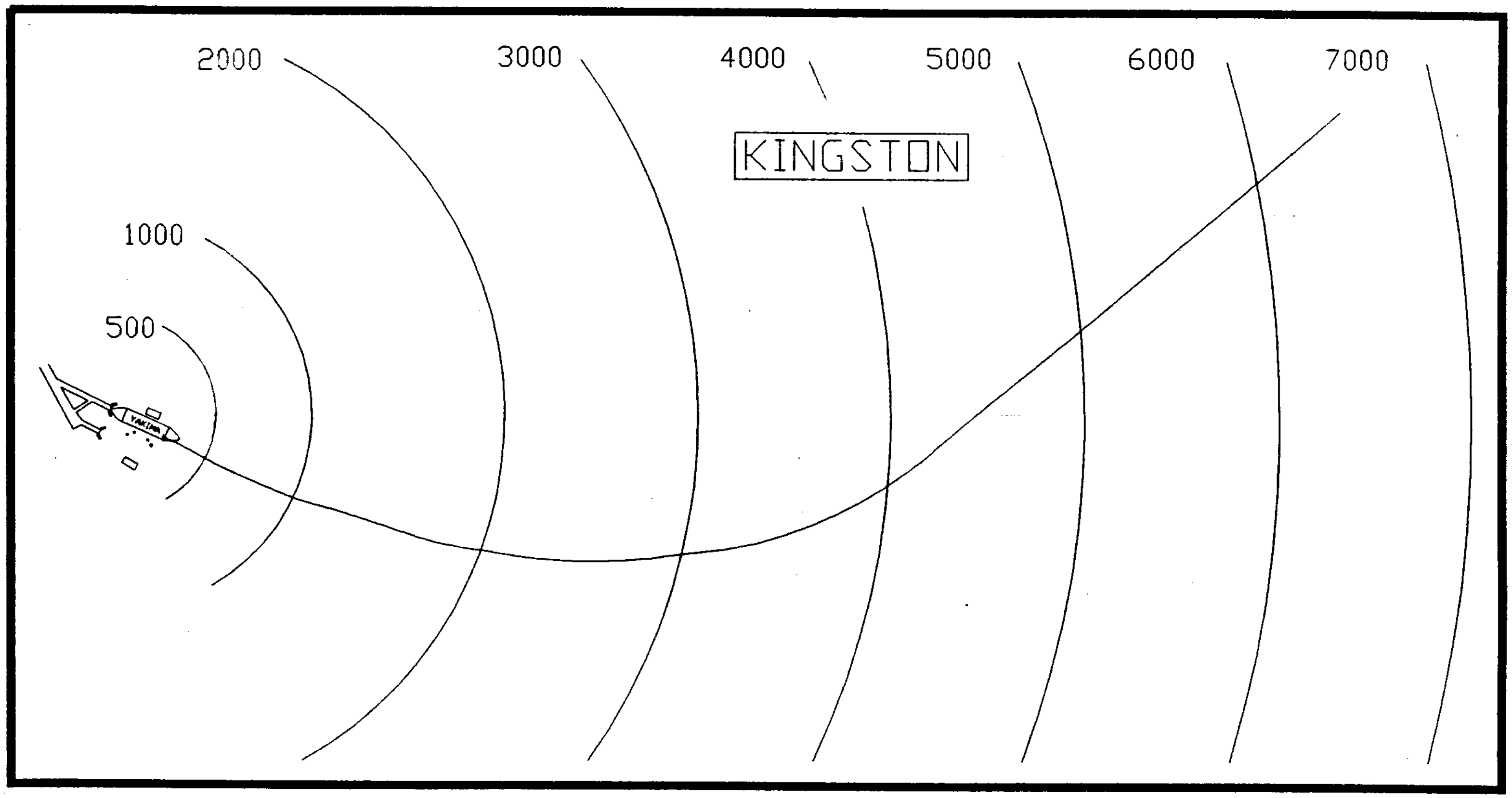

Figure E-67. Final Berthing Approach — 723KZZ6

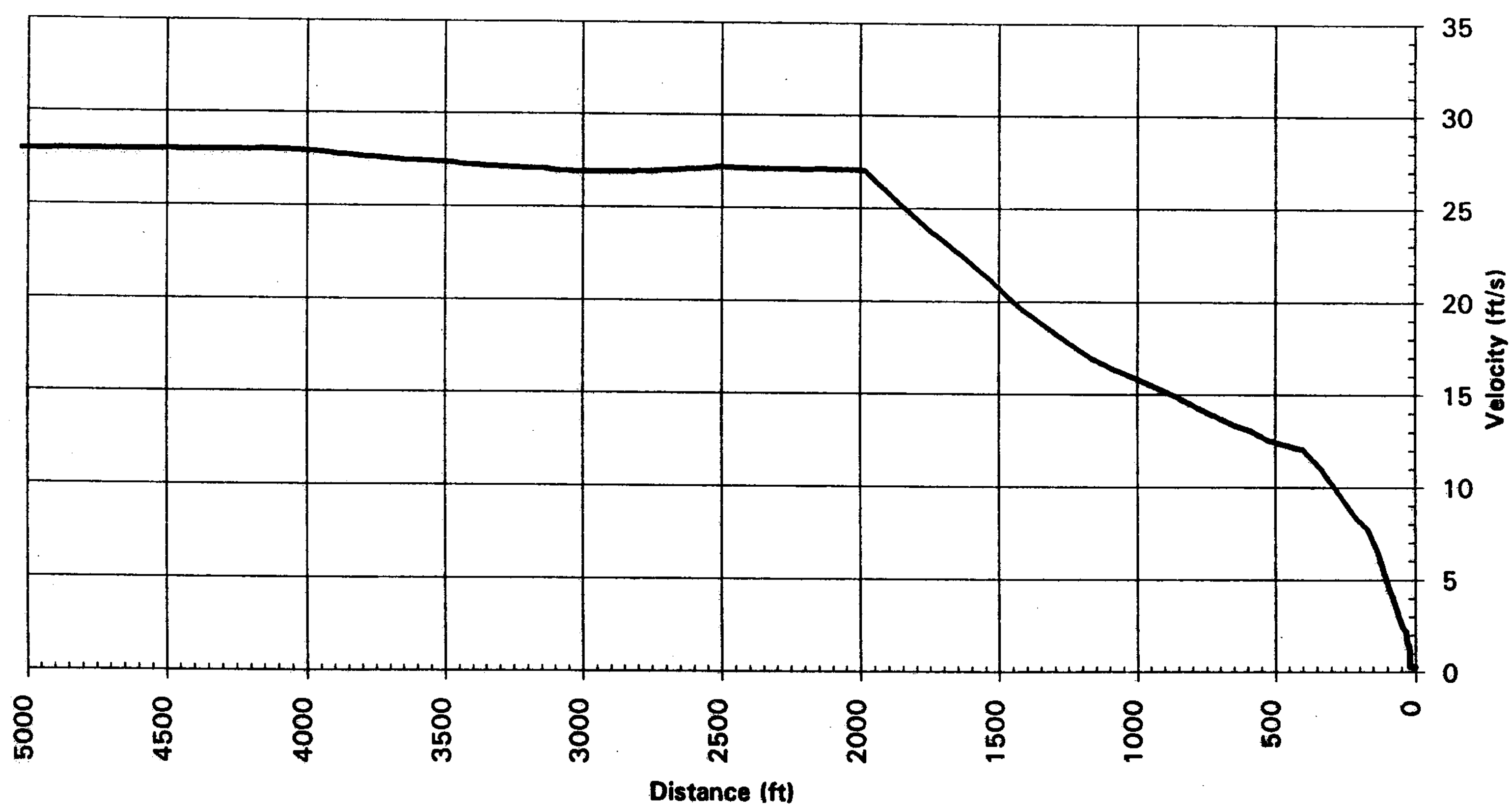

Figure E-68. Velocity vs. Distance from Kingston Landing Structure (5,000 ft.) — 723KZZ6

