FERRY LANDING DESIGN
PHASE I

WA-RD 253.2

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October 1993

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Transit, Research, and Intermodal Planning (TRIP) Division
in cooperation with the U.S. Department of Transportation
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16. ABSTRACT

A procedure is developed for selecting design criteria for the berthing energy fender systems at ferry landings. In particular, end berthing arrangements are considered. A sample of 568 landing events are reviewed to find the distribution of approach velocity for kinetic energy calculations. An upper bound for the berthing coefficient is also identified. The design procedure is developed that involves 1) identification of the upper limits of the approach velocity by analyzing a sample of berthing events, 2) selection of a safety factor by making systematic judgements, 3) selection of a berthing coefficient based on experimental results, and 4) selection of design berthing energy using the kinetic energy formula. Further research is recommended to improve the placement of landing aids and to develop design criteria for other landing structures.

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Technical Report

Research Project GC 8719, Task 16
Ferry Landing Structures Design - I

FERRY LANDING DESIGN
PHASE I

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DISCLAIMER

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SUMMARY

Ferries are an integral part the transportation system in the Puget Sound Region. Compared to other vessels, ferries land more often and spend a greater proportion of time using terminal facilities. Therefore, the proper design of landing structures is crucial for assuring efficient operation of the Washington State Ferries (WSF).

In most cases, the existing terminal structures have performed satisfactorily, However, it would be desirable to reduce the frequency of repairs, avoid the use of creosoted lumber (declared a hazardous substance that requires special disposal), and develop innovative structures. Innovations are required to improve safety and efficiency and address difficult foundation conditions.

Existing designs are based on empirical design criteria. They have evolved gradually, with designers making incremental improvements as necessary. Before innovative designs are developed, this research team feels it would be desirable to adopt a set of rationally-based design criteria. This project's objective is to recommend such design criteria for the wing wall of WSF's landing structures.

The wing walls act as a fender system at the ferry landing. They absorb energy by deflecting as they push against the vessel and bring it to a stop. They also guide the vessel to the transfer bridge and hold it in place during its call. There are two wing walls for each ferry landing. They are located just beyond the transfer bridge and set at a 40 degree angle from the centerline of the slip to funnel the bow of the vessel to the end of the transfer bridge.

A literature review showed that past research concentrated on design criteria for side berthing vessels. The berthing energy may be specified in three ways:

1. by selecting a design approach velocity and estimating the berthing energy, by calculating kinetic energy and the berthing coefficient,
2. by reviewing a statistical analysis of a sample of berthing events and selecting a design berthing energy that will result in an acceptable probability of failure, or

3. by using an impulse response function.

WSF vessels use end berthing maneuvers. Therefore, neither the approach velocities nor the berthing energies from the literature review were useable in WSF's situation.

Using a Closed Circuit Television (CCTV) System and a video recorder, the research team collected a sample of 568 berthing events at WSF's Edmonds Ferry Terminal. This sample was analyzed to find the distribution of approach velocities. The average approach velocity was 0.58 ft/sec (0.18 m/sec). The 95th percentile velocity was 0.91 ft/sec (0.28 m/sec), and the highest recorded approach velocity was 2.0 ft/sec (0.61 m/sec). The size of the vessel, summer vs. winter weather conditions had little influence on the approach velocity, while the wind speed had some influence.

The berthing coefficient was estimated by comparing the apparent kinetic energy of the vessel to the energy absorbed by the wing wall. Because wing wall's force vs. deflection relationship had been established by field testing, it was possible to estimate energy absorption after estimating the wing wall's deflections. The upper bound of the berthing coefficient for most events was found to be 0.60.

The following procedure is recommended in selecting design criteria for a ferry landing:

1. Obtain a sample of approach velocities and note the parameters that describe the upper limits of the distribution. Alternatively, use a sample from a landing that has similar characteristics.
2. Select a safety factor by considering the importance of the landing structure, vessel reliability, time and cost of repairs, and environmental factors that were not included in the sample.
3. Select the design berthing energy by considering the upper limits of the approach velocity distribution, the safety factor, the vessel's mass, and the berthing coefficient.
4. Consider two different design cases: Case *i* where the vessel lands in the wing walls' throat and Case *ii* where the vessel lands against one wing wall and later moves to the throat.

Specific recommendations should be reviewed and included in a manual for ferry landing design. In addition to design criteria, the manual should contain information on existing landing geometry and vessel characteristics. Further research should be conducted to collect samples for other locations and to develop design criteria for other structures.

The effect of wind and current on the berthing maneuver was difficult to detect using the methodology developed for this project. This is because only the last 5 feet to 15 feet (1.5 m to 4.6 m) of the berthing maneuver was recorded, and the effects of wind and current may be more apparent during earlier stages of the berthing maneuver. In an ongoing portion of the project, researchers are tracking the berthing maneuver for its last 5,000 ft (1,500 m). The researchers hope to use the results to improve the placement of landing aids and to further develop design criteria with respect to berthing energy.

INTRODUCTION AND RESEARCH APPROACH

BACKGROUND

The Washington State Ferry System (WSF) consists of eight routes, 19 terminals (Figure 1), and 22 vessels (Figure 2), and conducts over 200,000 landings per year. Structures at a typical ferry landing terminal include a transfer bridge that provides a connection between the ferry and the land, a pair of wing walls that absorb berthing impacts and hold the ferry in place while at the dock, and dolphins that guide the ferry into the berth and hold it in alignment against cross currents and winds (Figure 3). Because of the 19 ft (6 m) tidal variation in the Puget Sound, the transfer bridge must be adjustable. A system using wire rope, counterweights, and pulleys is mounted in a steel and concrete or timber tower at the seaward end of the transfer bridge. This system provides a mechanism for adjusting the transfer bridge. The wing walls are constructed from creosoted wooden piles and timbers; these components are connected with bolts and cable lashings (Figure 4). Dolphins are either timber pile clusters (Figure 5) or floating structures. The floating dolphins are either steel or concrete pontoons that are moored by anchors (Figure 6).

The vessels range in displacement from 1,350 to 4,336 long tons (lt) (1,372 to 4,405 mt) (Figure 2 and Table 1) and are double ended, i. e., they have pilot houses, propellers, and rudders at both ends to eliminate the necessity of turning at the terminals. Like many ferries, WSF vessels head directly into the berth instead of approaching it from the side. During the berthing maneuver, the ferry slows by reversing the thrust of the propellers. Contact with the wing walls and other structures brings the vessel to a complete stop.

The Puget Sound region has experienced rapid population growth (23 percent increase from 1980 to 1990, according to U.S. Census Bureau statistics including Thurston, Mason, Pierce, Kitsap, King, Snohomish, Clallam, Jefferson, Island,

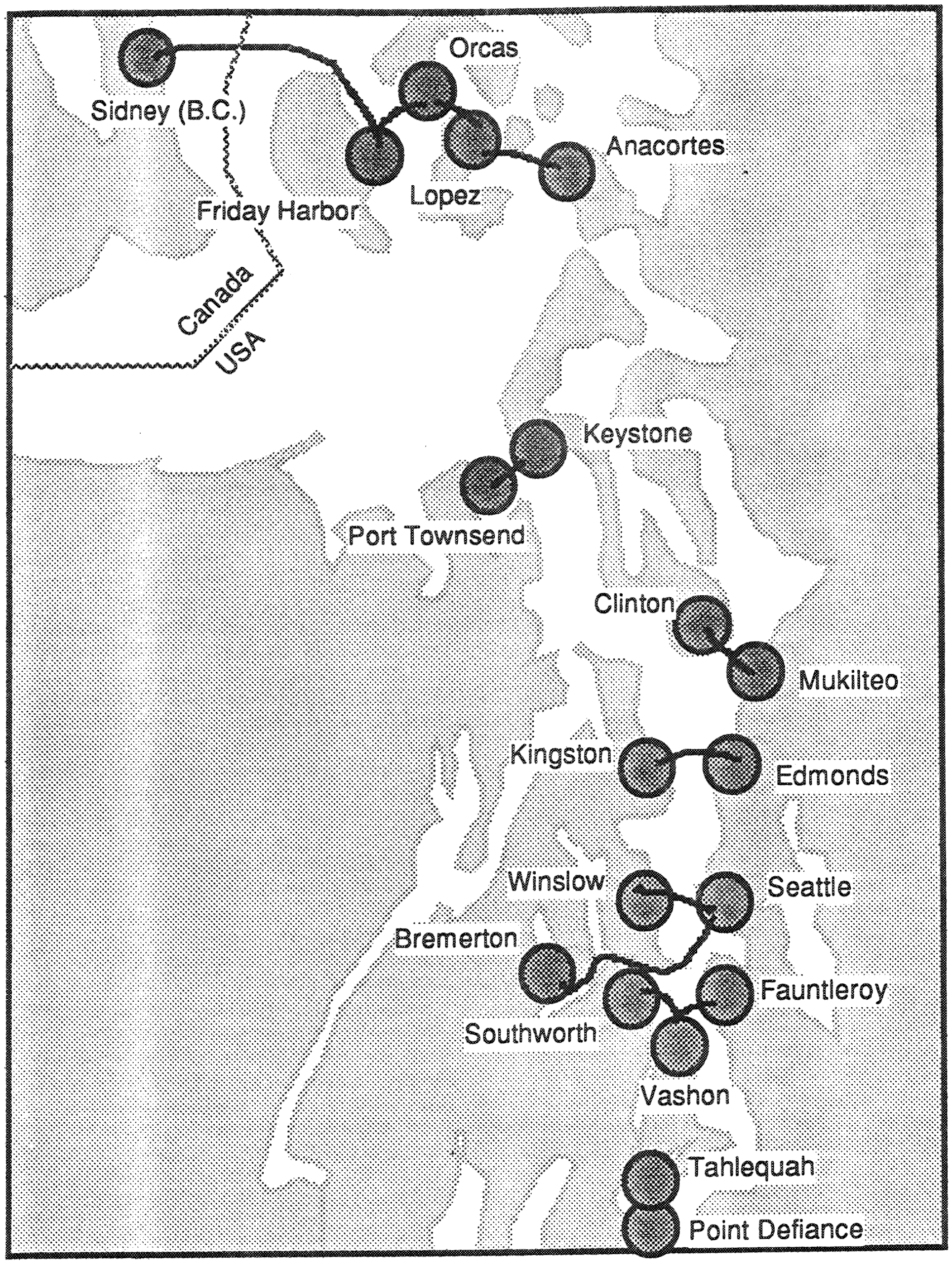
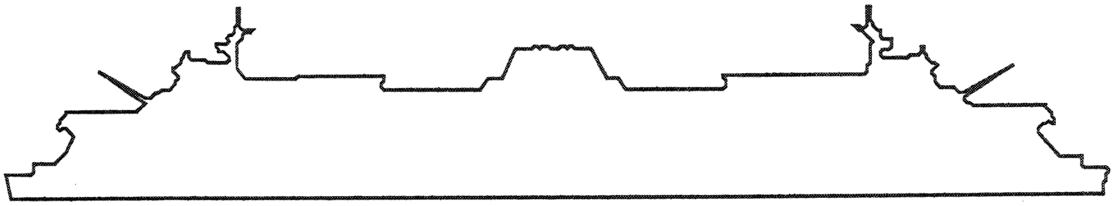
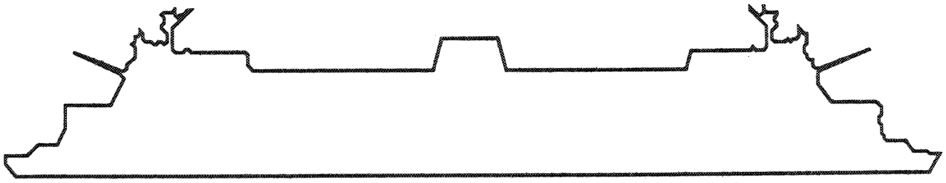


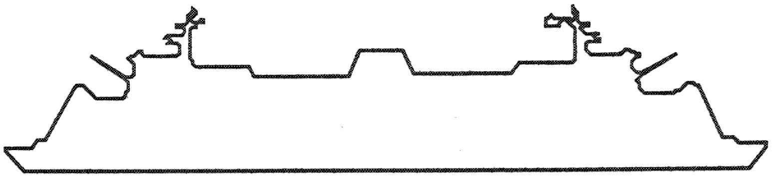
Figure 1. Ferry Routes



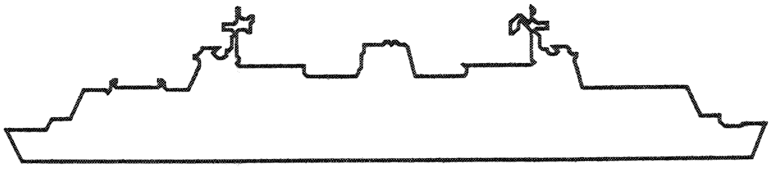
Jumbo Class



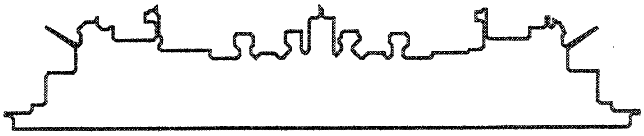
Super Class



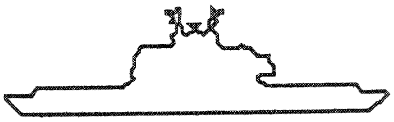
Issaquah Class



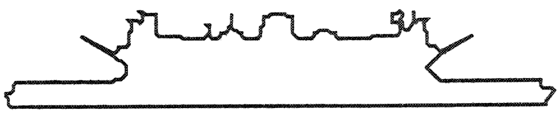
Evergreen State Class



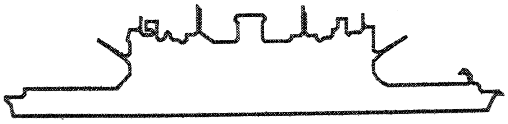
Steel Electric Class



Hiyu



Rhododendron



Olympic

Figure 2. Ferry Fleet

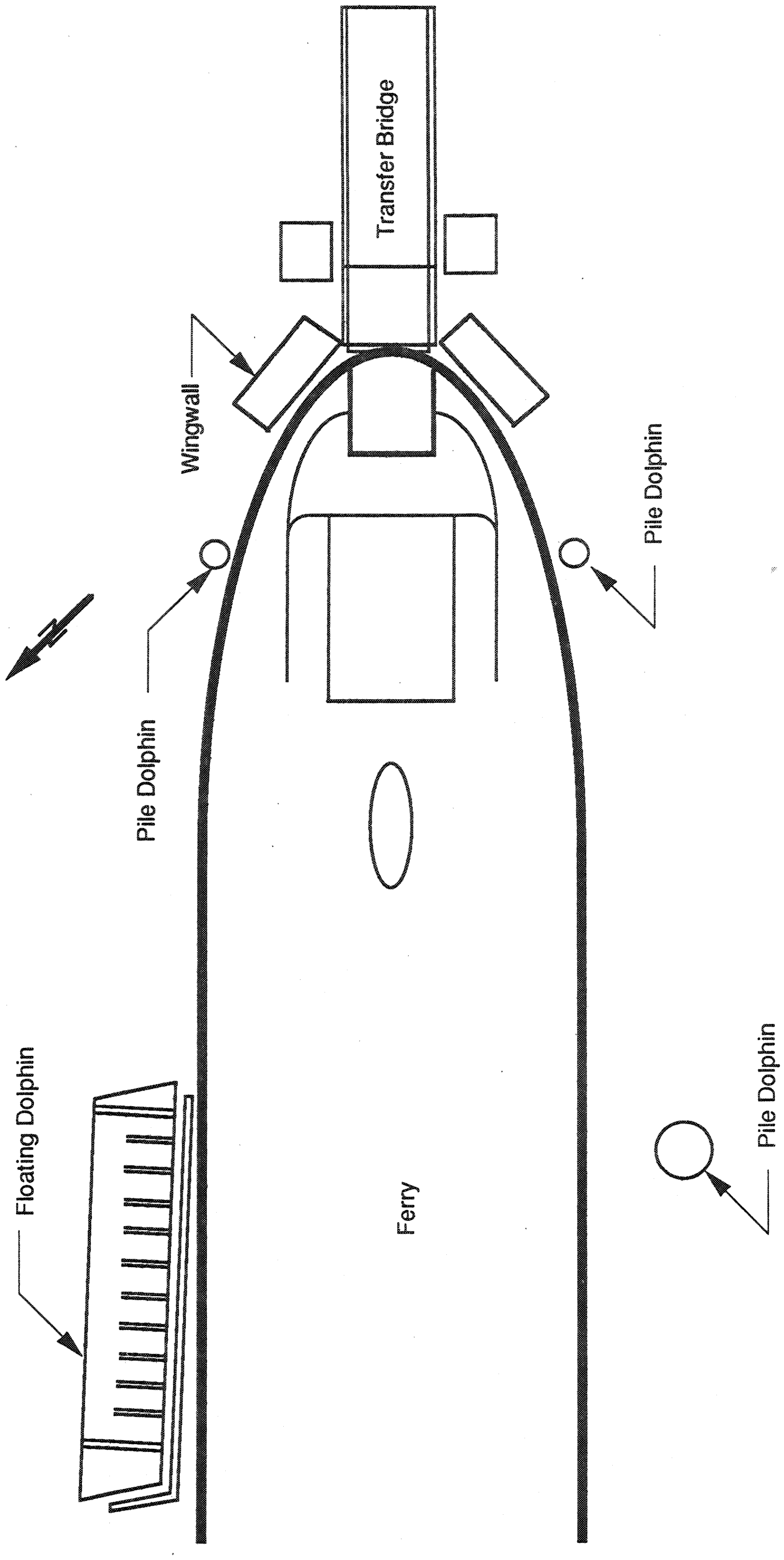


Figure 3. Layout of Edmonds Terminal

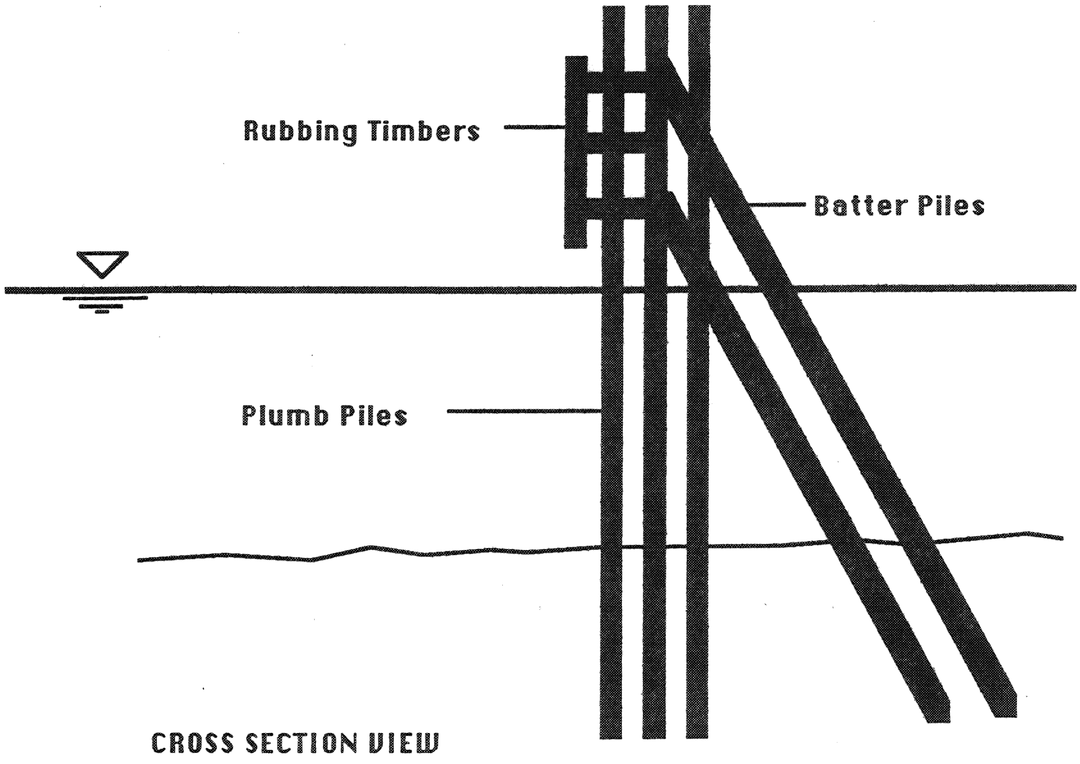


Figure 4. Wing Wall

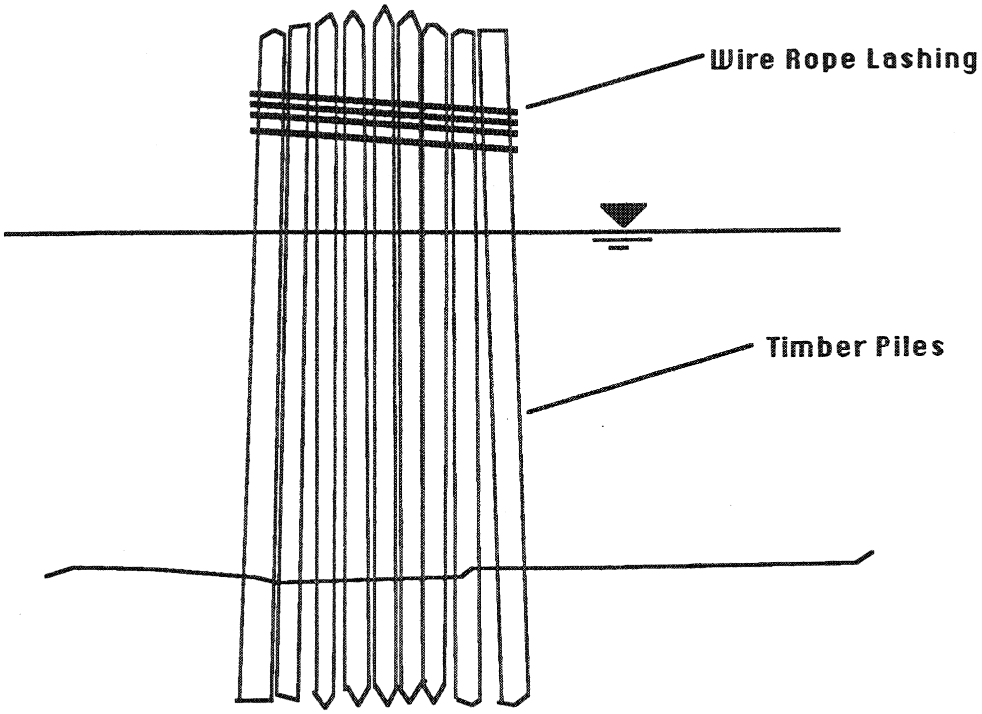


Figure 5. Pile Dolphin

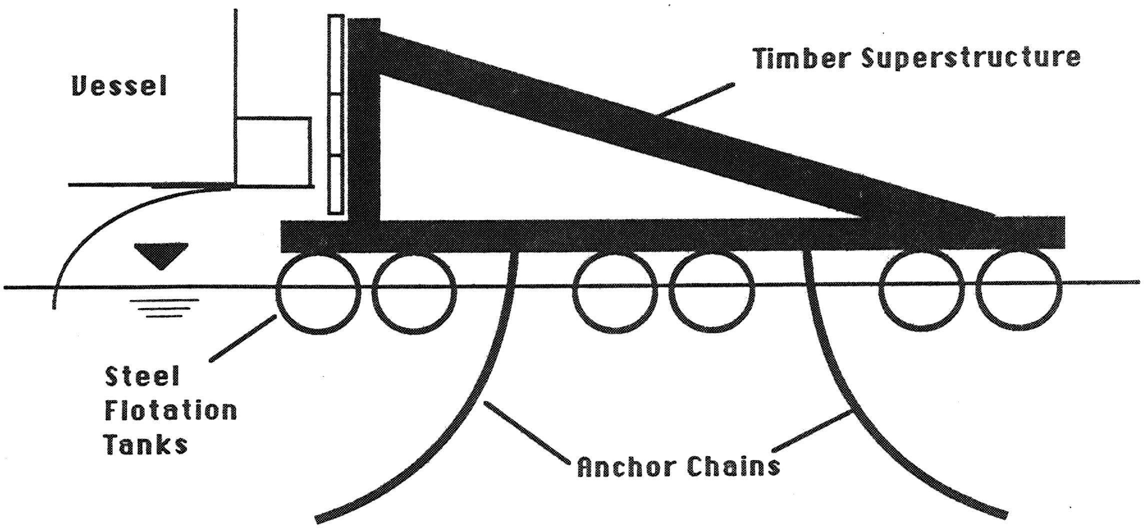


Figure 6. Floating Dolphin

Table 1. Vessel Characteristics

Class	Length ft (m)	Beam ft (m)	Draft ft (m)	Displ. lt[1] (mt)
Jumbo	440 (134)	87 (26)	18 (5.5)	4336 (4405)
Super	382 (116)	73 (22)	16 (4.9)	3283 (3335)
Issaquah	328 (100)	78 (24)	16 (4.9)	2943 (2990)
Evergreen State	310 (94)	73 (22)	15 (4.6)	2062 (2095)
Steel Electric	256 (98)	74 (23)	12 (3.7)	1806 (1834)
Rhododendron (typical small ferry)	226 (69)	63 (19)	12 (3.7)	1350 (1372)

[1] lt = long ton = 2240 lb.

Snohomish, Skagit, San Juan, and Whatcom counties). Ferry ridership has also increased for the same period: 20 percent in passengers and 38 percent in vehicles. [Note: 1980 figures were adjusted to eliminate the effect that temporary service (due to the Hood Canal Bridge sinking) had on the statistics.] In 1990, WSF moved 12,172,305 passengers and 9,113,347 vehicles (WSDOT Marine Division Traffic Statistics). In this environment, the reliability of the ferry system is critical; it is mandatory that terminal facilities perform reliably and well.

In most cases, existing terminal facilities performed satisfactorily; however, the development of new designs would be desirable for the following reasons:

1. Existing structures must be repaired and replaced frequently. A wing wall at a busy terminal may require yearly maintenance that involves development of plans and specifications, competitive bidding by construction contractors, mobilization of floating construction equipment, and interference with vessel operations. The cost, administrative effort, and delays in vessel operations are considerable.
2. The building material currently used, creosoted lumber, has been declared a hazardous substance. The Washington State Department of Transportation (WSDOT) retains responsibility for the proper disposal of hazardous substances, even after they have been placed in the landfill.
3. Propeller wash from vessels is scouring the harbor bottom near the terminal structures. Thus, longer pilings are required to provide a foundation for the structures. Such long timber piling are difficult to purchase. Alternatively, steel or concrete piling could be used.

4. Innovative structures could be developed that would improve safety in the case of catastrophic events, such as the loss of propulsion during the berthing maneuver. Innovation could also increase the efficiency of pedestrian loading and improve the aesthetics of the structures.

The existing design is not based on a set of rational design criteria. Rather, it has evolved gradually, with designers making incremental improvements as necessary. However, if completely new designs that use different construction materials are developed, it would be desirable to develop a set of rationally-based design criteria. The objective of this research project is to begin developing such rationally-based criteria.

STATE-OF-THE-ART SURVEY

A state-of-the-art survey was conducted for the design and construction of fender systems at ferry landings. Activities included a literature review and visits to Scandinavia, British Columbia, and Alaska. The state-of-the-art review is provided in Appendix A, and is summarized in the following paragraphs.

The ferry landing's fendering system absorbs energy by providing a reaction force as it deflects and stops the vessel. The timber wing walls are the fendering system for WSF's present landing structures. The energy absorption requirements are estimated by the following three methods:

1. Estimating the approach velocity and certain coefficients, and calculating the requirements for energy absorption. Several references provide tables, graphs, and charts to aid in the selection of proper design criteria.
2. Performing a statistical analysis of berthing energy for several landing events by observing the fender's deflection and inferring berthing energy from the deflection vs. energy relationship of the fender system.
3. Performing a numerical analysis with the impulse-response function. This method is mathematically complex and has not gained widespread acceptance as a design method.

A considerable amount of research has been performed using the second method for side-berthing vessels, such as oil tankers and container ships. However, no studies were found for end-berthing vessels such as WSF ferries. Little information has been gathered via the first method that would aid in the selection of design criteria for end-berthing ferries. PIANC's *Report of the International Commission for Improving the Design of Fender Systems* summarizes available knowledge on fender systems (in Chapter 4), and ferry landing design (in Chapter 9). (1) These chapters are reproduced in Appendices B and C. Additional information on fender selection is provided in Appendix D.

Researchers visited other ferry landing facilities and found that timber structures had been replaced by steel or concrete structures that incorporate rubber fenders to absorb energy. Fender units are faced with either timber or UHMW (ultra high molecular weight) polymer. In many locations, especially in Scandinavia and Europe, vessels berth against massive concrete or steel-sheet pile structures.

RESEARCH APPROACH

Approach velocity and berthing energy measurements were made at the Edmonds ferry terminal as part of the effort to improve Ferry Landing Design Criteria. This section reviews the situation at Edmonds Terminal and then discusses the procedures that were used in the study.

Edmonds Terminal is located 15 miles north of Seattle and provides access to ferries bound for Kingston, on the Kitsap Peninsula (Figure 7). Approximately 25 landing events occur per day. During the summer, two Super Class vessels are used (usually the MV *Yakima* and the MV *Hyak*). During the winter, one Super Class vessel (usually the MV *Yakima*) and one smaller vessel (usually the MV *Tillikum*, Evergreen State Class) are used. The slip centerline is normal to the shoreline and the prevailing winds blow along the shore, mostly from the southwest (Figure 7). Shelter from south winds is provided by Point Edwards. There is no shelter from north winds coming from the Strait of Juan de Fuca. Heavy north wind events occasionally occur during the winter. Ferry service is often cancelled when such events occur.

Vessels traverse the Puget Sound by making an "S" curve from Kingston to Edmonds and land in Edmonds by heading northeast along the shore and then turning southeast as they arrive (Figure 7). Preliminary visual observations and discussions with

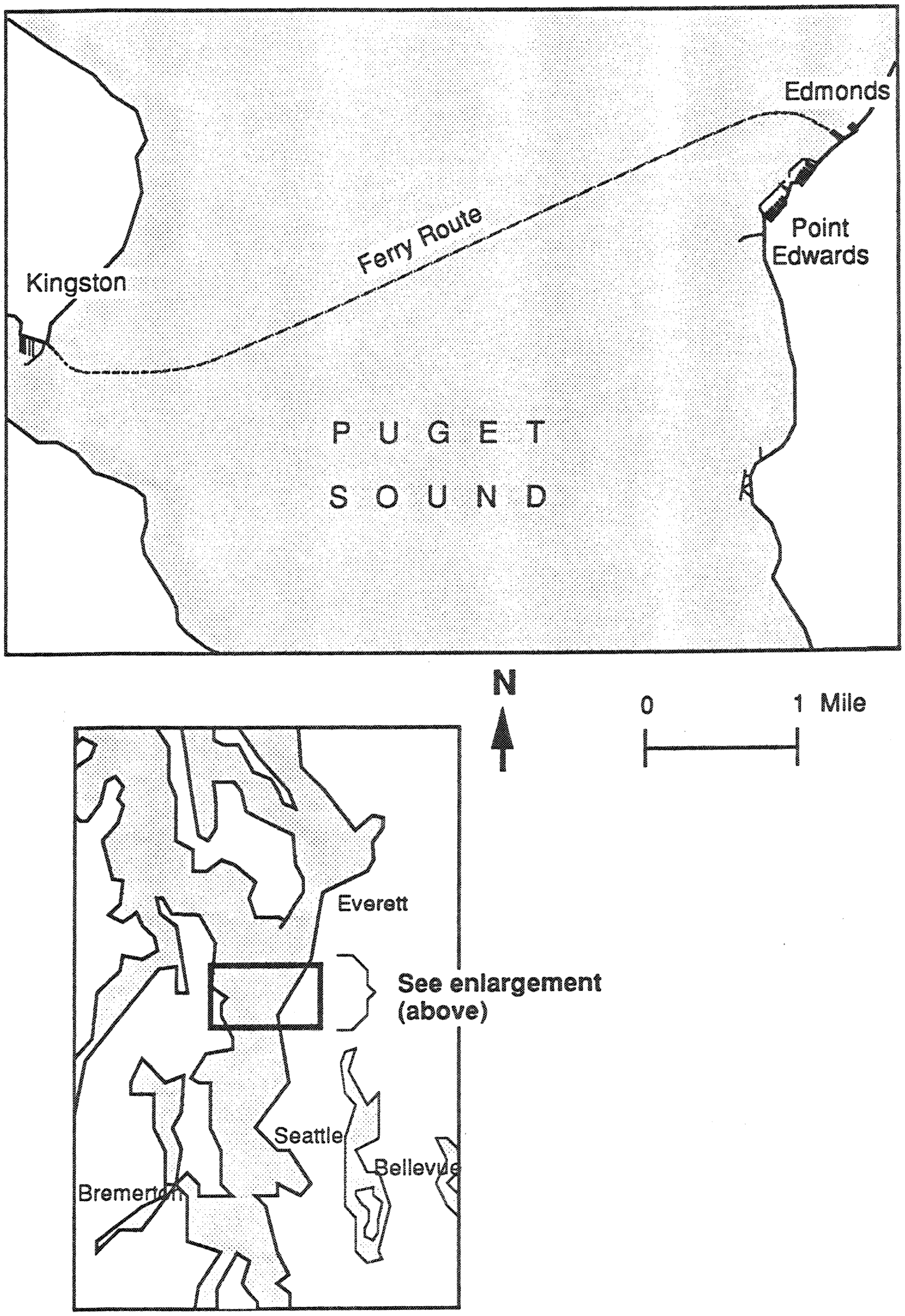


Figure 7. Project Location

the vessel crews indicated that the north wing wall was favored to land against because of the prevailing winds from the south and because of the turn that is executed shortly before the landing. The north wing wall had apparently received more wear than the south wing wall and was less stiff, despite the the extra row of plumb piling that was placed there.

The research approach involved using closed-circuit television to record video images of berthing events. These events were reviewed to obtain the approach velocity and wing wall deflections. Since the force vs. deflection relationship for certain locations on the south wing wall was determined by field testing, berthing energy could be inferred by knowing the deflection for events at these locations. Probability density functions, $q(V)$ and $q(E)$, were developed for approach velocity and berthing energy, respectively. The design criteria were then developed after examining (V) and $q(E)$.

Two closed-circuit television cameras were mounted on the walkway connecting the counterweight towers at WSF's Edmonds Terminal (Figure 8). Each camera was aimed to view one of the wing walls. A split image was recorded that simultaneously showed events that occurred at each wing wall (Figure 9). The date and time was imprinted on the video image. A motion detector was installed to initiate recording when the ferry arrived. A detailed description of the equipment is provided in Appendix E.

It is possible that the crews could have altered their landing strategies because of the presence of the CCTV system and this study; however, conversations with WSF employees indicated that this was probably not the case as they showed little concern regarding the study. The crews were asked to land as usual, but to favor the south wing wall. It seems likely that during the 10-month period of recording activities, the CCTV system became part of the normal routine and had little effect on the crews' landing strategies. During the course of the study, one landing occurred that damaged the north wing wall and required repairs. At the time, both cameras were aimed at the south wing wall in attempt to obtain more detailed deflection data. Thus, the incident was not recorded.

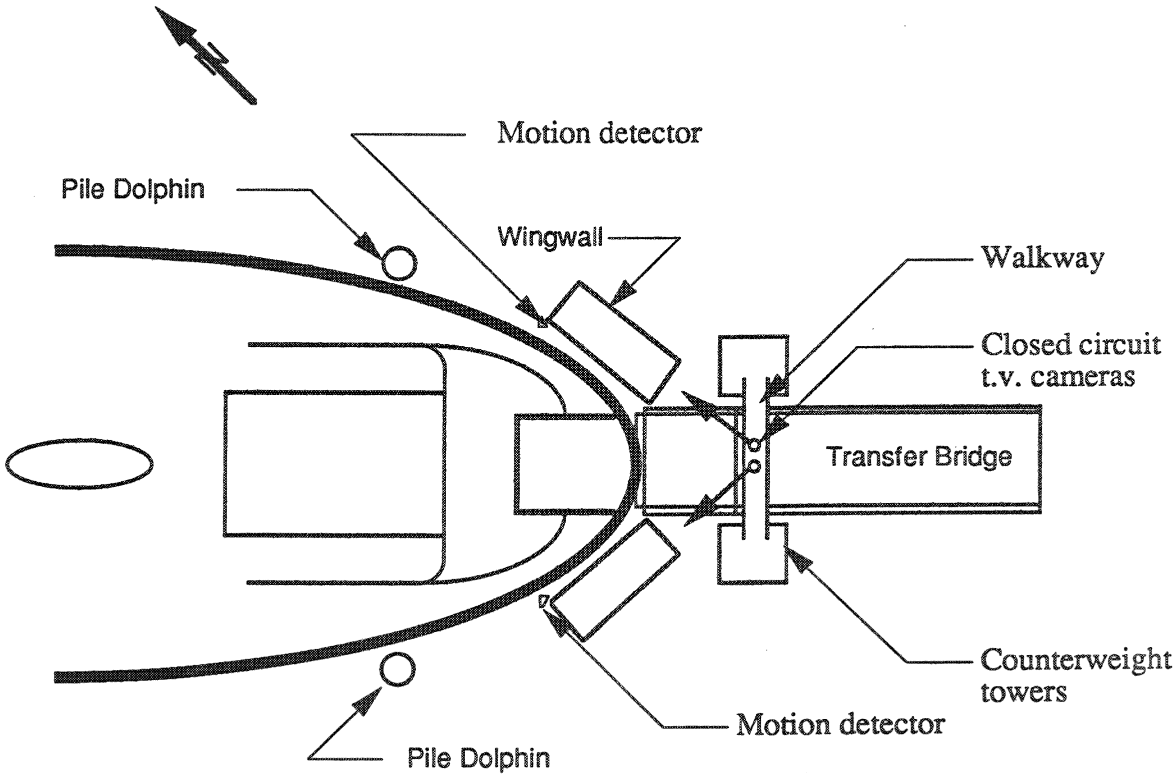


Figure 8. Test Layout

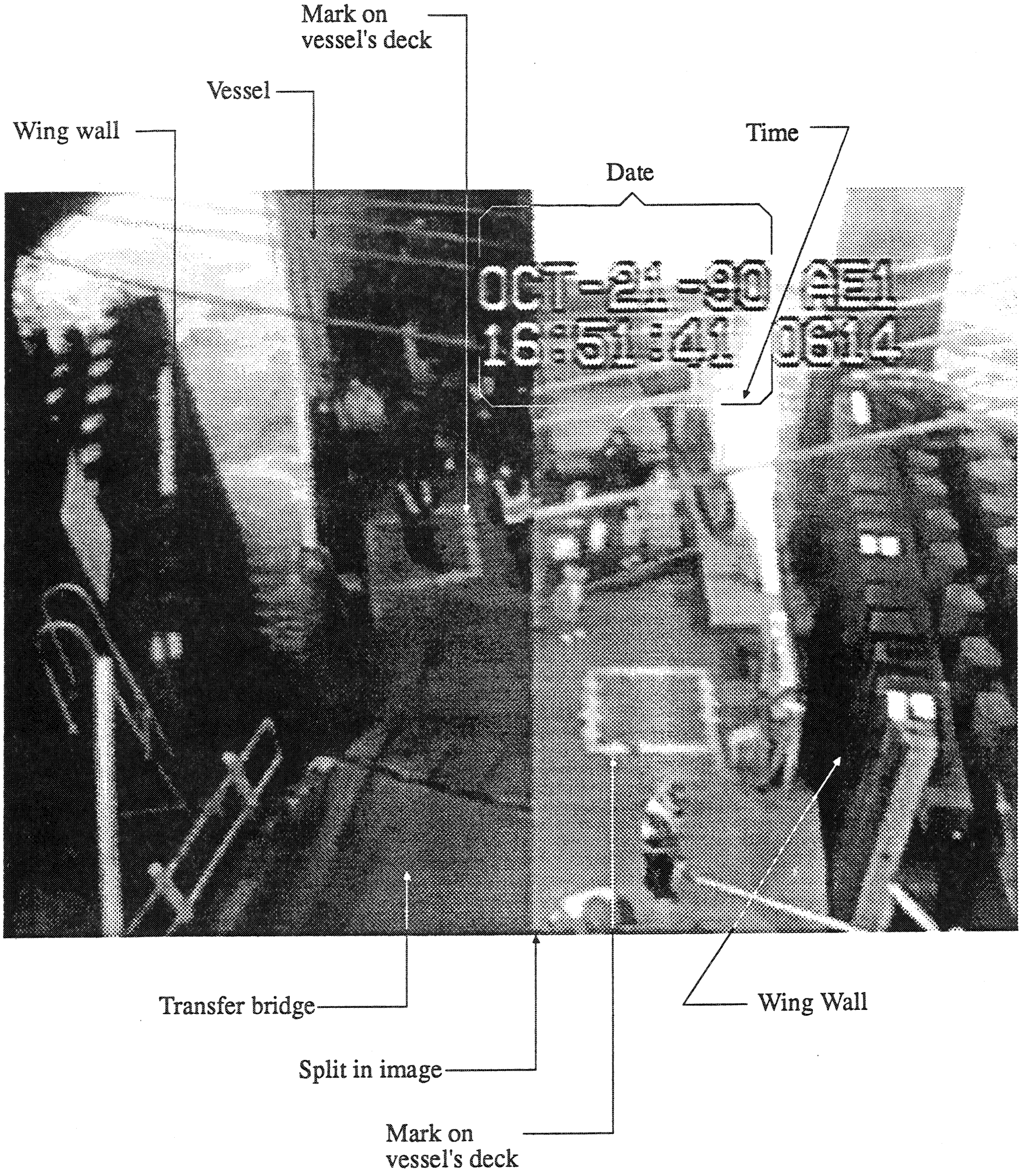


Figure 9. A Typical Scene from the Video Recording System at the Ferry Landing

Over 1,500 berthing events were recorded over a period of 10 months. Appendix F provides a calendar indicating the dates of video-recording operation. For some video tapes, every event that was recorded was analyzed. This produced a baseline data set of 568 events (Appendix G). Otherwise, the recordings were scanned to select events where the deflection of the south wall was greater than 4 in. and deflection of the north wall was greater than 6 in. This provided a special data set of 102 events that resulted in relatively high berthing energy (Appendix H). A larger deflection limit was selected for the north wall because it was apparent that the north wall's deflections were greater than the south wall's deflections for events of the same energy.

The approach velocity *(V)* was estimated by scaling the video images with marks of known size on the deck of the ferry (Figure 9). The position of the vessel was plotted for the last 10 to 20 seconds of the vessel's approach. Thus, an estimate of V for the last 5 ft to 15 ft (1.5 m to 4.5 m) of its approach was provided. For each event, the following was noted: V perpendicular and parallel to the face of the wing wall (V_{perp} and V_{para}, respectively), position of the impact, the name of the vessel, and the deflection at each end of the wing wall (s_{near} and s_{far}). If several impacts were recorded for one landing, the approach velocity of the first impact was considered. The location of the impact was also noted by observing which plumb pile was closest to the point of impact. Plumb piles were equally spaced along the 26 ft length of the wing wall and were numbered 1 through 11, starting at the throat. An anemometer was installed for the last 4 months of data collection. During this time, a record of the wind speed and direction was also provided. Instruments to measure the velocity of the current could not be provided due to the project's budgetary constraints. Attempts to correlate current velocity in the terminal area with the tide cycle did not produce consistent results. Eddies from the vessel's propeller wash upset the local flow pattern for several minutes after the vessel departed.

An element of judgment was required for estimating from the video images. Experienced observers provide differing estimates after watching the same recordings.