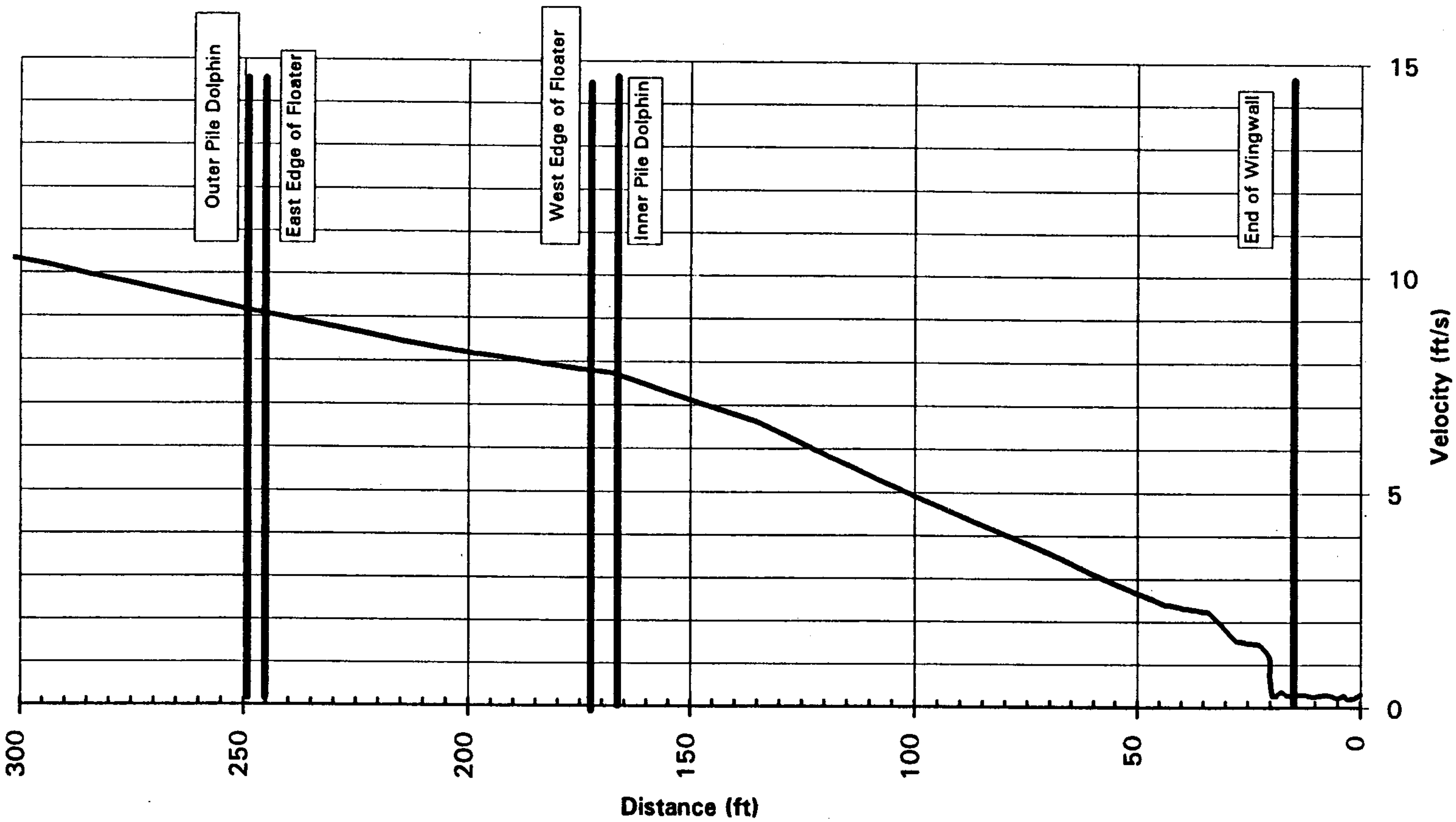

Figure E-69. Velocity vs. Distance from Kingston Landing Structure (300 ft.) — 723KZZ6

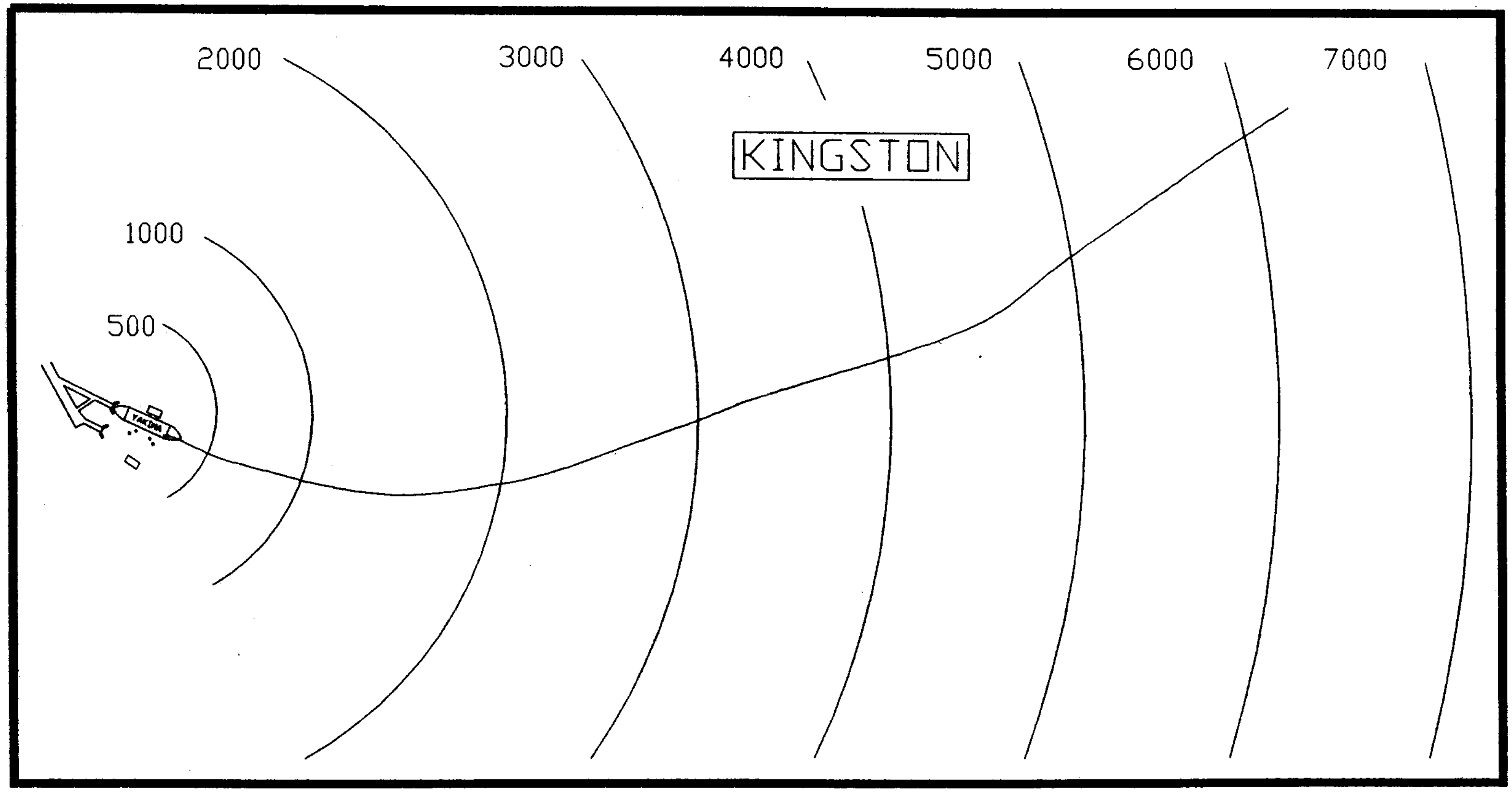

Figure E-70. Final Berthing Approach — 723KYY3

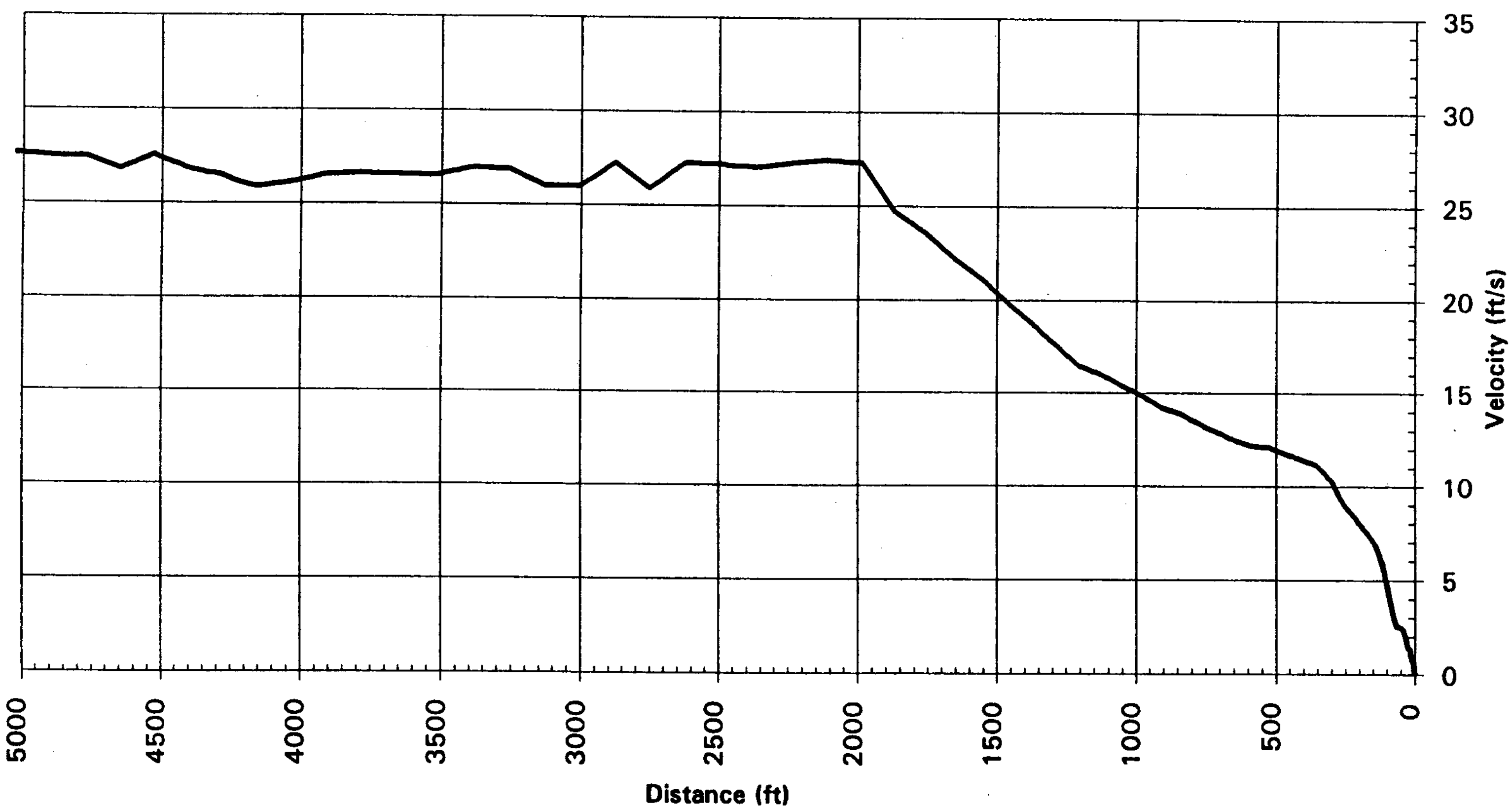

Figure E-71. Velocity vs. Distance from Kingston Landing Structure (5,000 ft.) — 723KYY3

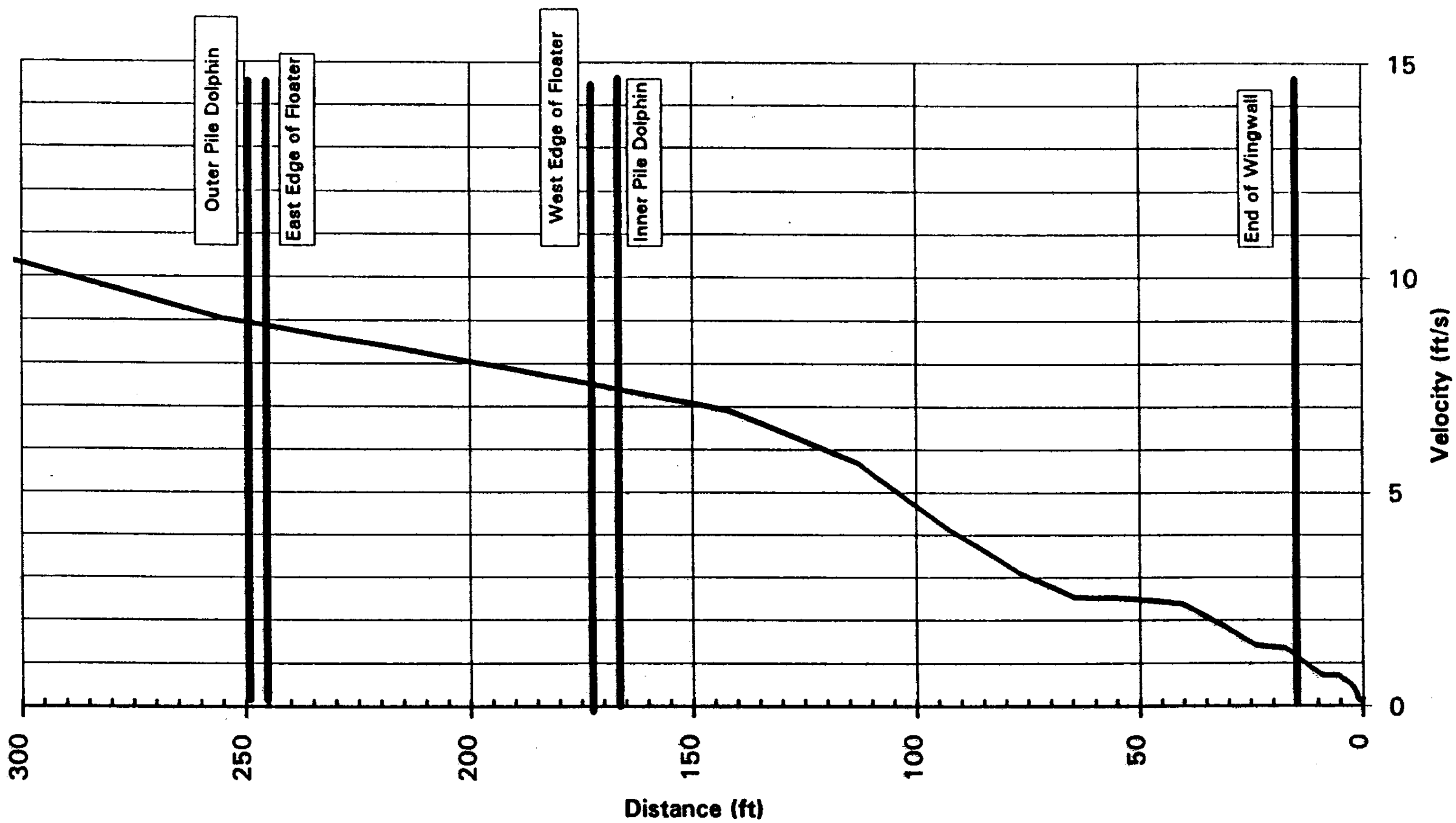

Figure E-72. Velocity vs. Distance from Kingston Landing Structure (300 ft.) — 723KYY3