Moffit and Bouchard state that the confidence interval for one measurement may be computed if the standard deviation of a series of similar measurements is known. (2) The 90 percent confidence interval is estimated by

$$I_{90} = 1.6449\sigma$$

where σ = the sample standard deviation of a group of measurements

For five berthing events, four researchers provided comparative estimates for the same data (Table 2). For each event, the standard deviation and mean was taken by the four researchers for

1. the impact location,
2. the perpendicular component of the approach velocity, and
3. the parallel component of the approach velocity and the deflection at
    - a. the near end of the wing wall, and
    - b. the far end of the wing wall.

These data were analyzed to provide an estimate of the standard deviation for readings taken by one researcher. It is likely that there was some bias among the researchers as they interpreted the video images. Although this bias compromises the accuracy of this estimate, it does provide a basis for computing rough confidence intervals for each of the measurements.

The measurement comparison was analyzed to provide the following 90 percent confidence interval for a single reading: ± 2 piling for the location of impact, ± 0.2 ft/sec for the approach velocity, and ± 1.5 in. for wing wall deflection.

The data were sorted into subsets so that comparisons could be made to find how different factors affected $q(V_{perp})$. The factors considered were:

1. Summer vs. winter weather conditions. In the Puget Sound area, summers tend to have calm winds and high visibility, while the opposite is true in the winter. It is accepted practice to increase the design V for winter-like weather conditions. To find the influence of the season on $q(V)$, a comparison was made between $q(V)$ for the summer months (April through September) and the winter (February) for the MV *Yakima*. The MV *Yakima* was chosen because it is the only vessel on the Edmonds to Kingston run that operates in both summer and winter.

Table 2. Comparative Estimates of Berthing Data

		Velocity			Deflection	
Event	Reviewer	Position	Perpen- dicular	Parallel	Near	Far
1	#1	3.00	0.50	0.15	2.7	-1.0
	#2	2.00	0.55	0.28	2.8	-2.0
	#3	1.00	0.56	0.22	2.0	0.0
	#4	4.00	0.60	0.30	2.5	0.0
	Std. Dev.	1.29	0.04	0.07	0.35	1.26
	90% half interval	2.15	0.07	0.11	0.59	2.09
2	#1	1.00	0.22	0.17	2.6	-2.0
	#2	2.00	0.11	0.12	2.4	0.0
	#3	1.00	0.15	0.29	3.0	-1.0
	#4	1.00	0.00	0.30	4.0	0.0
	Std. Dev.	0.50	0.09	0.09	0.71	0.96
	90% half interval	0.83	0.15	0.15	0.18	1.59
3	#1	4.00	0.51	0.61	3.0	0.0
	#2	5.00	0.57	0.60	1.3	1.0
	#3	3.00	0.67	1.00	3.0	0.5
	#4	3.00	0.45	0.80	1.5	0.0
	Std. Dev.	0.96	0.09	0.19	0.93	0.48
	90% half interval	1.59	0.16	0.31	1.54	0.80
4	#1	7.00	0.50	0.50	5.5*	-3.0*
	#2	10.00	0.92	0.63	-0.90	3.1
	#3	8.00	0.67	0.83	-2.5	1.5
	#4	11.00	0.57	0.47	-1.5	4.0
	Std. Dev.	1.83	0.13	0.123	0.808	1.26
	90% half interval	3.04	0.18	0.16	1.34	2.10
5	#1	5.00	0.43	0.35	1.00	2.00
	#2	4.00	0.38	0.45	0.80	0.50
	#3	3.00	0.33	0.50	0.50	0.00
	#4	3.00	0.30	0.45	1.50	0.00
	Std. Dev.	0.96	0.06	0.06	0.42	0.95
	90% half interval	1.59	0.10	0.10	0.70	1.57
Average 90% half interval		1.84	0.16	0.19	1.01	1.46

*Assumed to be an error. Not included in analysis.

2. Size of vessel. It is accepted practice to assume that V increases as w, the vessel's displacement, decreases. To find the influence of w on $q(V)$, a comparison was made between $q(V)$ for the MV *Yakima* (Super Class, w= 3,283 lt) and the MV *Tillikum* (Evergreen State Class, w=2,062 lt) during the month of February. These vessels are normally assigned to the Edmonds-Kingston run during the winter months.

3. Different vessels of the same size. Although it is accepted practice to assume that V is the same for similar vessels, there may be differences in V because of differences in the crews' operating practices and minor differences in the vessels. During the summer months (April through September), two Super Class vessels (the MV *Yakima* and the MV *Hyak)* are assigned to the Edmonds-Kingston run. A comparison was made of $q(V)$ for these two vessels.

4. North wing wall vs. south wing wall. The prevailing winds and the landing's geometry may cause differences in V for the two wing walls. A comparison for $q(V)$ was made for the north and south wing walls.

For each subset, comparative histograms were developed; then the mean, median, standard deviation, and range were calculated. The overall $q(V)$ was compared to the normal distribution using the chi-squared goodness of fit test.

An analysis was conducted to find the percentage of impacts at each pile location, L, and to determine whether V_{perp} varies with L. L is an integer that corresponds to the pile number for the first row of plumb piles with L=1, the pile nearest the throat and L=12, the pile at the outer end on the wing wall. The data were sorted by L, and the number of impacts at each L was noted. Additionally, the average V_{perp} was calculated for all impacts at each L.

The influence of L on the approach angle, q, was also investigated. The approach angle was calculated as

$$\theta \quad = \quad \arctan(V_{para}/V_{perp})$$

Researchers also investigated the influence of the wind speed, U, on V_{perp}. In February 1991, anemometer readings were examined to provide time histories for U (Appendix G). Researchers reviewed these time histories to provide entries for U for each landing. An analysis was conducted to find if periods of high wind resulted in a higher proportion of fast landings than did periods of calm. The landings were sorted into three categories: $U < 7$ mi/hr, 7 mi/hr $\leq U < 14$ mi/hr, and $U \geq 14$ mi/hr. The chi-squared goodness of fit test was applied to find if the proportion of high speed landings was significantly higher on windy days than on calm days.

The berthing coefficient C was estimated by comparing two calculations for the berthing energy, which were each based on separate field measurements. One calculation provided the kinetic energy based on the approach velocity:

$$E_v = 1/2\ (w/g)V_{perp}^2 \tag{5}$$

Equation 5 is similar to Equation 1, except that C is missing from Equation 5. The other calculation provided berthing energy from deflection measurements:

$$E_s \quad = \quad h(s)\,|_{s_{max}} \quad = \quad \int_0^{s_{max}} g(s)ds \tag{6}$$

where E_s = berthing energy calculated from fender deflection

$h(s)$ = the energy vs. deflection relationship for the wing wall

$g(s)$ = the force vs. deflection relationship for the wing wall

For this project, $g(s)$ was developed for selected locations on the south wing wall at Edmonds Terminal from field test data recorded by R. Jones and C. T. Jahren. (3) The test was accomplished by pulling on the wing wall with a barge-mounted winch. One hundred kips (45.6 mt) of force and 4 in. (10.2 cm) of deflection were measured during the test. The force was limited by the holding power of the barge's anchors. After slack is removed from the wing wall, $g(s)$ is a linear relationship. To use $g(s)$ for this study, it is necessary to extrapolate the linear portion of the field test results. For piles 3, 6, and 9, $h(s)$ was calculated directly from $g(s)$. For piles 4, 5, 7, and 8, $h(s)$ was estimated by interpolating from the values of $h(s)$ for piles 3, 6, and 9. $h(s)$ for pile 2 was assumed to be the same for pile 3. Eighteen berthing events were analyzed. This provided a data set for analyzing $q(E_s)$, the probability density function for berthing energy based on deflection, and $q(C_{est})$, the probability density function for the estimated berthing coefficient.

C is estimated by

$$C_{est} = E_s/E_v$$

where C_{est} is an estimate of the berthing coefficient.

In addition to the factors specified for C in the definitions for Equation 2, C_{est} is also influenced by the thrust of the propulsion system, difficulties obtaining accurate deflection measurements, and uncertainties in developing $h(s)$.

FINDINGS

The frequency histogram for approach velocity of 568 events baseline sample is depicted in Figure 10. The approach velocity ranged from zero to 1.28 ft/sec (0.39 m/sec) with an average of 0.58 ft/sec (0.18 m/sec). The average and maximum for $q(V_{perp})$ are 0.44 ft/sec and 1.00 ft/sec (0.13 m/sec and 0.30 m/sec), respectively. V_n is the approach velocity that exceeds n percent of the other occurrences. The 95th percentile velocity (V_{95}) was 0.91 ft/sec and 0.75 ft/sec (0.28 m/sec and 0.23 m/sec) for $q(V)$ and $q(V_{perp})$, respectively. In the special data set of 102 high deflection landings, the highest reported approach velocity was 2.0 ft/sec or 0.61 m/sec; the average was 0.85 ft/sec (0.26 m/sec) and V_{95} was 1.24 ft/sec (0.38 m/sec). Other statistics are summarized in Table 3.

Visual inspection of the total approach velocity distribution, $q(V)$, suggests that it is normally distributed. However, the chi-squared test rejects this hypothesis at the $\alpha = 0.10$ level (Table 4). Deviations in the upper tail are the primary cause for rejection. Visual inspection of $q(V_{perp})$ indicates a lower distribution of velocity. Several occurrences of velocities in the 0.0 ft/sec to 0.1 ft/sec range are evident. These result from landings where the vessel's approach is primarily parallel to the face of the wing wall.

Visual inspection shows that the approach velocity distribution is similar for the following subsets of data (Table 2):

1. north and south wing wall (Figure 11),
2. winter and summer seasons (Figure 12),
3. Super Class (MV *Yakima*) and Evergreen State Class (MV *Tillikum*) vessels (Figure 13), and
4. MV *Yakima* and MV *Hyak* (Figure 14).

Note that in some cases for $q(V_{perp})$, occurrences are concentrated in the range that includes 0.5 ft/sec. It is likely that researchers selected 0.5 when they were unsure of the correct value because it was a round number.

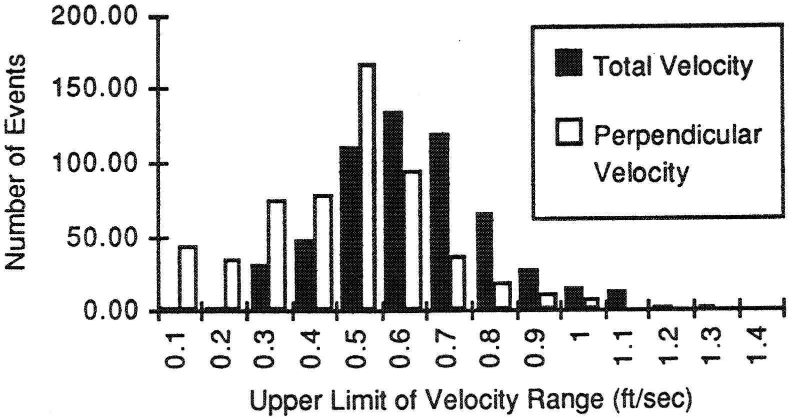


Figure 10. 568 Berthing Events

Table 3. Descriptors of Approach Velocity Distributions

	Approach Velocity ft/sec (m/sec)															
	Combined Distribution 568 Events		MV *Yakima* Summer Runs		MV *Yakima* Winter Runs		MV *Ilyak* Summer Runs		MV *Tillicum* Winter Runs		South Wing Wall		North Wing Wall		High Deflection Events	
	Total	Perpendicular	Total	Perpendicular	Total	Perpendicular	Total	Perpendicular	Total	Perpendicular	Total	Perpendicular	Total	Perpendicular	Total	Perpendicular
Mean	0.58 (0.18)	0.44 (0.13)	0.59 (0.18)	0.43 (0.13)	0.58 (0.18)	0.45 (0.14)	0.59 (0.80)	0.43 (0.13)	0.57 (0.17)	0.43 (0.13)	0.59 (0.18)	0.47 (0.14)	0.58 (0.18)	0.39 (0.12)	0.85 (0.26)	0.76 (0.23)
Std. Dev.	0.18 (0.05)	0.19 (0.06)	0.19 (0.06)	0.20 (0.06)	0.18 (0.05)	0.18 (0.05)	0.17 (0.05)	0.22 (0.07)	0.17 (0.05)	0.16 (0.05)	0.18 (0.05)	0.19 (0.06)	0.18 (0.05)	0.20 (0.06)	0.24 (0.07)	0.24 (0.07)
V_{50}	0.57 (0.17)	0.45 (0.14)	0.58 (0.18)	0.47 (0.14)	0.56 (0.17)	0.50 (0.15)	0.57 (0.17)	0.45 (0.14)	0.56 (0.17)	0.45 (0.14)	0.56 (0.17)	0.50 (0.15)	0.57 (0.17)	0.42 (0.13)	0.83 (0.25)	0.73 (0.22)
V_{90}	0.80 (0.24)	0.65 (0.20)	0.85 (0.26)	0.63 (0.19)	0.80 (0.24)	0.65 (0.20)	0.83 (0.25)	0.69 (0.21)	0.78 (0.24)	0.60 (0.18)	0.83 (0.25)	0.73 (0.22)	0.78 (0.24)	0.60 (0.18)	1.12 (0.34)	1.00 (0.30)
V_{95}	0.91 (0.28)	0.75 (0.23)	0.96 (0.29)	0.75 (0.23)	0.90 (0.27)	0.75 (0.23)	0.85 (0.26)	0.70 (0.21)	0.84 (0.26)	0.70 (0.21)	0.90 (0.27)	0.80 (0.24)	0.90 (0.27)	0.70 (0.21)	1.24 (0.38)	1.20 (0.37)
Number of Events	568		200		108		152		50		287		279		102	

Table 4. Chi-Squared Goodness of Fit Test

Upper Limit of Velocity Range	Expected Number of Occurences for a Normal Distribution	Actual Number of Occurrences	χ^2
0.0			
0.1	2.22	1.00	0.67
0.2	7.67	2.00	4.19
0.3	24.48	31.00	1.74
0.4	55.78	48.00	1.08
0.5	97.30	111.00	1.93
0.6	121.44	135.00	1.51
0.7	114.51	119.00	0.18
0.8	81.45	65.00	3.32
0.9	41.86	27.00	5.28
1.0	15.68	14.00	0.18
1.1	4.54	13.00	15.74
1.2	0.91	3.00	4.81
1.3	0.17	2.00	19.64
1.4	0.00	0.00	
		Total	60.27

Degrees of freedom:

Categories	13
Estimate of mean and std. dev.	<2>
	<1>
Total	10

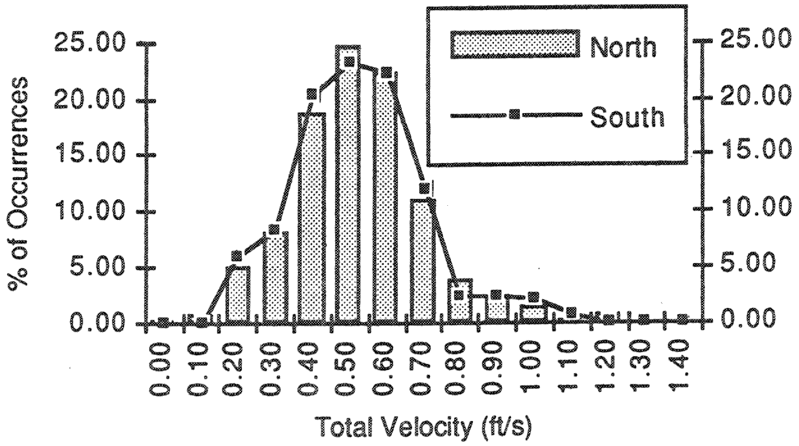
Critical values for χ^2 for α	= 0.100 -	15.98	<	60.27	
	= 0.050 -	18.30	<	60.27	(Conclude
	= 0.025 -	20.48	<	60.27	distribution
	= 0.010 -	23.20	<	60.27	is non-normal.)
	= 0.005 -	25.19	<	60.27	

Note: $\chi^2 = \sum \frac{(f_i - F_i)^2}{F_i}$

where f_i = actual number of occurrences

F_i = expected number of occurences

(a)



(b)

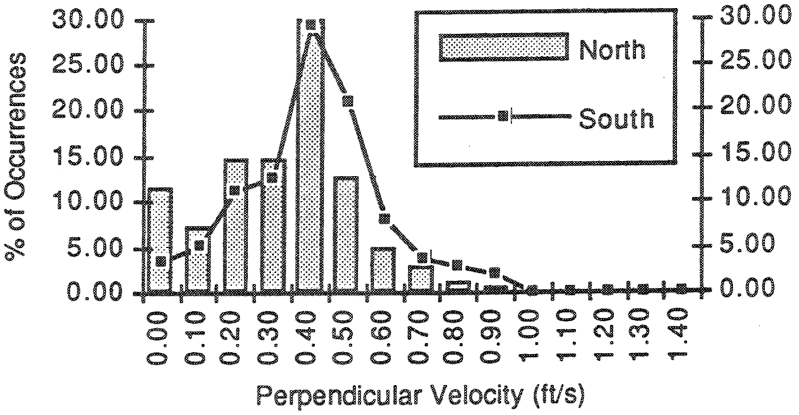
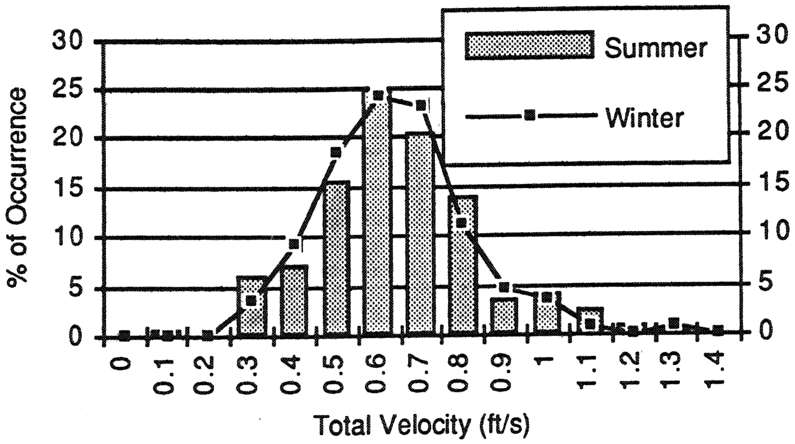


Figure 11. Comparison of North and South Wing Wall Approach Velocities, a) Total Velocity and b) Perpendicular Velocity

(a)



(b)

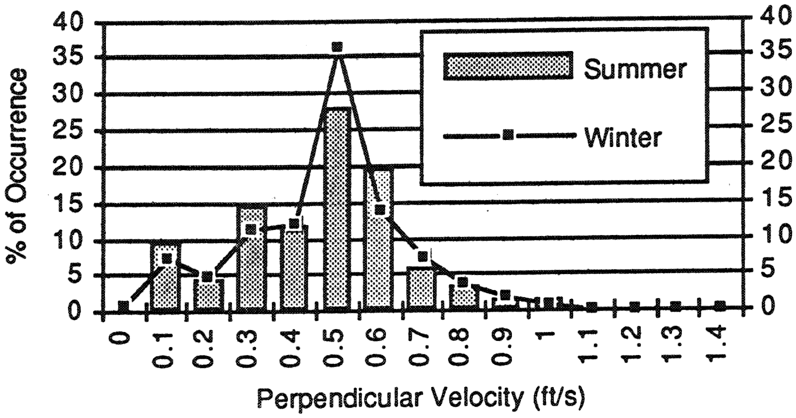


Figure 12. Comparison of Summer (April through September) and Winter (February) Approach Velocities, a) Total and b) Perpendicular

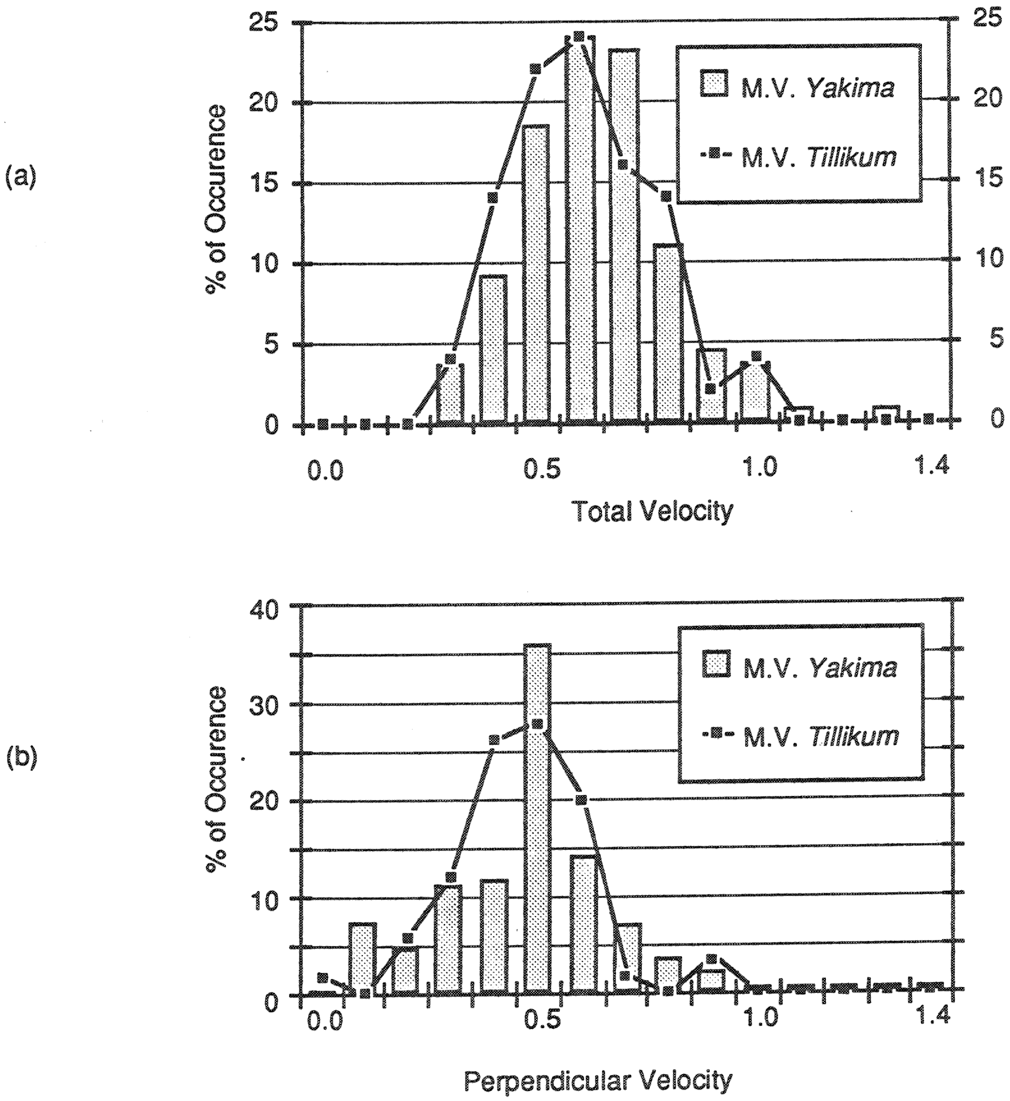


Figure 13. Comparison of Approach Velocity for Large Ferry (M.V. *Yakima,* 3283 lt or 3335 mt) and Small Ferry (M.V. *Tillikum,* 2062 lt or 2095 mt)

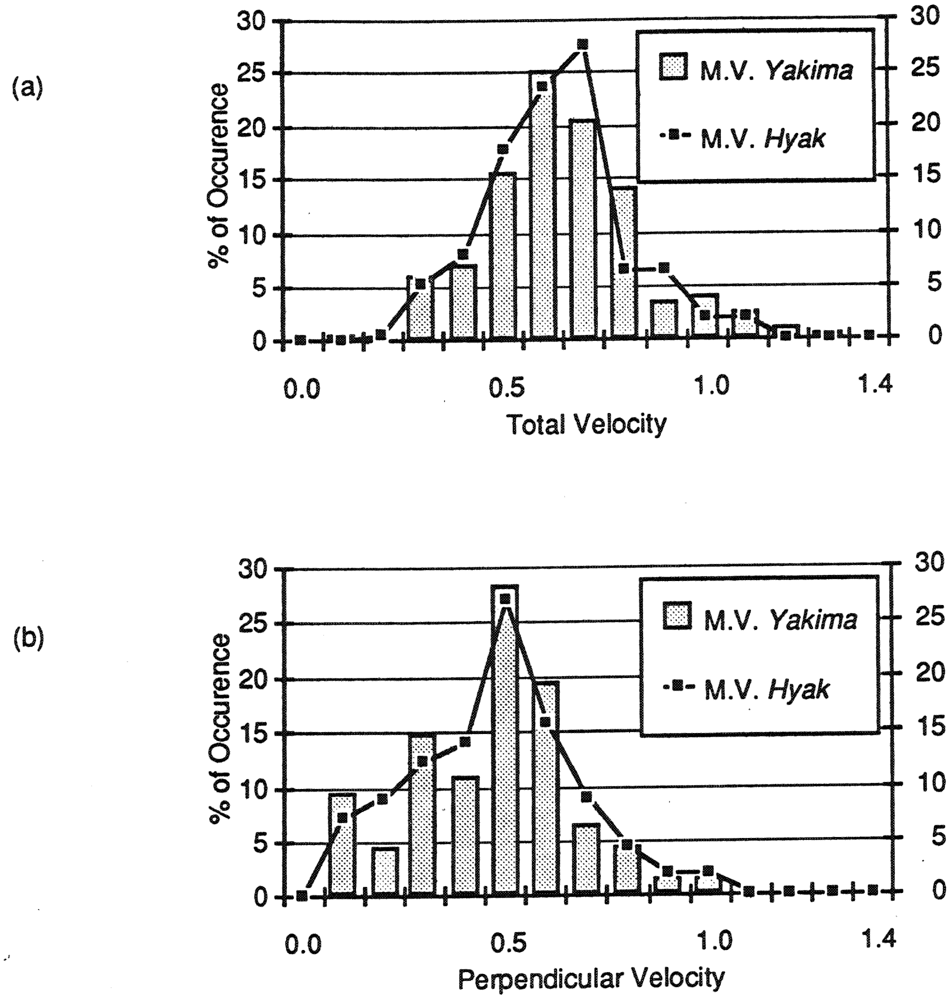


Figure 14. Comparison of Vessels of the Same Class, a) Total and b) Perpendicular

For most landings, the approach angle is greater than 45 degrees (Figures 15 and 16). For an approach angle of 90 degrees, the component of the approach velocity that is parallel to the face of the wing wall equals zero. The wing walls are set at a 40 degree angle from the centerline of the slip. Thus, a vessel that is moving parallel to the centerline of slip would have an approach angle of 40 degrees. At Edmonds, the dolphins confine the vessel so that most of its motion is parallel to the centerline of the slip. The approach angles that exceed 40 degrees may be the result of a sideways drift due to wind or current. Side thrust from the propeller due to rudder position is another possible cause for high approach angles.

The research team conducted an analysis to determine whether there was a relationship between the approach angle and the approach velocity. A scatter plot of approach velocity vs. approach angle (Figure 17) shows that no events occurred where the approach velocity was greater than 0.80 ft/sec and the approach angle was less than 25 degrees. Thus, higher approach velocities are associated with higher approach angles. Examination of the data set of 102 high deflection approaches reveals the same trend. These events had higher approach velocities (Figure 11) and higher approach angles (Figure 17) than did the data set of 568 events.

The location of the landing events was also reviewed. Visual inspection of Figure 18 reveals that most berthing events involve the first piles on either side of the wing wall's throat. The distribution between the north and south wing wall is similar. However, recall that the crews were asked to favor the south wing wall as they landed their vessels. The approach velocities V_{50} and V_{75} vary little in location, except for piles 7 through 10, which had few events (Figures 19 and 20). The approach angle is higher for most locations on the south wing wall than on the north wing wall (Figure 21).

Wind speed was available for 134 landings. Visual review of histograms indicates that higher approach velocities are associated with higher wind speeds (Figure 22). Researchers developed a contingency table and conducted a chi-squared analysis to

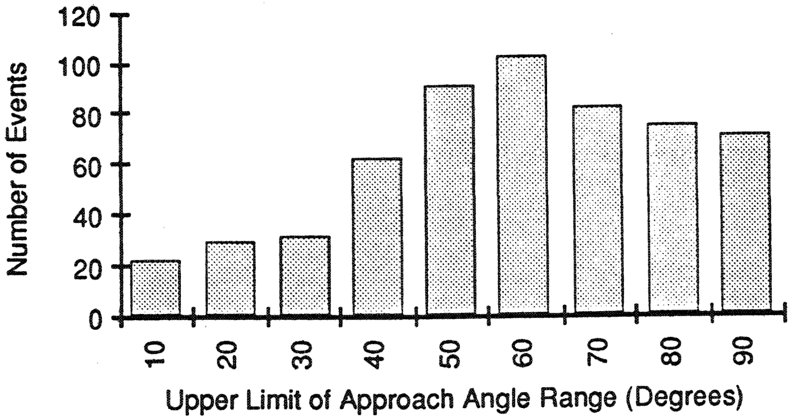


Figure 15. 568 Berthing Events

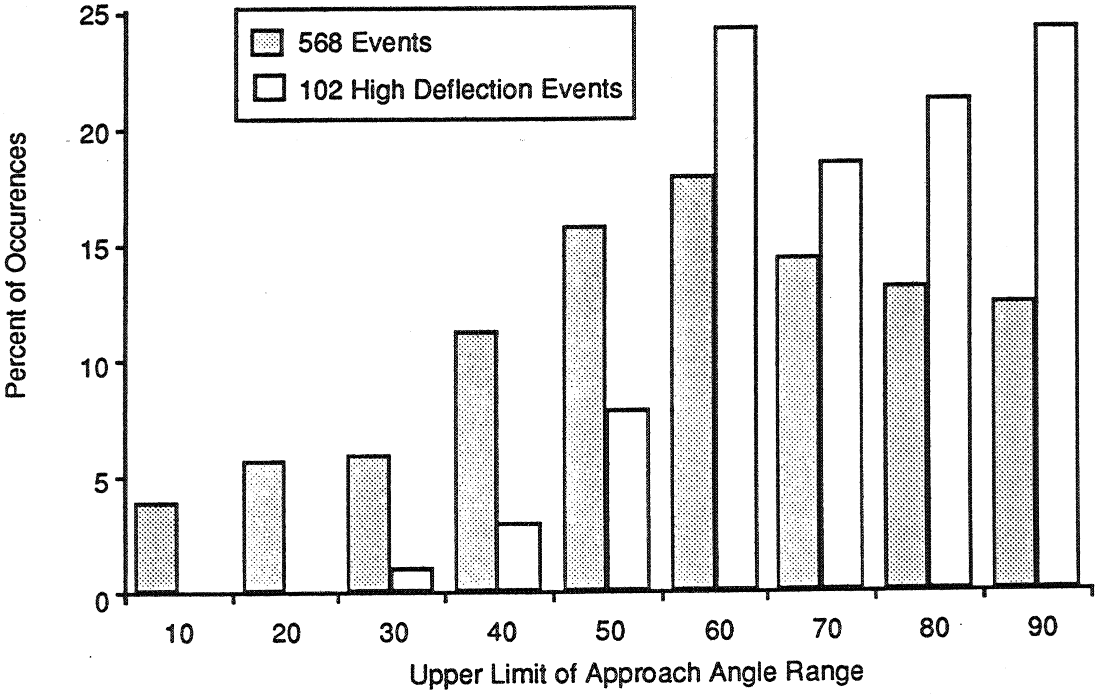


Figure 16. Approach Angle Distribution

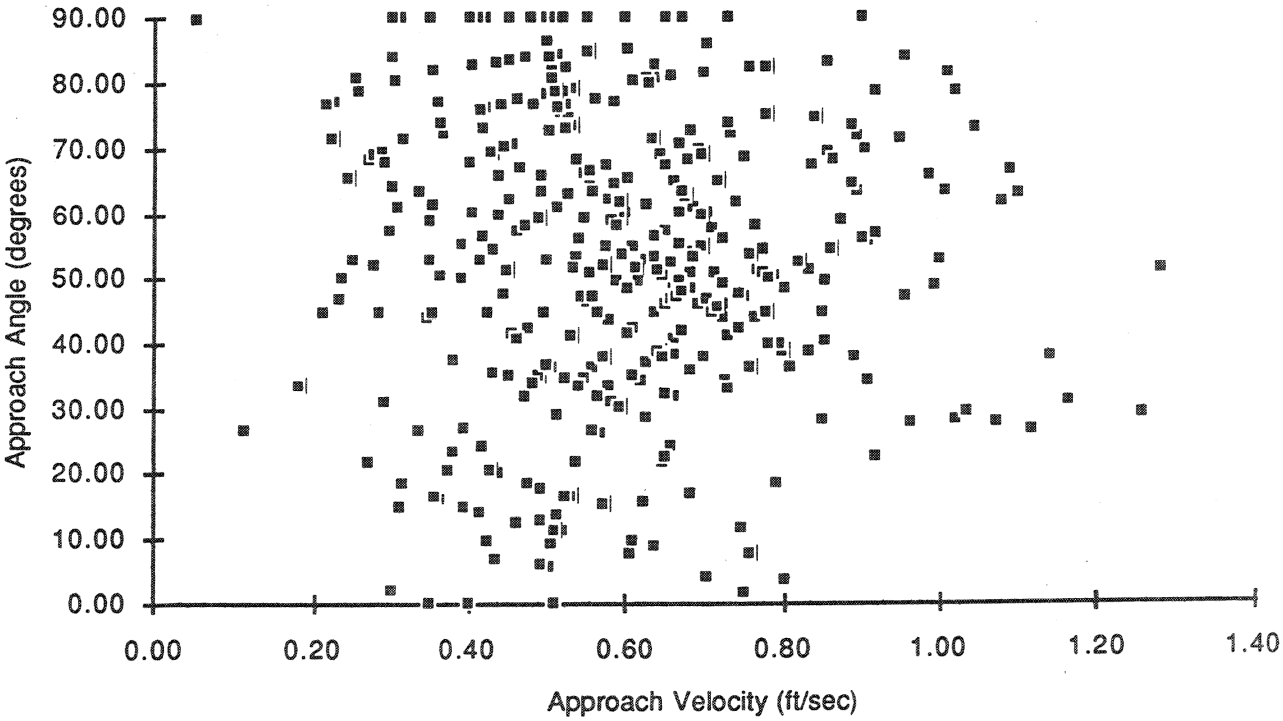


Figure 17. Approach Velocity vs. Angle - 568 Events

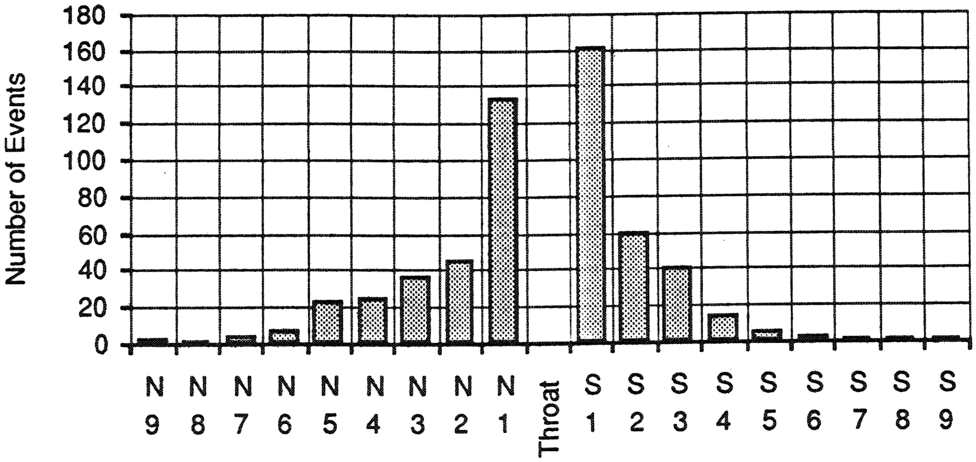


Figure 18. Location of Events by Pile Number, 568 Events

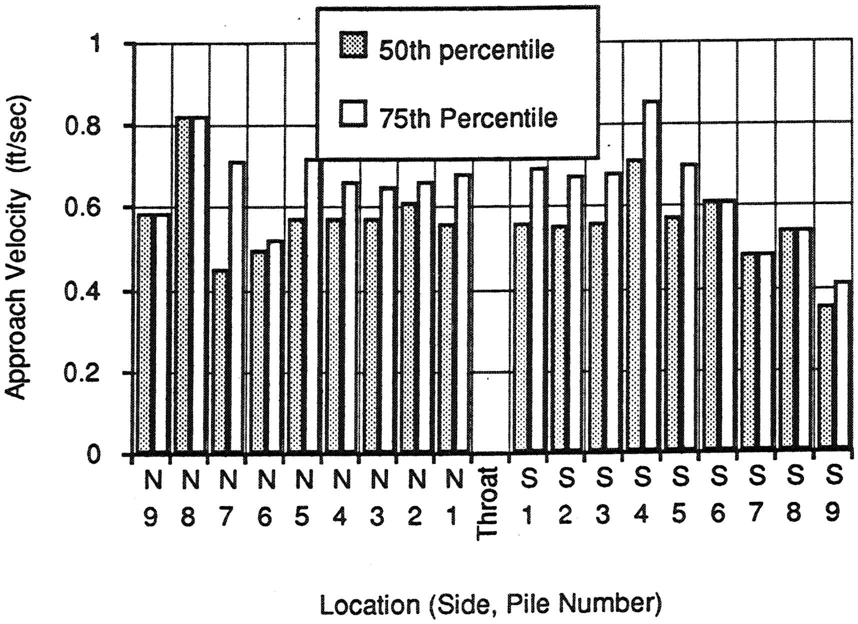


Figure 19. Total Approach Velocity by Location

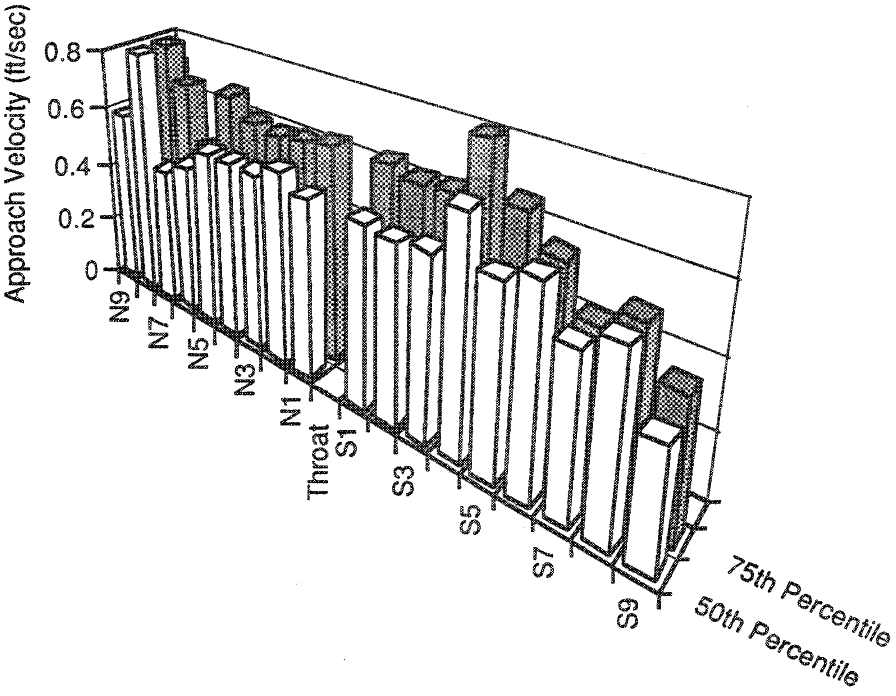


Figure 20. Perpendicular Approach Velocity by Location

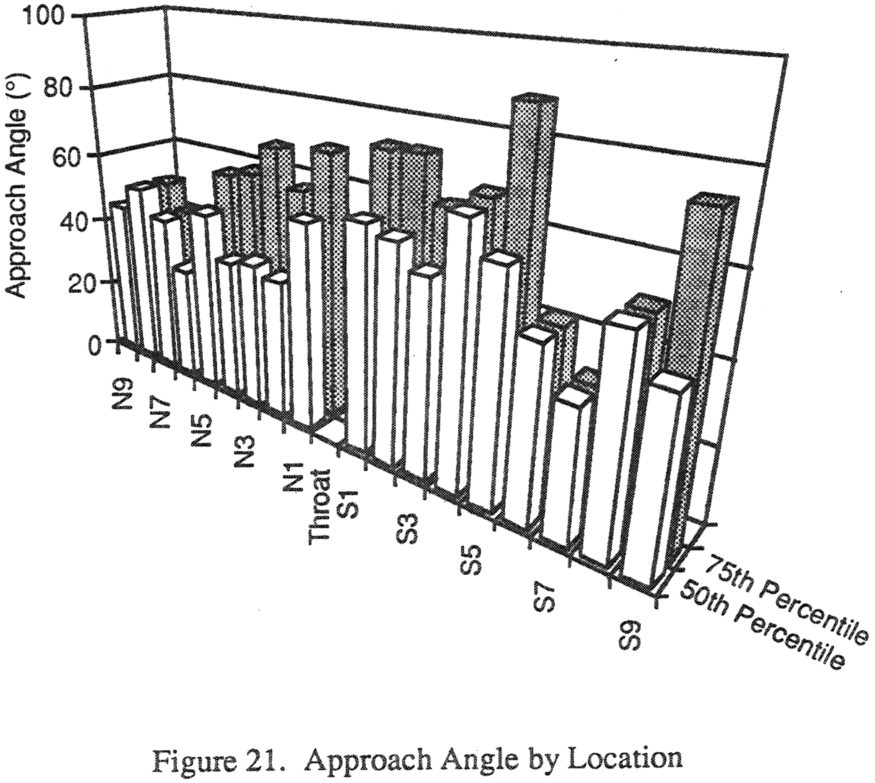


Figure 21. Approach Angle by Location

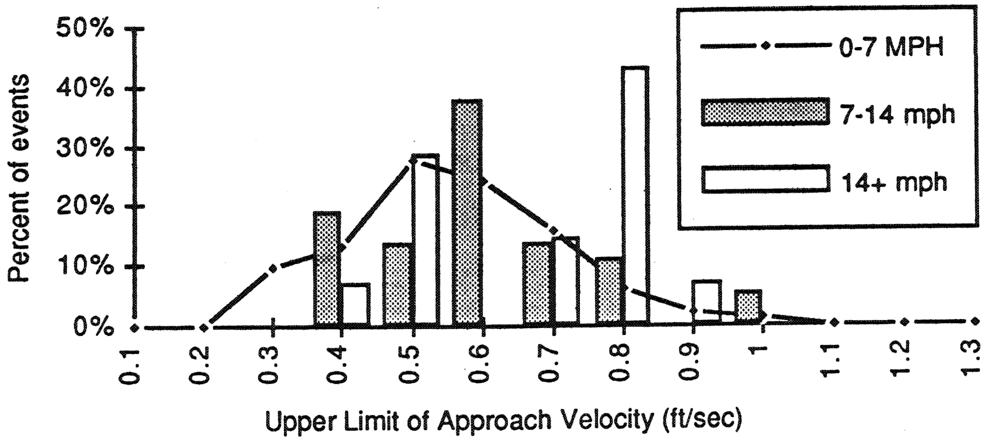


Figure 22. Approach Velocity Distribution for Various Wind Speeds

Table 5. Chi Squared Analysis of Wind Speed vs. Approach Velocity

	Wind Speed	'0-7	'7-14	'14-	Total
	Count	85	37	14	
Below 0.64 ft/sec	Expected (75%)	63.75	27.75	10.50	
	Observed	67.00	29.00	7.00	
	χ^2	0.17	0.06	1.17	1.39
Above 0.64 ft/sec	Expected (25%)	21.25	9.25	3.50	
	Observed	18.00	8.00	7.00	
	χ^2	0.50	0.17	3.50	4.17
				Total χ^2	5.55

Degrees of Freedom (DOF)
(Rows - 1) * (Columns - 1) = 2
Critical value of χ^2 @ $\alpha = 0.10$ for DOF = 2
➡ $4.60 < 5.55$

Therefore, approach velocity is not assumed to be independent of wind speed.

Table 6. Berthing Energy Observations

	$q(E_s)$ ft-kips	$q(E_V)$ ft-kips	$q(C_{est})$
Average	4.3	32.8	0.15
50th percentile (median)	2.1	28.6	0.11
75th percentile	9.2	45.4	0.30
Maximum	31.1	103.1	1.09

determine whether this visual indication was statistically significant (Table 5). They hypothesized that approach velocity was independent of wind speed. A fast landing was defined as one that exceeded $V_{75} = 0.64$ ft/sec for a sample of 134 events. The events were sorted into three categories: $W < 7$ mph, $7 \leq W < 14$, and $W \geq 14$. The chi-squared analysis showed that a greater proportion of fast landings occurred at times of higher wind speed. A hypothesis that approach velocity is independent of wind speed was rejected at $\alpha = 0.10$.

Berthing energy (E_s) was estimated from deflection measurements for 18 events. Measurements ranged from 0.3 ft-kips to 31 ft-kips. E_{s50} was 2.1 ft-kips ; values of berthing energy from velocity measurements ranged from 7 ft-kips to 103 ft-kips, while E_{V50} was 28.6. C_{est} ranged from 0.02 to 1.09 (except for one very low energy event in which $C = 2.75$ and $E_V = 0.29$ ft-kips). C_{est50} was 0.11. Other statistics are shown in Table 6. A scatterplot was developed showing E_S vs. E_V for each event (Figure 23). The line marked $C = 0.60$ serves as the upper bound for all but one event. The results indicated that there was considerable dispersion in C_{est} where

$$C_{est} = E_s/E_V$$

In addition to the factors specified for C in the definitions for Equation 2 (Appendix A), C_{est} is influenced by several other factors:

1. *The thrust of the propulsion system.* If the propulsion system is providing reverse thrust, it is dissipating a portion of the vessel's kinetic energy; thus, the wing wall may not be absorbing all of the vessel's kinetic energy. In most cases it was impossible to tell the extent to which reverse propulsions were used during the landing.

2. *Difficulties obtaining accurate deflection measurements.* Recall that the 90 percent confidence interval for deflection measurements was ± 1.5 in.

3. *Uncertainties in developing h(s).* $h(s)$ was calibrated by obtaining $g(s)$ after pulling on the wall in a perpendicular direction and measuring deflections at the top of the rubbing timbers. Actual berthing events cause force that is exerted parallel to the wall. As the wall deflects to mobilize resistance to these parallel forces, the wall's stiffness may change in the perpendicular direction. Additionally, the stiffness of the wall may depend on the speed at which the berthing forces were applied. The calibration tests did not account for energy that was absorbed by the face timbers.

The above factors are the likely cause of the dispersion of $q(C_{est})$.

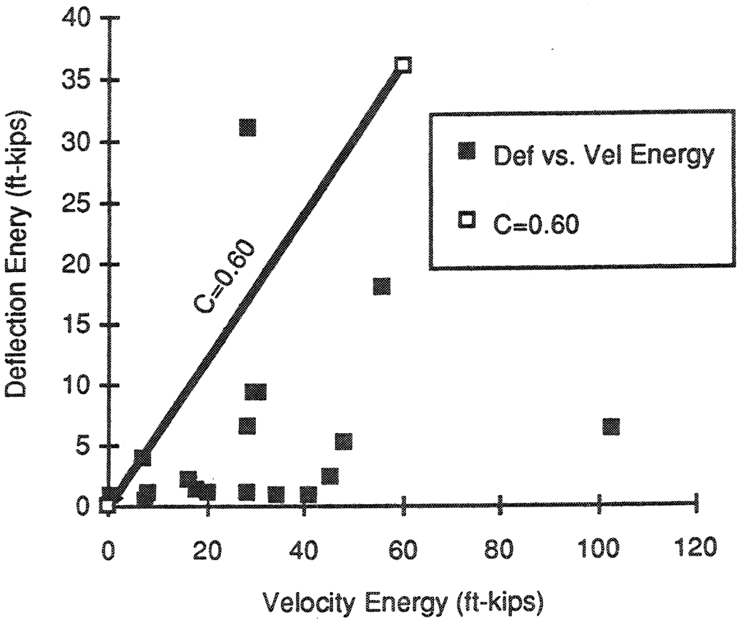


Figure 23. Deflection Energy vs. Velocity Energy

INTERPRETATION, APPRAISAL, AND APPLICATION

None of the recorded events caused visible damage to the structure; and so it seems reasonable that any ferry landing structures built in the future should be able to accommodate these events without damage. Therefore, $q(V)$ as developed by this study, is assumed to reflect the randomness of the approach velocity for ordinary berthing maneuvers. Unusual or catastrophic events might occur due to mechanical failure, such as the failure of the propulsion system as the vessel lands, or human error. Since reverse propulsion is required to stop the vessel, an accident is almost certain to occur in this circumstance. It is doubtful that the frequency or severity of such events can be predicted by analyzing $q(V)$ because the causes of events such as propulsion failures are different from the causes of random variation in $q(V)$.

In most cases, it is uneconomical to provide sufficient energy absorption to stop a vessel during a catastrophic landing without inflicting permanent damage on either the vessel or the fender system. However, Ishii developed concepts for innovative landing aids that may reduce the negative consequences of catastrophic landings under some circumstances. (4) Ishii suggested that it may still be possible to stop the vessel with minimum damage to the vessel, if the landing aid is destroyed during the collision — in such a case, the destruction of the landing aid allows the absorption of kinetic energy.

By considering three types of berthing events, it is possible to develop a set of appropriate design criteria:

1. **Type I — No Damage.** A fender system should perform adequately for most berthing events for its entire service life. Repairs are limited to normal maintenance.
2. **Type II — Repairable Damage.** A fender system may be damaged by unusually hard berthing events. Repairs are limited to replacement of a portion of the system. The system may be analyzed to identify probable repair requirements, and contingency plans may be made to accelerate the repair process.
3. **Type III — Catastrophic Damage.** A fender system and its supporting structure may fail during a catastrophic occurrence. If the

structure yields sufficiently, deceleration forces are limited as the vessel is brought to a stop; this would limit injuries and vessel damage. An example of a catastrophic occurrence would be a propulsion failure as the vessel applies reverse thrust to stop.

Engineers could develop wing wall design criteria for Type I berthing events for terminals similar to Edmonds on the basis of information from this study. Additional research will be required to develop design criteria for Type II berthing events and for all types of events involving dolphins. Ishii provided information that may be used to develop design criteria for Type III events for terminals similar to Edmonds.(4)

When design criteria are developed, both the load and the resistance of the structure are considered. The actual values of both the load and resistance are uncertain. Possible probability density functions for load, $q(S)$, and resistance, $q(L)$, are depicted in Figure 24. A prudent planner will design a structure so that its expected resistance will exceed most of the loads that it will experience. For a failure to occur, an unusually high load must be imposed on an unusually weak structure.

Manipulation of probability density functions is too difficult for day-to-day use with design criteria. Instead, point values (i.e., single numbers) are substituted for the probability distributions. In developing such design criteria, two questions must be asked:

1. What point values will be used to characterize the design load and design resistance?, and
2. By how much shall the design resistance be separated?

A common method is to select an unusually large load, S_l, and an unusually small resistance, R_s (Figure 24). The design is considered adequate if

$$R_s \geq FS_l \qquad (3)$$

where F = the factor of safety.

Table 7 lists some factors of safety that are currently used. Larger factors of safety are used in cases where $q(S)$ and $q(R)$ have large dispersions or where the consequences of failure are highly undesirable. For example, the recommended factor of safety for wire rope is 3.0 to 5.0 (Ref 5. on Table 7). The strength of wire rope is uncertain because it is

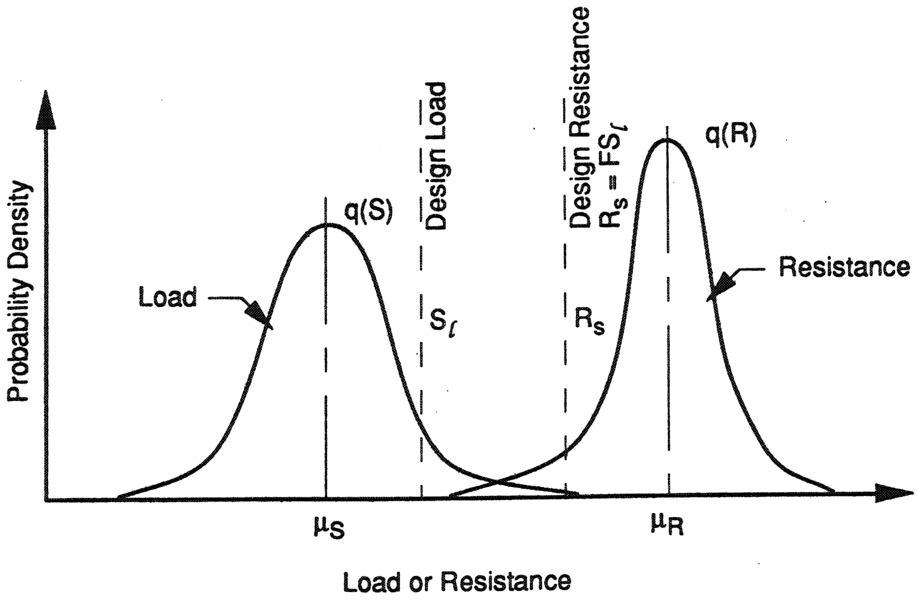


Figure 24. Development of Design Criteria from Probability Density Functions of Load and Resistance

Table 7. Safety Factors

Steel[1]		
Tension	1.67 - 2.22 (0.45f_y to 0.60f_y)	Allowable stress design
Shear	2.5 (0.40f_y)	
Bending	1.33 - 1.67 (0.60f_y to 0.75f_y)	
Steel[2]		
Dead load	1.2	Load and resistance factor design
Live load	1.5	
	Note: Stress reduction factor from ultimate stress is 0.90 in most cases.	
Concrete[3]		
Dead load	1.4	Load and resistance factor design
Live load	1.7	
	Note: Stress reduction factor from ultimate stress is 0.85 for shear and 0.90 for bending	
Cellular cofferdam[4]		
Permanent loads	1.5 to 3.0	Depending on failure mode
Temporary loads	1.25 to 3.0	
Seismic load	1.1 to 1.5	
Wire rope		
Rigging and Hoisting[5]	3.0 to 5.0	

---

[1] *Manual of Steel Construction, Allowable Stress Design*, 9th edition, American Institute of Steel Construction, Chicago, IL, 1989.

[2] *Manual of Steel Construction, Load and Resistance Factor Design*, 1st edition, American Institute of Steel Construction, Chicago, IL, 1986.

[3] ACI Manual of Concrete Practice, American Concrete Institute, Detroit, MI, 1979.

[4] U. S. Army, *Design of Sheet Pile Cellular Structures, Cofferdams, and Retaining Walls*, Draft, U. S. Army Corps of Engineers, Washington, D.C., not dated.

[5] *Wire Rope Users Manual* (Second Edition), Wire Rope Technical Board, Stevensville, MD, 1981.

subject to fatigue as it bends over pulleys, and deterioration as it is exposed to the environment. The load is uncertain because of the dynamic component of a suspended load. Failure is undesirable because death of or injury to a worker could result. By contrast, the factor of safety for steel or concrete design is lower because concrete strengths and building loads are more predictable and because the design profession has had considerable experience with these types of designs. If a failure occurs, it is likely that other members in a building will be able to support the load and prevent total collapse.

Using the factor of safety method, the design approach velocity, V_d, for Type I berthing events may be selected by

$$V_d = FV_n \tag{3}$$

where V_n = the approach velocity that exceeds n percent of the events

F = factor of safety.

The design is considered adequate if the kinetic energy that results from the design approach velocity does not exceed the design limits for the fender system.

As n becomes smaller, V_d is less influenced by the unusually high speed events that are observed during the data collection period, but if n is too small, the dispersion of $q(V)$ is not indicated in the results. As F is increased, the structure becomes more robust and is able to withstand a greater proportion of unusual events that are not included in $q(V)$. Little is known about the approach velocity distribution of such unusual events. Therefore, the selection of the factor of safety will be a matter of judgment rather than calculation. However, this process does result in more rationally-based design criteria because the design approach velocity is based on an upper percentile of the observed distribution of approach velocity, $q(V)$.

In many cases, structures that are developed according to such criteria will be able to survive events that exceed the design load, as.the failure strength for most materials exceeds their design strength. Also, in some cases, a limited failure might not compromise the usefulness of a structure. For example, the design load of a fender system may be defined to prevent yielding in the steel supporting piles. In this example, an unusually hard landing may *technically* cause failure in the pilings by bending them back an inch, but might *not impair the function* of the fender system.

Using the factor of safety method, the design berthing energy for Type I berthing events may be selected by

$$E_d \geq 1/2(w/g)\, C\, (F_V V_n)^2 \tag{5(a)}$$

where V_n = the approach velocity that exceeds n percent in $q(V)$, the probability distribution for approach velocity for normal landing events, and

F_V = factor of safety based on approach velocity.

V_n is an indicator of the dispersion of $q(V)$. Although a formulation involving the standard deviation could be used, V_n is preferred because it is more appropriate if $q(V)$ is a non-normal distribution. Alternatively, the design berthing energy could be selected by

$$E_d \geq [1/2\, (w/g)\, C\, V_n^2]\, F_E \tag{5(b)}$$

where F_E is the factor of safety based on the berthing energy.

Note that for equivalent designs, $F_E = F_V^2$. This is because the energy varies by the square of the velocity, thus doubling the velocity and quadrupling the energy. A factor of safety that is based on energy would result in smaller energy absorbing requirements for the same factor of safety. However, approach velocity as a concept can be understood and grasped more easily than berthing energy. For example, it would be easier to explain to a ship's master that the fender system was designed to accommodate twice the highest observed berthing velocity than twice the highest observed berthing energy. Furthermore, except under unusual circumstances, the ship's master can control the berthing velocity. Therefore, it is advisable to base the safety factor on approach velocity rather than berthing energy. Thus, F_V is the factor of safety that is discussed in this paper.

The following procedure is proposed for Type I events:

1. Obtain a sample of approach velocities, and note the parameters that describe the upper limits of the sample's distribution.

2. Select *n*. *n* must be large enough so that V_n responds to *q(V)*'s dispersion, but small enough so that V_n is not unduly affected by a few large measurements.

3. Select *F* by considering the following factors:

    a. Consider the importance of the landing structure. Are there alternative berths at the same landing? If there is only one berth, are there alternative modes of transportation (such as driving a longer distance around a body of water), or will a community, such as an island, be isolated without ferry service? Higher factors of safety should be provided for structures that have few alternatives.

    b. Consider environmental factors, especially wind and current, which may not have been present when the sample was taken. Time and budget limitations may prevent designers from obtaining a sample that represents extreme environmental conditions relevant to terminal design. Also, it may be necessary to use a sample from a different location with modifiers. The presence of adverse environmental factors may justify an increase in the safety factor because they increase the difficulty of the landing.

    c. Consider the time and cost required to repair the system. If repairs are easy and inexpensive, then the limit for Type I events can be lowered. If repairs are difficult and expensive, then the limit for Type I landings can be raised.

    d. Consider the vessel's maneuverability and reliability. Higher safety factors should be considered when vessel problems occur frequently.

    Tables should be developed to guide designers in the selection of *F* as they consider these factors. As *F* is selected, the design should receive input from a multi-disciplinary committee that can help to evaluate trade-offs between economy, safety, and service reliability.

4. Select *C* by Equation 2.

5. Calculate E_d by Equation 5(a).

EXAMPLE APPLICATION OF PROPOSED DESIGN METHOD

This section provides a set of example calculations for design criteria for the Edmonds Ferry terminal. The factors of safety that are used in this example are for illustration purposes. Although they serve as a starting point for further discussion and research, these example safety factors should be reviewed by designers and vessel operators before they are adopted as design criteria.

None of the events recorded in the Edmonds sample caused visible damage to the structure. It seems reasonable that any future ferry landing structures should be able to accommodate such landings without damage. Therefore, the case study's sample provides an appropriate basis upon which design criteria for Type I events can be developed.

The next step is to select a value for n. Recall that n must be large enough so that V_n responds to $q(V)$s dispersion, but small enough so that V_n is not unduly affected by a few large measurements. Several subsets of $q(V)$ are shown in Table 3. V_{95} varies little from one subset to another, yet it serves as an indication of $q(V)$s dispersion. Therefore,

$$n = 95$$

Discretion must be exercised in selection of the factor of safety (F) so that it provides a sufficiently robust design. Consideration of the following facts will be helpful in selecting a safety factor. Arguments for a larger safety factor include

1. little is known about the approach velocity distribution for unusual events, and
2. ferry landings withstand an unusually large number of berthing events compared to other port facilities.

Arguments for a smaller safety factor include

1. the facility may be able to function after a landing in which the design velocity was exceeded because the ultimate strength of material may exceed the design strength or because a small failure might not impair the function of the facility, and
2. life safety issues are unlikely to be involved in Type I events (although they will be a consideration for Type II and Type III events).

Since the arguments for larger and smaller factors of safety are evenly split, a basic factor of safety of $F_b = 2.0$ is a possible starting point. This is similar to many engineering factors of safety (Table 7), but this factor of safety should be modified according to the previously mentioned considerations. Researchers will have to use further judgment to select the modification factors; Table 8 offers possible guidelines that could be used. (The values in Table 8 are provided only to illustrate the method.)

Table 8. Example of Safety Factor Modifiers

$$F = F_1 \times F_2 \times F_3 \times F_4 \times F_b$$

Modifier	Unfavorable	Neutral	Favorable
F_1 = Importance	F_1 = 1.125 if the ferry slip is the only surface transportation access for an island. F_1 = 1.125 if the ferry slip is the only one at a terminal where inconvenient detours would be required in case of a shutdown.	F_1 = 1.0 for the main slip at a multi-slip terminal.	F_1 = 0.875 for an auxiliary slip at a multi-slip terminal.
F_2 = Environmental	F_2 = 1.125-1.50 if the sample of berthing events does not include severe environmental conditions that are known to increase the approach velocity.	F_2 = 1.00 if the sample is representative of significant environmental conditions.	F_2 = 0.75-0.875 if severe environmental conditions present in the sample are not present at the landing (e.g. the sample was collected at a location with more severe conditions, or improvements are made to eliminate wind and current).
F_3 = Repair factor	F_3 = 1.125-1.250 if repairs are expensive and difficult, requiring mobilization of heavy construction equipment and long shutdowns for the slip.	F_3 = 1.0 if repair involves slip closures for less than a day and construction equipment is mobilized with little difficulty.	F_3 = 0.875 if repair does not close the slip and construction equipment is easily mobilized.
F_4 = Vessel factor	F_4 = 1.125-1.250 if vessels are unreliable or difficult to maneuver.	F_4 = 1.0 if vessels have average maneuverability and reliability.	F_4 = 0.875 if vessels are highly reliable and easily maneuvered.
F_b = Basic factor of safety	For this example, F_b = 2.000		

The factor of safety (F) for the Edmonds Ferry Terminal can be selected in the following manner:

1. This terminal has only one slip, so if the landing structure is closed, the Edmonds to Kingston route cannot operate. Vehicles can detour by driving around the Sound or by taking one of four other ferry crossings. Thus, the importance modifier —

   $$F_1 = 1.125$$

2. The wind and current conditions are moderate, neither easy nor difficult. (4) The sample from Edmonds displayed a wide range of environmental conditions. Therefore,

   $$F_2 = 1.000$$

   Ishii conducted a survey in which WSF's on-board employees rated the relative difficulty of the terminals (Table 9). The results provide researchers guidance in applying the Edmonds sample elsewhere.

3. Suppose that the fender system is designed to fail by destroying a part that can be repaired with a crew consisting of a small barge-mounted crane and a crew of six. Such crews are readily available, and the barge can be positioned so that the slip is not closed. Therefore,

   $$F_3 = 0.875$$

4. The vessels that use the Edmonds Ferry Terminal received ratings that indicated they were slightly more difficult to control than other vessels in WSF's fleet (Table 10). Therefore,

   $$F_4 = 1.125$$

The resulting safety factor is:

$$1.125 \times 1.000 \times 0.875 \times 1.125 \times 2.000 = 2.215, \text{ say } 2.2$$

Two different approach geometries should be considered. The approach velocity and berthing coefficient will differ depending on the geometry selected.

In Case i, the vessel lands in the throat and is stopped by both walls simultaneously (Figure25(a)). The fenders near the throat should be designed to withstand a Case i event.The wing walls must stop the vessel's total kinetic energy because little rotation may occur after the landing; therefore, $C_e = 1.0$. Since the fender system's combined reaction is directly opposite the line of travel, the vessel's total velocity [$q(V)$] should be considered as a design velocity.

Table 9. Ratings of Difficulty of Terminals

Terminal	Mean
Anacortes	4.6
Lopez	3.8
Orcas	3.3
Shaw	3.9
Friday Harbor	2.9
Keystone	6.5
Port Townsend	2.9
Mukilteo	3.8
Clinton	3.0
Edmonds	3.2
Kingston	2.8
Seattle	2.2
Winslow	2.2
Bremerton	2.1
Fauntleroy	2.9
Vashon Heights	2.7
Southworth	3.5
Tahlequah	5.7
Point Defiance	3.6

Table 10. Questionnaire Responses Regarding Vessel Characteristics

Class	**Controllability[1]**	**Reliability[2]**
Jumbo	2.2	1.9
Super	3.1	2.6
Issaquah	1.9	3.6
Evergreen State	2.5	2.8
Steel Electric	2.6	3.0
Rhododendron	4.1	3.6
Olympic	4.0	3.8
Hiyu	2.5	2.7

Rating Scheme:
1 = Easy to land
7 = Difficult to Land

[1] Response to the question: "Which vessels are easiest to control during landing? (Assuming there are no mechanical failures.)

[2] Response to the question: "Which vessels give you the greatest confidence during the landing maneuver?" (Consider the vessel's reliability as well as the vessel's handling characteristics.)

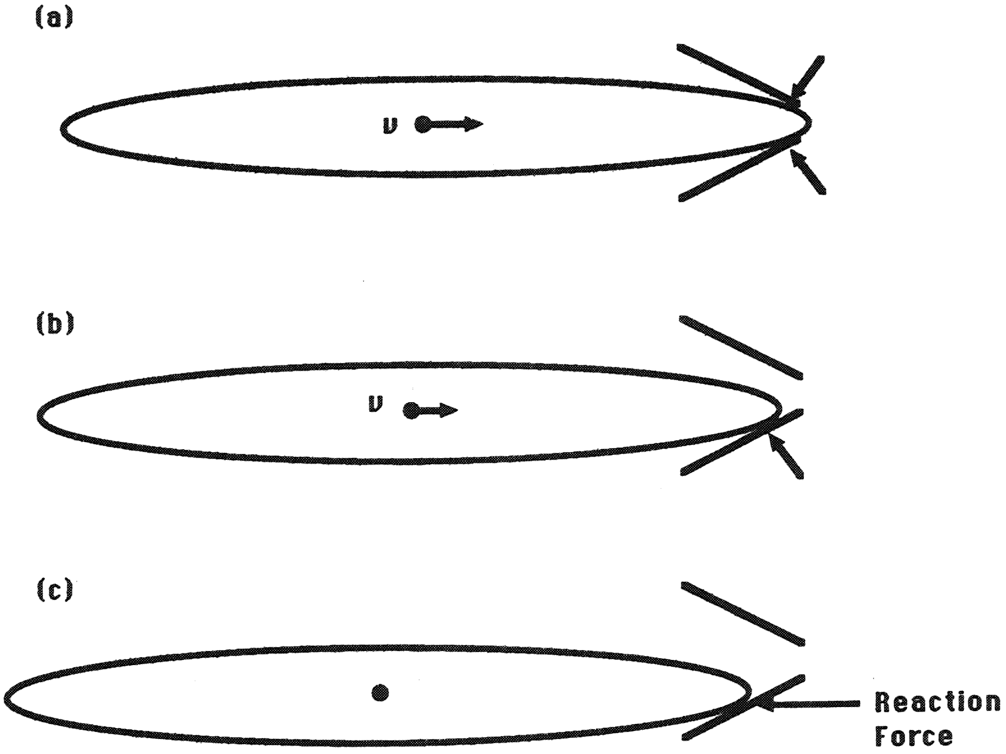


Figure 25. Three Cases for Wing Wall Design

Therefore, the Case *i* design approach velocity is:

$$0.91 \times 2.2 = 2.002, \text{ say } 2.0 \text{ ft/sec}$$
$$(0.28 \times 2.2 = 0.616, \text{ say } 0.62 \text{ m/sec})$$

The other factors in the berthing coefficient are selected as follows:

- For end-berthing vessels, such as those used by WSF, PIANC states that $C_m = 1.0$. (4)
- Since the terminal structures at Edmonds do not trap water for a cushioning effect to occur, $C_b = 1.0$.
- Since WSF's vessels have a rigid belt rail that engages the fenders, little energy will be absorbed by the vessel; therefore, $C_s = 1.0$.

The resulting berthing coefficient is:

$$C = 1.0$$

The Case *i* berthing energy for a Super Class Vessel (displacement = 3,283 lt or 3,335 mt) is:

$$1/2 \times (3283 \times 2240/32.2) \times 2.0^2 = 456{,}765 \text{ ft-lb, say } 460 \text{ ft-kips}$$
$$(1/2 \times 3335 \times 0.62^2 \approx 642, \text{ say } 640 \text{ kNm})$$

(Note: 640 kNm = 460 ft-kips due to differences in rounding numbers.)

In Case *ii*, the vessel hits one wing wall and bounces off, setting the vessel in rotation (Figure 25(b)). The fenders in the middle and outer ends of the wing wall should be able to withstand a Case *ii* event.

Unless the fenders' reaction force is in line with the vessel's center of gravity (Figure 25(c)), the vessel will rotate. Also, the vessel will usually slide along the wing wall. It is possible, but unlikely, that no rotation will result from the impacts that $C_e = 1$. However, designing for C_e would result in an extremely conservative design because the simultaneous occurrence of the design speed and the reaction force acting on a line through the center of gravity is an extremely unlikely event. Experimental evidence from this study shows that 0.60 is an upper bound for the berthing coefficient.

The velocity's component that is normal to the face of the wing wall is considered in fender calculations. Therefore, the vessel's perpendicular velocity [$q(V_{perp})$] should be considered as a design velocity is selected. Therefore, the Case *ii* design approach velocity is

$$0.75 \times 2.2 = 1.65, \text{ say } 1.6 \text{ ft/sec}$$
$$(0.23 \times 2.2 = 0.506, \text{ say } 0.51 \text{ m/sec})$$

The Case *ii* berthing energy for a Super Class Vessel (displacement = 3,283 lt or 3,335 mt) is

$$1/2 \times (3283 \times 2240/32.2) \times 0.6 \times 1.6^2 = 175{,}348 \text{ ft-lb, say } 175 \text{ ft-kips}$$
$$(1/2 \times 3335 \times 0.51^2 \times 0.6 = 258, \text{ say } 260 \text{ kNm})$$

(Note: 260 kNm ≅ 175 ft-kips due to differences in rounding)

CONCLUSIONS AND RECOMMENDATIONS

This section summarizes the findings of this project, gives recommendations, and outlines future implementation and research.

The findings of this project indicate that the *q(V)* for the wing walls is not affected by the size of the vessel, summer vs. winter conditions, or the side of the wing wall (north vs. south). The wind speed appears to have some influence on the berthing event at the wing walls. Conversations with crew members, visual observations, the results of the literature review, and intuition would suggest that wind would have a more pronounced influence on the approach velocity. The wind's effect may be limited at the wing walls but more pronounced at the outer landing aids, such as the dolphins. Contacts with these structures were not recorded by the CCTV system because this study focused on the wing walls. The difficulty posed by the wind could result in awkward vessel positions, or in decisions to abort the landing before the vessel is close to the wing wall, rather than result in higher approach velocities. It would be useful to monitor the approach of vessels for greater distances to observe their complete approaches.

Ishii developed a procedure to estimate the maximum landing velocity of a vessel for a Type III event that is initiated by a propulsion failure. (4) The procedure involved examining video images to estimate the velocity distribution at 500 ft from the landing; the research team assumed that three standard deviations above the average velocity is the maximum credible velocity at that point. Drag resistance was estimated and final approach velocity was calculated from the equations of motion. The resulting design approach velocity was 17 ft/sec. This is recommended as the Type III design approach velocity for terminals that are similar to Edmonds. Other terminals will have other design approach velocities depending on local circumstances. For example, at Winslow, vessel speeds are restricted in order to reduce wake. Thus, the Type III design approach velocity will be lower there.

This study has developed design criteria for Type I and Type III berthing events for wing walls. However, to gain a better understanding of the berthing process and to develop design criteria for other landing aids, a broader view is required. In an on-going project, researchers will monitor the last 2,000 ft (600 m) of the vessel's approach. A Global Positioning System operating in differential mode will track the vessel's position and velocity. The vessel's heading, the wind speed, and the wind direction will also be recorded concurrently. When possible, researchers will take notes on the vessel's operation while data are being collected.

The data will be analyzed to find the range of velocity and position for several berthing events. The results will be displayed on maps of the terminal area with lines tracing the path of the vessel to the berth. Indications of the vessel's heading and velocity will also be provided.

The same type of consideration should be given to vessel characteristics as the geometry and design of landing structures are developed. Geometry and design considerations are made when parking lots, bus terminals, and loading docks are designed. A set of guidelines similar to AASHTO Design Criteria should be developed for ferry terminals. The results of GPS tracking experiments along with information on vessels obtained from the literature could be used to develop such criteria.

In developing design criteria for Type II and III events, incidents involving high speed collisions should also be considered. Fortunately, such incidents are rare, and it is unlikely that any incidents of this type will be observed during the study period. Instead, design velocities will be developed on the basis of hypothetical incident scenarios. The results of GPS observations will be analyzed to define credible, but unusual, combinations of vessel position, speed, and heading that will mark the start of the hypothetical incident. The hypothetical incident could be initiated by mechanical failure, severe environmental conditions, or human error. Calculations will be developed to estimate the approach velocity that results from the incident. Recommendations will also be developed regarding the placement of landing aids to improve the berth's safety.

CONCLUSIONS

A rational framework for ferry landing fender design has been presented. Fenders should be designed so that no damage occurs during normal events, yet to yield in the case of catastrophic events to minimize structural damage to the vessel and personal injuries. Design criteria for normal events are based on the upper limit of an approach velocity sample. A safety factor is selected by making systematic judgments pertaining to the importance of the structure, environmental factors, time and cost of repairs, and vessel characteristics. The result is a design berthing energy for the fender system.

Designers may use the Edmonds Ferry Terminal Case Study as a point of comparison for their own samples. The following conclusions were drawn:

- The distribution approach velocity, $q(V)$, for wing walls at Edmonds has an average of 0.58 ft/sec and a 95th percentile of 0.91 ft/sec. The maximum observed approach velocity was 2.0 ft/sec.
- The displacement of the vessel and winter vs. summer conditions have little effect on the distribution of approach velocities at the wing walls.
- Wind speed has some effect on the approach velocities at the wing wall.
- Most of the berthing events occur at the piles near the throat.
- Most of the approach angles exceeded 45 degrees.
- Few low approach angles were observed with higher approach velocities.
- It is difficult to obtain estimates of the berthing energy by observing the deflection of the existing wing wall system with a video camera. Uncertainties include calibration of the force vs. energy relationship for the wing wall and estimation of the deflections. The stiffness of the wing wall may be dependent on time and the nature of the impact.
- $C = 0.60$ appears to be an upper bound for the berthing coefficient for an impact with one wing wall.

RECOMMENDATIONS

The following recommendations are made:

- The design criteria for ferry landing structures should be developed according to three types of berthing events:

    1. **Type I — No Damage.** A fender system should perform adequately for most berthing events for its entire service life. Repairs are limited to normal maintenance.

    2. **Type II — Repairable Damage.** A fender system can be damaged by unusually hard berthing events. Repairs are limited to replacement of a portion of the system. The system can be analyzed to identify probable repair requirements, and contingency plans may be made to accelerate the repair process.

    3. **Type III — Catastrophic Damage.** A fender system and its supporting structure can fail during a catastrophic occurrence. If the structure yields sufficiently, deceleration forces are limited as the vessel is brought to a stop; this would limit injuries and vessel damage. An example of a catastrophic occurrence would be a propulsion failure as the vessel applies reverse thrust in order to stop.

- The design berthing energy should be based on the upper limits of a sample of berthing events, multiplied by a safety factor.

- The safety factor should be varied according to the importance of the structure, ease of repair, vessel reliability, and environmental conditions not included in the sample.

- Further research should be conducted to approach velocity distributions for locations other than Edmonds, and for structures other than wing walls.

- The distribution for berthing energy should be developed by observing deflection on fender systems that allow better deflection vs. energy calibrations.

- Further research should be conducted to develop design criteria for Type II and Type III events. Historical records should be consulted to develop a model for predicting severe accidents.

- WSDOT should review these recommended design criteria and develop a design manual for ferry landings.

IMPLEMENTATION

Many technology transfer activities took place during the course of this project. Meetings with WSF designers were held to present intermediate results. These intermediate results have been used to develop revised wing wall designs for the Kingston landing and other locations.

The application section outlines a recommended approach for the development of rational design criteria for WSF. This approach should be reviewed by WSDOT's marine division and considered for formal adoption. A ferry landing design manual should be developed for WSDOT staff and design consultants retained by WSDOT. The design manual should include the following:

- procedures for selecting the location of landing aids,
- standard drawings and designs for typical structures at a ferry landing,
- design criteria,
- vessel information,
- characteristics of each terminal:
    - wind
    - current
    - bathimetry
    - vessel schedule
    - upland facilities
    - existing landing aids

Such a manual would serve as a comprehensive, invaluable aid for ferry landing design. It may also serve as a model document for other organizations that design ferry landings.

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APPENDIX A

STATE-OF-THE-ART SURVEY

APPENDIX A

STATE-OF-THE-ART SURVEY

A survey of state-of-the-art ferry landing design and construction was conducted as part of the research for developing ferry landing design criteria. This survey included a literature review and visits to ferry landings in British Columbia, Alaska, Denmark, Sweden, and Norway. The results of this survey are described herein.

Fender systems must absorb the kinetic energy associated with a vessel's approach velocity. The kinetic energy, KE, of a vessel is calculated as follows:

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

where w = weight of vessel,

V = approach velocity (usually the component normal to the face of the fender system),

g = acceleration of gravity, and

C = a coefficient that accounts for the vessel's approach angle, the eccentricity of impact, and various hydrodynamic effects. (1, 2, 3)

Because kinetic energy varies with the square of the velocity, proper selection of the design velocity is imperative. Most references include tables or graphs that provide a design velocity as a function of the vessel's displacement and the degree of environmental exposure at the berth. For large ships, PIANC recommends the following design approach velocities: (3)

1. very favorable conditions: 10 cm/sec,
2. in most cases: 15 cm/sec, and
3. very unfavorable conditions with cross currents and/or much wind: 25 cm/sec.

PIANC cautions that the probability of exceeding these design approach velocities "appears to be rather high." With regard to ferries, PIANC suggests increasing the design velocity by 15 percent to 20 percent . (3)

Some ferry systems use guiding or side fenders. Typically they are placed along the berth for one ship length from the throat or end fenders. Instead, Washington State Ferries (WSF) uses pile dolphins or floating dolphins. PIANC recommends that side fenders be designed with an approach angle of 15 degrees. PIANC reports the use of the following design approach velocities for European ferry landings: (3)

1. Seaward end: 1.5 to 3.0 m/sec
2. Landward end: 0.5 to 1.0 m/sec

The above velocities are total velocities, rather than the component normal to the face of fenders. PIANC also affirms that 50 cm/sec is an adequately conservative design velocity for end fenders.

The coefficient C is calculated by:

$$C = C_e C_m C_b C_s \qquad (2)$$

where C_e = eccentricity factor
C_m = mass factor
C_b = configuration factor
C_s = softness factor

The eccentricity factor, C_e, is provided to account for the reduction in the amount of energy that must be absorbed when a vessel has an eccentric impact. If a vessel is performing a side berthing maneuver and the bow or stern impacts the fender system, the vessel begins to spin around its center of gravity. Some of the kinetic energy is transferred to this spinning motion instead of being absorbed by the fender system. Calculated values of C_e vary according to the geometry of the berthing event. If a vessel heads directly into the throat of the wing walls, $C_e = 1.00$. If a vessel stops just short of the wing walls and then moves sideways because of wind or current, C_e is much lower, possibly as low as 0.10.

The factor C_m is provided to account for the entrained water that is carried into the berth with the ship. The movement of this water must be stopped along with the movement of the vessel. WSF ferries make end-on landings. PIANC (3) states, "For determining the mass factor, only the actual displacement of the vessel should be taken into account, since hydrodynamic effects associated with axial ship motion are very small," therefore, $C_m = 1$. (3)

The factor C_b is provided to account for energy that is absorbed by water trapped between the side of a vessel and a continuous landing structure (e.g., retaining wall or solid bulkhead). WSF landings have no structures that tend to trap water as a vessel berths, therefore, $C_b = 1$.

The softness factor, C_s, represents the proportion of energy absorbed by deflections of the fender system vs. deflections of the vessel's hull. Car ferries typically have rub strips that contact the fenders. These rub strips are an extension of the car deck, making the hull very stiff in relation to the fender system. For ferries, $C_s = 1.0$.

PIANC describes a statistical approach for designing fender systems. A cumulative probability distribution for the berthing energy, $Q(E)$, is developed by observing several berthing events. The berthing energy, E, is estimated by observing the deflections in the fendering system and knowing the energy vs. deflection relationship. If $Q(E)$ matches a known probability distribution (e.g., normal or lognormal), and if the design life and the number of berthing events are known, a relationship between E and the probability of excess can be developed.

By reviewing the results of several studies, PIANC developed a database of 4,926 berthing events involving bulk cargo ships with displacements ranging from 15,000 metric tons to 400,000 metric tons. (3) On the basis of this data, researchers concluded that $Q(E)$ can be approximated by a lognormal distribution, and that current condition and displacement were the parameters that had the most influence on the berthing energy. In selecting a design energy, PIANC suggests that designers consider two situations: (3)

1. the ordinary (but rare) design situation that should lead to no damage and no excess of the allowed maximum deformations of the elastic fender units (i.e., at working stresses); and
2. a critical situation corresponding to the maximum energy that can be absorbed in the fender and the supporting structure at yield (i.e., at yield stresses and without any factors of safety).

PIANC states that a risk factor of 63 percent may be acceptable for requiring major repairs to the fender system during the system's lifetime.

The impulse response function (IRF) is a numerical method that accounts for interactions between the vessel, the surrounding water, and the fender system in a precise and systematic manner. (4, 5) This has been confirmed by model tests and some full scale tests. (5) This method is more mathematically complex than the Kinetic Energy method and has not gained widespread acceptance as a design method. However, it is potentially useful for side berthing shallow-draft situations in which entrained water (C_m) is significant.

Pankchik and Ladegaad describe the ferry landing design criteria for Danish State Railways and the procedure that was used to design a new landing facility at Helsingør, Denmark. (6) Computer simulation of vessel approaches was an important part of the design procedure.

In a related project, Ishii surveyed WSF's on-board staff to learn how environmental factors, types of vessels, and locations of landings influence the approach velocity. (7) He found that wind, current, and fog were the environmental factors that most influenced the approach velocity. Terminals with strong, unpredictable currents were the most difficult to land. On a scale of one to seven, the most difficult terminal received an average rating of 5.7, while the easiest terminal received a rating of 2.1. Most vessels were described as being relatively easy to land. Respondents indicated a desire for a landing structure that could safely absorb emergency impacts associated with propulsion failures.

SCANDINAVIA

Several ferry terminals have recently been constructed in Denmark, Sweden, and Norway. Some of these terminals were visited to assess state-of-the-art ferry terminal construction in Scandinavia (Figure A-1).

In most cases, the vessels berth against massive concrete wharves that are shaped to fit the vessel (Figure A-2). Alternatively, the fender units are mounted on steel piles or cellular sheet pile structures. Fender units consist of steel panels and rubber, energy absorbing elements. The steel panels are designed as a closed box. They are faced with UHMW-PE (ultra-high molecular weight polyethylene) to reduce the coefficient of friction, thus reducing shear forces when the vessel slides along the fender. MV fender elements are arranged in "V" patterns and absorb energy by deforming, as shown in Figure A-3.

The contact pressure for ferries that have belt rails is concentrated on a narrow horizontal slice of the panel. If contact is near the top or the bottom of the panel, only one set of fender elements compresses, thus, only one set of elements participates in energy absorption (Figure A-4). In extreme cases, one end of the panel may strike the hull of the vessel. Two methods have been developed to address this problem. (6) The first method involves mounting the fender panel on a support that extends to a hinge located at the dredge line (Figure A-5). With this design, both fenders must deform equally and share in absorbing energy. Also, rotation at the point of contact with the belt rail is limited. This design was used for the passenger and car ferry terminal in Helsingør, Denmark, and for the truck, car, and passenger ferry terminal in Trelleborg, Sweden.