APPENDIX G

THROTTLE SETTING VS. TIME FROM LANDING STRUCTURE PLOTS

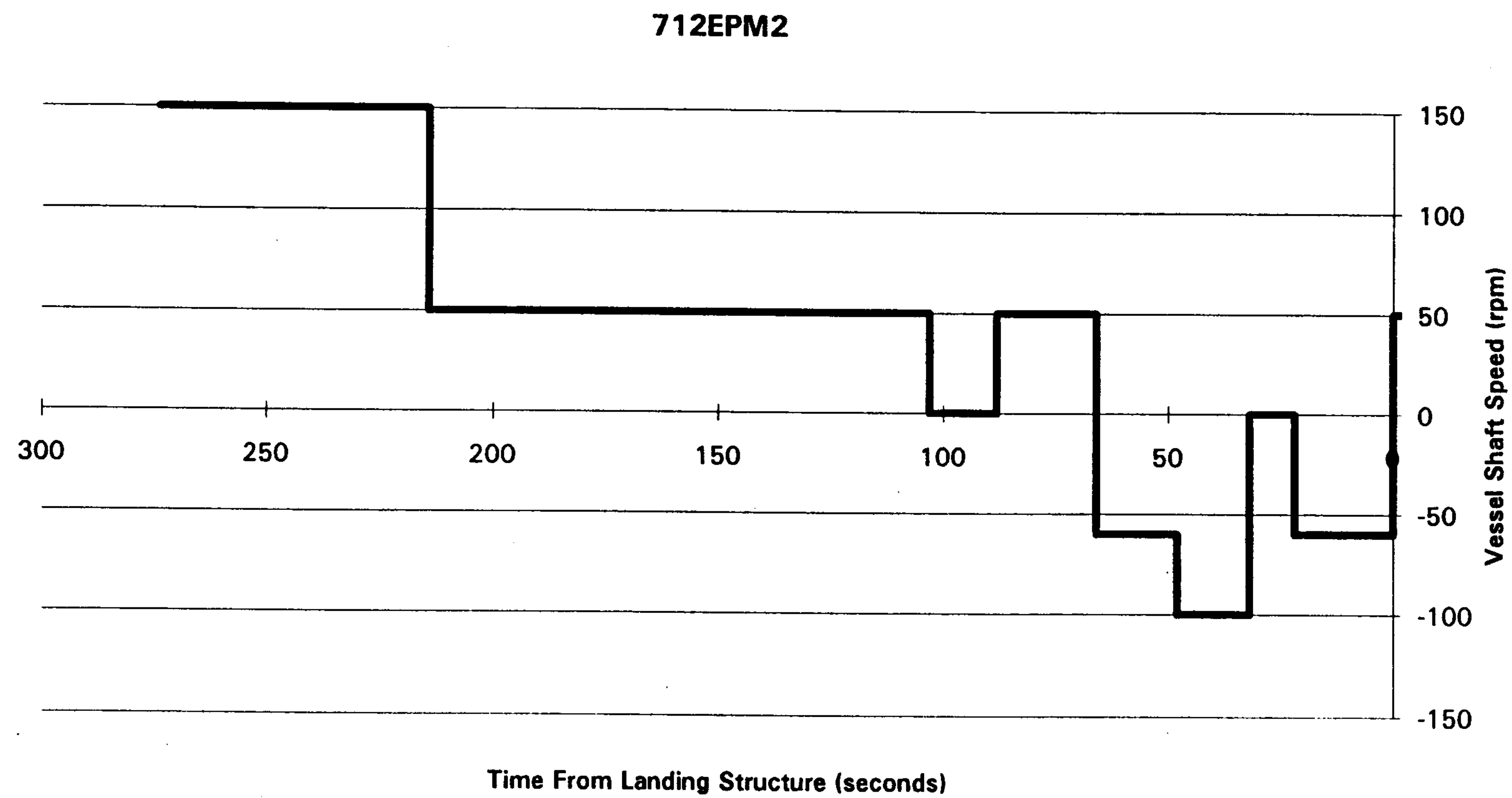

Figure F-1. Throttle Setting vs. Time from Landing Structure — 712EZZ2

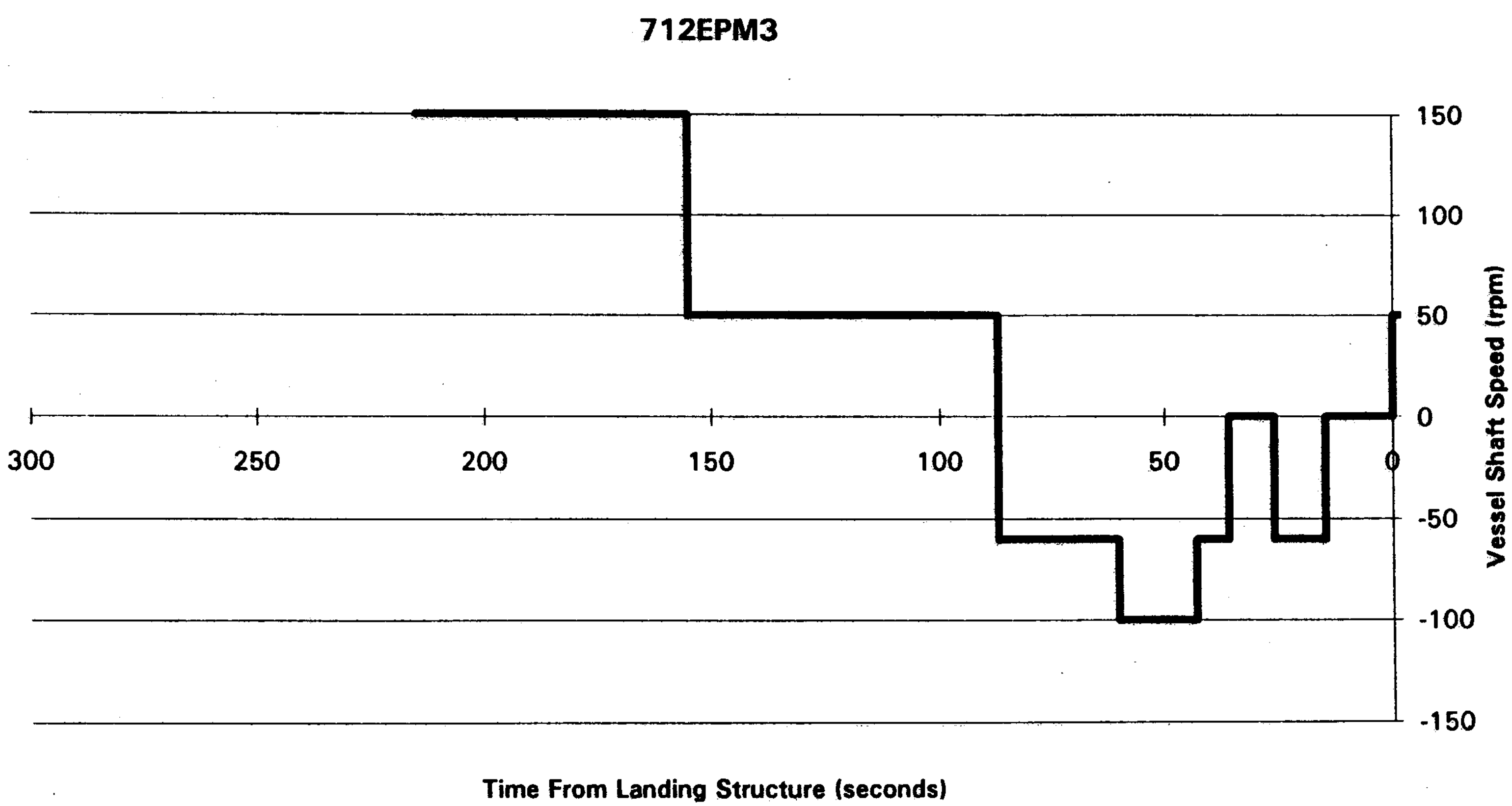

Figure F-2. Throttle Setting vs. Time from Landing Structure — 712EZZ3

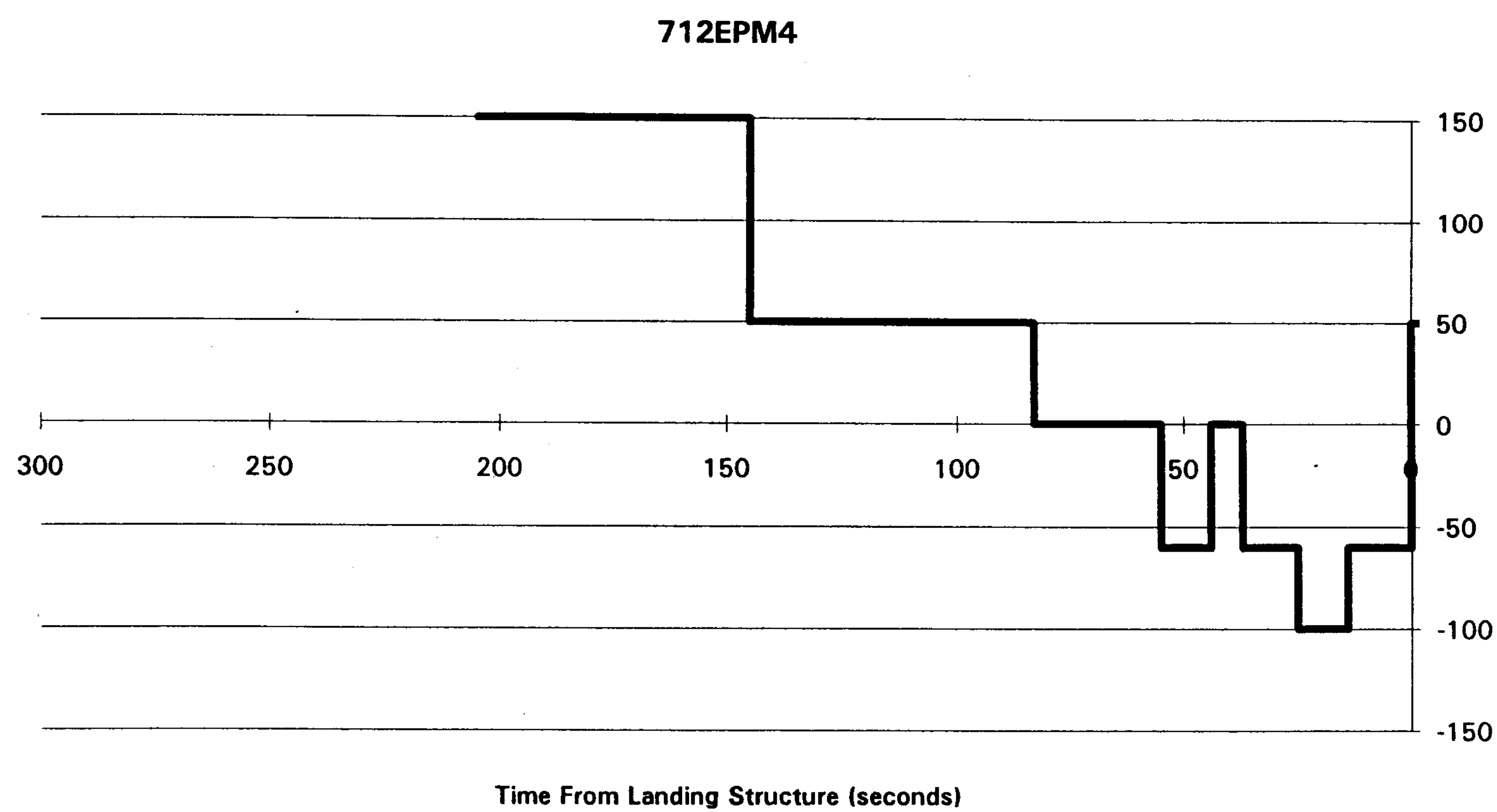

Figure F-3. Throttle Setting vs. Time from Landing Structure — 712EZZ4

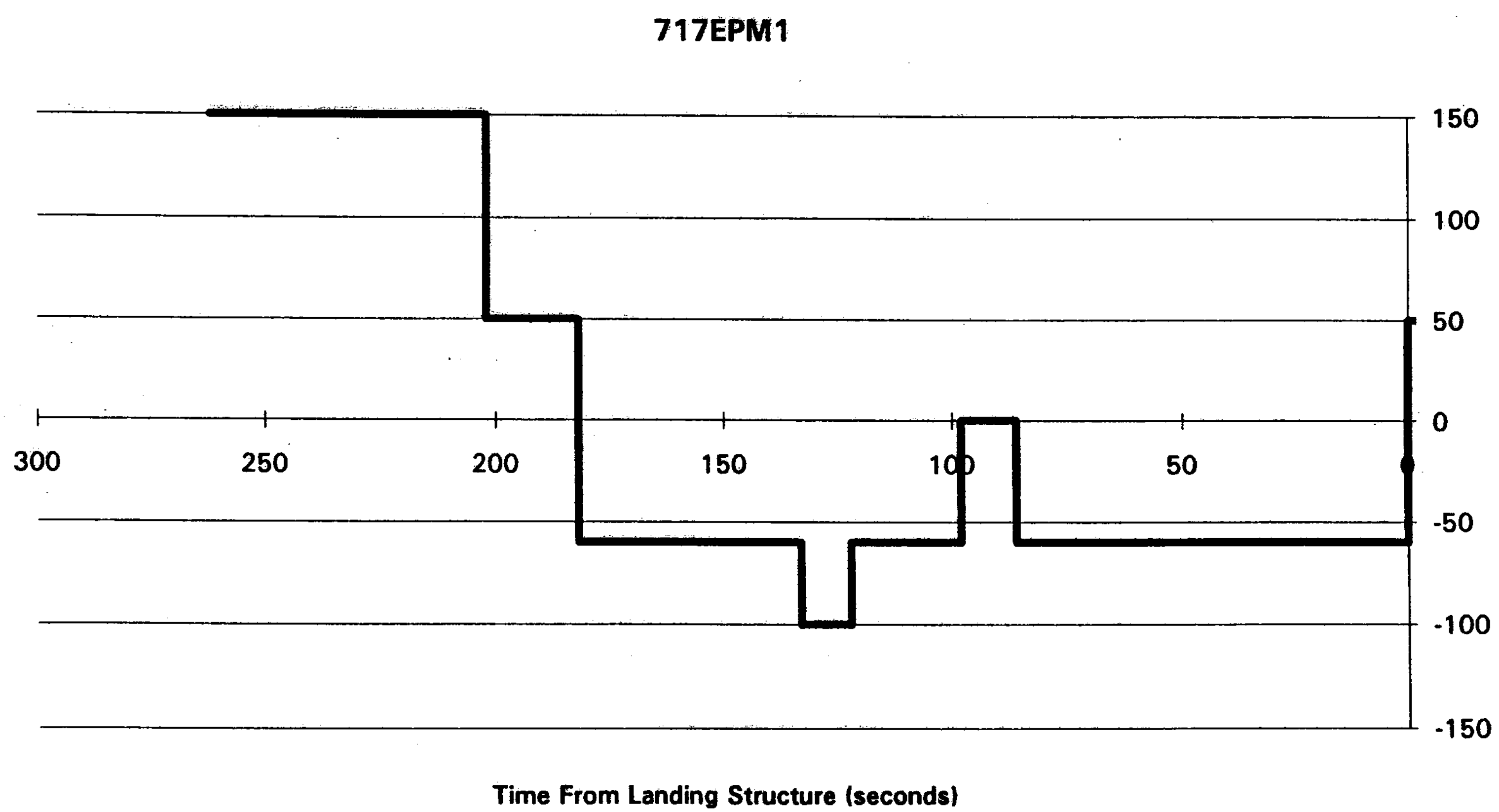

Figure F-4. Throttle Setting vs. Time from Landing Structure — 717EZZ1