An alternative method for addressing the rotation problem is to provide hinges on a vertical axis on one side of the fender panel. The other end of the hinge is anchored to the mounting structure for the fender unit (Figure A-6). The hinge prevents rotation at the contact point in the same way hinges on a door prevent the top from moving unless the bottom moves. (Another example is if a salesperson puts their foot in the door, one cannot

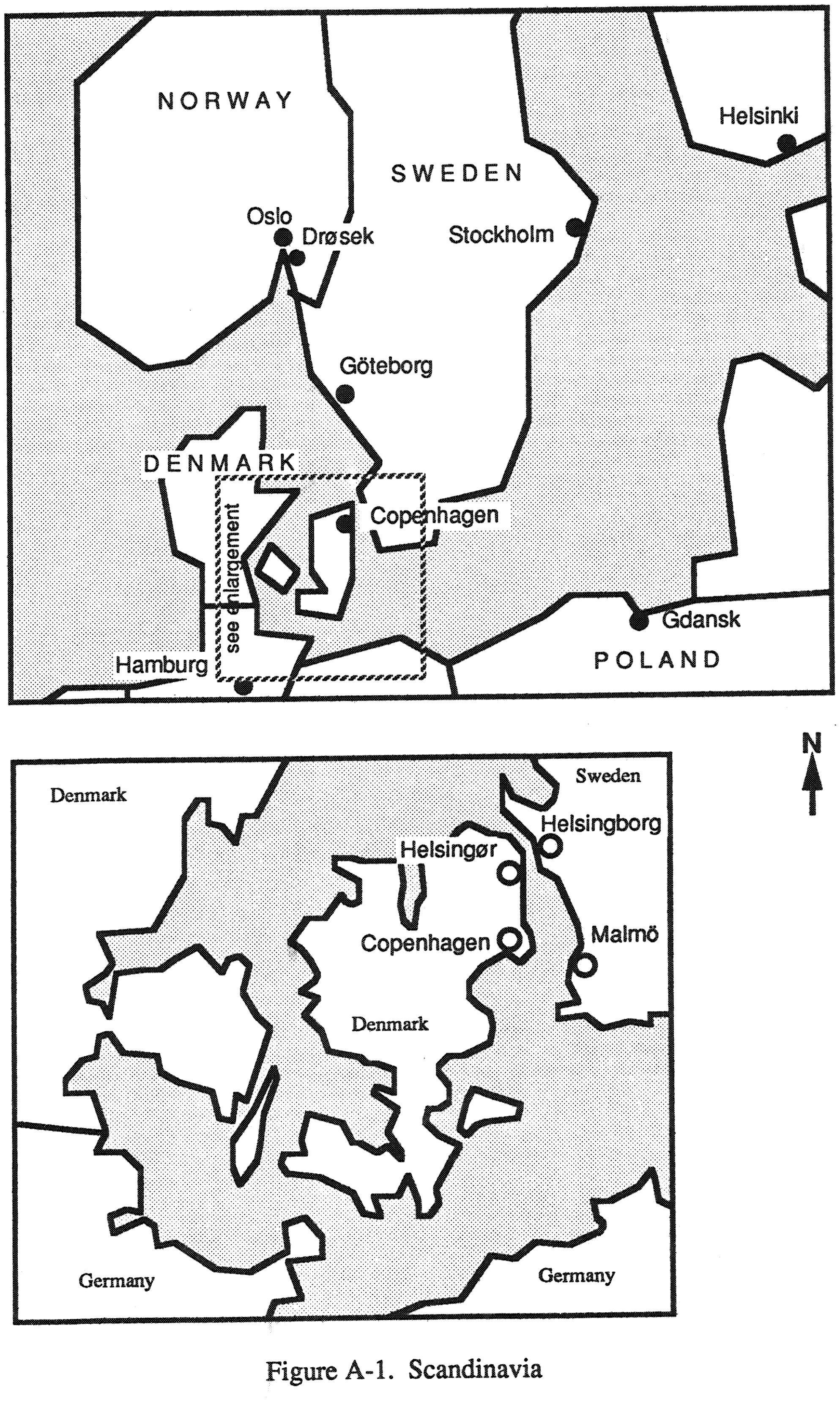

Figure A-1. Scandinavia

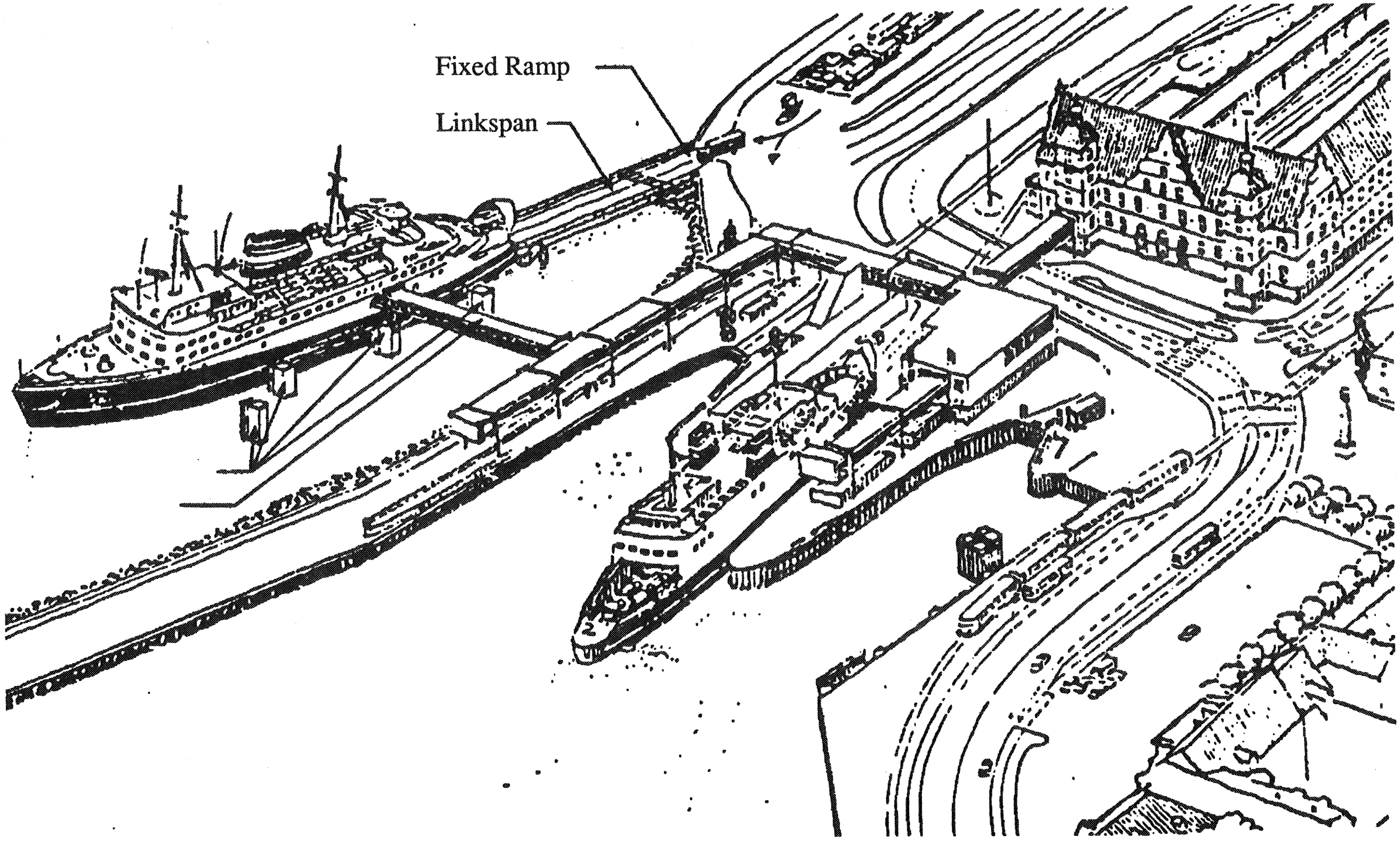

Figure A-2. Danish State Railways Ferry Terminal at Helsingør (source: Skaarup and Jespersen)

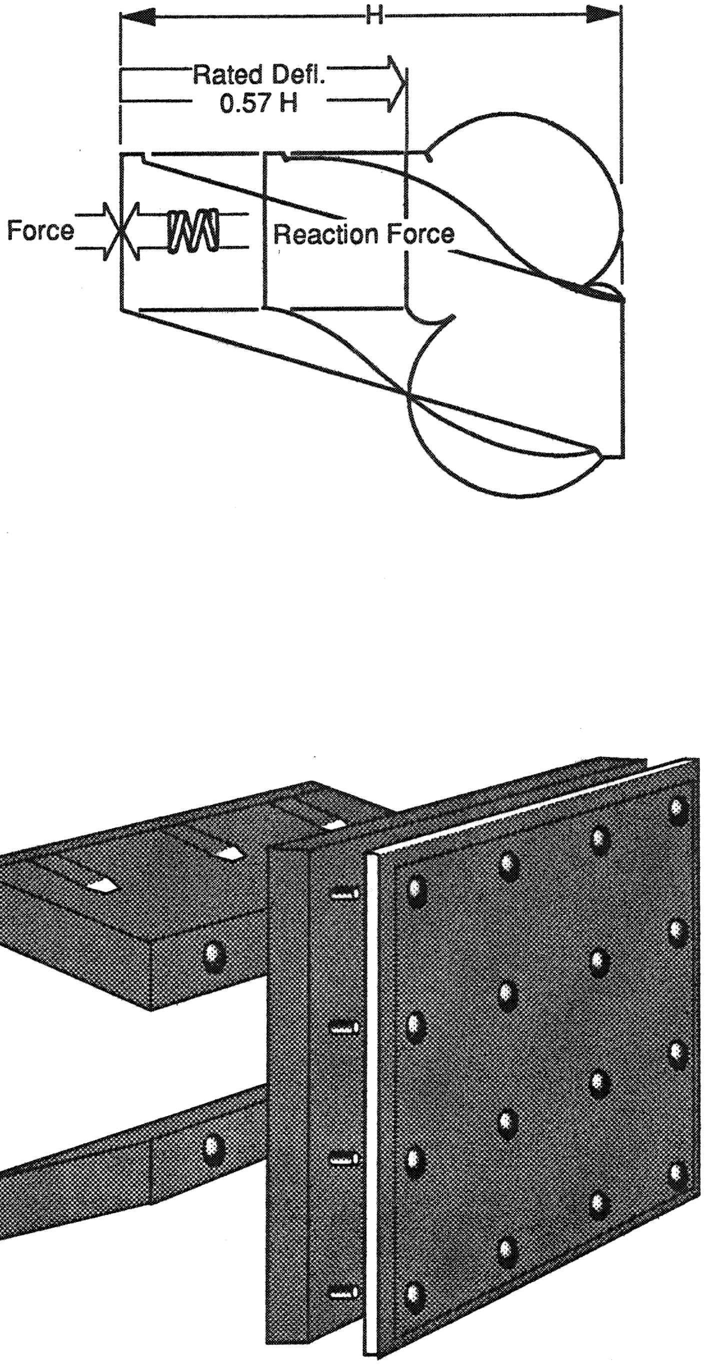

Figure A-3. MV Fenders

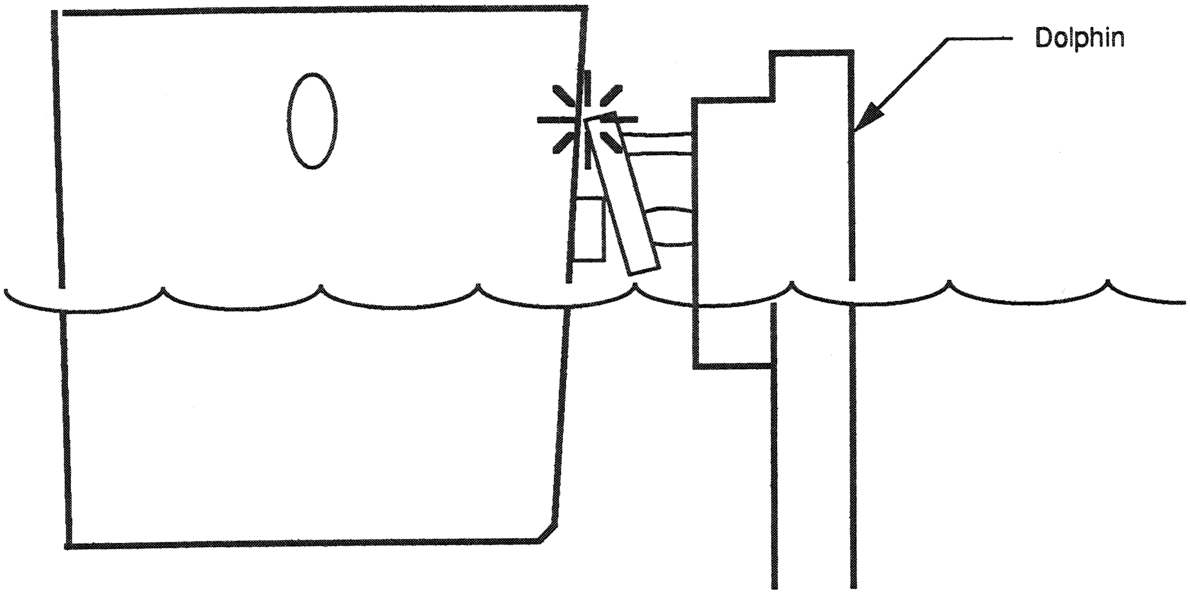

Figure A-4. Potential Problem with Fenders

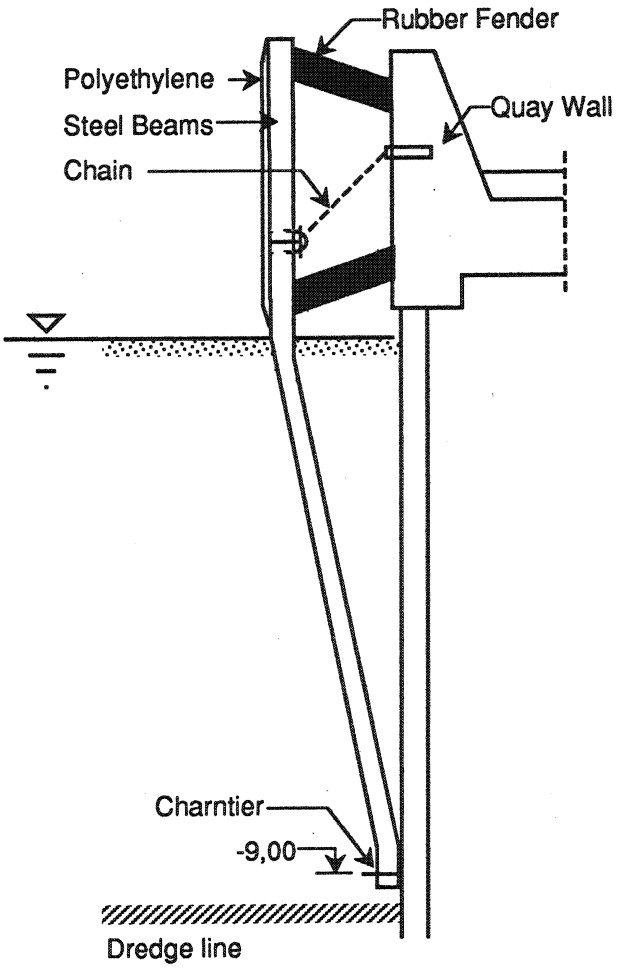

Figure A-5. Parallel-guided Fender (after Pankchik and Ladegaard, 1991)

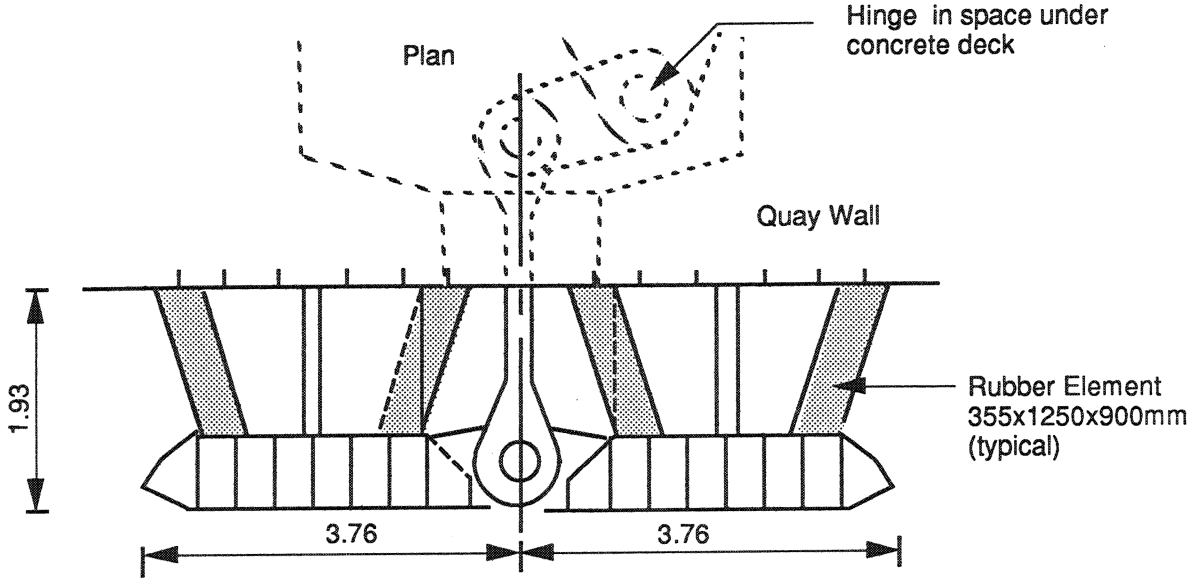

Figure A-6. Parallel-guided Double Fender Using Hinges (Plan view; dimensions in meters. After Pankchik and Laddegaard, 1991) close it by pushing on the door knob.) This design was used for the railway freight terminal in Copenhagen, Denmark.

The fenders at the new ferry landing at Helsingør were mounted on open ended bottle-shaped monopiles (Figure A-7). (8) The steel monopiles were selected because they could be prefabricated and installed more quickly. Additionally, because of the geotechnical conditions, it would have been difficult to develop the required tension resistance for tension piles if pile clusters had been used. The bottle shape was used because a large section was required at the bottom to resist movement and bear against the soil, and a small section was desirable at the top to minimize ice forces.

The outer end of the transfer bridge is supported by a semi-submersible buoyancy tank (Figure A-8). Movement during wave events is reduced because the cross section of the structure that passes through the water surface is relatively small. The height of the bridge can be changed by adjusting the water level in the tank. The transfer bridge can be linked to the vessel so that relative motion between the bridge and the vessel is reduced. Similar transfer bridges have been installed at other locations in Scandinavia, including Drøbek, Norway (Figure A-1). In some cases, energy absorbing units have been placed at the abutment end of the link span to absorb berthing impacts.

The ferry terminal at Helsingborg, Sweden has been rebuilt recently. Plans for the fender layout are shown in Figure A-9. Requirements for the fenders units are provided in Table A-1. Vessel data are provided in Table A-2. The specifications require higher stiffness for the fenders located near the throat (Type 1 and Type 2) because it is necessary to hold the vessel in close alignment for the transfer of rail traffic. (9) Requirements at other rail transfer locations are similar. Project financing included a combination of private and public funds. The resulting facility combines extensive retail uses with the transportation terminal.

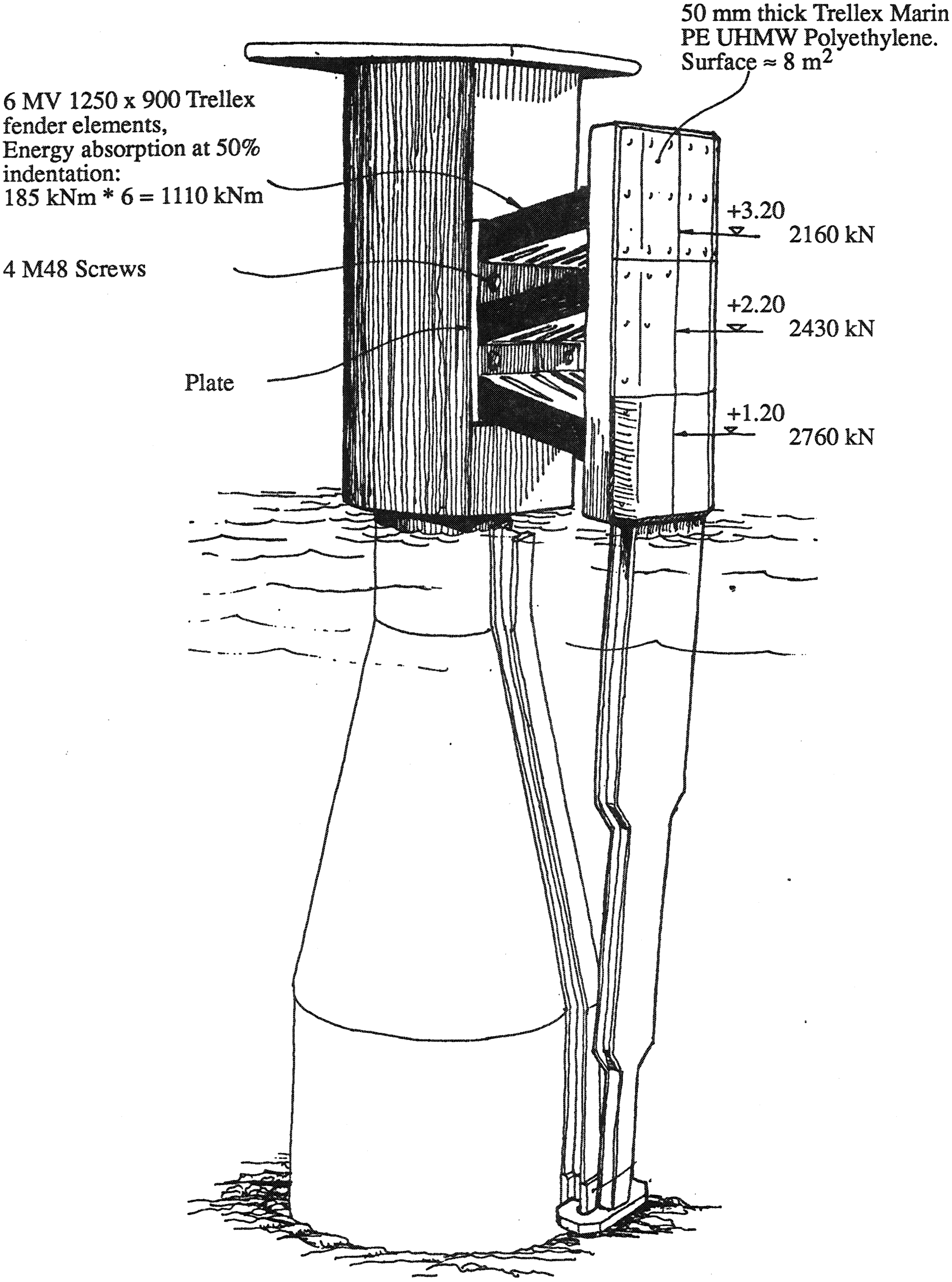

Figure A-7. Monopile Dolphin (courtesy of Trelleborg AB)

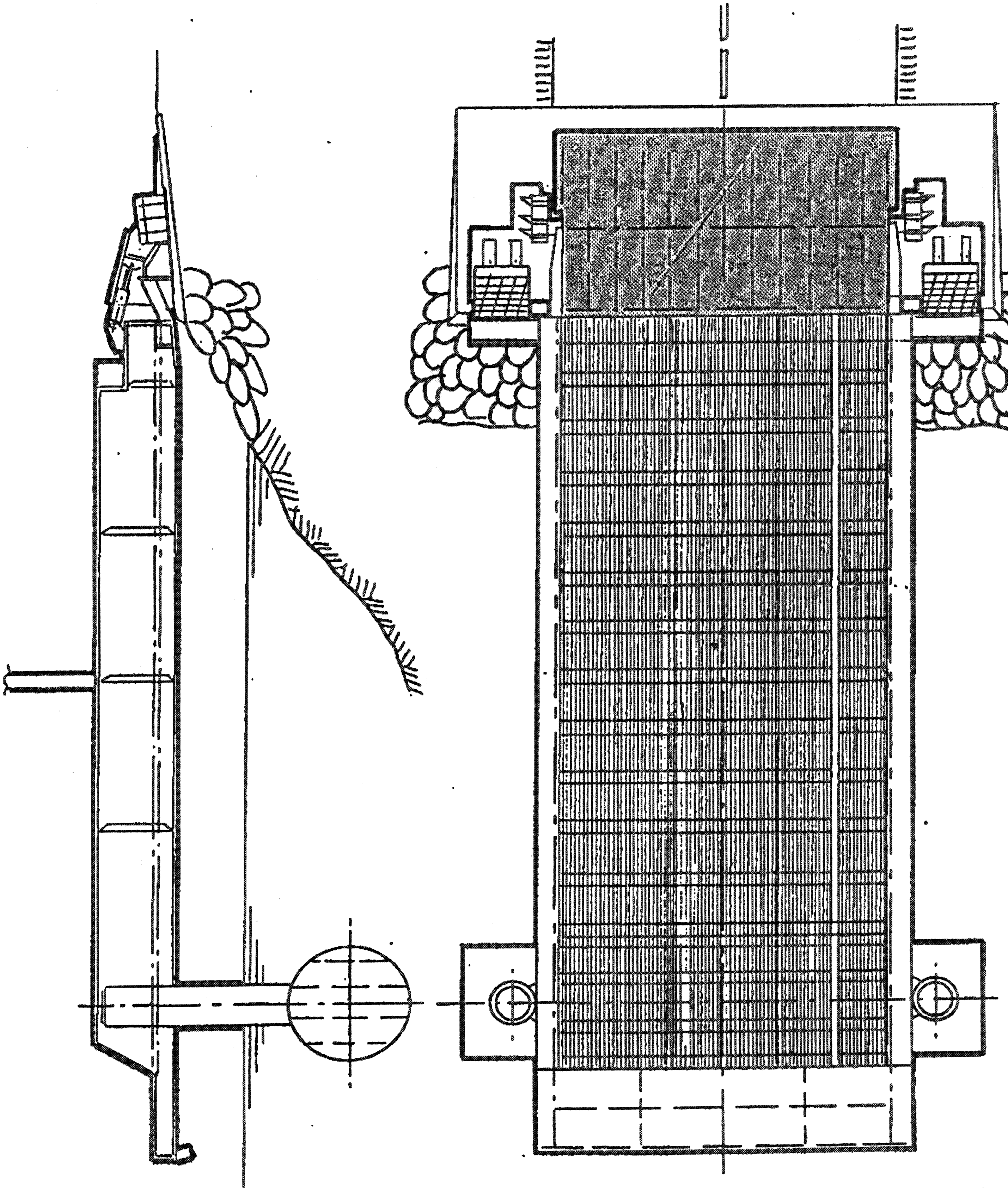

Figure A-8. NorEnt Ferry Access Bridge (courtesy of NorEnt AB)

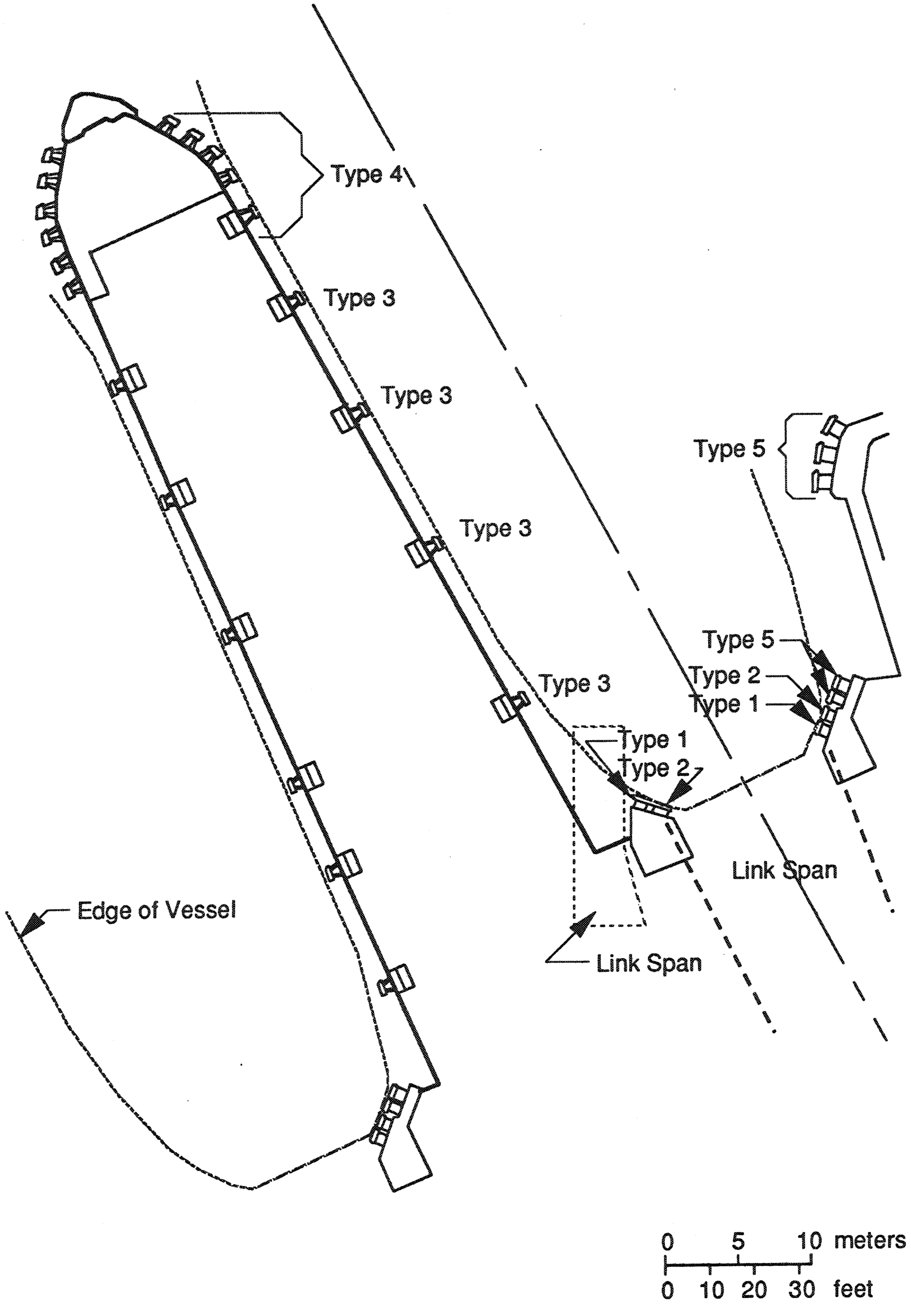

Figure A-9. Fender Layout at Helsingborg, Sweden
(Source: Scandiaconsult)

Table A-1. Fender Specifications (9)

Type	Approach Velocity ft/sec (m/sec)	Approach Angle Degrees	Energy Absorption ft-k (kNm)	Height in (mm)	Deflection in (mm)
1	1.64 (0.5)	90	443 (600)*	49 (1,250)	(330)
2	1.64 (0.5)	45	221 (300)*	49 (1,250)	(330)
3	4.92 (1.5)	10	192 (260)	55 (1,400)	60%**
4	4.92 (0.5)	35	369 (500)	71 (1,800)	60%**
5	1.64 (0.5)	45	221 (300)	67 (1,700)	60%**

* Type 1 and Type 2 are hinged together. Combined energy absorption is 553 (750 kNm).

** 60% of height or stand-off distance.

Table A-2. Data — Ferry HH90 (9)

Length overall (l.o.a.)	365 ft (111.2 m)
Length propeller to propeller	348 ft (106.0 m)
Overall width between rub strips	93 ft (28.2 m)
Draught	18 ft (5.5 m)
Displacement	2,263 lt (2,300 mt)
Number of passengers	1,250 each
Number of private cars	238 each
Lane length for trucks	1,764 ft (539 m)
Number of 90 ft (27.5 m) rail cars	3 each on 3 tracks
Normal speed	12.0 knots
Maximum speed, enforced	15.0 knots
Max load on rub strip	
near bow or stern	205 kips/ft (3,000 kN/m)
other areas	137 kips/ft (2,000 kN/m)

The Port of Gothenburg, Sweden, has developed a method of protecting concrete structures from salt water deterioration by encasing them in stainless steel in the splash zone. An annulus of 50 mm to 75 mm, filled with expansive grout, is left between the stainless steel sleeve and the structure. Repairs by this method have survived without maintenance for 25 years.

NORWAY

The researchers visited Ferry Service specialists at *Statens Vegvesen,* the Norwegian public highways department. In Norway, the ferries are viewed as an integral part of the public roads system because roads are often interrupted by long, narrow bodies of water (known as fjords) that are uneconomical to bridge. Although the vessels are owned and operated by the private sector, the public sector retains considerable control over schedules, fares, and choice of vessel type. The public sector also owns the terminal facilities. An unpublished memo was given to the author by *Statens Vegvesen* and is summarized below.

A uniform system of national tariffs has been developed, and fares are proportional to the distance traveled. In 1985, users paid 69 percent of the costs through fares. Fares are uniform throughout the year, despite a 68 percent increase in automobile traffic during the summer. The ferries operate at full capacity for automobiles, but not for passengers. The private sector vessel owners are paid a fixed amount to provide service, regardless of the fares that are collected. Planners at *Statens Vegvesen* are considering the development of an incentive plan for the private owners.

The ferries and their berths have been standardized to ensure that vessels can be transferred to different runs as necessary. Often, large vessels are used on runs that have high ridership levels and smaller vessels are used for runs that have low ridership levels. Additionally, demand levels can fluctuate from one part of the country to another, even though overall traffic does not experience any net change. The public sector may direct private sector operators to transfer ownership of vessels at what is determined to be a fair price.

New vessels must conform to one of 11 types of ferries. Open deck, double-ended ferries are used in sheltered waters, and closed deck, single-ended ferries are used in open water. Vehicle capacity ranges from 16 to 136 automobiles and crew size ranges from four to eight persons.

Statens Vegvesen considered the development of a catamaran ferry that would allow six lanes of traffic to load or unload at a time. This idea has not developed past the concept stage because the cost of providing necessary landing facilities was considered to be prohibitive.

Statens Vegvesen provided copies of design standards (in Norwegian) for their standard vessels and for fender systems. (10, 11) An unpublished fender design guide includes force vs. deflection curves for various types of tires that are used as fenders.

BRITISH COLUMBIA

The ferry system in British Columbia (BC Ferry) is similar to Washington's in many respects; however, crossing times are longer and vessels are larger in British Columbia. Many of the vessels load from two car decks, therefore, many of the transfer bridges are double-deck spans. Wing walls and guiding fenders are constructed from steel tube piles, and faced with timbers (Figures A-10 and A-11). Two rows of battered piles and two rows of plumb piles, 24 in. (610 mm) in diameter are the main structural elements. One row of the battered piles is skewed 45 degrees so that it can more effectively resist forces parallel to the face of the wing wall. The face timbers are supported by smaller 10.75 in. (273 mm) diameter tube piles. Between the face timbers and the first row of large diameter plumb piles, two sets of rubber fenders are separated by a timber frame. A revised fender system was installed at BC Ferry's Tsawwassen Terminal. It consists of steel panels and MV Fender units.

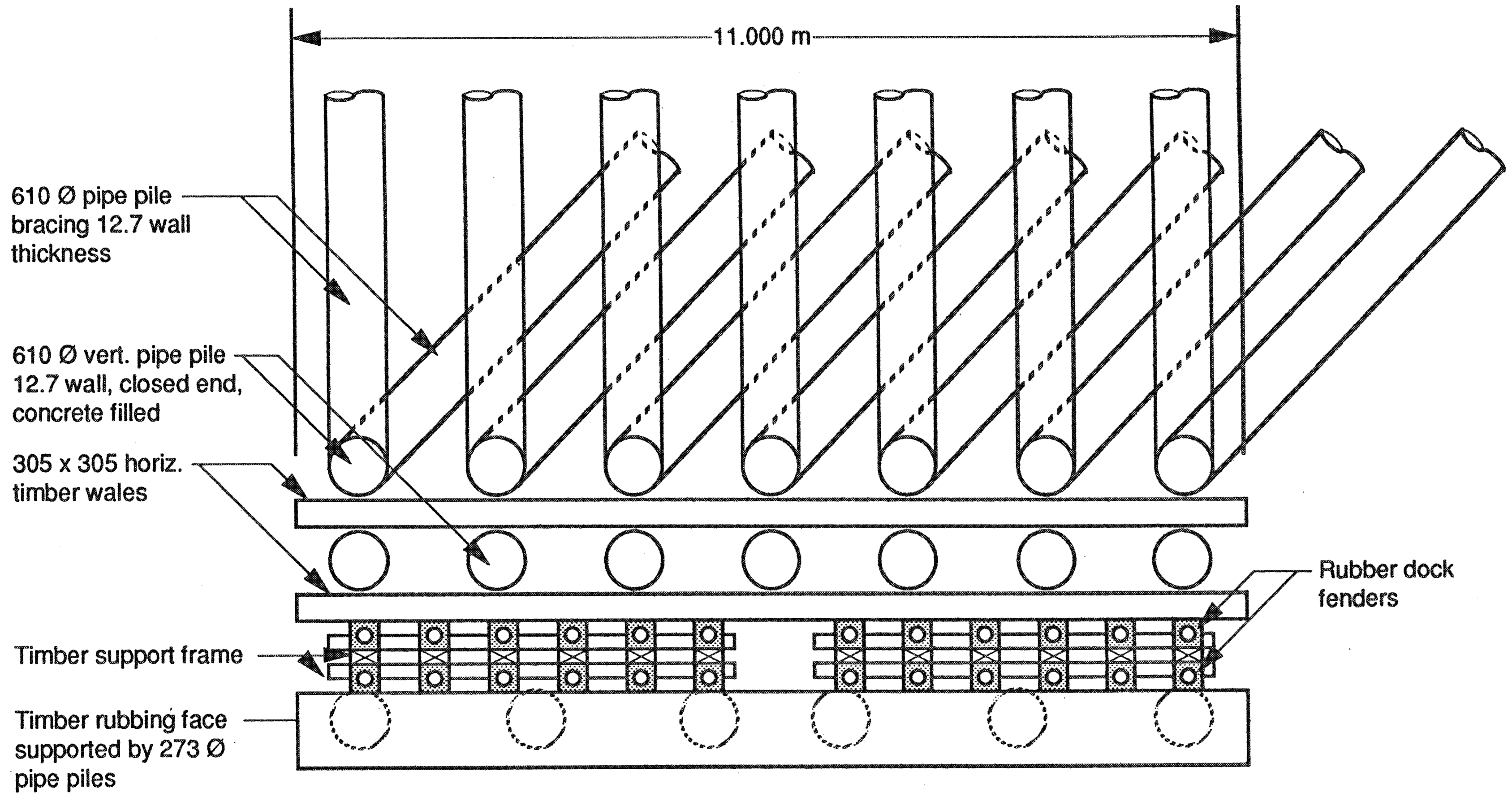

Figure A-10. Plan of West Wingwall – Langdale Ferry Terminal, British Columbia (Dimensions in milimeters and meters)

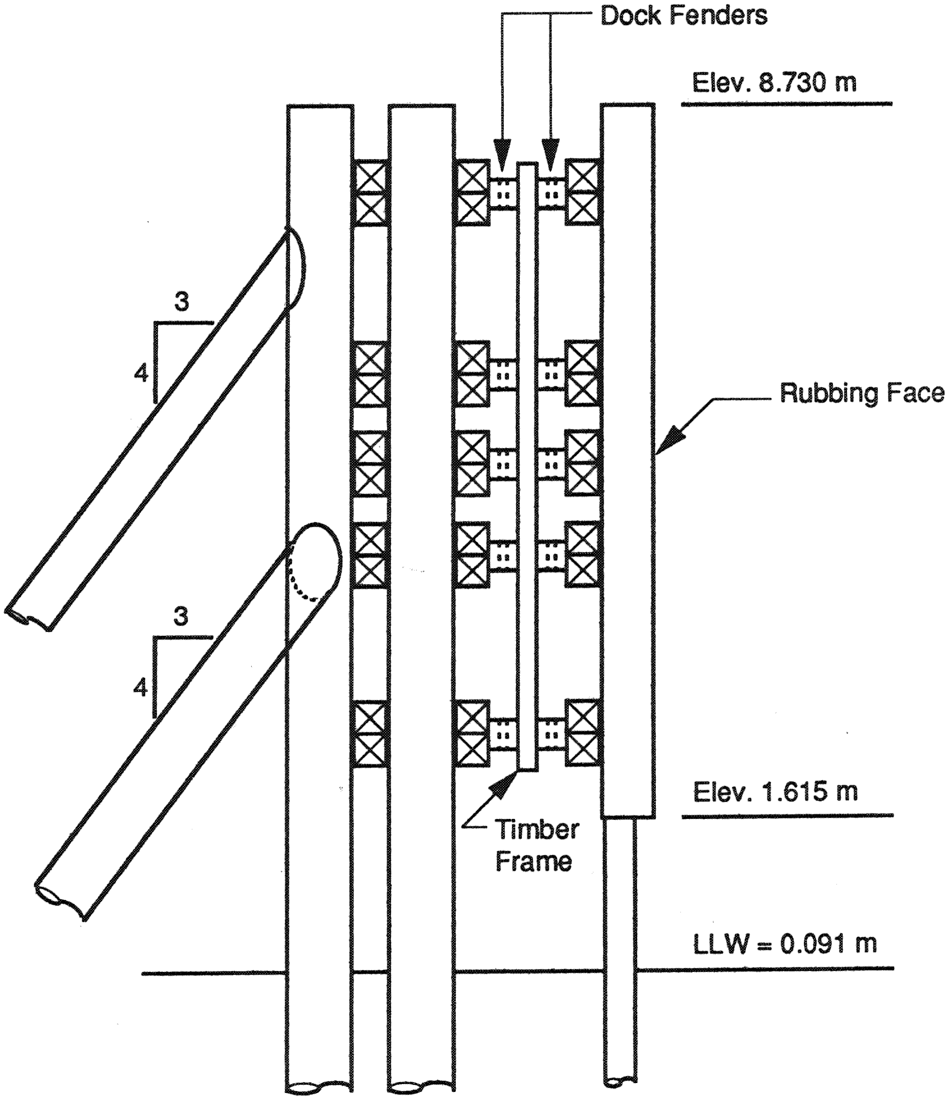

Figure A-11. Side Elevation of West Wing Wall –
Langdale Ferry Terminal

ALASKA MARINE HIGHWAY

Most Alaska Marine Highway (AMH) ferry terminals are arranged to accommodate side berthing and side loading. A typical fender structure is illustrated in Figures A-12, A-13, and A-14. Fender units, placed at 50-foot to 100-foot intervals, are designed to resist 30-foot kip berthing loads. Each fender unit has a face that is 16 ft wide and 34 ft tall. The facing material is Ekke, an extremely hard wood that is harvested in Africa. The fenders are supported by four 24 in. diameter tube piles. The walkway is supported by clusters of three 18 in. piles, two battered and one plumb. Two 40 in. outside diameter cylindrical rubber fender elements by 20 in. inside diameter cylindrical rubber fender elements separate each fender face from the walkway. This system was designed to minimize maintenance because construction mobilization expenses are high in southeast Alaska.