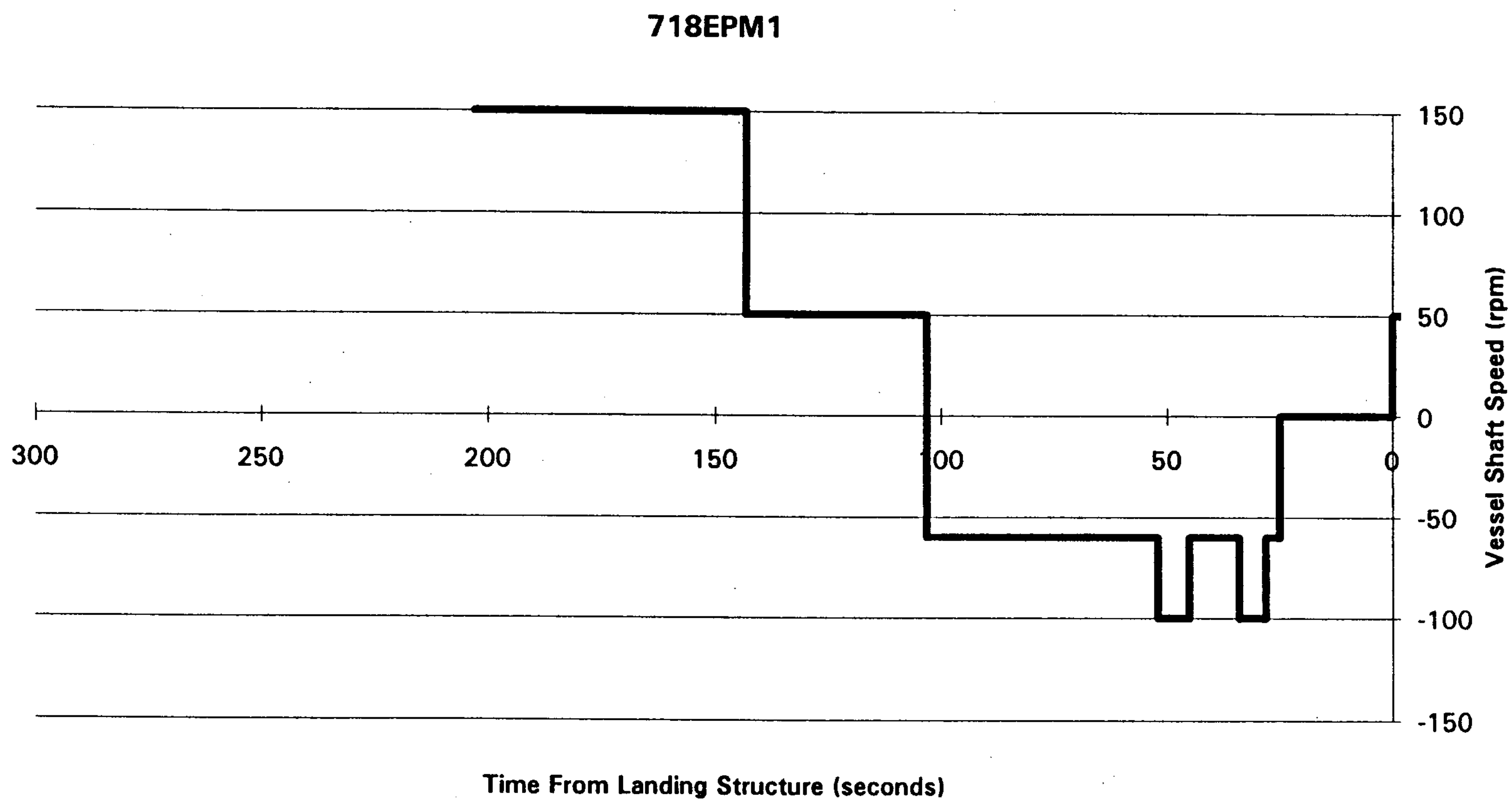

Figure F-5. Throttle Setting vs. Time from Landing Structure — 718EZZ1

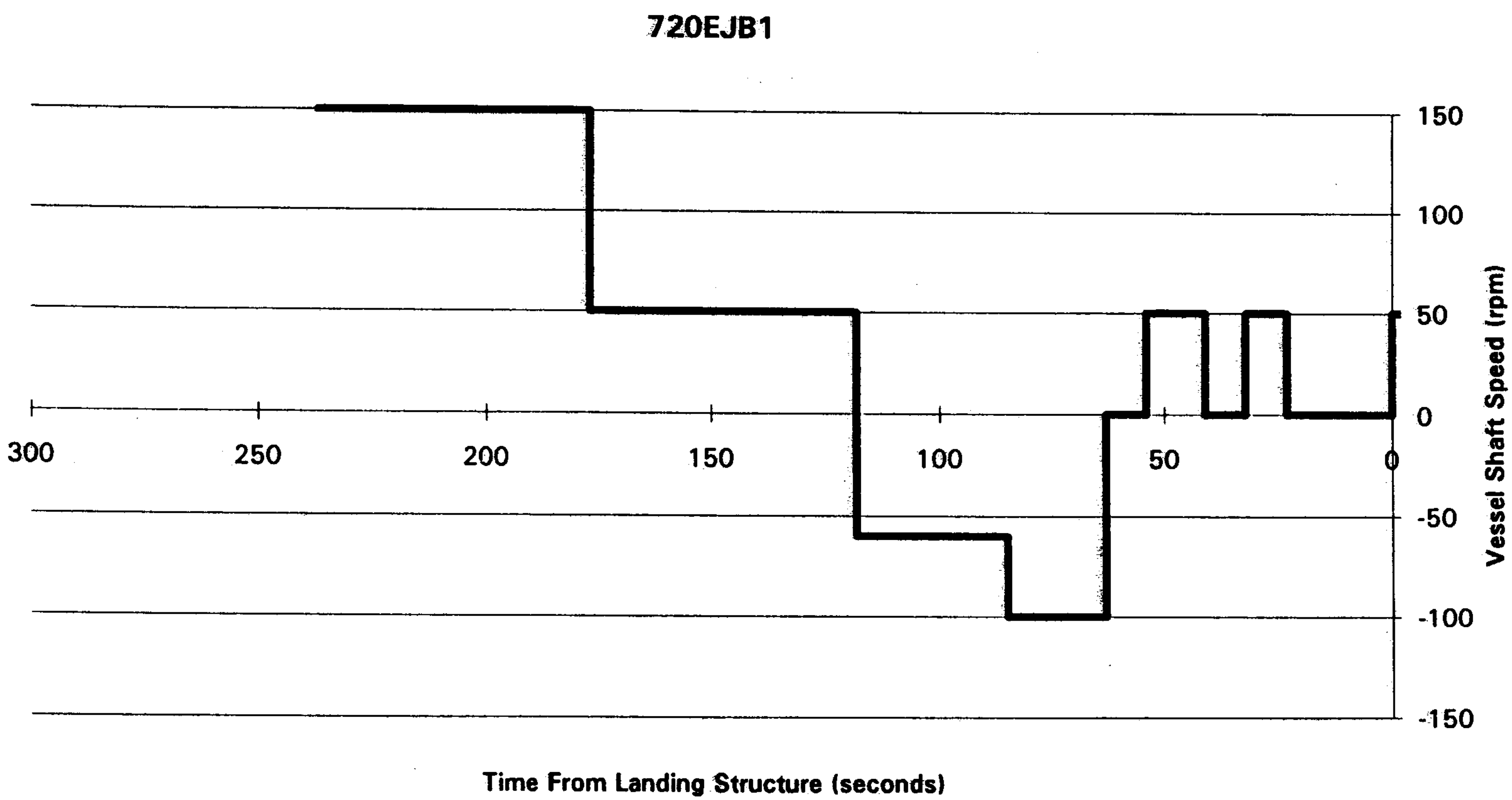

Figure F-6. Throttle Setting vs. Time from Landing Structure — 720EXX1

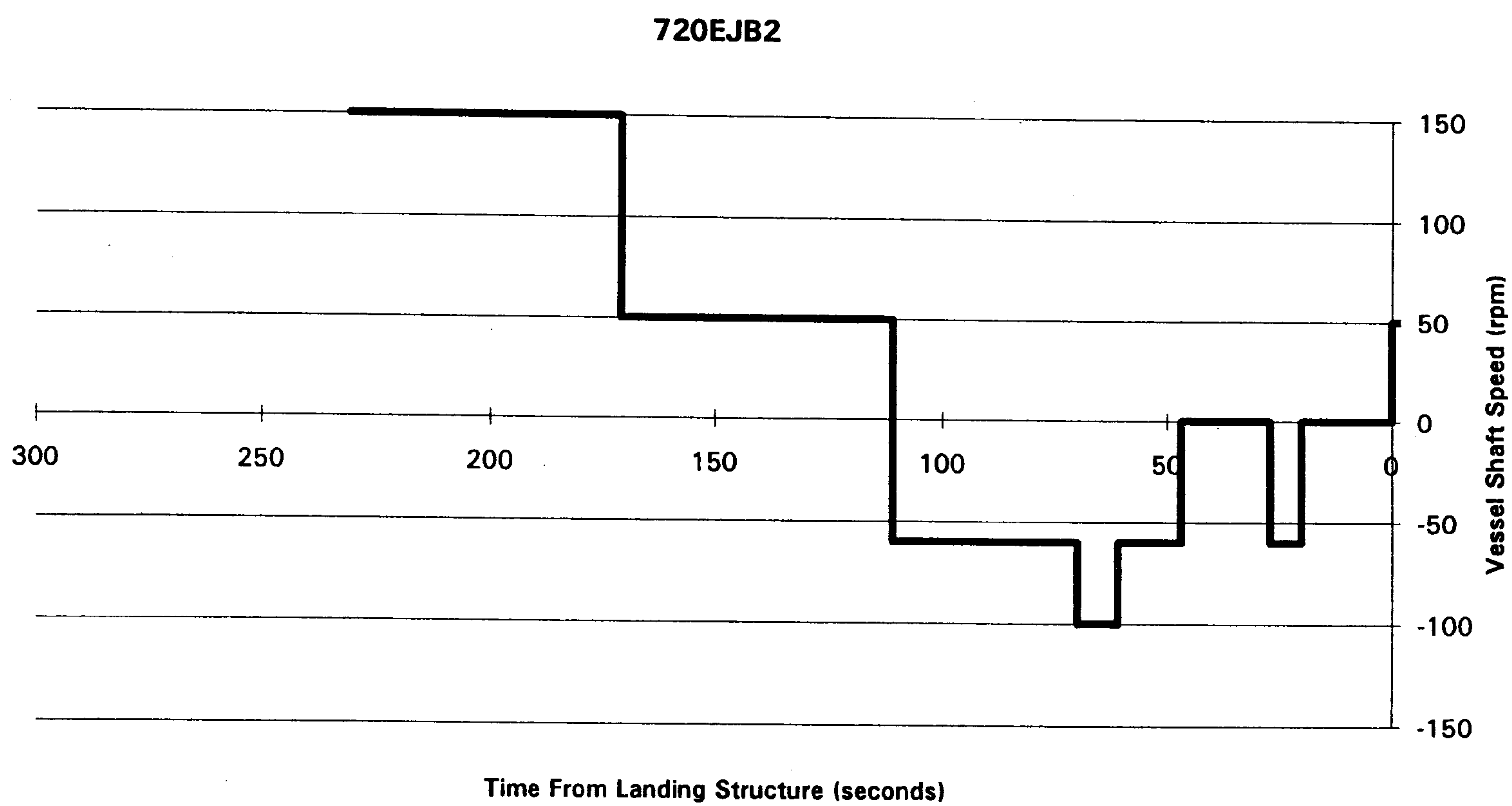

Figure F-7. Throttle Setting vs. Time from Landing Structure — 720EXX2

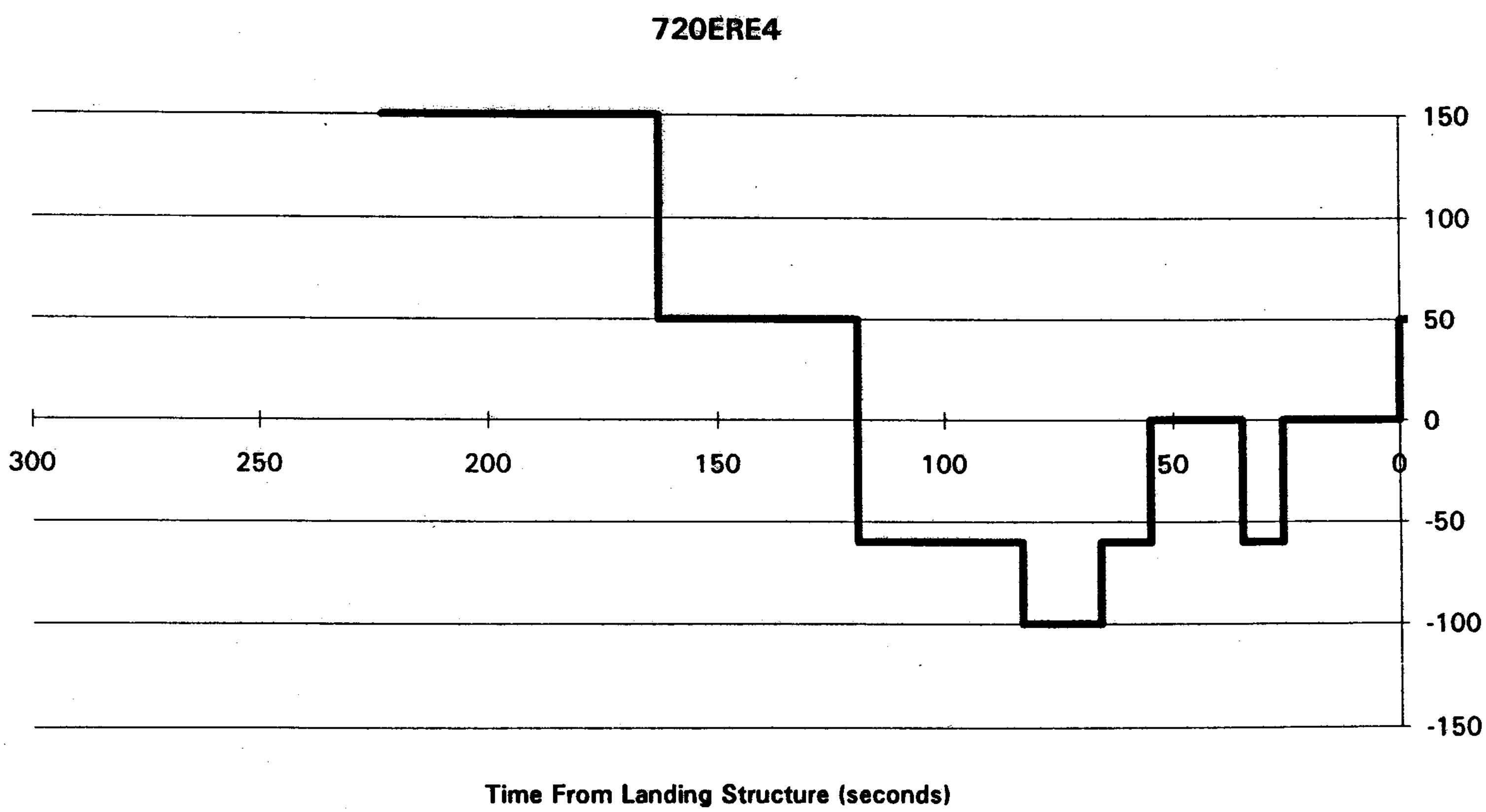

Figure F-8. Throttle Setting vs. Time from Landing Structure — 720EYY4

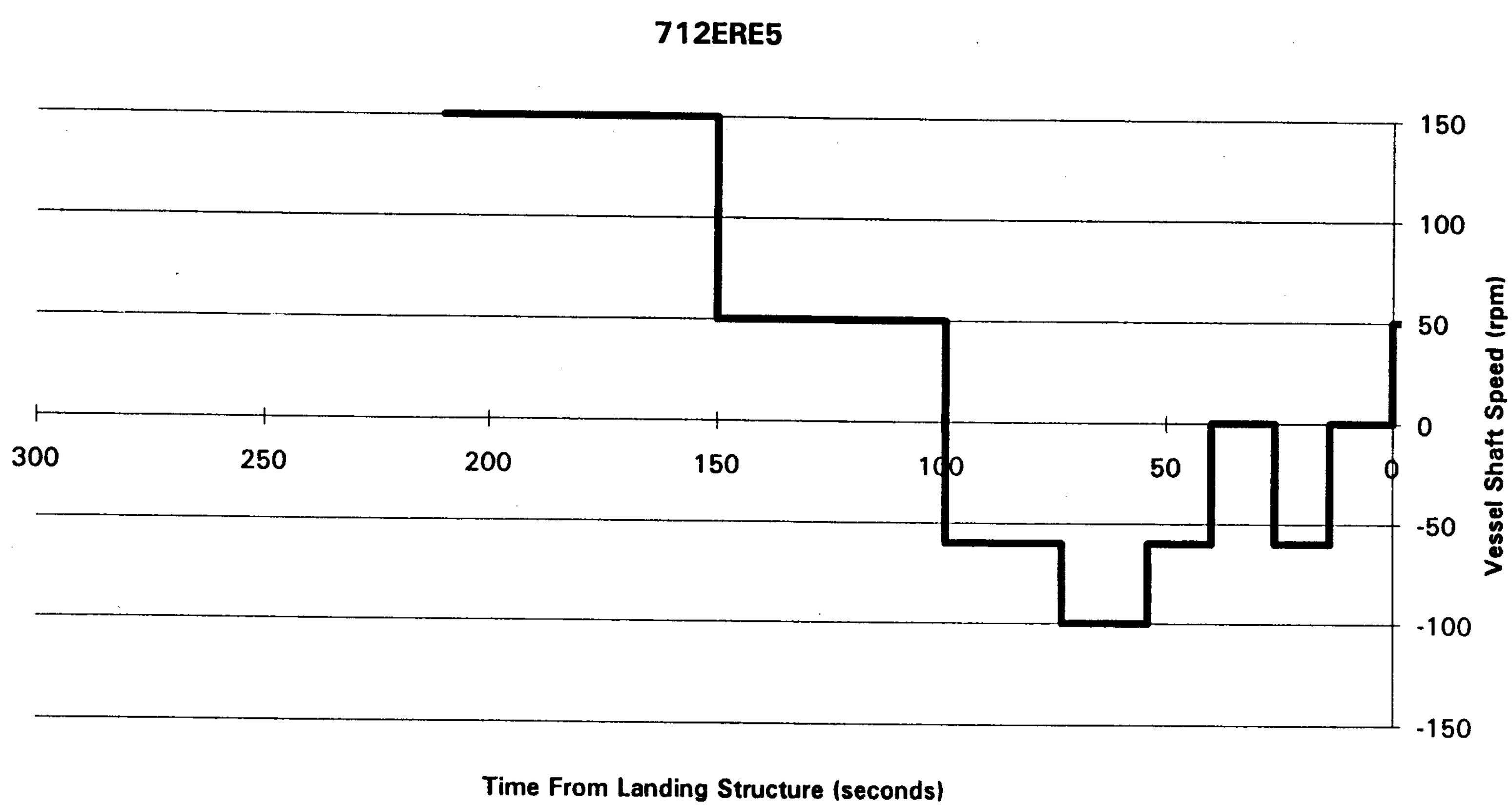