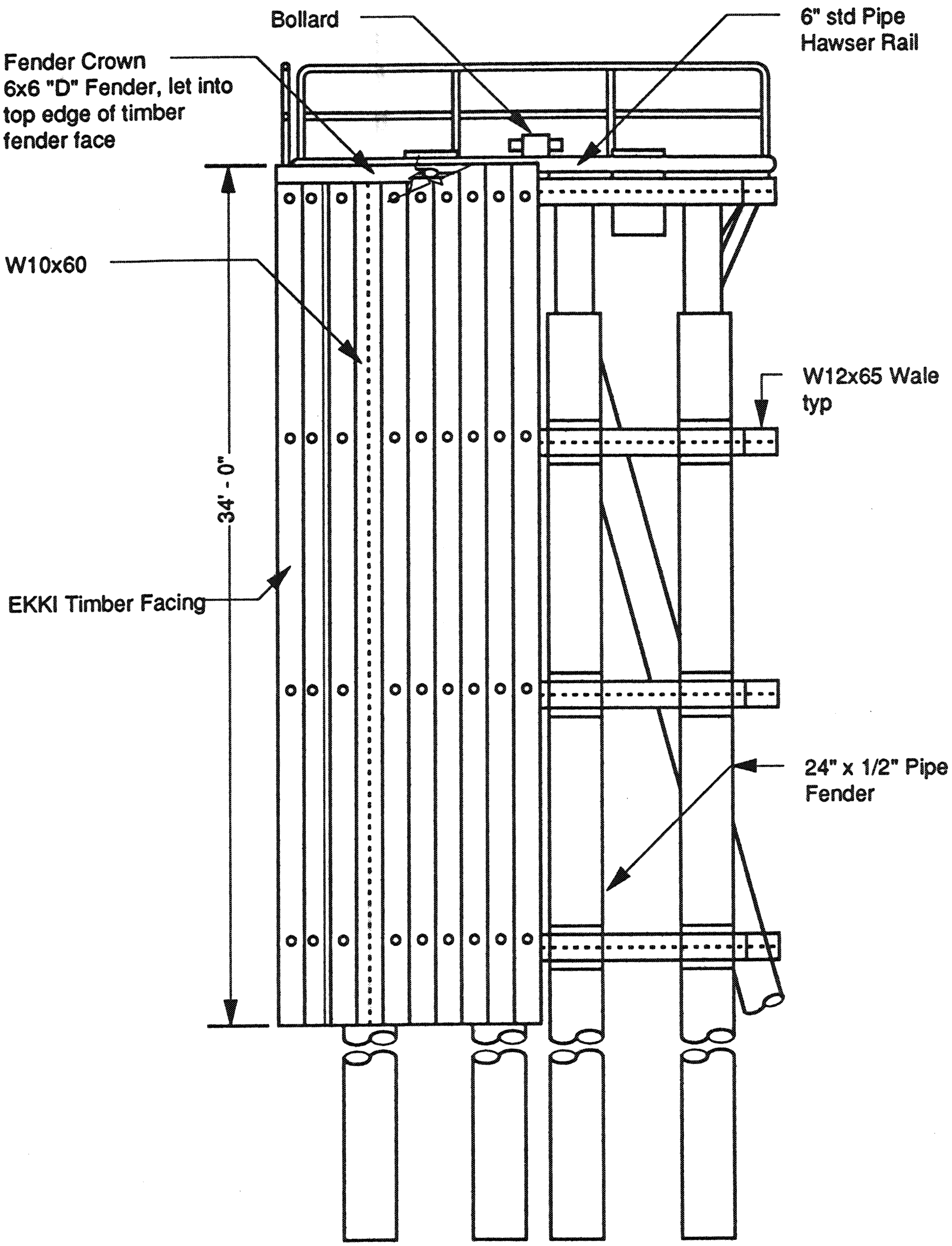

Figure A-12. Front Elevation of Mooring Structure – Ketchikan, Alaska

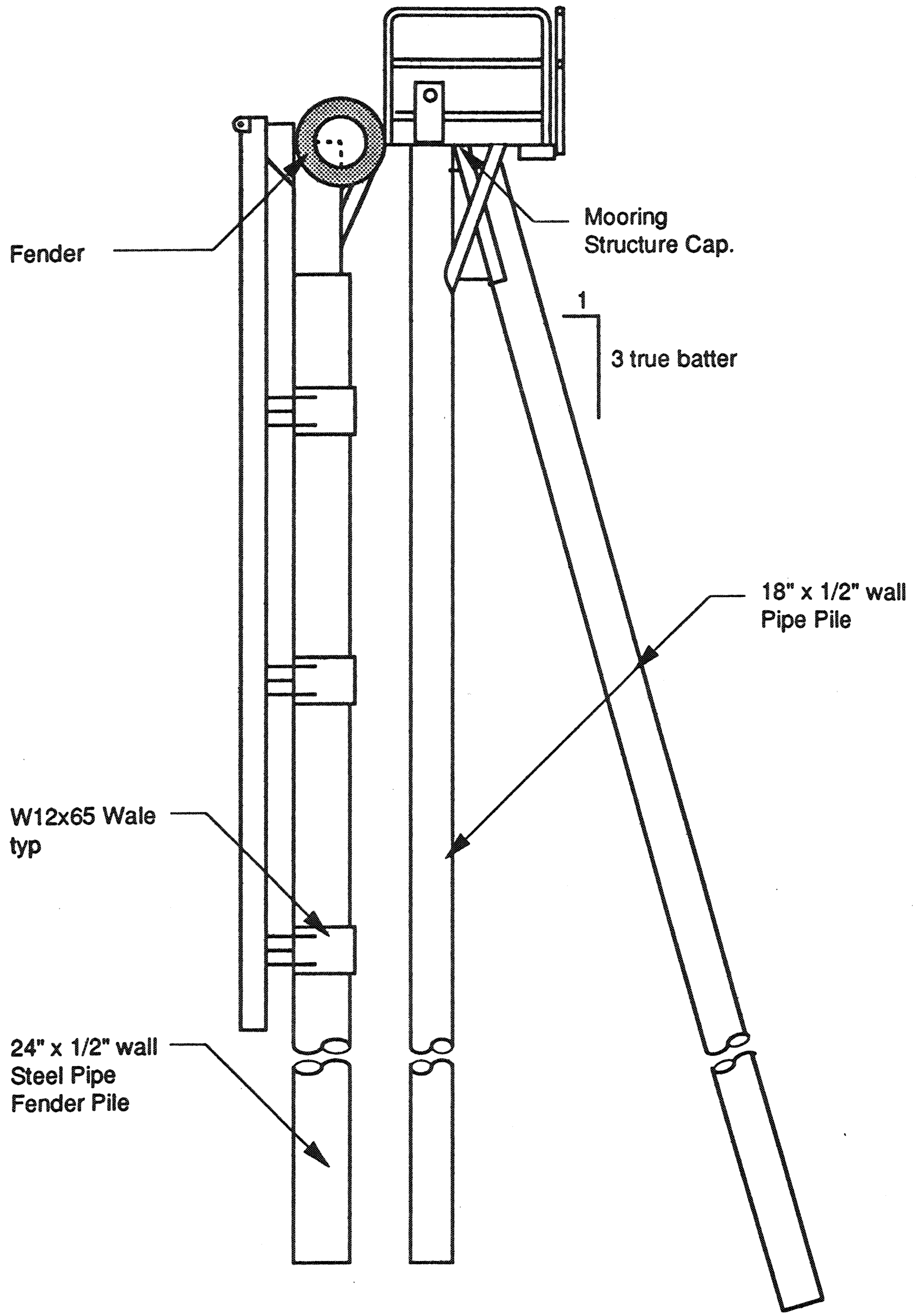

Figure A-13. Side Elevation of Mooring Structure – Ketchikan, Alaska

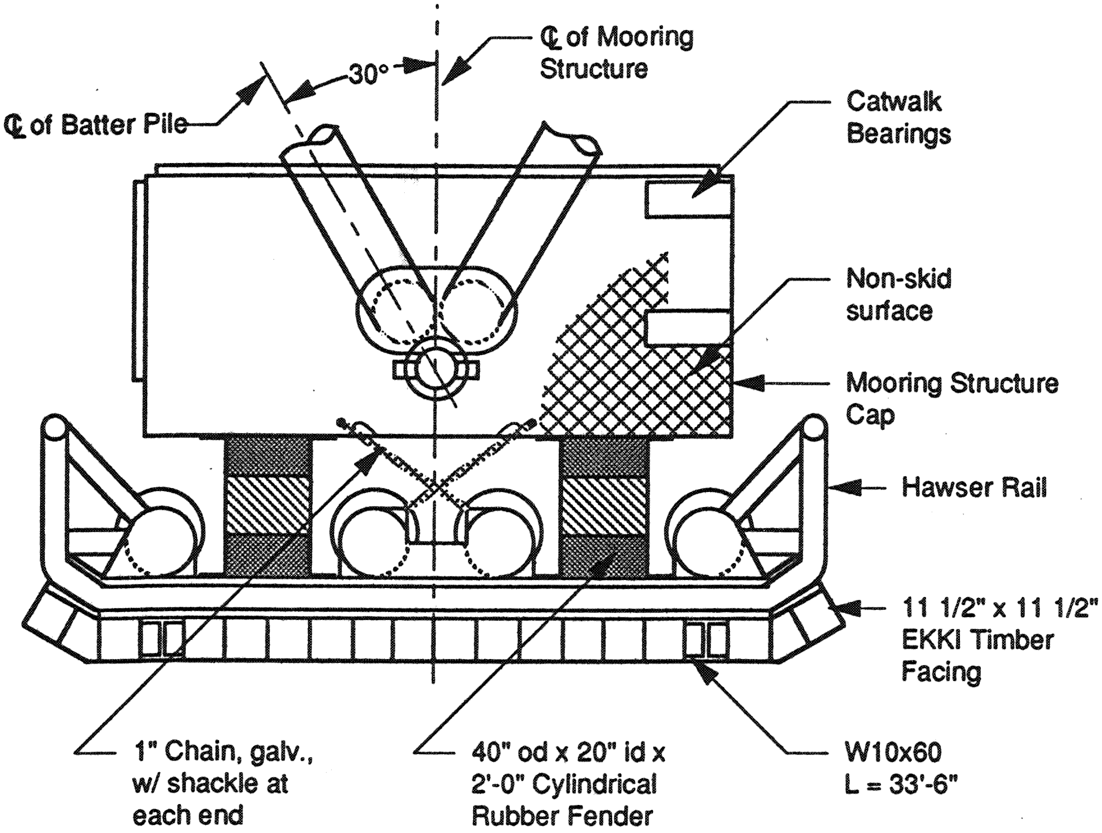

Figure A-14. Plan of Mooring Structure – Ketchikan, Alaska

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APPENDIX B

INVENTORY OF FENDER SYSTEMS

("Report of the International Commission for Improving the Design of Fender Systems," Brussels, Belgium: PIANC, 1984)

PU-REF

ASSOCIATION INTERNATIONALE PERMANENTE
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CONGRÈS DE NAVIGATION

PERMANENT INTERNATIONAL ASSOCIATION
OF
NAVIGATION CONGRESSES

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RÉFÉRENCE À RAPPELER :
IN REPLY PLEASE QUOTE :
N° 151 (DC/jc)

Brussels, 2 June 1992

Prof. Charles T. JAHREN,
Assistant Professor,
University of Washington,
Department of Civil Engineering,
121 More Hall FX-10,
SEATTLE, Washington 98195
U.S.A.

Dear Sir,

We hereby acknowledge receipt of your letter dated 27 May 1992.

The requested permission to include copies of Chapters 4 and 9 of the Report of the International Commission for Improving the Design of Fender Systems in the appendix of your final report is granted, provided the source of the information plus "Copyright by PIANC General Secretariat, Brussels, Belgium" is mentioned.

Yours sincerely,

Eng. B. FAES,
Secretary-General

CHAPTER 4

INVENTORY OF FENDER SYSTEMS

4.1 INTRODUCTION

The present chapter describes the different types of fender systems suitable for the berthing of large ships. The factors which influence the selection of a fender system are listed in Section 4.2. Descriptions of the principles and characteristics of the major categories of fender systems in common use are presented in Section 4.3, whereas a discussion and evaluation of the applicability of the various fender systems for the berthing of large ships is given in Section 4.4.

4.2 FENDER SYSTEM SELECTION CRITERIA

The selection of the best fender system for a particular situation depends on a great many factors which must be considered by the designer. The major factors which influence the selection process include the following:

- energy absorption requirements: The fender system must have sufficient energy absorption capacity to absorb the kinetic energy of the berthing vessel calculated as described in Chapter 2.
- reaction force: This is the force which is exerted on the ship's hull and on the berthing structure during impact. The reaction force has a significant effect on the cost of the berthing structure.
- deflection: This is the distance, perpendicular to the line of the quay, that the face of the fender system moves in absorbing the ship's kinetic energy. Generally, fender systems with greater deflection require cargo transfer equipment with greater reach capacity.
- hull pressure: This is the pressure exerted on the ship's hull by the fender unit and is derived by dividing the reaction force by the fender area in contact with the ship. Hull pressure must be limited to levels which will not cause permanent damage to the berthing ship. For a detailed discussion of this aspect of fender system design, refer to Chapter 7.
- reaction/deflection relationship: The nature of the reaction/deflection relationship determines the relative stiffness of the fender systems. For a discussion of this aspect of fender system design, refer to Section 2.3.6 and 4.4.
- angle of impact: The larger the angle between the ship's hull and the berthing line, the less efficient some fenders can become.
- deceleration factor: The rate at which the fender system causes the berthing ship to decelerate. This is particularly relevant for fender systems for ferries.
- long-term contact: This includes the changes in envirohmental conditions (i.e. wind, current, waves, and tide) during loading and unloading at the berth. The fender system should not "roll up," tear, abrade or be susceptible to other forms of damage when subject to long-term contact.
- coefficient of friction between the face of the fender system and the ship's hull; This determines the resultant shear force when the ship is berthing with longitudinal and/or rolling motion and may have a significant detrimental effect on the energy absorption performance of the fender system. The magnitude of the shear force also may have a significant effect on the cost of the berthing structure.
- safety factor for ship, berthing structure and fender; The more serious the consequences that would result should damage of the fender or supporting structure occur, the highger the safety factor should be. Such consequences may have to be evaluated based on capital investment, safety for the environment, continuation of terminal operations or combinations thereof. The mode of failure of a fender and its efect on the supporting structure should also be considered.

- costs: Capital costs for both the fender system and the structure, as well as operation, maintenance and repair costs, must be considered.

- capability of tug crews in assisting the berthing ship and dock labour in maintaining the fender system; The capability of the crews responsible for berthing the ship will have an effect on the energy absorption requirement of the fender system. Where maintenance is expected to be poor, a simple, possibly less efficient, fender system may be preferable to a system requiring a higher degree of maintenance.

- repetition factor: Fender types already used locally should be considered since their performance under actual conditions is known. Also there may be an advantage in having interchangeability of spares, particularly if the number of new fenders required is small.

- frequency of berthing operations: A high frequency of berthings normally justifies greater capital expenditures for the fender system.

- range of ship sizes expected to use the berth; While the energy absorption capacity of the fender system may be selected for the largest ship expected to use the berth, the fender system must be suitable for the full range of ships that the berth will accomodate. The effect of hull pressure and fender stiffness on the smaller vessels may have a significant influence on the selection and arrangement of the fenders.

- shape of ship's hull in contact with the fender system; Where vessels with unusual hull configurations or protrusions may be expected to use the berth or where the berth must accomodate barges, special attention must be paid to the selection and arrangement of the fender system.

- range of water level to be accomodated: The fender system must be suitable during the full range of water levels that may occur at the berth. The design must consider both the largest and smallest vessels, in both the loaded and light conditions, at high and low water levels. Where extreme water level variations occur, consideration should be given to the use of floating fender systems.

- degree of exposures: Where the berth is exposed to severe wind and/or wave action, the fender selection may be governed by the design mooring conditions rather than berthing conditions.

4.3 DESCRIPTION OF VARIOUS FENDER SYSTEMS

4.3.1 GENERAL

Fender systems can be categorized according to the mode by which they absorb or dissipate the kinetic energy of the berthing ship. Table 4.1 lists the various major categories of fender systems in common use. As can be seen from the table, most fender systems are based primarily on the principle of the conversion of kinetic energy of the ship into potential energy of the fender. Only the hydraulic fender which dissipates the kinetic energy in the form of heat generated through friction and the steel corrugated unit which dissipates the kinetic energy through the plastic deformation of steel, do not utilize this principle. The steel corrugated unit is always used in conjunction with another type of fender unit for which it serves as the energy absorbing equivalent of an electric fuse.

Table 4.1 lists only the major types of fender systems. Other systems exist which have either very limited application or have not been widely accepted. Also many existing fender systems are variations or combinations of several of the systems listed.

Table 4.2 lists the range of standard sizes, energy absorption capacities, reaction forces, rated maximum deflections and hull pressures for the various types of fender systems in use at the time this document is printed. Fender manufacturer's are constantly carrying out research and developing variations and improvements to these systems, so the fender system designer is advised to consult manufacturers regarding the availability of new fender units. Also, the various fender manufacturers may have different names for fender units of similar appearance and performance

TABLE 4.1 CATEGORIES OF FENDER TYPES

Mode of absorption of vessel's kinetic energy		Fender type
Conversion to potential energy by gravity force		1. Gravity
Conversion to potential energy by buoyancy force		2. Floating body
Conversion to potential energy by elastic deformation	Compression	3. Spring
		4. Bush
		5. End loaded rubber
		6. Pneumatic
		7. Foam - filled
	Compression/ bending	8. Side loaded rubber
		9. Buckling
	Shear	10. Shear
	Compression/ shear	11. Rubber/steel sandwich
	Torsion	12. Torsion
	Bending	13. Flexible pile
Dissipation as heat energy by friction		14. Hydraulic
Dissipation by plastic deformation		15. Steel corrugated unit

characteristics and Table 4.2 does not necessarily include all names for each basic type of fender unit.

Most of the characteristics listed in Table 4.2 are based on data published by fender unit manufacturers and actual fender performance may vary by as much as ten percent. Also, the characteristics are based on perpendicular impacts, and fender performance may vary considerably when subjected to angular impacts, which is often the case.

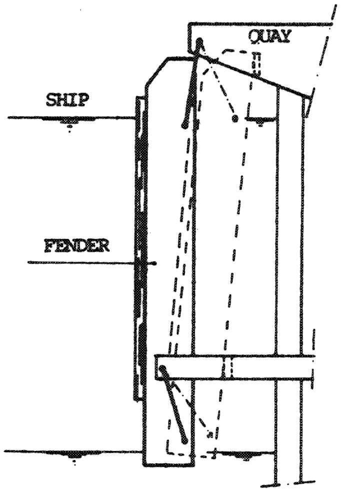


Fig. 4.1 Gravity fender

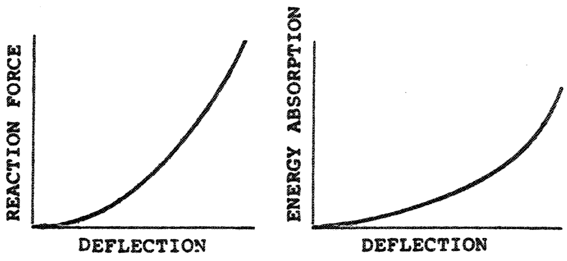


Fig. 4.2. Characteristics of gravity fender

4.3.2 GRAVITY FENDER

a) <u>Principle:</u> The kinetic energy of the berthing ship is converted primarily into potential energy of the fender by lifting a large mass upwards.

b) <u>Characteristics:</u> The characteristics of gravity fender systems are dependent on the specific construction. The illustrated gravity fender system has the reaction/deflection and energy/deflection relationships shown in Fig. 4.2.

c) <u>Evaluation:</u> Gravity fenders can be adapted to a wide range of berthing conditions, but:
- are expensive to install and difficult to maintain,

TABLE 4.2: FENDER TYPES AND CHARACTERISTICS*

Fender type	Standard sizes m	Energy absorption tf-m (x10kNm)	Reaction force tf (x10kN)	Rated deflection %	Hull pressure tf/m² (x10kN/m²)
1. Gravity	as	required	for	project	
2. Buoyancy	as	required	for	project	
3. Spring	as	required	for	project	
4. Bush (typical)	D = 1.5 L = 3.5	22		40	
5. End loaded rubber	D = 0.25 to 0.6 L = 0.37 to 0.9	1 to 17	10 to 75	50	panel required to distribute pressure
6. Pneumatic					
a) Floating	D = 0.3 to 6.0 L = 0.3 to 12	0.5 to 840	0.9 to 795	55 to 60	10 to 20
b) Fixed	H = 0.45 to 2.7 D = 0.6 to 3.6	1.3 to 231	13 to 385	55 to 60	29 to 34 (without panel) panel may be used to distribute pressure
c) Tyres	D = 0.6 to 3.0	0.25 to 92	7 to 513	21 to 54	70
7. Foam-filled	D = 0.9 to 4.5 L = 1.5 to 9.0	3 to 546	15 to 574	60	10 (ave.) 12 (peak)
8. Side loaded rubber					
a) Cylindrical	D = 0.15 to 2.8	0.15 to 500	4.5 to 790	50	30 to 62
b) D-type	0.15 to o.5	0.35 to 3.7	12 to 36	50	75 to 100
c) Cubic	0.2 to 0.5	2 to 10	65 to 130	50	200 to 300
9. Buckling					
a) Panel contact -longitudinal	H = 0.3 to 2.5 L = 1.0 to 4.0	2 to 800	16 to 730	45 to 55	panel req'd to distribute pressure
b) Panel contact -circular	H = 0.3 to 3.0	0.45 to 670	4 to 629	47.5 to 50	panel req'd to distribute pressure
c) Direct contact -longitudinal	H = 0.15 to 1.3 L = 1.0 to 4.0	0.3 to 216	6 to 380	45 to 55	80 to 150
d) Direct contact -circular	H = 0.27 to 2.5	0.45 to 604	4 to 629	42.5 to 50	29 to 67
10. Shear	H = 0.25 to 0.6	0.8 to 10	4 to 20	165	panel req'd to distribute pressure
11. Rubber and steel sandwich	H = 0.8 to 1.65	3.5 to 38	17 to 85	35 to 52	panel req'd to distribute pressure
12. Torsion	as	required	for	project	
13. Flexible pile	as	required	for	project	
14. Hydraulic	as	required	for	project	
15. Steel corrugated unit	H = 0.55	7.6 to 30	25 to 135	57	used with other fender unit

* Characteristics are based on perpendicular impacts. Fender performance under angular impacts varies with the type of fender.

- a heavy dock structure is required to carry the dead weight,
- an additional protection of the ship's hull is necessary.

If the fender is partly submerged, energy absorption capacity varies with varying water levels.
The use of gravity fenders has decreased with the introduction of less expensive and less cumbersome fender systems.

4.3.3 BUOYANCY FENDER

a) Principle: The kinetic energy of the berthing ship is converted into potential energy of the fender by submerging a hollow body.

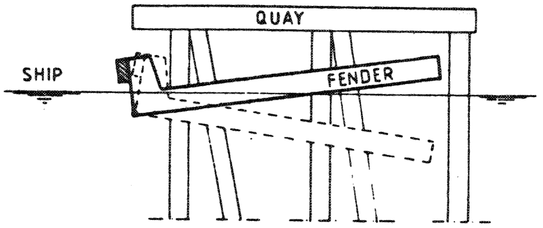


Fig. 4.3. Buoyancy fender

b) Characteristics: Buoyancy fender systems can be arranged to provide virtually any desired reaction/deflection relationship. The illustrated buoyancy fender system has the reaction/deflection and energy/deflection relationships shown below.

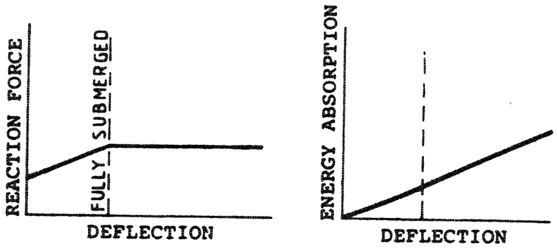


Fig. 4.4. Characteristics of buoyancy fender

c) Evaluation: Fenders with floating bodies can be adapted to a wide range of berthing conditions, but:
- are expensive to install and difficult to maintain,
- an additional protection of the ship's hull is necessary.
- the energy absorption capacity depends on the position of the fender in relation to the water level.

The use of buoyancy fenders has decreased with the introduction of less expensive and less cumbersome fender systems.

4.3.4 SPRING FENDER

a) Principle: The kinetic energy of the berthing ship is converted into potential energy of the fender by the elastic compression of a steel spring.

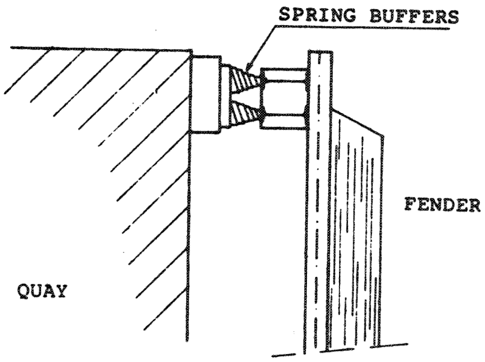


Fig. 4.5. Spring fender

b) Characteristics: The reaction force is directly proportional to the deflection.

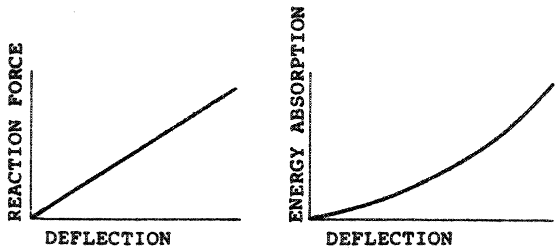


Fig. 4.6. Characteristics of spring fender

c) Evaluation:
- high quality, expensive materials are required.
- intensive maintenance is required.

The application of this type of fender has decreased in recent years, due to the development of rubber fender system components.

4.3.5 BUSH FENDER

a) Principle: The kinetic energy of the berthing vessel is converted into potential energy of the fender by elastic compression of bundles of branches from, for example, willow trees.

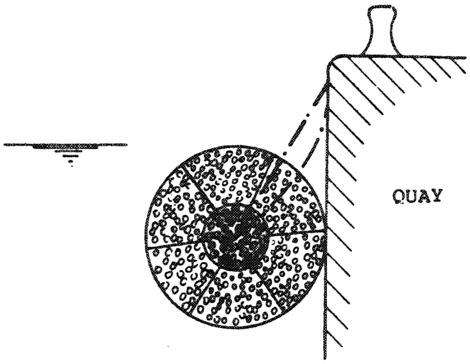


Fig. 4.7. Bush fender

b) Characteristics: The reaction force is an exponential function of the deflection.

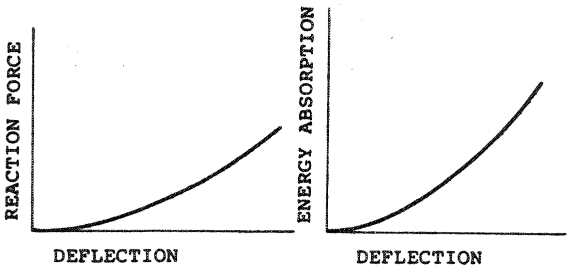


Fig. 4.8. Characteristics of bush fender

c) Evaluation: This type of fender should only be used if there is a cheap, local source of suitable timber, as its useful life is short. It is advisable to have spare fenders available to quickly replace those damaged.

4.3.6 END LOADED RUBBER FENDERS

a) Principle: The kinetic energy of the berthing vessel is converted into potential energy of the fender by elastic compression of hollow rubber elements with small length to diameter ratios.

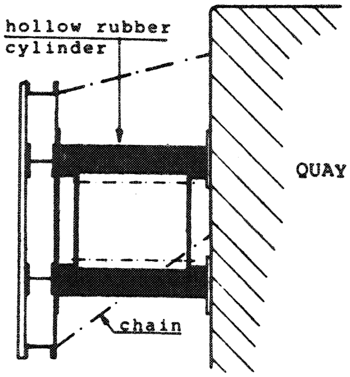


Fig. 4.9. End-loaded fender

b) Characteristics: The reaction force is an exponential function of the deflection.

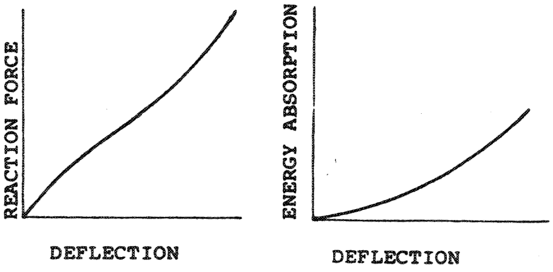


Fig. 4.10. Characteristics of end-loaded fender

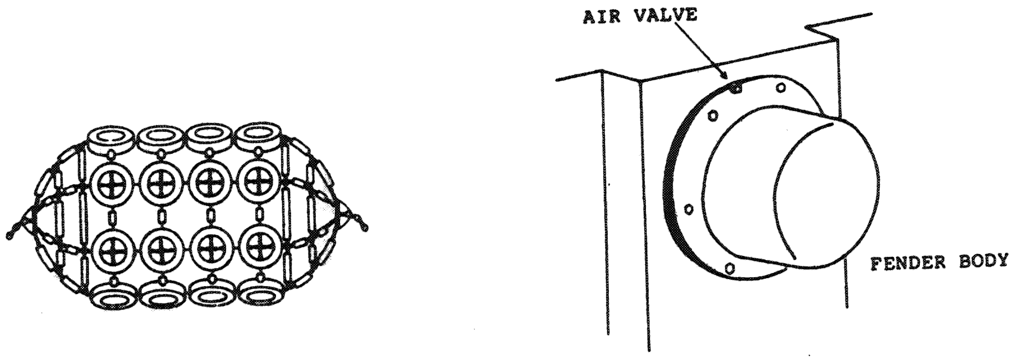
c) Evaluation:

- Easy to install, but can be sensitive to sunlight, low temperatures, fatigue and chemical pollution.
- Fender panel often necessary to protect ship's hull, and to minimize wear of the fender.
- Simple rubber fenders are commonly used where the energy absorption requirement is relatively small.

4.3.7 PNEUMATIC FENDER

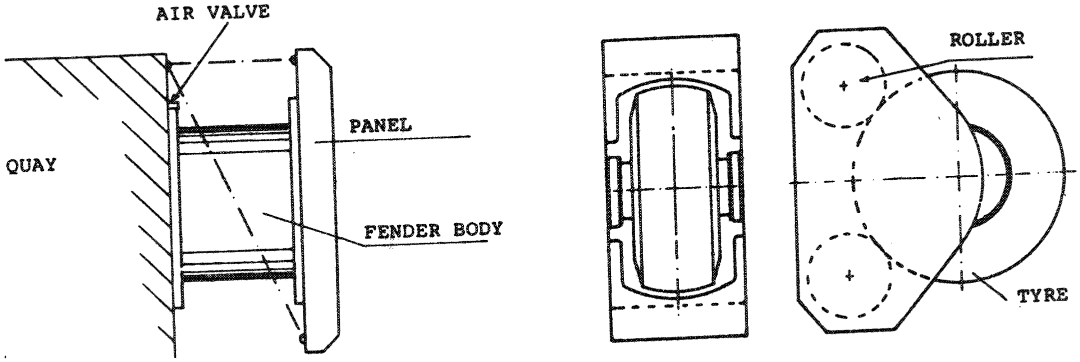
a) Principle: The kinetic energy of the berthing vessel is converted almost entirely into potential energy of the fender by elastic compression of air in the fender. Three basic types of pneumatic fenders are in common use: floating, air block and tyre.

The floating fender consists of a rubber or elastomeric bag filled with air. It floats on the water and rises and falls



FLOATING FENDER

AIR BLOCK FENDER



AIR BLOCK FENDER WITH PROTECTOR PANEL

PNEUMATIC TYRE FENDER

Fig. 4.11. Pneumatic fenders

with the tide and also adapts to the ship's movement and shape.

The air block fender is a large, hollow air-filled rubber bag that can be bolted to the quay wall.

The pneumatic tyre fender consists of a large diameter tyre (similar to an automobile tyre) mounted on an axle and installed on a quay wall. This type of fender is particularly suited for pronounced corners of quays and lock entrances where ships may have approach difficulties. Pneumatic tyres can be mounted with their axis of rotation horizontally or vertically.

b) <u>Characteristics:</u> The reaction force is an exponential function of the deflection.

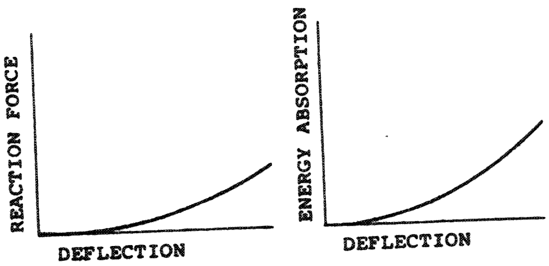


Fig. 4.12. Characteristics of pneumatic fenders

c) <u>Evaluation:</u>
- High energy absorption with comparatively small reaction force and hence low hull pressures.
- The ship/fender contact area can be large and directly related to the deflection of the fender.

- The surface pressure of the fender is uniform, resulting in a uniform hull pressure.
- A safety valve allows overloading.
- Oblique compression does not permanently distort the fender.
- Extremely cold temperatures do not appreciably affect the performance of the fender as the internal pressure can be adjusted.
- Fenders can be attached to all types of quaywalls with solid face.
- Internal pressures must be checked and adjusted periodically.
- Prone to damage by puncturing.
- The larger sizes are relatively bulky, resulting in large stand-off distances.
- Fenders tend to roll up when a tightly moored vessel discharges her cargo.
- The floating fender requires a suitable wire or chain system both to support and to prevent the fender from moving too freely in waves or swells.
- Protection for the outer "skin" of floating type fenders is generally provided by nets of tyres and chains.

4.3.8 FOAM FILLED FENDER

a) Principle: The kinetic energy of the berthing vessel is converted into potential energy by the compression of tiny pneumatic cells in the fender.
Foam-filled fenders are constructed of resilient, closedcell foam surrounded by a nylon reinforced elastomer skin. Additional protection against abrasion can be provided in extended nets in the form of tyres, elastomer coatings, etc.,

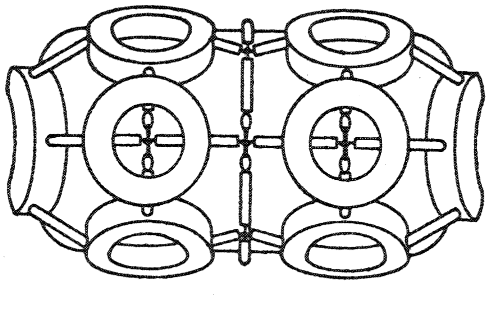


Fig. 4.13. Foam-filled fender with external tyre net

b) Characteristics: The reaction force is an exponential function of the deflection.

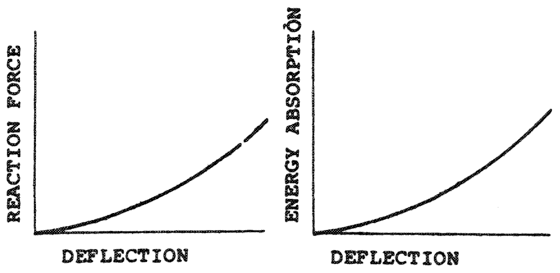


Fig. 4.14. Characteristics of foam-filled fenders

c) Evaluation:
- High energy absorption with comparatively small reaction force.
- Will not sink immediately if punctured.
- Cannot collapse if punctured.
- Oblique impacts can result in distortion of the foam core (cells can deform and may not recover their original shape).
- Surface pressure of the fender is not uniform when it is compressed, so the hull pressure over the contact area is not uniform.
- The chemical and physical composition of the foam can be varied during manufacture to suit particular energy requirements.
- A wire or chain system is often required to prevent the fender from moving too freely in waves or swell.

4.3.9 SIDE LOADED RUBBER FENDERS

a) Principle: The kinetic energy of the berthing vessel is converted into potential energy of the fender by a combination of compression and bending of the rubber elements.

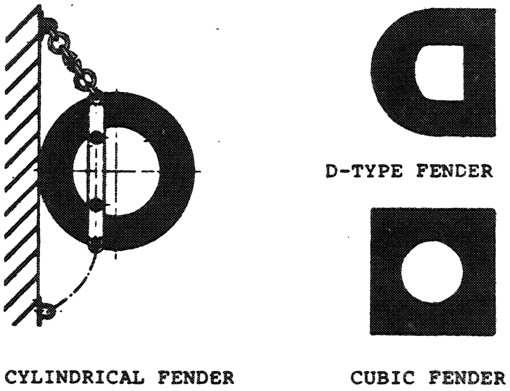


Fig. 4.15. Side-loaded rubber fenders

b) Characteristics: The reaction force is an exponential function of the deflection.

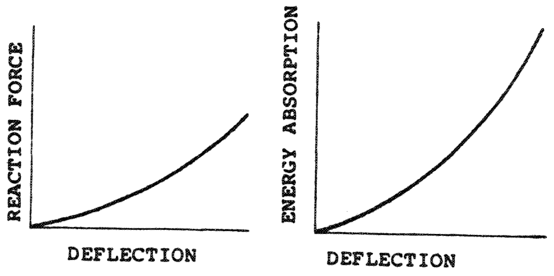


Fig. 4.16. Characteristics of side-loaded rubber fenders

c. Evaluation:

- Easy to install, but can be sensitive to sunlight, low temperatures, fatigue and chemical pollution.
- Many different shapes, sizes and manufacturers.
- Large horizontal friction loads may cause cutting of the rubber by the supporting frame.
- Generally only a small contact area with ship, giving rise to high hull pressures.

4.3.10 BUCKLING FENDERS

a) Principle: The kinetic energy of the berthing vessel is converted into potential energy of the fender by a combination of compression and bending of rubber elements. The types of fender units illustrated in Fig.4.17 and 4.18 represent the general types presently available. Not every type of fender unit produced by every manufacturer is illustrated.

The fender units have been grouped into two general categories: those that require a panel between the fender unit and the ship's hull in order to reduce hull contact pressure and those that do not.

b) Characteristics: The reaction force varies with the deflection as shown in Fig. 4.19 Initially a relatively high reaction is built up with a small deflection, which then maintains a virtually constant value over the full range of buckling deflection.

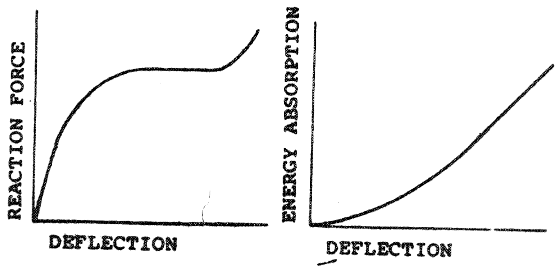


Fig. 4.19. Characteristics of buckling fender

c) Evaluation:

- These fenders are easy to install, but can be sensitive to sunlight, low temperatures, fatigue and chemical pollution.
- A protective panel is often necessary to protect the ship's hull, and to minimize wear of the fender.
- These fender types absorb relatively more energy per unit reaction for a given rated deflection.

4.3.11 SHEAR FENDER

a) Principle: The kinetic energy of the berthing vessel is converted into potential energy of the fender by elastic shear deformation of rubber. Shear fenders comprise rubber blocks vulcanized between two metal plates. The steel plates are encapsulated in rubber to protect them against corrosion.

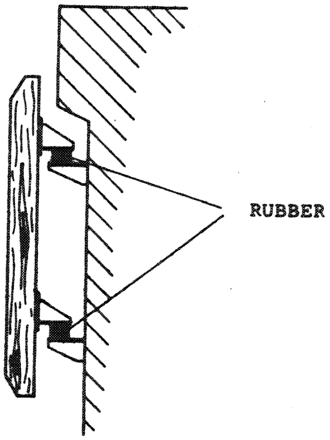
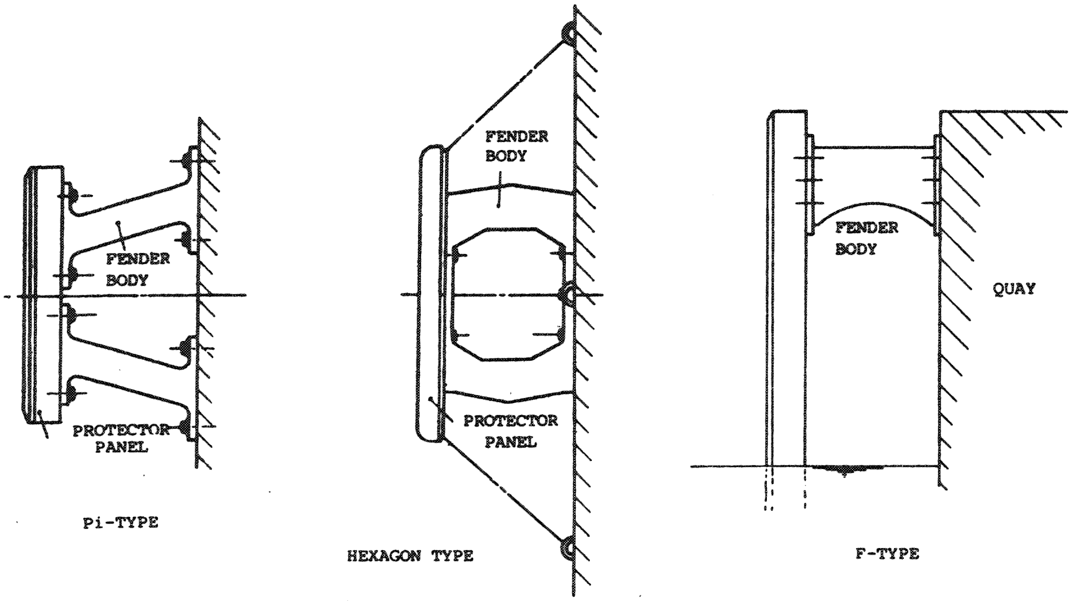


Fig. 4.20. Shear fender

b) Characteristics: The relationship between reaction force and deflection is linear.

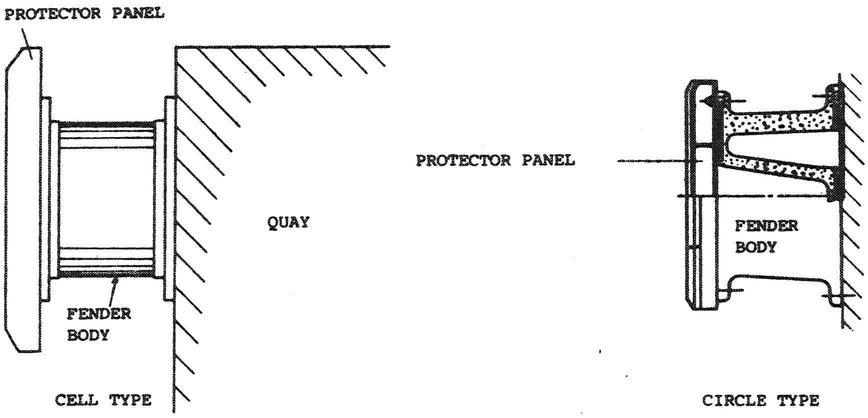


Pi-TYPE

HEXAGON TYPE

F-TYPE

LONGITUDINAL SHAPE

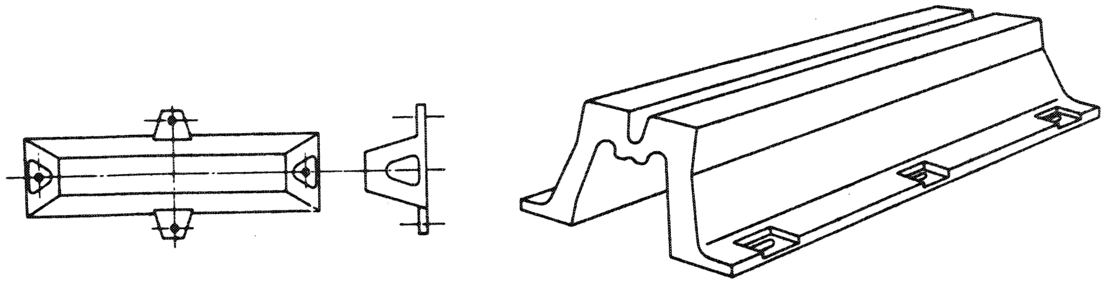


CELL TYPE

CIRCLE TYPE

CIRCULAR SHAPE

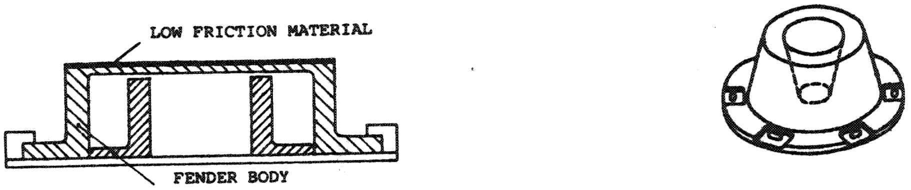
Fig. 4.17. Buckling fender with panel contact



V-SHAPE

SUPER M TYPE

LONGITUDINAL SHAPE



SUPER POT TYPE

CIRCLE TYPE

CIRCULAR SHAPE

Fig. 4.18. Buckling fender with direct contact

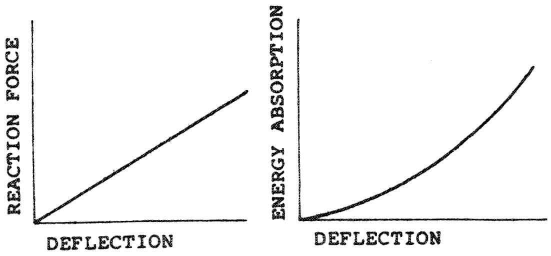


Fig. 4.21. Characteristics of shear fender

c) Evaluation:
- Contact must be made through a fender frame or panel to spread the impact over several units.
- Shear fenders are usually arranged to support the weight of the fender frame or panel without the need for piles or chains.
- Very sensitive to proper manufacturing because of the essential bond between the steel plates and the rubber.