Figure F-9. Throttle Setting vs. Time from Landing Structure — 712EYY5

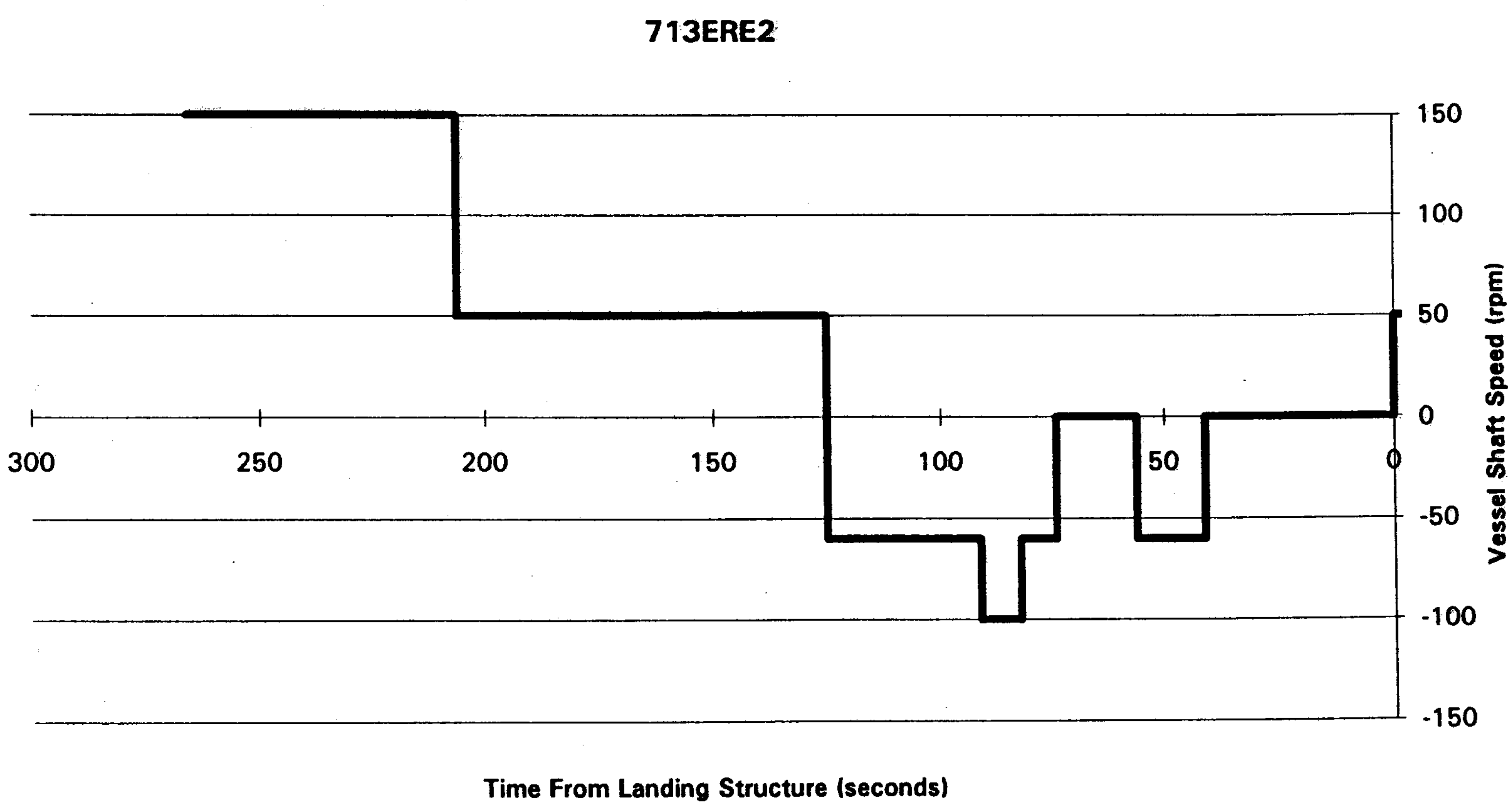

Figure F-10. Throttle Setting vs. Time from Landing Structure — 713EYY2

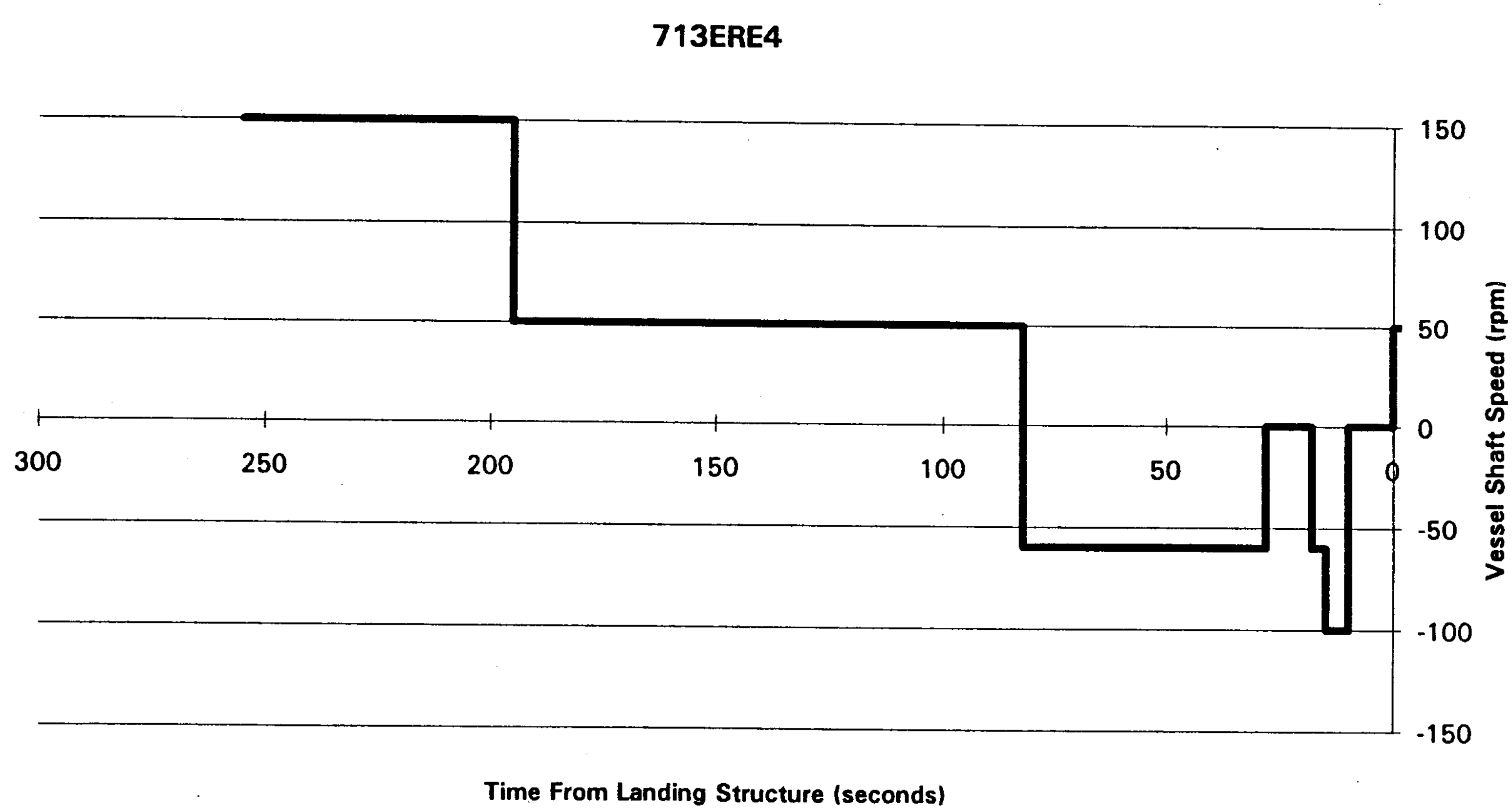

Figure F-11. Throttle Setting vs. Time from Landing Structure — 713EYY4