4.3.12 RUBBER AND STEEL SANDWICH FENDER

a) Principle: The kinetic energy of the berthing vessel is converted into potential energy of the fender by elastic shear and compression deformation of rubber. This type of fender consists of a series of sandwiches of rubber bonded between steel plates, assembled between prefabricated steel abutments and a central wedge.

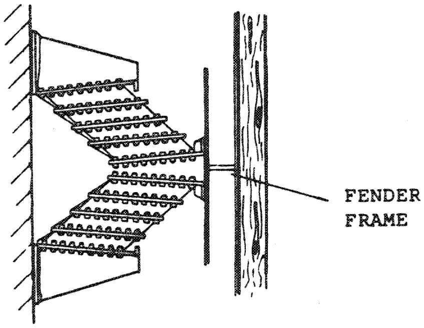


Fig. 4.22. Sandwich fender

b) Characteristics: The characteristics is one of decreasing stiffness.

c) Evaluation:
- The rated or "normal" deflection can occasionally be exceeded without destroying the fender (overload 50% of normal load producing 100% additional energy absorption).
- These fenders are not intended to be in direct contact with the hull of a berthing ship and require a strong fender frame, supported externally.

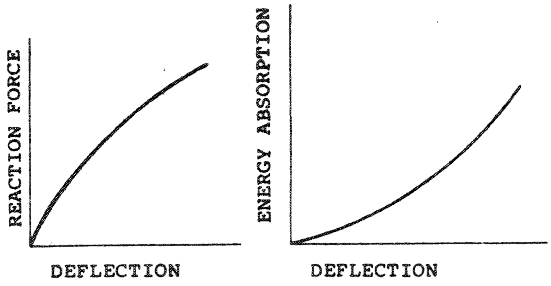


Fig. 4.23. Characteristics of sandwich fender

4.3.13 TORSION FENDER

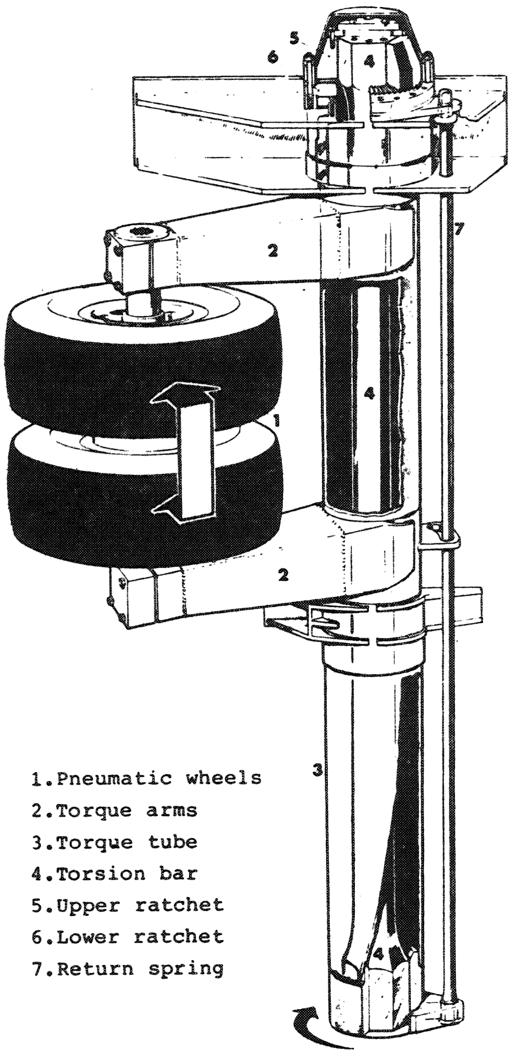


Fig. 4.24. Torsion fender

a) Principle: The kinetic energy of the berthing vessel is converted into potential energy of the fender by torsion of a steel bar.
The vessel is berthed against free running wheels. These pneumatic fenders do not absorb substantial energy, but rotate the torque arms and tube, thus winding a torsion bar. All energy is absorbed by the torsion bar.

b) Characteristics: The relationship between reaction force and deflection is linear.

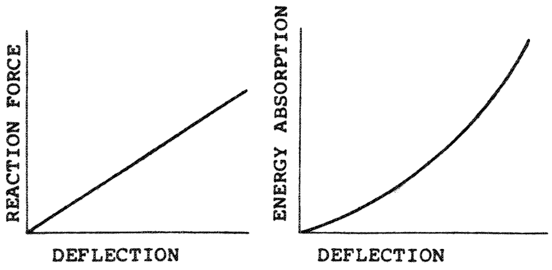


Fig. 4.25. Characteristics of torsion fender

c) Evaluation: Its complicated mechanics are difficult to repair.

4.3.14 FLEXIBLE PILE FENDER

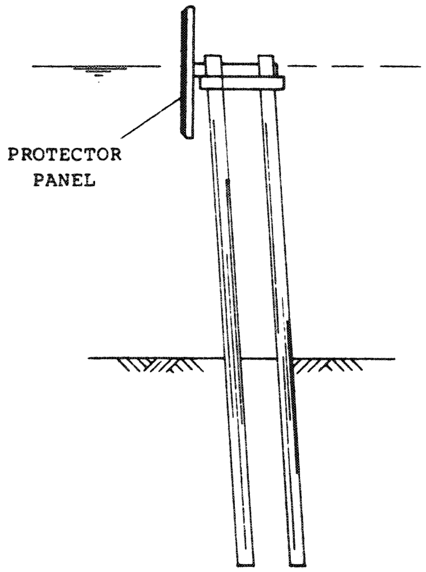


Fig. 4.26. Flexible pile fender

a) Principle: The kinetic energy of a berthing vessel is converted into potential energy of the fender by elastic bending of steel.

b) Characteristics: There is a linear relationship between reaction force and deflection.

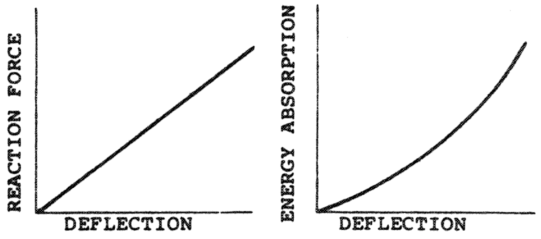


Fig. 4.27. Characteristics of flexible pile fender

c) Evaluation:

- This system combines the functions of a fender and a berthing structure.
- The flexibility and energy absorbing qualities of fender piles are reduced when the cantilevered length is shortened.
- Rubber fenders are often mounted at the top of the piles to give additional energy absorption capacity and to reduce hull pressures.
- The use of high strength steels causes construction difficulty if the piles are not driven to the design depth.
- In case of loads applied eccentrically, pile group rotation can lead to inefficiency of material use.
- At locations where wave action frequently induces significant stress levels in the piles, they must be designed to resist fatigue failure.

4.3.15 HYDRAULIC FENDER

a) Principle: The kinetic energy of the berthing vessel is converted into friction/heat energy by forcing a liquid through small openings.

b) Characteristics: Hydraulic fender systems can be arranged to exhibit virtually any desired reaction/deflection relationship. A typical hydraulic fender system has the reaction/deflection illustrated below.

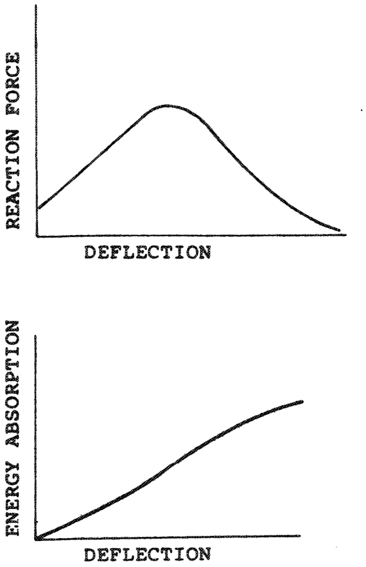
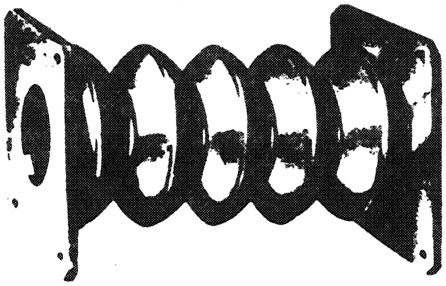


Fig. 4.28. Characteristics of hydraulic fender

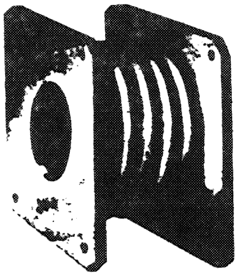
c) Evaluation:
- High quality materials are required and regular maintenance is needed.
- The hydraulic units are very compact and therefore the fenders are especially applicable to frontal impacts which occur, for example, during berthing of ferry-vessels.
- Since the kinetic energy of the berthing vessel has been dissipated in the form of heat, these fenders do not return to their original position.
- Since almost any reaction/deflection relationship can be arranged and since it is possible to vary the relationship, even during the berthing impact, this type of fender has potential for development for use at locations exposed to appreciable wave action.

4.3.16 PLASTIC ENERGY ABSORPTION CORRUGATED UNIT (PEACU)

a) Principle: The kinetic energy of the berthing vessel is dissipated by deforming the steel permanently. This type of fender is fabricated of plastic coated steel and its prime function is to be mounted in series with rubber fenders in order to take the occasional overload which exceeds the energy capacity of the rubbers.



BEFORE IMPACT



AFTER IMPACT

Fig. 4.29. Plastic energy absorption corrugated unit (PEACU)

b) Characteristics: During deformation the reaction force is almost constant.

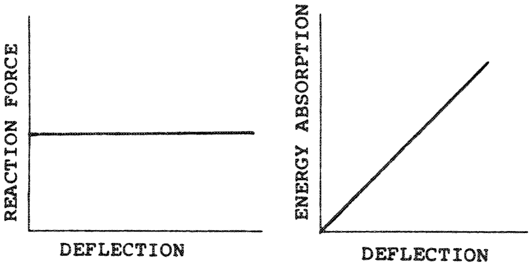


Fig. 4.30. Characteristics of plastic energy absorption corrugated unit

c) Evaluation:
- PEACU's were initially conceived as the energy absorbing equivalent of an electric fuse.
- The costs of this type of fender is only a fraction of the equivalent elastic fender.
- After overloading new PEACU's can be quickly and cheaply installed after removal of the old, damaged ones.

4.4 DISCUSSION AND EVALUATION OF THE VARIOUS FENDER SYSTEMS

The optimum fender system for any particular situation depends on a number of factors as outlined in Section 4.2. The fender system designer must evaluate the effect these factors will have on the capital and maintenance cost of the various types of fender systems which can satisfy the energy absorption requirements, as well as their supporting structures, and determine the system which will result in the lowest life cycle cost. Life cycle cost is the sum of the initial capital costs and the present worth of the annual maintenance and repair cost, over the expected useful life of the fender system and the supporting structure. While on the surface this appears to be a relatively simple and straightforward procedure, in actual practice it is often quite difficult to evaluate quantitively the effect of each factor on both the marine terminal and the vessels using it. Consequently, the fender system designer may have to consider some factors only on a qualitative basis, but he should not lose sight of the objective of minimizing life cycle cost. For further discussion of this subject refer to Appendix III, "Economic Evaluation of Oil Tanker Terminals," of Working Group No. 3 Report of the Final Report of the International Tankers Commission (1970-1974) published in PIANC Bullting No. 16, Vol. III/73.

Section 4.3 lists a great many varieties of fender systems which are available for the designer to select from. However, some of these systems are either outdated, having been replaced by more efficient systems, or are not suitable for berthing large vessels, ferries or Ro-Ro vessels.
The gravity, buoyancy, spring, bush and end loaded fender systems have all been successfully used in the past but, except in extremely unusual circumstances, would not be the optimum fender system for a modern port providing berthing facilities for large vessels. Shear fenders, within practical sizes, do not have sufficient energy absorption capacity. The rubber and steel sandwich fenders have been widely and succesfully used in the past but have, for the most part, been replaced by less expensive and more efficient buckling type fenders.

Torsion fenders have not been widely used and hydraulic fenders have been used only in special applications, such as ferry berthing.

The fender systems most widely used in new installations for berthing large vessels, ferries and Ro-Ro vessels are the buckling types, the pneumatic and foamfilled types, the side loaded rubber types and, where soil conditions are suitable, the flexible pile type. (Refer to Chapter 9 for a discussion of the special requirements for ferry and Ro-Ro berths.) Fig. 4.31 illustrates the reaction/deflection characteristics of these types of fender systems. The area under each of the reaction/deflection curves represents the energy absorbed by that type of fender. Each of the curves in the figure represents fender systems with equal rated reactions and equal energy absorption capability.
It is evident from Fig. 4.31 that, while the fenders of the various types illustrated provide equal energy absorption at equal rated reactions, the energy absorption capacity is achieved through different deflections, with the buckling type deflecting the least.

A comparison of the various types of fenders may alternatively be considered on the basis of equal rated reaction and equal deflection, as illustrated in Fig. 4.32. This situation often occurs when new fender units are installed in conjunction with, and consequently must be compatible with, an existing fender system. It may also occur when a replacement fender system is installed in an existing facility with cargo transfer equipment of limited reach. It is evident from the figure that the buckling type fenders have considerably more energy absorption capacity for a given reaction and deflection than the other types.

Comparing the various types of fender systems from the point of view of the reaction force that is developed for a given energy absorption capacity, as illustrated in Fig. 4.33, it is evident that the pneumatic, foam-filled and side loaded rubber type fender units are the "softest". They have greater energy absorption capacity at reaction levels less than their maximum rated reaction. This characteristics makes these fenders particularly attractive at berths which must accomodate a wide range of vessel sizes since the fenders will deflect significantly even when subjected to relatively small berthing impacts. In exposed locations these fenders may have a greater tendency to dampen ship motion under wave action, thus reducing mooring line forces induced by the moored ship's dynamic

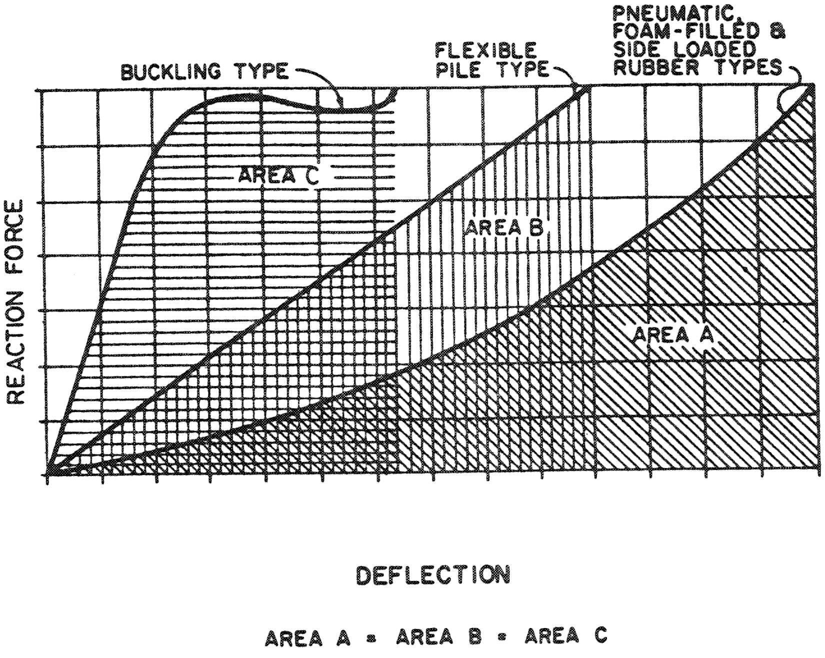


Fig. 4.31 Reaction/deflection characteristics of various types of fenders (Equal Energy)

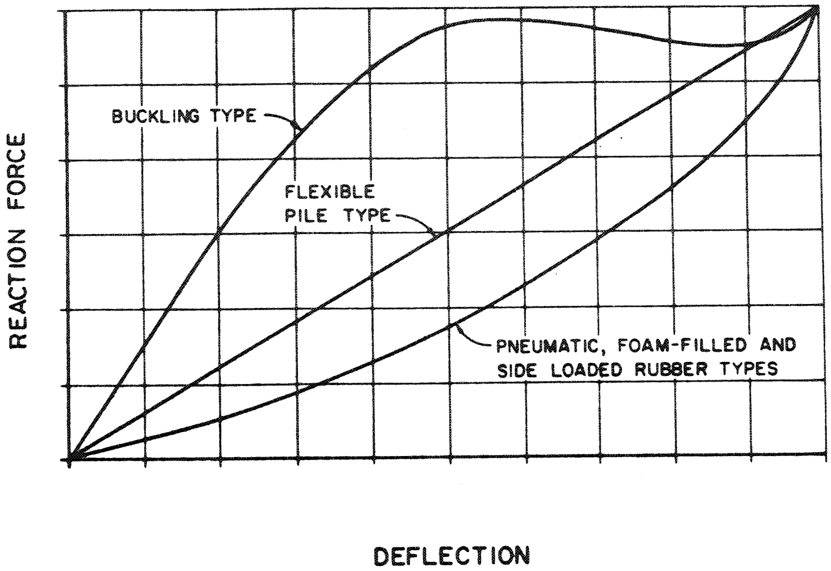


Fig. 4.32 Reaction/deflection characteristics of various types of fenders (Equal Deflection)

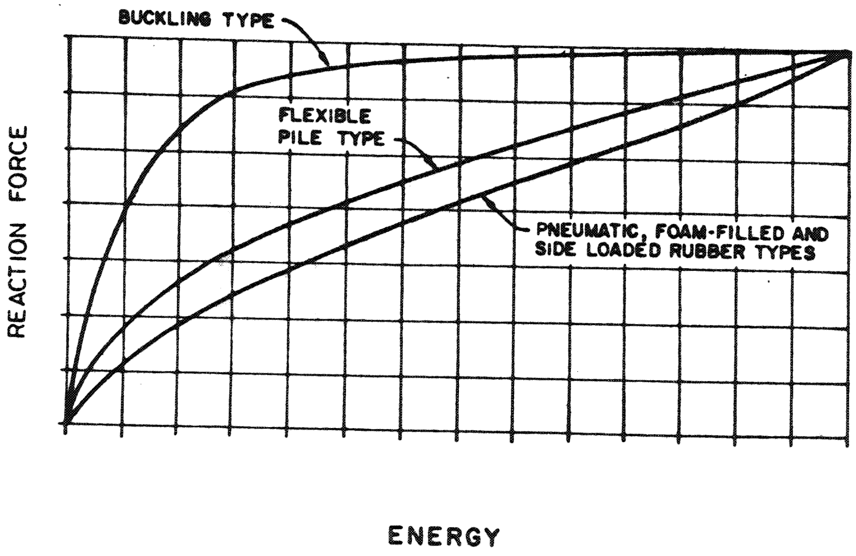


Fig. 4.33 **Reaction/energy characteristics of various types of fenders**

behavior. For a further discussion of "soft" fenders and "stiff" fenders, such as the buckling type, refer to "Stiff Fenders Versus Soft Fenders", by Prof. Fernando Vasco Costa, Section II - Theme 5 of the 4th International Harbour Conference, Antwerp.

Also to be considered in the selection of a fender system are the consequences of an accidental overload of the system. The buckling and side loaded rubber fenders "bottom out" if compressed beyond their maximum rated deflection, with resultant high reaction forces and the potential for severe damage to the berthing vessel and the support structure. The reaction of flexible pile fender systems will continue to increase at a uniform rate when overloaded until the yield stress of the pile steel is reached, at which point continued deflection will occur as the steel yields with no appreciable increase in reaction. Foam filled fenders, when compressed beyond their maximum rated deflection will exhibit a steadily increasing reaction and will incur permanent deformation and consequent loss of future energy absorption capacity. The pneumatic fenders are normally fitted with relief valves so that when overloaded they continue to absorb energy with no increase in reaction beyond that which corresponds to the relief valve setting and no permanent damage to the fender unit.

Since the buckling type fender systems have the highest energy absorption capacity for a given deflection and reaction, they are in very wide use. Due to the nature of the reaction/deflection/energy absorption relationship of these types of fenders, as illustrated in Fig. 4.33, the maximum reaction occurs during virtually every berthing operation and the berthing structure must be designed with this fact in mind. This fact also causes the fender to be relatively rigid when smaller ships use a berth designed for larger ones. Many buckling type fenders cause rather high contact pressures against the ship's hull and consequently require a panel to distribute and thus reduce the pressure. The panel must be sized and located to insure proper contact with both the largest and smallest vessels to use the berth. Another characteristic of these fenders which must be considered is their lowered performance when impacted by a vessel approaching at an angle to the berth and/or with a velocity component in the longitudinal direction. The reduction in energy absorption capacity may be as much as twenty percent when the approach angle is five to ten degrees, with additional reduction when combined with shear strain.

The floating pneumatic and foam-filled fenders have a similar appearance and similar reaction/deflection relationship. Compared to the buckling types, these fenders require greater deflection for a given reaction and energy absorption capacity, and consequently require a greater reach of the cargo transfer equipment. The pneumatic and foam-filled fenders present a very large surface to the ship's hull and consequently have low hull contact pressures. This eliminates the need for a panel between the ship and the fender. With the pneumatic and foam-filled types of fenders, the maximum reactions will normally occur only a very few times during the life of the facility, permitting the use of higher stress levels in the supporting structure. However, they require a rather large, solid face on the supporting structure which may increase its costs. The main difference between pneumatic and foam-filled fenders is that the former will lose its strength completely when punctured (a very rare occurence) and that the latter may lose a significant part of its energy absorption capacity under repeated heavy loadings.

The large, side loaded rubber fenders, particularly the cylindrical type, have found application in the berthing of large vessels where energy absorption requirements are not too high. Their relatively low cost sometimes makes then an attractive alternative in spite of their large deflection and/or high reaction compared with the buckling type fenders. Particular care must be exercised in mounting this type of fender to insure that it does not tear when subjected to lateral deflection. As for the pneumatic and foamfilled fenders, the side loaded rubber fenders will normally be subjected to their maximum reaction only a few times during the life of the facility. However, unlike the pneumatic and foamfilled fenders, the reaction on the ship's hull may be quite high.

Where soil conditions are suitable, the flexible pile type fender system is often very attractive. By combining the functions of fender and breasting structure, it is often possible to minimize the cost of the facility. The energy absorbing capacity of the piles is a function of their diameter, thickness, and length and the square of their yield strength. The flexible pile type system is often used in combination with one of the rubber type fenders or the pneumatic of foam-filled type fenders to increase its energy absorption capacity. The soil mechanics aspects of the design of this type of fender system is discussed in Chapter 8.

After determining the energy requirements and selecting the optimum fender type, the designer must exercise care in preparing the purchase specifications for rubber fender units. There are a number of different ways of specifying fender systems and consequently there is a wide range of ways to interpret these specifications.
Each fender manufacturer has his own method of selecting fenders according to specifications, which can sometimes lead to widely divergent fender capabilities to meet any particular installation specification. An article by Robert A. Young, titled, "Marine Fender Specifications", published in the proceedings of the "Ports 80" conference by the American Society of Civil Engineers, presents a further discussion of this problem, while in Annex 4.1 the Japanese standard for the inspection of solid rubber dock fenders is given as a practical example of an existing specification.

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ANNEX 4.1

JAPANESE INSPECTION STANDARD FOR SOLID RUBBER DOCK FENDERS

1. SCOPE

This standard stipulated for the material, performance, dimension and test methods in respect of solid rubber dock fender (hereinafter referred to as "Fender") to be used for the public wharves.

2. MATERIALS

2.1

The rubber for Fender shall be vulcanized natural or synthetic rubber, or the mixture of them. These shall be reinforced with carbon black and resistant to aging, seawater, oil, abrasion etc.

2.2

The rubber shall be homogeneous in quality, and free from the foreign materials, bubbles, injuries, cracks and other harmful defects.

2.3

When Fender is fitted with the integrated fixing steel plate, such plates shall be firmly bonded to the rubber body through the process of valcanization, and covered with rubber perfectly lest they should exposed.

2.4 Material Test

2.4.1

The rubber used for Fender shall comply with the specifications stipulated in Table 1.

2.4.2

If the Standard in Table 1 specified more than 2 kinds of test methods, the test shall be practised in accordance with the methods* mentioned below.

1) Hardness: Spring type hardness (Type A)
2) Aging: Aging test in heated air Temperature: 70 ± 1°C
Period of test: 96 hours
3) Compression set: With heat treatment
Temperature: 70 ± 1°C
Period: 22 hours

TABLE 1: STANDARD OF RUBBER COMPOUND

Test Item		Standard
Physical test	(Before Aging)	
	Tensile strength:	160 kgf/cm^2 (16MN/m^2) or more
	Elongation:	350% or more
	Hardness:	72° or less
	Compression set:	30% or less
	(After Aging)	
	Tensile strength	Not less than 80% of original values
	Elongation:	Not less than 80% of original Values
	Hardness:	(Original values +8o) or less and 76o or less

3. PERFORMANCE

3.1

The performance of Fender is expressed by the value of energy absorbed during the compression of Fender up to the prescribed deflection and the maximum value of reaction load thus generated.
The prescribed deflection is the deflection at which the ratio (E/R) of the value of energy absorption (E) to the value of reaction load (R) derived from the standard performance curve for Fender, makes maximum.

3.2

In the performance test of Fender, vertical compression test is used in general. Angular compression test is to be carried out if necessary. The compression process at the speed

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References:
*) Physical Testing Methods for vulcanized rubber (JIS K6301-1975): Published by Japanese Industrial Association, 1975.

2 - 8cm per minute is to be repeated for three times up to the prescribed deflection. The load and the deflection in each test shall be recorded with the precision of 0.1 tf (10kN) and 0.5 mm, respectively, unless otherwise specified.

3.3

The value of energy absorption is expressed in tf-m, and it is obtained by the reaction load/deflection curve up to the prescribed deflection.

3.4

The average data obtained in the second and third tests shall be the performance values. The average value shall be more than the prescribed performance value for the energy absorption and less than the prescribed performance value for the maximum reaction load.

3.5

For the performance test of Fender, the room temperatures at the time of test shall be recorded. The changes in performance characteristics due to the temperature are to be ascertained if necessary.

4. DIMENSION

4.1

The tolerances in the dimensions of Fender shall be as stipulated in Table 2.

TABLE 2: TOLERANCE OF DIMENSION OF FENDER

	Length	Width	Height	Thickness	
				Standard	Exception
Tolerance:	+4% -2%	+4% -2%	+4% -2%	+8% -2%	+10% -5%

Remark: The exception of thickness shall be applied for Fender smaller than and including 300 mm in height

4.2

If bolts are used for fixing Fender, tolerances for bolt holes on Fender shall be as stipulated in Table 3.

TABLE 3: TOLERANCE OF BOLTS HOLE ON FENDER

	Diameter of Hole for Bolt	Pitch of Holes
Tolerance:	±2 mm	±4mm

5. SAMPLING

The specimen for testing and inspecting the material, dimension and performance shall be sampled as specified in Table 4.
The specimen to be used for the material test shall be taken directly from the product or from the rubber prepared in the quality and under the condition of valcanization same as those of the products.

TABLE 4: NUMBER OF SAMPLING

Test Item	Number of Sampling
Material:	1 set from the lot of compound for the manufacture of Fender
Dimension:	All Fenders
Performance:	1 piece per 10 pieces (To raise the fractions to a unit)

6. RE-TEST

6.1 Material Test

If the specimen is found to fail to comply with the specification in Table 1, re-test shall be conducted with two additional sets of specimens. If these specimens satisfy the specifications, the entire lot is accepted as meeting the specifications.

6.2 Performance

If any specimen for test does not satisfy the specifications in Paragraph 3.4, retest shall be conducted on 1 piece per 5 pieces (to raise the fractions to a unit) of the remainder, excluding the rejected specimens. If this results in further rejects, tests shall be conducted on the all remainders.

7. MARKING

Fender shall be marked with the following items.

1) Size (height, length)
2) Date of manufacture or its abbreviation
3) Name of the manufacturer or its trade mark

APPENDIX C

FENDER FACILITIES FOR RO/RO SHIPPING AND FERRY BERTHS

("Report of the International Commission for Improving the Design
of Fender Systems," Brussels, Belgium: PIANC, 1984)

ASSOCIATION INTERNATIONALE PERMANENTE
DES
CONGRÈS DE NAVIGATION

PERMANENT INTERNATIONAL ASSOCIATION
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RÉFÉRENCE À RAPPELER :
IN REPLY PLEASE QUOTE :
N° 151 (DC/jc)

Brussels, 2 June 1992

Prof. Charles T. JAHREN,
Assistant Professor,
University of Washington,
Department of Civil Engineering,
121 More Hall FX-10,
SEATTLE, Washington 98195
U.S.A.

Dear Sir,

We hereby acknowledge receipt of your letter dated 27 May 1992.

The requested permission to include copies of Chapters 4 and 9 of the Report of the International Commission for Improving the Design of Fender Systems in the appendix of your final report is granted, provided the source of the information plus "Copyright by PIANC General Secretariat, Brussels, Belgium" is mentioned.

Yours sincerely,

Eng. B. FAES,
Secretary-General

CHAPTER 9

FENDER FACILITIES FOR RO/RO SHIPPING AND FERRY BERTHS

9.1. SPECIFIC PROBLEMS

The economic employment of Roll-on/Roll-off ships is only possible, if the relatively high shipping costs per ton pay load are counterbalanced by very short port times. The horizontal, rolling traffic during loading and unloading of cargo associated with this type of freighter, creates the necessary prerequisites therefore. It must also be ensured however, that

(a) the occupancy of the special berths in the ports is kept sufficiently low, as a result of which, waiting times for the Ro/Ro ships can be largely avoided, and that

(b) the berthing and departure manoeuvres of the ships are carried out quickly and efficiently, even under unfavourable conditions.

The latter condition, especially when ships are being berthed, compels the acceptance of certain risks, which can only be decreased or avoided by installation of sturdy fenders at the berths, provided with additional reserves in view of the required protection for ship and port structure.

At ferry berths for the transfer of wheeled land transporters (railway trains and motor vehicles), the foregoing applies to an even greater extent, because

- the ships often operate only on short travel routes, so that the necessary rentability of the transport chain compels observance of minimum port times,
- as a rule, the ferry service runs on fixed time schedules,
- the frequency of arrivals and departures at the berths can be extraordinarily high.

These operational circumstances require the provision of very special ferry berths on the one hand, which are adapted in their layout and structural design to the respective ship types, manoeuvres and loading operations, and on the other hand the availability of sturdy, efficient fenders, which ensure a minimum of repair and maintenance.

Both Ro/Ro vessels, as well as ferries for wheeled land transporters are, as a rule, loaded and unloaded at the stern or at bow and stern. Exceptions are ferries for combined transport, in which the railway waggons pass through the ship's ends and the motor vehicles through the side doors of the ship. As a matter of fact, these special loading operations bear influence on the layout and type of the berthing facilities. However, as far as the design of the respective fender facilities is concerned, the type of berthing manoeuvre is the decisive factor. Of special significance thereby is, whether the ship makes a straight-line approach to the pier under its own power, or whether it ties up at the berth moving transverse to the berthing face with tug assistance or under its own power.

Ferries are often equipped with a continuous fender beam at the level of the main car deck. The fender beam is able to transmit large forces to the hull of the ferry without causing any damage. As the contact between fender and ferry always will take place along the fender beam much higher loads than used for ordinary ships are permissible. The fender beam may be 0.2 to 0.3 m high and from 0.15 to 0.25 m wide, depending on the size of the ferry. Steel members support either a timber of a rubber member acting as a fender between the ferry and the fender on the structure.

9.2. SHIP BERTHING MANOEUVRES AND BASIC DESIGN CONCEPTIONS

9.2.1. TRANSVERSE SHIP APPROACH TO THE BERTH

Berthing alongside, transverse to the berth, may be considered mainly in the following cases:

(a) In ports with slight tidal range or minor water level fluctuations (e.g. locked harbours) normal general cargo berths are occasionally or temporarily used for handling of Ro/Ro ships. As these berths are not provided with any special facilities for

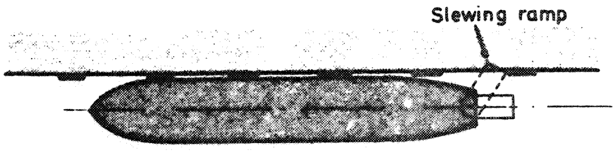

Fig. 9.1 - Ship with its own slewing ramp

rolling traffic, loading and unloading of vehicles proceeds across ship-owned slewing ramps (Fig. 9.1).

In such cases, the Ro/Ro vessels are tied up at the berth like normal freighters, with or without tug assistance. For the layout, dimensioning and structural design of the fenders, therefore, in principle, the bases which apply to normal freighter berths are to be used, even if with increased operational and technical demands.

(b) Where limited calling at the port by Ro/Ro ships and/or ferries does not yet permit the construction of special berth facilities reserved solely for these types of vessels, individual shipping berths are used both by normal freighters, as well as by Ro/Ro ships and/or ferries. In such a case, the particular quays are mostly supplemented by special shore-fixed or floating installations, which permit loading and unloading of the ships at either end, i.e. at the stern and/or bow (Fig. 9.2). A similar type of berth may also be appropriate for ferries with combined transport of railway waggons and motor vehicles, in which the waggons are rolled onto the quay over the bow or stern ramp and the motor vehicles through the side doors.

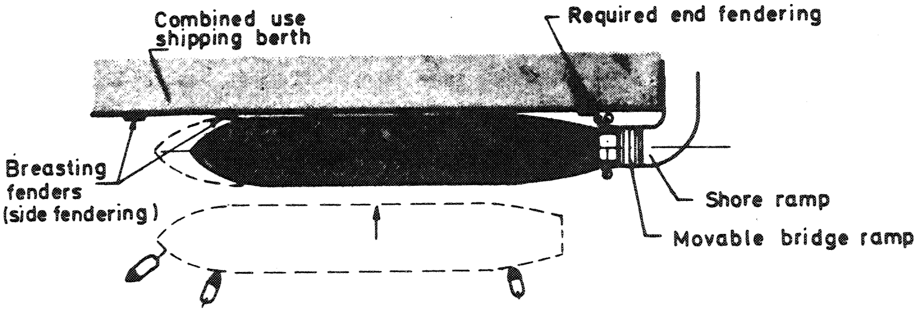

Fig. 9.2 - Shore-fixed or floating installations for Ro/Ro ships or ferries

At these types of berths as in case (a), the Ro/Ro ships and/or ferries are also brought parallel to the pier resting against breasting fenders, and only afterward shifted longitudinally to the shore-bound ramp facility. The fendering of such berths is therefore to be designed basically for the same requirements as in case (a). In addition however, additional structural measures should be initiated in the form of suitable end fenders, in order to protect any vulnerable mechanical or structural installations of the bridge ramp at the berth end, against damage during longitudinal shifting of the vessels. This applies especially, when the Ro/Ro ships themselves are only equipped with shorter stern ramps.

(c) At berths exclusively foreseen for the handling of Ro/Ro ships and/or ferries for wheeled transporters, and at which the loading or unloading operations can only proceed through the ship's bow or stern, the provision and use of quay walls are dispensed with as a rule, on economic grounds. The berth is then restricted to a row of breasting fenders or a continuous side fendering standing free in the water, and the ramp facilities at the landsided end of the berth, which as a rule should be equipped with a sturdy end fendering (Fig. 9.3).

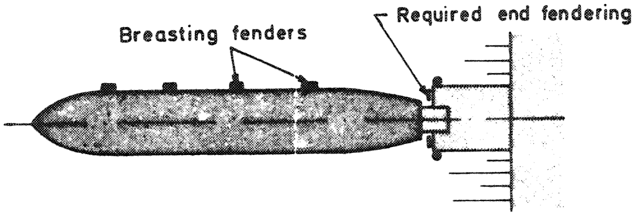

Fig. 9.3 - Head-on berthing with breasting fenders and end fenders

The berthing procedure in this solution corresponds to the ship manoeuvre described in (b), so that similar types and designs of fender structures are to be provided here.

9.2.2. HEAD-ON SHIP APPROACH TO THE BERTH

9.2.2.1. GENERAL

Berthing head-on is normally only practiced by inland ferries on rivers, canals and lakes, as well as on regularly scheduled deep-sea ferry services with shorter routes. (As inland ferries are not a subject of this report, the special problems prevalent there will not be gone into).

Safe berthing head-on presupposes that the ships are equipped with effective propulsion and rudder/steering mechanisms possessing especially quick change-over characteristics (Fig. 9.4). Thereby bow-thrusters, Schotteldrive and Voith-Schneider propellers enable shorter stopping distances, quick course corrections and lateral ship manoeuvres.

Beyond this however, special measures must also be taken on the harbour side, in order to allow quick and safe ship operations, as well as efficient and scheduled loading and unloading

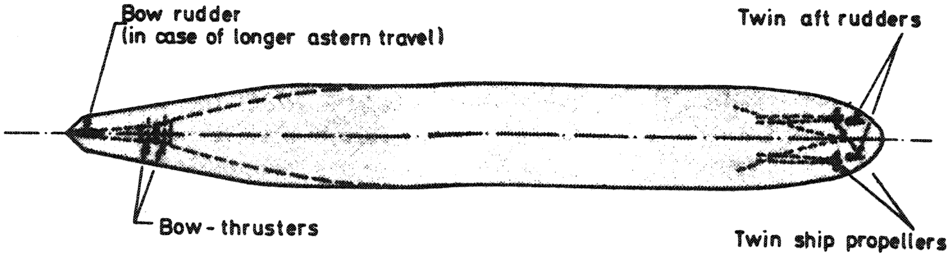

Fig. 9.4 - Ships manoeuvring equipment for head-on berthing

of ferries. Certain aspects, which should be of interest in connection with these requirements, are described in the following :

The structural installations of a ferry berth suitable for head-on ship berthing as a rule, consist of a one-sided guiding facility for the incoming vessel, and the bridge and/or shore ramp for the loading operations through the bow and/or stern of the ship (Fig. 9.5).

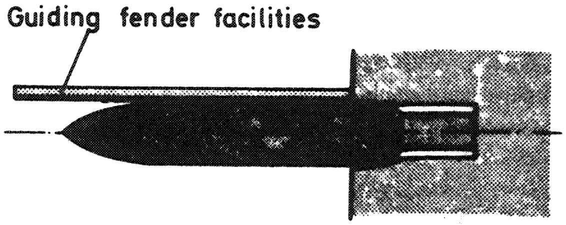

Fig. 9.5 - Guiding fenders one sided

In many cases however, a regular ferry bed with guiding facilities on both sides, is provided for operational reasons (Fig. 9.6).

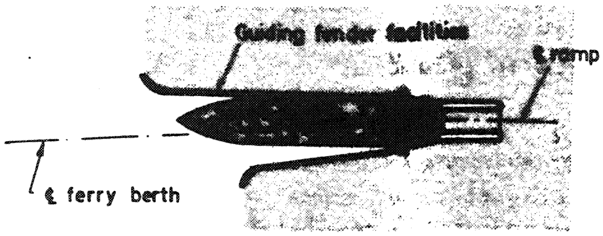

Fig. 9.6 - Guiding fenders both sides

The approach and berthing procedure of the ferries at such types of port facilities is determined by the axial-directed, straight-line forward movement of the vessel (Fig. 9.7). When berthing with the bow forward, it corresponds to a normal stopping manoeuvre, which starts with full travel speed in the area of the harbour entrance, continues with reduced velocity till the extreme end of the berth, and ends directly in front of the shore ramp at slightest speed. If the ship berths with the stern in front, the travel velocities in the approach area are less because of the interim turning manoeuvre.

In consideration of the foregoing described head-on berthing manoeuvre, the entire waterfront of the ferry berth must be covered by a sufficient number of single fenders, or even better, by a continuous fendering.

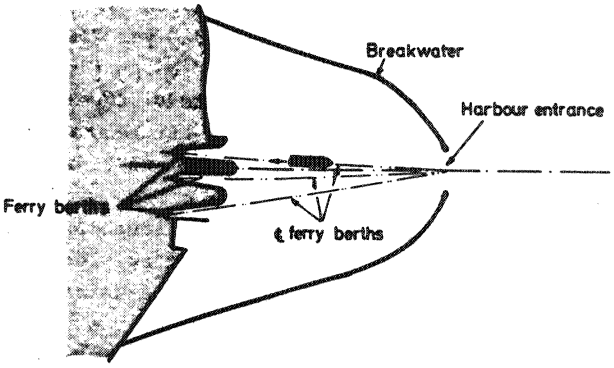

Fig. 9.7 - Typical approach and berthing procedure

Functionally, a distinction must be made between :
- guiding/side fenders, and
- end fenders.

For the design and the dimensioning of these fenders, special demands are placed for each type in accordance with their functions. These requirements deviate from the normal and customary, and lead to a different design basis.

9.2.2.2. GUIDING/SIDE FENDERS

Guiding/side fenders are not intended to reduce or to even absorb the axially-directed kinetic energy of the incoming vessel, whether through elastic deformations or friction. The functions of the guiding fenders are rather to assist the ferry in making final, slight course corrections during the stopping manoeuvre. Such fender facilities as a rule are therefore struck in only a small angle to ship travel direction, which may vary from place to place, along the fender face (Fig. 9.8). Especially at regular ferry beds this angle is already predetermined in its maximum size through the geometry of the berth. Since the travelling speed of the vessel likewise varies along the length of the guiding fender facilities, the ship's impact and therewith the loading and stressing of the fenders logically also changes.

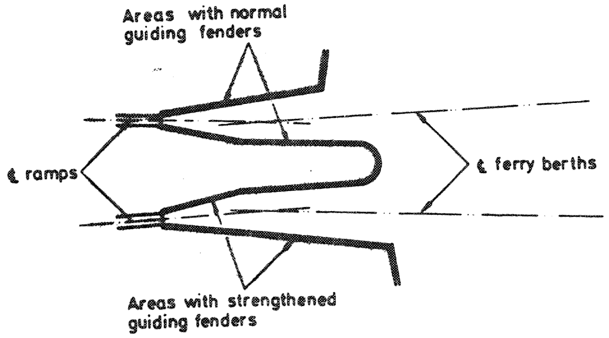

Fig. 9.8 - Guiding Fenders

9.2.2.3. END FENDERS

End fenders are installed solely at the inner end section of the berth (Fig. 9.9). They must absorb any residual kinetic energy of the incoming ferry and safely prevent jolting contacts between the ship and the movable bridge ramp.

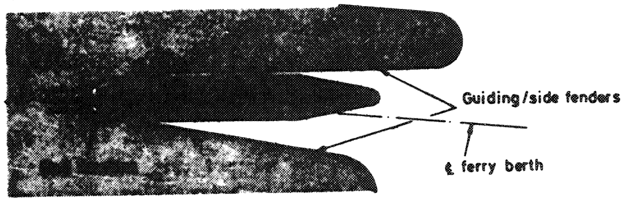

Fig. 9.9 - End Fenders

Sometimes, especially at railway ferry berths, the end fenders serve for bringing the ferry into the desired position in the immediate area of the bridge and/or shore ramp, and for holding it there during the entire period of laying time. In such cases their configuration is extensively determined by the bow or stern shape of the ferry, which should be uniform or as similar as possible for all vessels mooring at the ferry berth. Because of their particular function, this type of end fenders is to be designed relatively stiff, so that restoring forces of adequately large magnitude can be activated.

Sometimes, the final position of the ferry is fixed by a special locking device between the ship and the port-owned bridge ramp. In order to avoid heavy loadings on the movable ramp bearings, it is recommended however, to better adjust the final position of the ferry through moorings to the stiffer and less vulnerable foundation structures of the bridge ramp.

In both latter cases, the "positioning function" of the end fenders is not required. But nevertheless, the design of the end fenders as a rule creates difficulties, because the changing levels of the tidal water and of the ferry decks, as well as the special shapes of the ship hull ends are to be taken into account.

9.3. BASES OF DESIGN

9.3.1. DIMENSIONS OF RO/RO SHIPS AND FERRIES

The characteristic data of Ro/Ro ships in service are quite different in respect of length (L_{oa} and L_{pp}), breadth (B) and draft (d). Table 9.1 thus contains only average values, which however, should be adequate for the design of fenders.

TABLE 9.1

Ro/Ro Ship Data x)						
dwt	Displacement	L_{oa}	L_{pp}	B	d	C_b xx)
tons	MN	m	m	m	m	-
2,500	55	105	95	18	5.0	0.64
5,000	90	135	123	20	5.5	0.67
7,500	130	155	140	21.5	6.4	0.67
10,000	170	170	155	23	7.0	0.68
15,000	260	190	173	27	8.3	0.67
20,000	350	205	186	30	9.5	0.66

x) Data elaborated from [1], PIANC Report of the International Study Commission on the Standardisation of Roll-on/Roll-off Ships and Berths, 1978.

xx) C_b = block coefficient (approximate values).

The dimensions of ferries also vary very strongly, namely contingent on the type of land transport vehicles carried by the ship, and the number of loading decks. Relevant examples are furnished by data on the following ships, which have been listed according to their displacement in table 9.2.

TABLE 9.2

Ferry Data xx)							
Name of Vessel	grt	dwt	Dis-place-ment	L_{oa}	B	d	C_b
	tons [x 10^3 kN]	tons [x 10^3kN]	MN	m	m	m	
Railship I x)	5,322	7,096	130	150.0	21.6	6.5	0.64
Dronning Ingrid x)	10,607	4,490	119	145.0	23.1	5.8	0.63
Peter Pan	12,527	2,700	105	149.4	23.5	5.5	0.56
Nils Holgerson	12,515	2,700	105	148.9	24.0	5.5	0.55
Turella	10,600	2,300	-	136.1	24.2	5.4	-
Deutschland x)	6,119	1,730	93	144.1	17.2	5.9	0.65
Caribe	9,963	2,337	84	134.5	21.9	5.5	0.54
Danmark x)	6,352	1,740	79	145.0	17.2	5.5	0.60
Prince Oberon	7,933	1,778	71	134.0	21.0	4.9	0.54
Romsø	5,603	1,700	70	130.0	17.2	5.0	0.66
Trelleborg	-	-	68	130.0	18.1	5.3	0.57
Theodor Heuss x)	5,583	1,644	64.4	135.9	17.2	4.8	0.59
Dronning Margarethe II x)	-	-	63.4	133.0	17.2	4.5	0.64
Prince Hamlet	5,830	1,127	56	118.7	18.3	5.0	0.54
Princess of Vancouver x)	-	-	55	128.0	19.2	4.5	0.52
Knudshoved x)	-	-	52	109.0	17.7	4.6	0.61
Europafärjan	4,391	1,118	50	123.3	18.5	4.7	0.49
Cariddi x)	-	-	49	121.6	17.2	4.5	0.54
Napoleon	-	-	43	99.5	15.8	5.0	0.57
Maid of Kent	-	-	41	109.0	17.0	4.0	0.57
Vacationland	-	-	41	99.1	20.6	5.0	-
Kärnen x)	1,600	695	26.5	88.0	12.9	4.0	0.60
Ulisse	-	-	23	94.2	17.0	3.2	-

x) Ferry for railway or combined rail/road traffic.

xx) Ferry data from enquiries and/or technical literature.

9.3.2. BASIC CONSIDERATIONS AND RECOMMENDATIONS ON THE DESIGN OF FENDER FACILITIES WITH TRANSVERSE SHIP APPROACH

9.3.2.1. BREASTING FENDERS (SIDE FENDERING)

In the design and in the dimensioning of breasting/side fenders, at which Ro/Ro ships or ferries berth beam-on, the common standards and recognised fundamentals at normal shipping berths for handling of freighters of comparable size are to be applied. Beyond this, attention is called to the following aspects :

(1) The mutual interval of the breasting fenders in front of massive waterfront structures should be determined in such a manner, simultaneously taking into account the ship's hull shape and the spacing between the berthing face alignment and the front edge of quay, that a ship berthing at an angle of 5° (max 10°) does not come into contact with the massive port structure.

Where no tug assistance is employed, and where vessels cannot steam straight off the berth or are berthed in close proximity to one another, the practise of using the quay as a fulcrum to swing the bow, and/or stern, off the quay is frequently used. Thereby the square "cut off" type stern, which is a characteristic feature of many Roll-on/Roll-off vessels, is held against the quay and the bow thruster is used to swing the bow out into the stream. In such cases, it is considered necessary to provide a panel of fendering, so that the vessels' stern can rest on the panel and thus damage to the quay is avoided. These panels should be located close to the bridge ramp and are not to be designed to take berthing loads.

(2) Breasting fenders in front of massive waterfront structures should reach as far as possible to the upper surface of the apron, so that on the one hand the structure is protected against contact with the projecting forecastle of the vessels, on the other hand however, the quay upper surface remains free for setting down the slewing or side ramps. The bottom edge of the fenders is to be so determined, that even at lowest freeboard depth and low water levels ships cannot catch, but rather still have an adequately large contact surface toward the fenders.

Where open berths are affected by swell and tidal variations, movement of the vessel is likely to take place. In many cases the vessel is held firmly against the fenders by breast moorings and the continuous rubbing which occurs as the vessel moves up and down, rolls and pitches, should be taken into consideration in the design and robustness of the facing member of the fender system.

(3) Ease of maintenance should be designed into any fender system, particularly where sophisticated sprung fendering units are pro-

vided. Maintenance must be given high priority, particularly on a berth where the utilisation is very high. It is suggested that the fender system is designed in such a manner, that in the event of damage, units can be removed and replaced very easily by new ones, and that the damaged units can be repaired away from the berth. The fender unit itself may be designed with weak links, so that the connection to the permanent structure is not distorted in the event of damage to the fender.

(4) Because of the open compartment design of Roll-on/Roll-off vessels, and hence the lack of internal bulkheads, it is common practise for the ships to have belted hulls. This protection is generally located at the level of the main trailer deck. The negative effect of this arrangement is that a point load is applied to the fenders. A further disadvantage is, that in tidal berths these projecting belts can override the fender system on a rising tide and when the tide ebbs this strake can sit on the fender or quay and imposes very heavy vertical loads on the system, unless the fenders are designed to deflect the vessel off the quay when this is taking place.

On many of the older vessels this belt consists of a substantial timber member secured at intervals by flat metal straps. When such a vessel moves along the quay the flat strips can act like the teeth of a chainsaw and considerable wear can take place very rapidly.

(5) Free-standing fenders according to section 9.2.1, para (c) should consist of a row of at least 4 single fenders, and then be arranged as shown in Fig. 9.10.

For the magnitude of L, the length of the smallest regular berthing vessel has to be taken. If the berth is also used by ships, whose length exceeds the value of 1.25 L, the row of fenders should be supplemented towards the water side for expediency, by further single fenders.

The above recommendations result from the following basic requirements :

- during the berthing manoeuvre, a clear distance to the outer end of the bridge or shore ramp of L/6 $\geq$ 10 m should be maintained,
- during the interim berthing of the vessel, i.e. before its longitudinal hauling to the ramp facilities, the ship should be supported by at least two fenders with a spacing of L/3. The same applies, when the vessel is in its final position.

The sketches of Fig. 9.11 show the proposed berthing procedure and the required fender locations.

(6) The required energy absorption capacity of the outer fenders can be determined as discussed in Chapter 2 and depends on the largest ship using the berth. The assumption should be proceeded from thereby, that the ships berth at an angle of about 5° to 10° against the fender face alignment. The energy absorption capacity of the inner breasting fenders can be selected at a lower magnitude, whereby the possibility for the occurrence of berthing impacts by smaller vessels must be considered.

(7) Provided a statistical approach in the determination of the energy absorption capacity of the individual fenders is not possible due to lack of data, berthing vel-

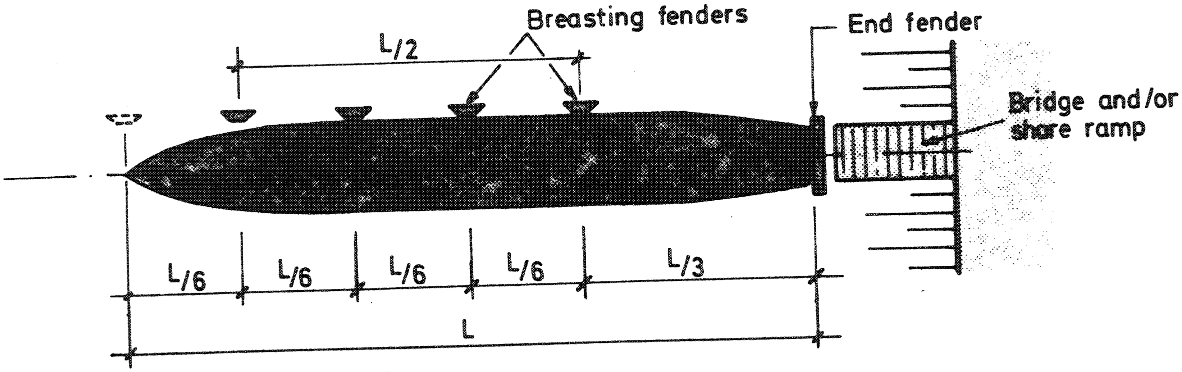

Fig. 9.10 - Typical layout free standing fenders

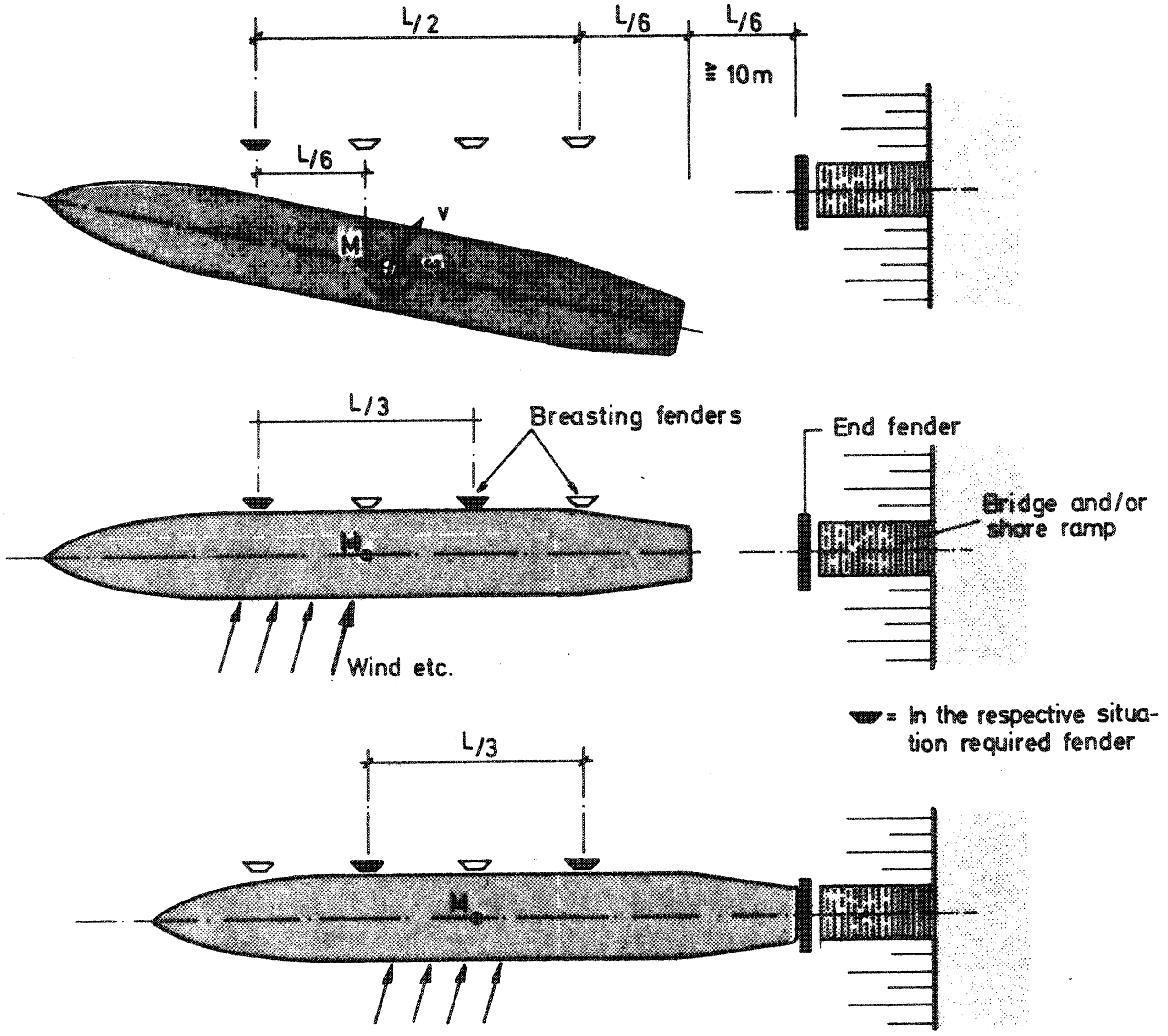

Fig. 9.11 - Proposed berthing procedure

ocities should be used as could be expected at the berthing of conventional freighters of comparable sizes, taking into proper account the locally prevailing conditions. It is urgently recommended however, in view of the pressure of time in Ro/Ro traffic or of ferry services, to allow for a surcharge of 15 or 20 % on these berthing velocities. This seems to be especially appropriate when the ships tie up at the berth without tug assistance.

(8) If the energy absorption capacity of the fenders is to be determined according to section 2.2, notice should be taken that the radius of gyration of the ship (k) is a function of the block coefficient (C_b) as shown in Fig. 2.1 of section 2.2 and that C_b is substantially lower for Ro/Ro ships and ferries than for normal freighters or bulkcarriers (see tables 9.1 and 9.2).

It must further be taken into consideration, that the centre of gravity of railway ferries as a rule, and above all of Ro/Ro ships, does not lie in the middle of the ship's length , but more toward the stern.

(9) Ro/Ro ships and ferries possess very large windage areas at relatively small mass and displacement. A check should therefore always be made, whether the breasting fenders have adequate stiffness and a sufficiently large bearing capacity for the absorption of statical and dynamic wind loads. Under prevailing circumstances, the effects of currents and hydrodynamic effects due to passing vessels should also be taken into account.

9.3.2.2. END FENDERS

For berths, at which ferries and Ro/Ro ships approach beam-on, end fenders are loaded only at the subsequent longitudinal hauling of the ships. Thereby, they must completely absorb any residual kinetic energy (E) remaining from the moving ship (Displacement = D), which is to be brought to a complete stop directly in front of the bridge or shore ramp. The following therefore applies for the design of the fender :

$$E = \frac{1}{2} \cdot M \cdot v^2$$

For determining the mass (M) only the actual displacement of the vessel should be taken into account, since hydrodynamic effects at axial ship motion are very small. A value of at least 0.15 m/s should however be used for the ship's impact velocity (v).

If the berth is utilised only by ferries with standardised shape at bow and/or stern, the end fendering could be installed at both sides of the ship's end. It then may also serve for bringing the vessel into the desired final position in front of the bridge or shore ramp. The extremity of the ship's end remains completely free thereby, so that ship's ramps and/or parts of the bridge ramp can be moved without hindrance (Fig. 9.12).

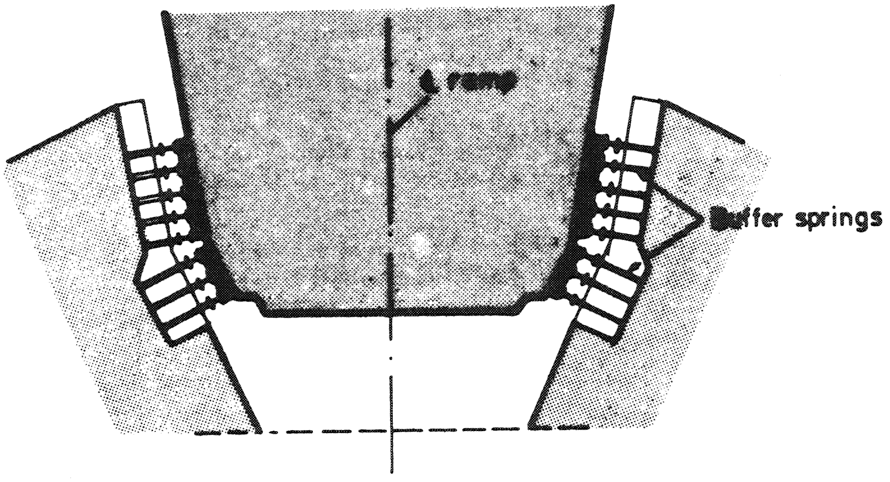

Fig. 9.12 - Arrangement for end fenders with standardized ships

Such solutions are not possible for the end fenders at berths for Ro/Ro ships, because with these vessels, both the hull shape, as well as the breadth and the freeboard depth of the ships vary.

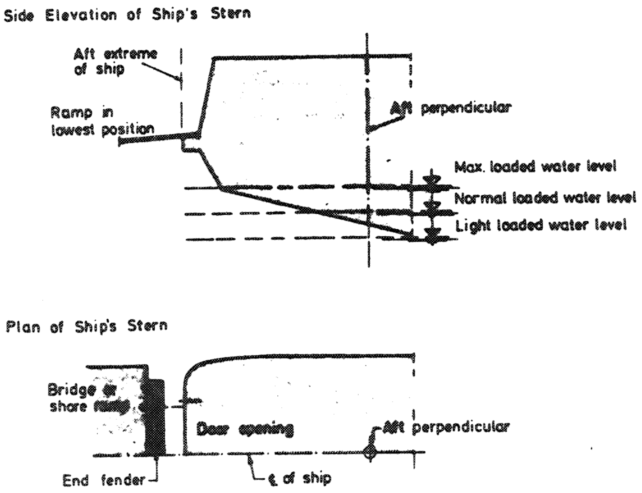

Fig. 9.13 - Typical cross-section of ship with ship ramp

The sketches in figures 9.12 and 9.13 clearly show, that particular problems arise in the designing of the end fenders, especially since the clearance for the movements of the stern ramp of the ship is not be restricted. In that respect, it would be advantageous, if the ship's ramps were to be long enough to provide adequate clearance between the bow or stern extremities of the vessel and the shore structure. This would enable dispensing with the problematic end fendering, and at the same time would ensure that ship and structure could not come into contact with each other while the vessel is being tied up,or if ranging or sheering of the vessel occurs.

In some cases, in which end fendering had to be foreseen for protection of ship and structure, a raisable and lowerable horizontal buffer beam protected by timbers or rubber fenders, was installed independent of the bridge ramp (Fig. 9.14). The beam was designed floatable and floodable, so that its elevation could be adjusted at all times to the prevailing operational requirements. As the stiff buffer beam is supported horizontally by 2 flexible elastic steel dolphins installed on both ends, such a type of fendering can also absorb greater-magnitude impact forces and kinetic energies without difficulty.

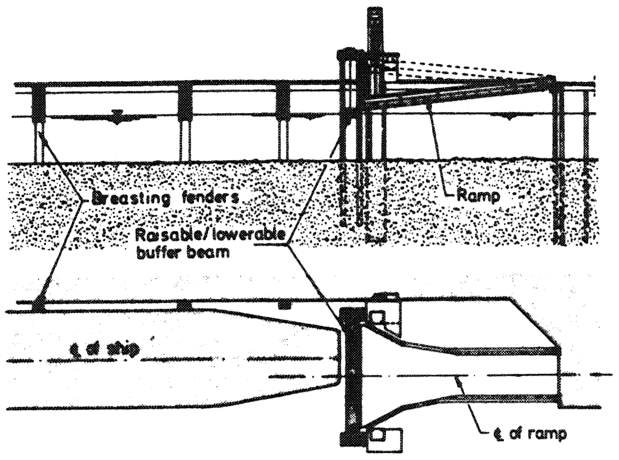

Fig. 9.14 - End fendering independant from bridge ramp

9.3.3. BASIC CONSIDERATIONS AND RECOMMENDATIONS ON THE DESIGN OF FENDER FACILITIES WITH HEAD-ON SHIP APPROACH

9.3.3.1. SHIP VELOCITIES AND STOPPING DISTANCES

Since ferries with short service routes normally operate under a strict time-schedule, the capacity of their propulsion engines is as a rule extraordinarily high. This ensures, that the ferries reach their respective destination independent of prevailing weather conditions, and at the same time, attain an adequately high travel speed and thus a peak turn-around frequency. Ships' engines and their output are however, also most important for the berthing of the head-on approaching vessels, whereby especially the manoeuvring properties of the ferry during stopping play an essential role. Besides the prevailing twin-screw drive today, which prevents the ship from swinging to starboard also with astern engine operation, bow thrusters or similar acting engines (e.g. Voith-Schneider) are normally installed in modern ferries. This permits controlled movement in all directions, even for larger ships.

Both following diagrams (Fig. 9.15), which are based on manoeuvring tests with the ferry "Deutschland", are admittedly not transferable to other vessels, but nevertheless furnish sufficient general information on stopping times and decrease of ship speed as are to be expected of modern ferries.

In the graphs, it denotes :

v = ship speed [knots] (1 knot ≈ 0.5 m/sec)
s = passed travel distance [m]
t = passed duration of time [sec]
n = engine revolutions per minute [Rpm]

Of importance in this connection is the obvious fact, that an acceleration of the ship up to -0.10 or even -0.15 m/s^2 can be figured on during the end phase of the stopping manoeuvre. The residual stopping distance of a ferry still in travel at 8 knots = approx. 4.1 m/s, may thus range only between 55 and 85 m. The remainder stopping time may lie between 25 and 40 sec. If the length of ferry piers with continuous guide

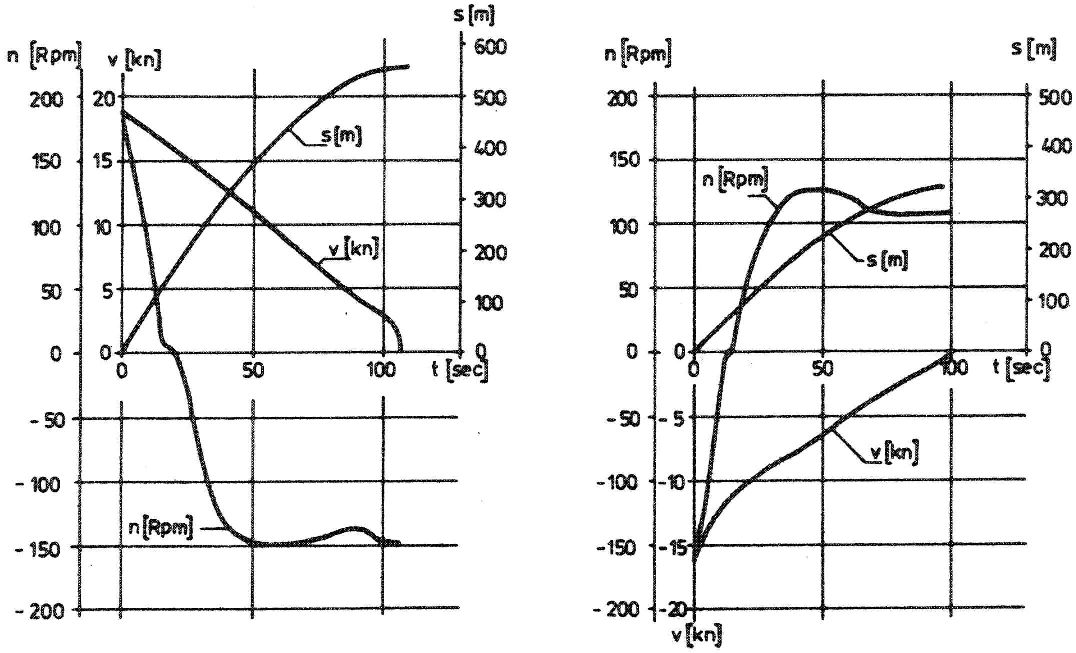

Fig. 9.15 - Ferry manoeuvring tests :
(left) : Stopping manoeuvre, initial speed 18.8 knots ahead (9.4 m/sec)
(right): Stopping manoeuvre, initial speed 15.8 knots astern (7.9 m/sec)

walls is observed, which normally is about 1.3-fold ship length, it becomes apparent that very high approach speeds of the ferries must still be figured on, especially at the sea-side end of the guide walls. For example, peak speeds of up to 4.2 m/s were measured at the outer end of the ferry berth in Grossenbrode/Baltic Sea. The Danish State Railways experienced approach velocities exceeding 2.1 m/s at their port facilities.

9.3.3.2. GUIDING/SIDE FENDERS

The statistical approach to determine the required energy absorption capacity of the guiding/side fenders, or the berthing velocity of the design ship is to be preferred whenever sufficient information is available.

In case of a kinetic determination of the necessary energy absorption capacity of the guiding/side fenders, it should proceed from in principle, that the ship's speed component parallel to the face of the continuous fender, is not decreased by berthing impacts or by the thereby occurring frictional forces, but rather solely by the astern acting propulsion forces of the ferry. Thus only the ship's speed component directed transverse to the fender face, should be considered in the computations (Fig. 9.16).

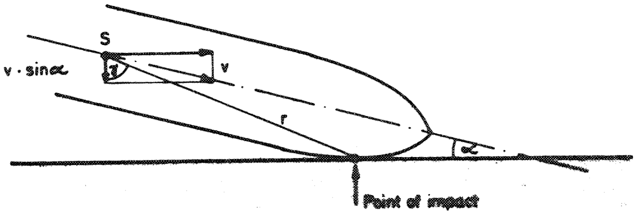

Fig. 9.16 - Kinetic determination of energy absorption capacity
S = centre of mass

The following formula then applies for the required energy absorption capacity of the guiding/side fenders :

$$E = \frac{1}{2} \cdot \frac{D}{g} \cdot C_m \cdot C_s \cdot \frac{k^2 + r^2 \cdot \cos^2\gamma}{k^2 + r^2} \cdot (v \cdot \sin\alpha)^2$$

In this formula, it denotes :

E = Energy absorption capacity
D = Ship's displacement
g = Acceleration of gravity
C_m = Added mass factor
C_s = Energy reduction factor considering the stiffness of the ship's hull and its own fendering
k = Radius of gyration
r = Distance between ship's center of gravity and point of impact
v = Design ship velocity

The above equation may be used in the design of continuous fender walls, as well as of single guiding/side fenders. It shows much similarity with that on Section 2.2, but it takes into account the large forward movement of the ship, typical for ferries.

A value of 15° (maximum 20°) is recommended as angle α for the ship approach. Smaller angles may be assumed, when the geometry of the ferry bed already prescribes an upper limit. The magnitude of r and the angle γ result from the configuration of the ship's hull. The factor C_m for taking into account the hydrodynamic effects, should be determined in accordance with Section 2.2.2. Since ferries are generally provided with encircling rubbing strips, a value of 0.90 appears reasonable for the reduction factor C_s which takes into account the energy portion absorbed by the ship's hull and/or its fendering.

Whilst the magnitude D is clearly defined by the displacement of the largest ferry to be handled, generally applicable approximate values for the design ship velocity v cannot be indicated. The reasons are that, on the one hand, there is very little data available on executed field measurings and, on the other hand, that the locally prevailing influences/parameters do not permit general rules. The design ship velocities indicated in table 9.3 can therefore only serve for general information. Ferry-boats of the Danish State Railways operating between Helsingør and Helsingborg have recently been equipped with special apparatus measuring the ships' approach velocity during the berthing manoeuvres. In both places, speeds exceeding 1 1/2 m/sec were recorded at the berth entrance. The same was observed for the Great Belt ferries. The design ship velocity has therefore been increased at these facilities to 2 m/sec, which still is considered rather low.

As far as the design of the guiding/side fenders is concerned, the following recommendations should be taken properly into account :

(1) In selecting a sufficiently conservative design ship velocity, proper consideration should be given to the manoeuvring properties of the ships and the locally prevailing conditions, but also to the number of special berths available, the number of berthings per year etc.

(2) A continuous guiding fendering is to be preferred. It may be composed either of

TABLE 9.3

Ferry Facility	Ferries (highest displacement)	Design Ship Velocity		
		sea-sided end of berth	middle of berth	land-sided end of berth
	tonnes [x 10 kN]	m/s	m/s	m/s
Korsør/Nyborg	11,900	2.0	-	0.5
Rødby	7,900	1.5	-	0.5
Knudshoved/ Halsskov	7,000	1.5	1.0	0.5
Grossenbrode	6,400	2.6	1.2	0.4
Puttgarden	6,400	3.0	2.0	1.0
Korsør/Nyborg	6,340	1.5	-	0.5
Dover	4,100	2.0	-	1.0

large-size fender panels, which are supported by rubber units mounted on rigid structures, or of continuous steel girders frames covered with timber etc. and supported by elastic steel piles or dolphins.

(3) The fendering should cover the full tidal range, and extend up to a level well above the extreme position of the ferries' rubbing strips during highest operational water levels.

(4) The fendering should be designed sufficiently "soft", in order to reduce the loads on the supporting structures, as well as the frictional forces in view of required repair and maintenance.

(5) The outer fender elements should be of hardwood timbers of sufficient strength (Basralocus, Bongossi, Greenheart etc.), which may be covered by sliding fender material manufactured from specially processed high density polyethylene or similar.

(6) All fender elements, mounting accessories and the like should be designed to resist ship impact as well as the thereby occurring horizontal and vertical frictional forces.

(7) In the selection of rubber fender units, sufficient safety margin in their energy absorption capacity should be taken into consideration, in order to prevent any overloading of the supporting rigid structures in case of extraordinary heavy ship impact.

(8) In principle and as far as applicable, the aspects, considerations and recommendations described in Section 9.3.2.1 should also be taken properly into account, when designing guiding and side fenders for berths with head-on ship approach.

9.3.3.3. END FENDERING

Insofar as the operational and other local requirements permit, the end fendering should be installed transverse to ship centre line, directly in front of the ramp facilities. End fenderings, which enclose the stern or the bow of the ferry on both sides (see Fig. 9.12) admittedly assist a correction of the final ship position. However, because of their oblique position to the ship axis, during impact of vessel they activate considerable lateral forces (wedging effect), which make necessary the construction of comparatively heavy foundations.

Regardless, whichever solution is selected, it must be ensured in the design of the end fendering, that :

(1) the free clearance of the bridge ramp during motion remains guaranteed at all tidal water levels and deck positions of the ferry,

(2) the fendering can fulfill its functions at all operational tidal water levels and simultaneously prevailing extreme ship deck positions,

(3) an adequate energy absorption capacity for interim storing of the residual ship's energy is available (it is recommended to fix the ship design velocity adequately conservative at ≧ 0.50 m/s), and

(4) the fendering is designed adequately "soft", so that the inertia forces acting on ship, cargo and passengers remain within the necessary limits, even in case of very hard berthing contact. The passengers may be hurt by falling due to the sudden horizontal inertia forces. (Calculations have shown that accelerations as high as two thirds of the acceleration of gravity may act on passengers at certain locations on the ferry. Also cars may be moved by impact forces, resulting in damage to the cars.) The reason for the increased inertia forces encountered on ferries is the much higher approach velocity.

As for the rest, the remarks contained in section 9.3.3.2 also apply analogously, for the end fendering required for head-on ship approach.

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APPENDIX D
FENDER DESIGN

APPENDIX D

FENDER DESIGN

This appendix provides a review of basic concepts in fender design. This discussion is based in part on a presentation given by Mr. Ed Kiedaisch at an American Association of Port Authorities Technical Seminar in 1991. (1)

Fender systems help to absorb the energy of a vessel as it stops against the berth. Fenders do this by applying a reaction force to the vessel as they deform. The elements that deform may be constructed from rubber, steel, or timber. (See Appendix B for further information.) Post-tensioned concrete piles have also been tested for use in fender systems. (2) If rubber is used as the deforming element, it must be allowed to deform by bending or buckling, as shown in Figure D-1. Cubical blocks of rubber will deform little under large loads.

The amount of energy absorbed is:

$$E_S = h(s)\,\Big|_{s_{max}} = \int_0^{s_{max}} g(s)ds$$

where $h(s)$ = energy vs. deflection relationship,
$g(s)$ = force vs. deflection relationship, and
s = deflection.

Typical graphs for $g(s)$ for various fender types are shown in Figure D-2. Curve A is typical of foam, pneumatic, or side-loaded cylindrical fenders. Curve B is typical for fenders that deform in shear and for the linear elastic range of piling and springs. Curve C is typical of buckling rubber elements.

A simplified, hypothetical version of $g(s)$, shown in Figure D-3, may be used to explain differences in various fender systems. When deformation begins, each fender system immediately provides its maximum reaction. The reaction is constant until the point of maximum deflection. The amount of energy absorbed is equal because

$$E = R_1 D_1 = R_2 D_2 = R_3 D_3.$$

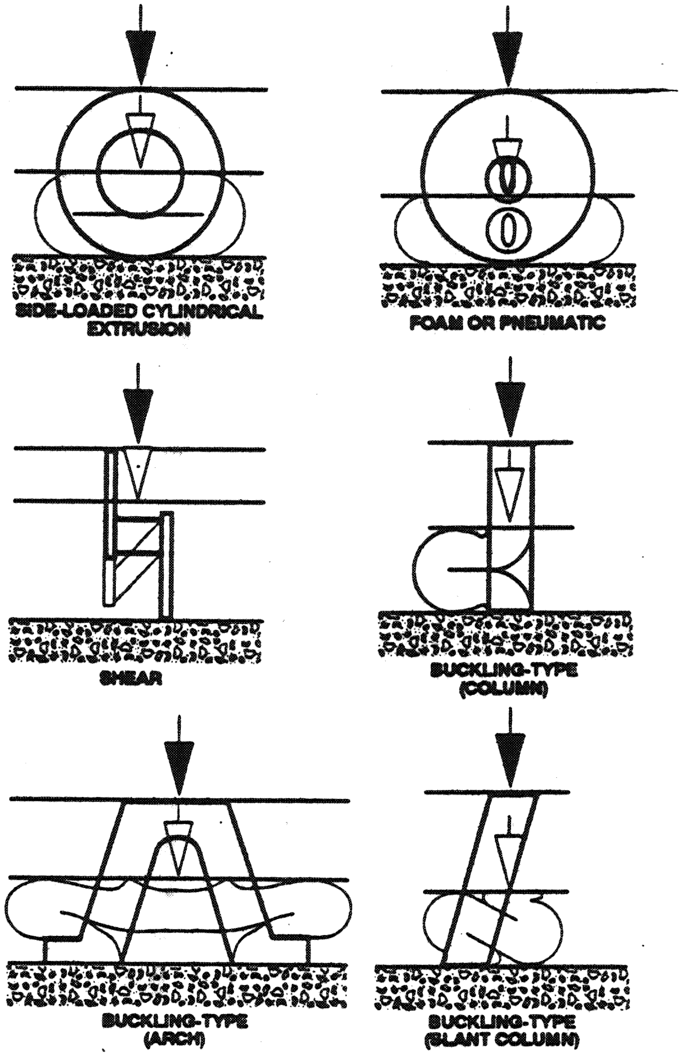


Figure D-1. Deformation fo Fenders (Courtesy of Trellex Morse, Inc.)

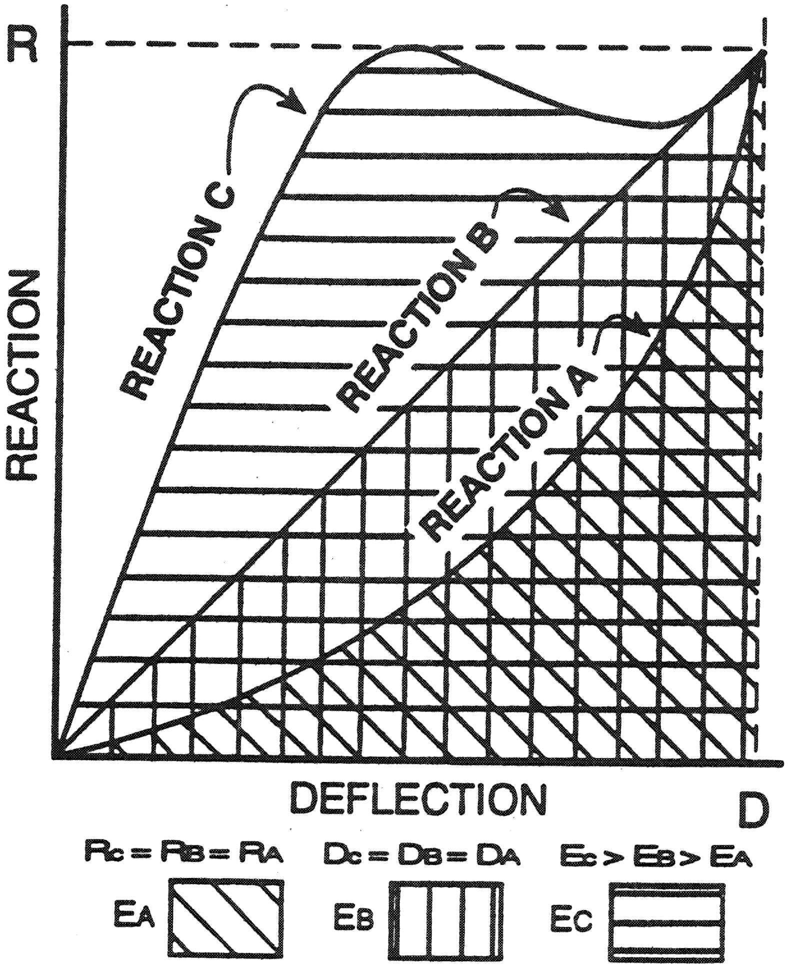


Figure D-2. Reaction vs. Deflection Relationships for Fenders
(Courtesy of Trellex Morse, Inc.)

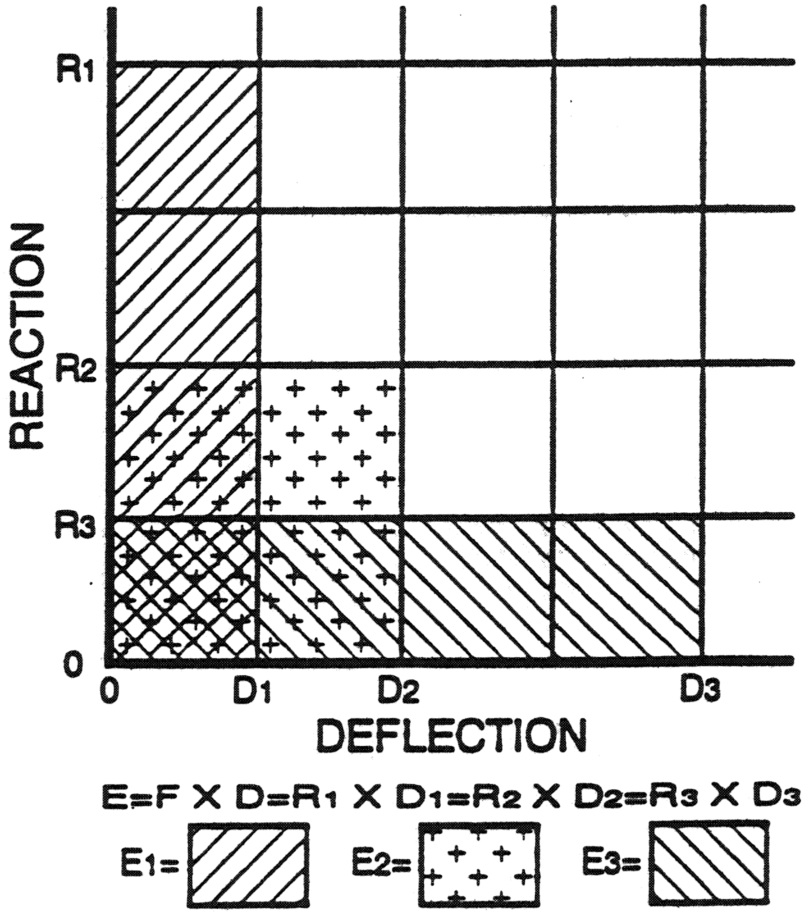
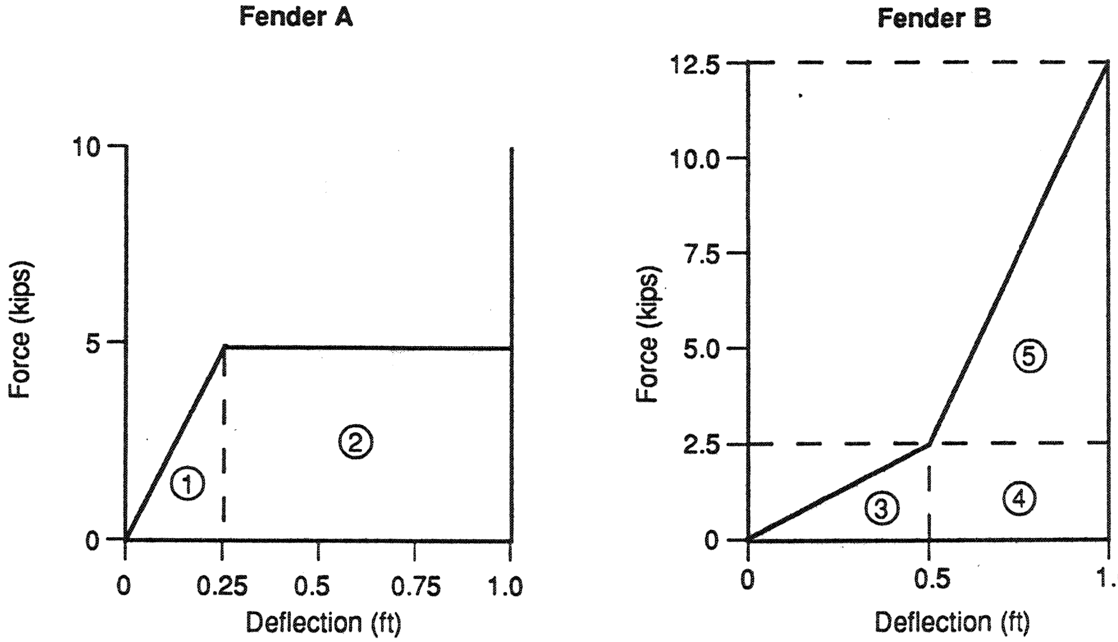


Figure D-3. Hypthetical Deflection vs. Reaction Relationships
(Courtesy of Trellex Morse, Inc.)

Note that the fender system that allows the smallest reaction has the largest deflection. It is desirable to limit the reaction because high reactions require more expensive supporting structures for the fenders. High reactions increase the likelihood of vessel damage and the deceleration that stops the vessel, thus compromising passenger comfort and safety.

Practical considerations cause designers to limit deflections. The maximum deflection is less than the height or standoff of the fender system (Figure D-1). This is because at maximum deflection, some space is required for the buckled fender elements. The standoff for the largest fender units is 3 ft to 6 ft (1 m to 2 m) For a given deflection, a fender that reaches high reaction forces at small deflections (Curve C, Figure D-2) will require a smaller reaction than other fender systems (Curves A and B, Figure D-2). (An example is given in Figure D-4.) However, for berthing events that do not require the full energy absorbing capacity of the fender system, reactions and decelerations will be higher for fenders with Curve C than for Curves A or B (Figure D-4). This will be a more prominent consideration at multi-purpose berths that accommodate vessels of several different sizes. Also, for low-energy berthing events, the lower reaction force may result in a smaller stress cycle for a fatigue critical member.

This discussion shows that it is important to consider the reaction (force) vs. deflection relationship when choosing the fender system. By minimizing the required reaction, the designer may reduce the cost of the supporting structure, increase vessel safety, and increase passenger comfort. Reactions might be minimized by increasing the allowable deflection and by selecting a fender that develops large reactions at small deflections. However, if differing amounts of berthing energy are to be absorbed in each event, a fender system that develops small reactions at low deflections will reduce the reaction and deceleration for low energy events.



g(s) for Fender A is shown above. The maximum deflection is 1.0 ft. For Fender B, g(s) between 0.0 and 0.5 ft is as shown above. If Fenders A and B have equal energy absorbing capacity, what reaction is required for Fender B at s = 1.0 ft. if g(s) is linear between 0.5 and 1.0 ft?

Energy Absorbtion

Fender A

① (0.25 * 5)/2 = 0.625
② 0.75 * 5 = 3.750
= 4.375 ft kips

Fender B (Designed for the same amount of energy absorbtion as Fender A)

③ (0.25 * 5)/2 = <0.625>
④ (2.5 * 0.5) = <1.25>
⑤ Required energy absorbtion 2.5 ft kips

Additional reaction required (above 2.5 k) 2.5/(0.5 * 0.5) = 10. Required reaction for Fender B = 10 + 2.5 = 12.5 k. This exceeds the reaction for Fender A by 7.5 kips.

Suppose that a vessel with a displacement of 18.0 long tons approaches a fender at 1.0 ft/sec. What are the maximum accelerations for Fenders A & B? Assume that for the berthing coefficient, C = 1.0.

$E = 1/2MV^2 = 1/2(18 * 2240/32.2) * 1.0^2 = 626$ ft-lb. = 0.626 ft-kips ≈ 0.625 ft-kips.

Reaction for Fender A @ 0.625 ft-k = 5 kips = 5,000 lb
$F = MA \rightarrow A = F/M = 5{,}000/(18 * 2{,}240/32.2) = 3.99$ ft/sec $^2 \approx 4.0$ ft/sec^2 or 1/8 G

Reaction for Fender B @ 0.625 ft-k = 2.5 kips = 2,500 lb
$A = 2{,}500/(18 * 2{,}240/32.2) = 2.0$ ft /sec ^{2} or 1/16 G

Figure D-4. Example Calculations

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APPENDIX E
DESCRIPTION OF EQUIPMENT

APPENDIX E

DESCRIPTION OF EQUIPMENT

The equipment that was used in the Ferry Landing Design Criteria study is described herein. Both the individual components and the integrated arrangement are included. A closed-circuit television system (CCTV) recorded the landing events. Infrared (IR) motion detectors mounted on the landing structures detected the presence of the ferry, for the video recorder operated only when the ferry was at the landing. An anemometer detected wind speed and direction and fed a signal to a data logger. The data in the data logger were transferred to a personal computer, where they were then reduced and reformatted. A list of equipment is provided in Table 1, and a detailed description of the equipment is provided in the following paragraphs.

Two CCTV cameras were placed on the overhead walkway that spans the counterweight towers at the Edmonds Terminal. One camera viewed each wing wall. A split image was provided to the video recorder so that both wing walls could be viewed simultaneously as the vessel landed. The split image was provided by a splitter board that was mounted in one of the cameras. This board collected the signals from both cameras and sent a split image to the video recorder. Black and white tube-type cameras were used. Chip-type cameras (that are, in some respects, superior) were also available. However, the chip-type camera available at the time this study was done could not produce a stable split image.

To maintain the cameras at proper operating temperatures, they were placed in heated, weather-proof enclosures. One of the cameras had a remote pan-tilt head and remote focus and zoom lenses. The researchers originally planned that a full-time operator would follow the vessel's approach with the pan-tilt camera. Installation of the IR motion detectors eliminated the need for the operator, so the cameras were left in a fixed position. The researchers' original intent was to infer berthing energy by observing deflections.

Since calibrating the energy vs. deflection relationships for the wing wall proved difficult, collection of berthing velocity data was more attractive. To obtain berthing velocity, it was necessary to observe marks of known size on the car deck of the vessel. The researchers found that the wide-angle view was most appropriate for this task. Therefore, the cameras were fitted with wide-angle lenses. The cameras were located 25 ft to 50 ft from their subjects. By reviewing video images, researchers could detect movements of 1 in. to 2 in. (A schematic wiring diagram is shown in Figure E-1.)

Power for the cameras was supplied by 24 volt transformers that were mounted directly to wall plugs. This 24 volt system eliminated the need to re-wire the camera location area for higher voltage power. The video signal was transmitted via a coaxial cable. The video coaxial cable, and the power and remote control wires spanned the 100 ft distance from the counterweight tower to the waiting room by aerial catenary. The video cable stretched due to wind forces and self weight. As it stretched, the coaxial separation was reduced until the cable malfunctioned and failed to transmit the split image video signal throughout the month of January 1991. Since a single image could be transmitted, researchers continued to operate one camera. The south camera was operated because the force vs. deflection relationship was known for the south wing wall. The coaxial cable was replaced at the end of January 1991. The new cable included a steel messenger wire that supported the self weight of the coaxial cable and prevented the cable from stretching under load.

The IR motion detectors were mounted on the ends of the wing walls and aimed into the berth. They were connected so that both had to be tripped before the video recorder would start, which was done to prevent birds from tripping it. The output signal of the motion detectors was connected to the alarm circuit of the video recorder. After the alarm circuit was tripped, the video recorder recorded from 1 minute to 3 minutes. The recorder was usually tripped twice for each landing, once when the vessel arrived and once when it departed. When six hour-long videotapes were used, approximately 48 hours' worth of data, or fifty landings, could be recorded. The videotape recorder imprinted the time and the date on the videotape image for easy reference.

The anemometer was located on the steel pipe near the southwest corner of the waiting room. The signal was processed by a POD 13 signal conditioner and recorded on a Rustrac Ranger data logger by Gultin Graphic Instruments Division, East Greenville, Rhode Island 02818. The data logger was downloaded on a weekly basis to a personal computer. PRONTO software was used to provide graphical displays and databases of the data.

As part of a study to assess the feasibility of moving the ferry terminal to the Union Oil Terminal and Point Edward (1 mile south of the existing terminal), another anemometer was placed at that location. Since 120 Vac power was not available, the data logging system for this was powered by a deep cycle 12 volt marine battery. A dc-to-dc power converter was used to maintain the voltage when the battery's charge was low.

Table E-1. Equipment Lists

Equipment List for Berthing Observation

Item	Description	Quantity
1.	Panasonic #WV-1504x black and white camera	1 ea.
2.	Panasonic #WV-141 black and white camera	1 ea.
3.	Panasonic #WV-Q91 screen splitter	1 ea.
4.	Panasonic AG-1050 event recorder	1 ea.
5.	Pelco PM-2000 camera mounts	2 ea.
6.	Pelco MPT-24DT pan/tilt controller	1 ea.
7.	Pelco PT-175 motorized pan/tilt head	1 ea.
8.	Basler TR-2400 transformers	2 ea.
9.	Pelco EH-4500-2 environmental enclosures	2 ea.
10.	Pelco MLZ6DT lens controller	1 ea.
11.	Pelco TVJ6-B2 zoom lens	1 ea.
12.	Pentax C31619, 16 mm, FL.4 lens	1 ea.
13.	Panasonic NVT-120SPT tapes	10 ea.
14.	Pelco AH-2000 adjustable heads	2 ea.
15.	Panasonic TR-124MA 12-inch monitor	1 ea.
16.	Multiconductor control wire — 6 pair	200 ft.
17.	18 gauge 2 conductor power cable	200 ft.
18.	RG59/U coaxial cable	200 ft.
19.	Visonic SRN-2000 passive infrared detector	2 ea.
20.	Moose Products 12 volt transformer	1 ea.
21.	Relay board	1 ea.

Equipment List for Wind Observation

Item	Description	Quantity
1.	Young Model 05103 wind monitor	1 ea.
2.	Rustrac Range intelligent data logger	1 ea.
3.	POD 13 signal conditioner	2 ea.

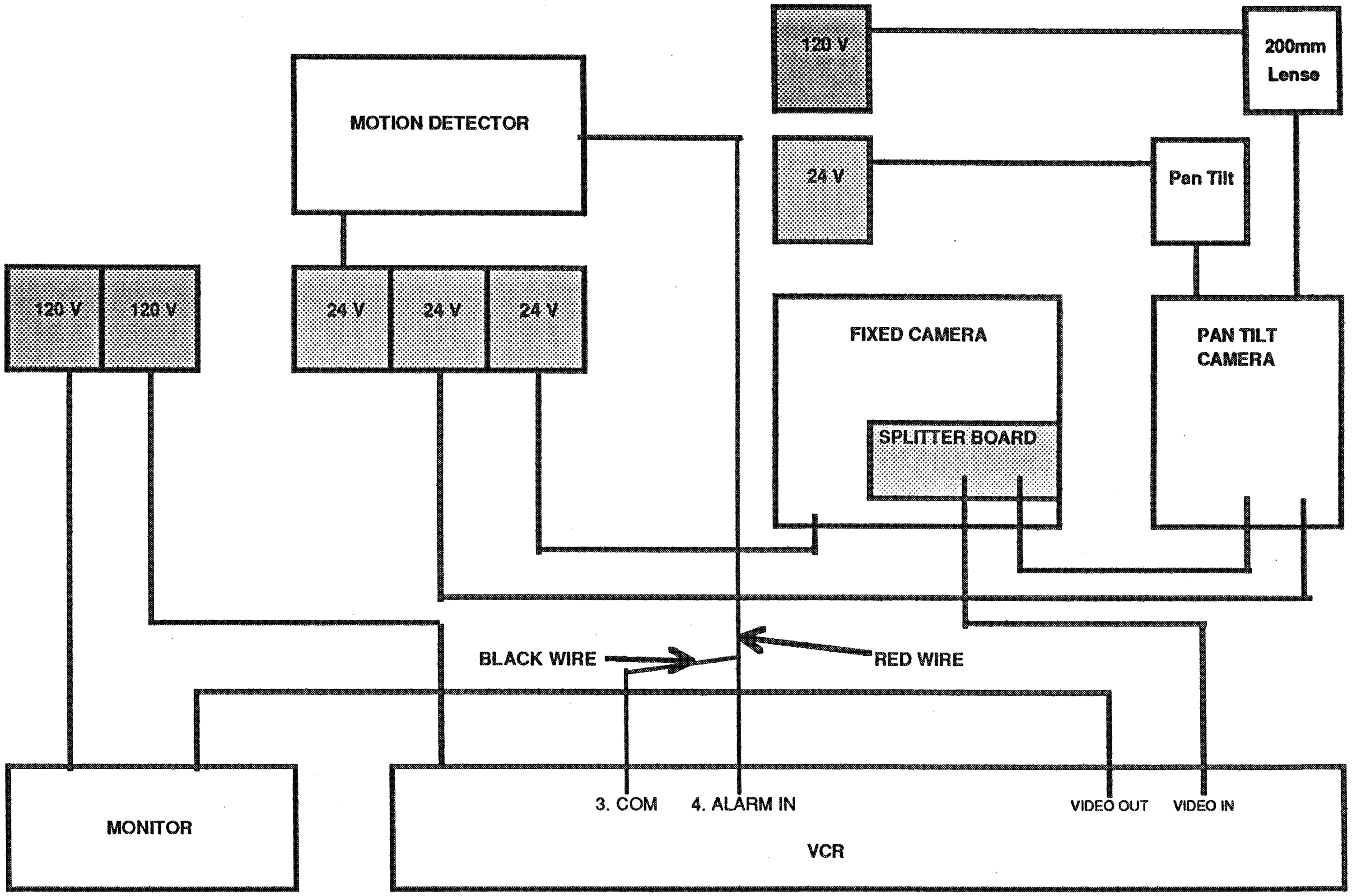

Figure E-1. Schematic Wiring Diagram for CCTV System

APPENDIX F

CALENDAR OF DATES OF OPERATION

	APR. '90		MAY '90		JUNE '90		JUL. '90		AUG. '90		SEPT. '90		OCT. '90		NOV. '90		DEC. '90		JAN. '91		FEB. '91	
DATE	REC.	CALC.	REC.	CALC.	REC.	CALC.	REC.	CALC.	REC.	CALC.	REC.	CALC.	REC.	CALC.	REC.	CALC.	REC.	CALC.	REC.	CALC.	REC.	CALC.
1							22										10	1			10	
2			3				5		36	6											19	
3																	11	2			8	
4							15								25	1						
5					9		19				6						6					
6							11				8											
7			8				24										14					
8							8										10	1				
9							11						48	3	9	3						
10							25															
11																	10	1				
12							23						53	0			10	1			3	
13			7				14														19	
14							24														20	
15							7		36	6							20	3			14	
16							19															
17							22								32	1						
18							24												65	5		
19							14				5											
20					10																	
21					9		72	19					35	4								
22																					24	
23																					23	
24	10						48	14					20	1								
25																					25	
26													27	2							21	
27							36	8														
28													31	1								
29							44	6							16							
30					19																	
31							31	11					64	5			6					

REC. = Number of berthing events recorded during the time period

CALC. = Number of berthing events where velocity was calculated

Note: If CALC. column is blank, then CALC=REC.

Boxed in dates indicate that the tape was scanned to find high defelction events. Only high deflection events were calculated.

APPENDIX G

BASELINE DATA SET OF 568 EVENTS

Date	Time	Ship	Dir.	# hit	V-Per.	V-Paral	V-Tot	Ap.Ang.	v-per	N(in.)	F(in.)	w(mph)	T(FT)	NOTES/ COMMENTS	
					VELOCITY (FT/S)				v par	delta	delta				
		Position			NORTH & SOUTH					N	F	wind	tide		
4/24/90	11:15	T	N	1	0.50	0.24	0.55	64.36	2.08	9.60	0.00		-1.10	RPM 0 -> 0	
4/24/90	11:15	T	N	1	0.50	0.24	0.55	64.36	2.08	9.60	0.00		-1.10		
4/24/90	11:55	Y	S	3	0.18	0.15	0.23	50.19	1.20	0.00	-		-0.50		
4/24/90	11:55	Y	S	3	0.18	0.15	0.23	50.19	1.20	0.00	-		-0.50		
4/24/90	14:04	T	N	3	0.33	0.45	0.56	36.25	0.73	9.00	0.80		2.70		
4/24/90	14:50	Y	N	1	0.41	0.60	0.73	34.35	0.68	10.20	0.00		3.30		
4/24/90	15:34	T	N	1	0.65	0.30	0.72	65.22	2.17	10.80	-2.30		5.50		
4/24/90	16:16	Y	N	1	0.50	0.31	0.59	58.20	1.61	8.40	1.00		8.70	RPM 0 -> 0	
4/24/90	16:54	T	S	1	0.55	0.40	0.68	53.97	1.38	0.30	-		10.30		
4/24/90	17:36	Y	N	1	0.60	0.20	0.63	71.57	3.00	9.50	0.00		10.60		
4/24/90	18:10	T	S	3	0.43	0.35	0.55	50.86	1.23	0.10	-		11.20		
4/24/90	18:54	Y	N	4	0.55	0.30	0.63	61.39	1.83	8.40	2.30		11.00		
5/2/90	11:18	T	N	5	0.17	0.38	0.42	24.10	0.45	6.00	3.60		7.90		
5/2/90	11:59	Y	N	1	0.22	0.10	0.24	65.56	2.20	8.40	0.00		7.80		
5/2/90	12:32	T	N	3	0.30	0.15	0.34	63.43	2.00	4.80	1.20		7.50		
5/7/90	13:30	Y	N	2	0.50	0.43	0.66	49.30	1.16	7.80	0.90		4.00	RPM 0 -> 0	
5/7/90	14:04	T	N	5	0.20	0.50	0.54	21.80	0.40	2.40	2.50		4.60		
5/7/90	14:50	Y	N	1	0.30	0.40	0.50	36.87	0.75	11.00	-2.00		7.10		
5/7/90	15:36	T	S	1	0.15	0.15	0.21	45.00	1.00	0.05	-		8.90	N Wall not shown	
5/7/90	16:21	Y	N	1	0.75	0.65	0.99	49.09	1.15	13.20	0.00		9.40		
5/7/90	16:57	T	N	5	0.45	0.25	0.51	60.95	1.80	10.00	3.60		9.80		
5/7/90	17:44	Y	N	1	0.25	0.60	0.65	22.62	0.42	12.00	-1.50		10.10		
5/7/90	18:13	T	N	5	0.23	0.30	0.38	37.48	0.77	2.40	2.80		10.00		
5/13/90	15:33	Y	N	6	0.45	0.40	0.60	48.37	1.13	1.20	3.60		7.70		
5/13/90	16:14	T	S	2	0.50	0.30	0.58	59.04	1.67	0.00	-		8.10	RPM 0 -> 0	
5/13/90	16:57	Y	N	1	0.47	0.05	0.47	83.93	9.40	9.00	-1.10		8.70		
5/13/90	17:35	T	N	1	0.43	0.18	0.47	67.29	2.39	7.20	-0.50		9.10		
5/13/90	18:55	Y	N	1	0.05	0.00	0.05	89.89	500.00	8.30	0.00		10.40		
5/13/90	19:37	T	S	1	0.31	0.17	0.35	61.26	1.82	0.00	-		10.80		
5/13/90	20:26	Y	S	1	0.50	0.22	0.55	66.25	2.27	0.20	-		11.20	RPM 0 -> 0	
5/20/90	14:05	Y	S	3	0.44	0.22	0.49	63.43	2.00		1.00		1.20		
5/20/90	14:52	T	N	5	0.30	0.03	0.30	84.29	10.00	4.00	7.00		3.00		
5/20/90	15:33	Y	S	2	0.52	0.07	0.52	82.33	7.43	0.13	-0.50		8.30		
5/20/90	16:14	T	N	5	0.22	0.05	0.23	77.20	4.40	3.50	5.00		9.30		
5/20/90	16:54	Y	S	8	0.43	0.32	0.54	53.34	1.34		3.50		10.10		
5/20/90	17:36	T	N	4	0.50	0.00	0.50	89.99	5000.00	10.00	3.00		10.40	RPM 0 -> 0	
5/20/90	18:16	Y	S	1	0.45	0.25	0.51	60.95	1.80	0.00	3.00		10.30		

Date	Time	Ship	Dir.	# hit	V-Per.	V-Paral	V-Tot	Ap.Ang.	v-per	N(in.)	F(in.)	w(mph)	T(FT)	NOTES/ COMMENTS
					VELOCITY (FT/S)				v par	delta	delta			
		Position			NORTH & SOUTH					N	F	wind	tide	
5/20/90	18:54	T	S	1	0.90	0.30	0.95	71.57	3.00	0.00	-2.40		10.10	
5/20/90	19:39	Y	N	4	0.17	0.16	0.23	46.74	1.06	6.00	2.40		10.00	
6/20/90	16:17	H	S	1	0.50	0.15	0.52	73.30	3.33	-0.10	1.00		10.80	RPM 0 -> 0
6/20/90	16:54	Y	S	1	0.40	0.18	0.44	65.77	2.22	0.00	-1.00		11.00	
6/20/90	17:40	H	S	1	0.47	0.28	0.55	59.22	1.68	0.15	-2.60		10.90	
6/20/90	18:12	Y	S	1	0.55	0.30	0.63	61.39	1.83	-0.05	-1.70		10.70	
6/20/90	18:53	H	S	4	0.80	0.30	0.85	69.44	2.67	-0.17	0.00		9.80	
6/20/90	19:37	Y	S	5	0.25	0.16	0.30	57.38	1.56	0.00	-1.00		9.40	
6/20/90	20:22	H	S	3	0.35	0.11	0.37	72.55	3.18	0.05	-0.08		8.40	
6/20/90	21:01	Y	S	2	0.60	0.51	0.79	49.64	1.18	0.40	0.50		8.00	
6/20/90	22:20	Y	S	3	0.65	0.24	0.69	69.73	2.71	-0.09	-2.40		7.60	
6/20/90	23:36	Y	S	1	0.45	0.10	0.46	77.47	4.50	0.00	-1.20		8.40	
6/21/90	6:13	H	S	1	0.40	0.00	0.40	89.99	4000.00	-0.15	-1.20		5.10	
6/21/90	6:53	Y	S	1	0.33	0.25	0.41	52.85	1.32	0.05	-1.00		2.60	
6/21/90	7:34	H	S	3	0.35	0.20	0.40	60.26	1.75	-0.20	0.00		0.40	
6/21/90	8:13	Y	S	2	0.50	0.10	0.51	78.69	5.00	-0.25	0.00		-0.40	
6/21/90	9:03	H	S	1	0.45	0.20	0.49	66.04	2.25	0.05	-0.50		-0.15	
6/21/90	9:47	Y	S	2	0.50	0.30	0.58	59.04	1.67	0.40	0.00		-3.30	
6/21/90	10:33	H	S	1	0.20	0.20	0.28	45.00	1.00	0.20	0.00		-3.40	
6/21/90	11:13	Y	S	2	0.55	0.25	0.60	65.56	2.20	-0.30	-1.00		-3.40	
6/21/90	20:56	Y	S	2	0.60	0.38	0.71	57.65	1.58	0.10	-3.00		8.10	
6/30/90	9:47	Y	N	2	0.38	0.22	0.44	59.93	1.73	10.20	1.00		4.00	
6/30/90	10:32	H	N	4	0.43	0.55	0.70	38.02	0.78	8.40	1.00		4.80	
6/30/90	11:12	Y	N	3	0.25	0.50	0.56	26.57	0.50	9.60	2.00		5.30	
6/30/90	11:52	H	N	3	0.55	0.65	0.85	40.24	0.85	12.00	1.50		6.30	
6/30/90	12:32	Y	N	5	0.65	0.55	0.85	49.76	1.18	7.80	6.00		6.50	
6/30/90	14:07	Y	N	4	0.75	0.50	0.90	56.31	1.50	12.00	2.00		7.30	
6/30/90	14:48	H	N	4	0.65	0.10	0.66	81.25	6.50	11.00	3.00		7.50	
6/30/90	15:34	Y	N	1	0.32	0.35	0.47	42.44	0.91	12.00	0.00		6.70	
6/30/90	16:11	H	N	3	0.17	0.60	0.62	15.82	0.28	7.20	0.00		5.30	
6/30/90	16:55	Y	N	1	0.08	0.30	0.31	14.93	0.27	3.00	0.00		5.10	Never moved south wall
6/30/90	17:33	H	N	1	0.73	0.00	0.73	89.99	7300.00	13.50	2.00		5.00	
6/30/90	18:16	Y	N	3	0.40	0.50	0.64	38.66	0.80	5.30	1.20		5.50	
6/30/90	18:52	H	N	2	0.50	-0.05	0.50	84.29	-10.00	12.00	1.00		5.80	RPM 0 -> 0
6/30/90	19:36	Y	S	2	0.50	0.13	0.52	75.43	3.85	0.00	-1.50		6.50	RPM 0 -> 0
6/30/90	20:27	H	S	2	0.55	0.12	0.56	77.69	4.58	0.13	-2.40		8.00	
6/30/90	20:54	Y	N	1	0.25	0.75	0.79	18.43	0.33	3.60	0.00		8.70	N Wall not shown
6/30/90	21:44	H	N	3	0.43	0.10	0.44	76.91	4.30	7.80	2.00		9.90	
6/30/90	22:18	Y	S	3	0.27	0.15	0.31	60.95	1.80	0.00	-1.20		10.60	
6/30/90	23:39	Y	N	2	0.50	0.20	0.54	68.20	2.50	8.40	-		10.90	RPM 0 -> 0

Date	Time	Ship	Dir.	# hit	V-Per.	V-Paral	V-Tot	Ap.Ang.	v-per	N(in.)	F(in.)	w(mph)	T(FT)	NOTES/ COMMENTS
					VELOCITY (FT/S)				v par	delta	delta			
		Position			NORTH & SOUTH					N	F	wind	tide	
7/1/90	6:51	Y	S	2	0.15	0.25	0.29	30.96	0.60	0.04	-1.00		1.60	
7/1/90	8:13	Y	S	3	0.20	0.20	0.28	45.00	1.00	0.00	0.00		2.10	
7/1/90	9:02	H	N	2	0.15	0.30	0.34	26.57	0.50	7.20	1.20		2.70	
7/1/90	9:50	Y	N	1	0.45	0.30	0.54	56.31	1.50	12.50	1.10		3.80	
7/1/90	10:33	H	N	2	0.10	0.45	0.46	12.53	0.22	8.40	0.00		4.00	
7/1/90	11:21	Y	S	4	0.35	0.10	0.36	74.05	3.50	0.25	-2.60		5.00	
7/1/90	11:56	H	N	5	0.51	0.38	0.64	53.31	1.34	1.50	9.60		6.50	N-wall hit first
7/1/90	12:47	Y	S	2	0.60	0.48	0.77	51.34	1.25	0.00	-2.40		7.10	
7/1/90	13:20	H	N	2	0.55	0.35	0.65	57.53	1.57	11.40	0.00		7.80	
7/1/90	14:08	Y	N	3	0.60	0.50	0.78	50.19	1.20	11.90	2.00		8.10	
7/1/90	15:35	Y	S	3	0.48	0.65	0.81	36.44	0.74	0.66	-1.80		7.70	
7/1/90	16:13	H	N	2	0.45	0.00	0.45	89.99	4500.00	9.00	0.00		7.50	
7/1/90	16:55	Y	N	2	0.47	0.40	0.62	49.60	1.18	10.80	-1.50		6.90	
7/1/90	17:32	H	S	2	0.50	0.50	0.71	45.00	1.00	0.28	0.00		6.70	
7/1/90	18:12	Y	N	1	0.50	0.30	0.58	59.04	1.67	13.20	-1.00		6.50	
7/1/90	18:53	H	N	2	0.50	0.05	0.50	84.29	10.00	12.50	-1.50		6.30	
7/1/90	19:36	Y	N	2	0.60	0.60	0.85	45.00	1.00	12.00	-2.00		6.40	
7/1/90	20:30	H	N	4	0.27	0.40	0.48	34.02	0.68	5.40	1.00		7.10	
7/1/90	20:58	Y	S	3	0.30	0.30	0.42	45.00	1.00	0.00	-2.00		7.80	
7/1/90	21:48	H	S	1	0.35	0.10	0.36	74.05	3.50	0.00	0.00		9.00	
7/1/90	22:17	Y	S	2	0.55	0.35	0.65	57.53	1.57		0.00		9.40	
7/1/90	23:04	H	S	3	0.63	0.08	0.64	82.76	7.88	-0.10	-1.00		10.00	
7/1/90	23:32	Y	S	4	0.50	0.50	0.71	45.00	1.00	0.00	-2.00		10.40	
7/2/90	5:33	Y	N	1	0.50	0.00	0.50	89.99	5000.00	10.80	-2.00		4.50	
7/2/90	6:15	H	S	2	0.50	0.40	0.64	51.34	1.25	0.00	-2.50		3.30	
7/2/90	7:32	H	N	1	0.80	0.40	0.89	63.43	2.00	12.10	-1.00		2.90	
7/2/90	9:49	Y	S	2	0.10	0.35	0.36	15.95	0.29	0.40	0.00		2.90	N&S wall contact at = time
7/4/90	13:18	H	N	1	0.05	0.70	0.70	4.09	0.07	2.20	0.00		5.00	
7/4/90	14:01	Y	S	2	0.33	0.25	0.41	52.85	1.32	0.00	-2.00		6.10	
7/4/90	14:46	H	S	3	0.35	0.40	0.53	41.19	0.88	0.45	-2.00		7.60	
7/4/90	15:32	Y	S	4	0.53	0.22	0.57	67.46	2.41		0.00		8.80	
7/4/90	16:24	H	N	3	0.47	0.28	0.55	59.22	1.68	7.20	1.00		9.90	
7/4/90	16:55	Y	S	2	0.40	0.38	0.55	46.47	1.05	0.00	-1.00		10.20	
7/4/90	17:34	H	N	3	0.30	-0.25	0.39	50.19	-1.20	10.20	0.00		10.50	
7/4/90	18:11	Y	S	1	0.35	0.08	0.36	77.12	4.38	-0.06	-2.10		10.30	
7/4/90	18:53	H	N	2	0.35	0.85	0.92	22.38	0.41	9.60	-1.50		10.00	SLOW
7/4/90	19:37	Y	S	3	0.13	0.35	0.37	20.38	0.37	0.10	-0.50		9.50	N-wall contact dur. S-wall rebound
7/4/90	20:22	H	N	2	0.30	0.40	0.50	36.87	0.75	10.80	0.00		8.60	
7/4/90	20:58	Y	N	3	0.90	0.18	0.92	78.69	5.00	3.00	-1.80		8.20	
7/4/90	22:31	Y	S	1	0.63	0.10	0.64	80.98	6.30	-0.10	-2.00		7.90	

Date	Time	Ship	Dir.	# hit	V-Per.	V-Paral	V-Tot	Ap.Ang.	v-per	N(in.)	F(in.)	w(mph)	T(FT)	NOTES/ COMMENTS
					VELOCITY (FT/S)				v par	delta	delta			
		Position			NORTH & SOUTH					N	F	wind	tide	
7/4/90	23:12	H	N	4	0.45	0.00	0.45	89.99	4500.00	7.20	2.00		8.20	
7/4/90	23:42	Y	N	3	0.51	0.15	0.53	73.61	3.40	10.80	1.50		8.40	
7/5/90	5:32	Y	N	6	0.30	0.43	0.52	34.90	0.70	2.00	7.20		6.00	
7/5/90	6:12	H	S	2	0.25	0.40	0.47	32.01	0.63	0.55	-1.80		5.20	
7/5/90	6:55	Y	N	2	0.35	0.56	0.66	32.01	0.63	10.60	-2.50		2.70	
7/5/90	7:31	H	N	1	0.40	0.40	0.57	45.00	1.00	11.40	-2.00		1.60	
7/5/90	8:12	Y	N	2	0.30	0.55	0.63	28.61	0.55	9.60	-2.80		1.10	
7/5/90	9:04	H	N	1	0.50	0.13	0.52	75.43	3.85	10.20	2.00		-0.60	
7/5/90	9:49	Y	N	4	0.45	0.38	0.59	49.82	1.18	9.60	2.40		-1.10	Contact w/ both sides 1sec apart
7/5/90	11:20	Y	S	1	0.30	0.25	0.39	50.19	1.20	0.25	2.40		0.40	
7/5/90	12:09	H	S	3	0.31	0.00	0.31	89.98	3100.00	-0.20	-1.00		0.70	
7/5/90	12:41	Y	S	2	0.85	0.28	0.89	71.77	3.04	-0.17	2.40		1.90	
7/5/90	13:33	H	S	2	0.55	0.50	0.74	47.73	1.10	0.10	2.40		4.00	
7/5/90	14:52	H	N	1	0.48	0.90	1.02	28.07	0.53	10.20	-2.00		7.40	
7/5/90	16:16	H	N	1	0.11	0.48	0.49	12.91	0.23	10.50	0.00		9.50	N & S wall contact almost eq. time
7/5/90	16:53	Y	N	4	0.40	0.51	0.65	38.11	0.78	10.00	3.00		10.40	
7/5/90	17:37	H	N	5	0.43	0.50	0.66	40.70	0.86	7.20	6.00		10.70	
7/5/90	18:12	Y	S	1	0.51	0.13	0.53	75.70	3.92	-0.06	-2.40		11.00	
7/5/90	19:36	Y	N	5	0.80	0.60	1.00	53.13	1.33	4.80	7.20		10.50	
7/5/90	20:26	H	N	2	0.55	0.00	0.55	89.99	5500.00	12.00	-2.00		9.70	
7/5/90	20:56	Y	N	1	0.35	0.50	0.61	34.99	0.70	9.00	-1.00		9.00	
7/6/90	5:33	Y	S	3	0.50	0.10	0.51	78.69	5.00	0.00	-1.00		7.50	
7/6/90	6:12	H	S	4	0.60	0.25	0.65	67.38	2.40	0.00	-1.00		6.40	
7/6/90	6:50	Y	N	1	0.65	0.35	0.74	61.70	1.86	12.00	-2.50		4.10	
7/6/90	9:02	H	S	3	0.53	0.43	0.68	50.95	1.23		-1.00		0.20	
7/6/90	9:47	Y	N	4	0.50	0.60	0.78	39.81	0.83	11.40	2.80		-1.00	
7/6/90	11:13	Y	S	3	0.60	0.53	0.80	48.54	1.13	0.23	-2.40		-1.50	
7/6/90	12:36	Y	N	2	0.35	0.50	0.61	34.99	0.70	8.10	6.00		-1.00	
7/6/90	13:15	H	N	3	0.51	0.00	0.51	89.99	5100.00	7.20	4.80		0.40	N-wall hit first
7/6/90	22:16	Y	N	1	0.75	0.51	0.91	55.78	1.47	12.00	-2.00		7.60	
7/6/90	23:33	Y	S	2	0.50	0.07	0.50	82.03	7.14	0.00	-1.50		7.80	
7/7/90	5:30	Y	S	1	1.00	0.30	1.04	73.30	3.33	-0.32	-3.40		8.20	
7/7/90	6:51	Y	N	1	0.55	0.30	0.63	61.39	1.83	10.80	-3.20		5.50	
7/7/90	8:11	Y	S	1	0.75	0.45	0.87	59.04	1.67	0.00	-4.00		3.50	
7/7/90	9:07	H	N	2	0.45	0.50	0.67	41.99	0.90	10.20	-2.30		0.60	
7/7/90	9:46	Y	S	1	0.60	0.20	0.63	71.57	3.00	-0.05	-2.40		-0.30	
7/7/90	10:31	H	N	1	0.40	0.30	0.50	53.13	1.33	12.00	-1.50		-1.50	
7/7/90	11:15	Y	N	3	0.10	0.60	0.61	9.46	0.17	9.60	-1.00		-1.70	No shot of S far wall -delta f at approx S8
7/7/90	11:56	H	N	1	0.38	0.50	0.63	37.23	0.76	9.60	-3.00		-1.40	
7/7/90	12:36	Y	N	2	0.32	0.48	0.58	33.69	0.67	7.20	-2.00		-1.00	

Date	Time	Ship	Dir.	# hit	V-Per.	V-Paral	V-Tot	Ap.Ang.	v-per	N(in.)	F(in.)	w(mph)	T(FT)	NOTES/ COMMENTS
					VELOCITY (FT/S)				v par	delta	delta			
		Position			NORTH & SOUTH					N	F	wind	tide	
7/7/90	13:18	H	N	1	0.25	0.05	0.25	78.69	5.00	7.20	-1.00		0.30	
7/7/90	14:02	Y	S	1	0.25	0.04	0.25	80.91	6.25	0.00	-1.00		1.30	N Wall not shown
7/7/90	14:48	H	N	1	0.25	0.10	0.27	68.20	2.50	12.00	-2.00		2.50	N Wall not shown
7/7/90	15:32	Y	N	1	1.00	-0.15	1.01	81.47	-6.67	16.80	-2.50		4.90	
7/7/90	16:13	H	N	3	0.25	0.60	0.65	22.62	0.42	9.00	1.00		7.60	
7/7/90	16:53	Y	S	1	0.30	0.25	0.39	50.19	1.20	0.00	0.00		9.60	
7/7/90	17:34	H	N	1	0.35	0.00	0.35	89.98	3500.00	9.60	-2.00		9.70	
7/7/90	18:14	Y	S	1	0.55	0.45	0.71	50.71	1.22	0.00	-2.50		10.90	
7/7/90	18:52	H	N	1	0.45	0.10	0.46	77.47	4.50	9.60	-2.00		11.50	S-wall hit during constant contact
7/7/90	19:36	Y	S	3	0.53	0.25	0.59	64.75	2.12	-0.10	-2.30		11.60	
7/7/90	20:21	H	N	2	0.35	0.50	0.61	34.99	0.70	12.00	-2.00		11.50	
7/7/90	20:56	Y	S	3	0.65	-0.10	0.66	81.25	-6.50	0.60	-1.00		11.40	
7/7/90	21:43	H	S	4	0.60	0.00	0.60	89.99	6000.00	-0.30	-2.00		11.30	
7/7/90	22:17	Y	N	1	0.60	-0.40	0.72	56.31	-1.50	12.10	-2.60		11.20	
7/7/90	23:39	Y	S	1	0.50	0.10	0.51	78.69	5.00	-0.12	-1.00		11.10	
7/8/90	6:51	Y	S	1	0.35	0.40	0.53	41.19	0.88	0.20	-1.50		6.90	
7/8/90	8:12	Y	N	3	0.60	0.10	0.61	80.54	6.00	11.10	-2.00		4.00	
7/8/90	9:03	H	S	2	0.67	0.00	0.67	89.99	6700.00	-0.27	-1.00		2.20	
7/9/90	15:38	Y	N	1	0.30	0.41	0.51	36.19	0.73	10.90	-3.00		3.70	
7/9/90	16:16	H	N	2	0.40	0.75	0.85	28.07	0.53	10.20	-1.50		5.10	
7/9/90	16:54	Y	N	1	0.45	0.45	0.64	45.00	1.00	10.80	-4.60		7.20	w/ N-wall
7/9/90	17:38	H	N	1	-0.50	0.48	0.69	46.17	-1.04	10.00	-0.50		8.50	
7/9/90	18:13	Y	S	1	0.45	0.00	0.45	89.99	4500.00	-0.25	-1.50		10.90	S-wall hit off of N-wall rebound
7/9/90	18:54	H	N	1	0.45	0.35	0.57	52.13	1.29	11.50	-2.00		11.60	
7/9/90	19:36	Y	S	2	0.60	0.50	0.78	50.19	1.20	0.15	-2.00		10.90	
7/9/90	20:21	H	N	1	0.10	0.15	0.18	33.69	0.67	6.00	0.00		9.70	
7/9/90	20:57	Y	N	1	1.00	0.80	1.28	51.34	1.25	14.60	-6.00		8.90	
7/9/90	22:17	Y	N	1	0.50	0.95	1.07	27.76	0.53	10.20	-2.10		8.50	
7/9/90	23:33	Y	N	1	0.60	1.00	1.17	30.96	0.60	13.50	-1.80		8.20	
7/10/90	5:31	Y	N	5	0.51	0.90	1.03	29.54	0.57	7.50	1.50		8.90	N-wall hit first
7/10/90	6:12	H	N	4	0.45	0.40	0.60	48.37	1.13	12.00	1.00		9.50	
7/10/90	6:52	Y	N	6	0.10	0.40	0.41	14.04	0.25	4.00	4.00		8.80	No shot of S far wall -delta f at approx S8
7/10/90	7:32	H	S	1	0.51	0.12	0.52	76.76	4.25	-0.15	-2.00		8.30	N-wall hit first
7/10/90	8:12	Y	N	3	0.30	0.35	0.46	40.60	0.86	8.40	2.40		7.60	
7/10/90	9:02	H	N	3	0.10	0.35	0.36	15.95	0.29	5.40	0.00		5.40	No shot of S far wall -del. f @ appx. S8
7/10/90	9:47	Y	S	3	0.50	0.45	0.67	48.01	1.11	0.40	-2.40		3.50	
7/10/90	10:32	H	N	2	0.10	0.75	0.76	7.59	0.13	9.50	-2.30		1.90	No shot of S far wall -delta f at approx S8
7/10/90	11:16	Y	N	2	0.25	0.51	0.57	26.11	0.49	9.00	1.00		0.20	
7/10/90	12:42	Y	N	2	0.45	0.85	0.96	27.90	0.53	6.00	-2.00		-1.10	
7/10/90	13:16	H	N	3	0.40	0.30	0.50	53.13	1.33	9.60	-1.50		-1.40	

Date	Time	Ship	Dir.	# hit	V-Per.	V-Paral	V-Tot	Ap.Ang.	v-per	N(in.)	F(in.)	w(mph)	T(FT)	NOTES/ COMMENTS
					VELOCITY (FT/S)				v par	delta	delta			
		Position			NORTH & SOUTH					N	F	wind	tide	
7/10/90	14:04	Y	N	5	0.10	0.51	0.52	11.09	0.20	3.50	2.50		-0.90	
7/10/90	14:48	H	N	3	0.25	0.05	0.25	78.69	5.00	7.80	0.00		0.00	No south wall hit
7/10/90	15:31	Y	N	4	0.10	0.30	0.32	18.43	0.33	7.20	0.00		1.00	
7/10/90	16:12	H	N	2	0.51	0.43	0.67	49.86	1.19	12.30	-2.60		2.10	N-wall hit first
7/10/90	16:57	Y	S	1	0.60	0.50	0.78	50.19	1.20	-0.05	-2.20		4.40	
7/10/90	17:32	H	N	1	0.12	0.50	0.51	13.50	0.24	7.40	0.00		5.70	
7/10/90	18:13	Y	S	2	0.10	0.34	0.35	16.39	0.29	0.25	0.00		6.40	
7/10/90	18:51	H	N	1	0.00	0.51	0.51	0.01	0.00	6.60	-1.50		9.40	N-wall.
7/10/90	19:38	Y	S	2	0.50	0.30	0.58	59.04	1.67	0.05	-1.00		10.40	
7/10/90	20:20	H	N	2	0.10	0.50	0.51	11.31	0.20	6.10	-1.00		12.10	No hit on N wall, parallel all the way
7/10/90	20:57	Y	N	4	0.15	0.50	0.52	16.70	0.30	10.20	6.60		10.90	
7/10/90	22:19	Y	S	1	0.50	0.50	0.71	45.00	1.00	0.15	-2.00		10.40	
7/10/90	23:13	Y	N	1	0.60	0.25	0.65	67.38	2.40	12.50	-2.00		8.80	
7/11/90	5:33	Y	N	3	0.45	0.35	0.57	52.13	1.29	10.80	-1.50		8.40	
7/11/90	6:11	H	N	2	0.15	0.55	0.57	15.26	0.27	4.30	0.00		9.10	S wall hit during N wall rebound
7/11/90	20:22	H	N	5	0.50	0.60	0.78	39.81	0.83	8.40	1.50		11.50	
7/11/90	20:58	Y	N	2	0.25	0.45	0.51	29.05	0.56	11.40	-2.30		12.20	
7/11/90	22:18	Y	N	4	0.27	0.60	0.66	24.23	0.45	8.40	2.00		11.40	
7/11/90	23:32	Y	S	1	0.40	0.00	0.40	89.99	4000.00	-0.22	-1.50		9.50	
7/12/90	5:32	Y	N	2	0.45	0.25	0.51	60.95	1.80	12.10	0.00		6.90	
7/12/90	6:12	H	S	3	0.55	0.51	0.75	47.16	1.08	0.61	-2.40		7.50	
7/12/90	6:52	Y	N	3	0.25	0.50	0.56	26.57	0.50	9.60	-2.00		8.40	
7/12/90	7:32	H	S	3	0.25	0.50	0.56	26.57	0.50	0.51	-2.10		8.70	No S-wall hit
7/12/90	8:12	Y	S	1	0.75	0.50	0.90	56.31	1.50	0.10	-3.20		8.80	
7/12/90	9:02	H	N	2	0.40	0.25	0.47	57.99	1.60	12.20	-2.20		8.10	
7/12/90	9:49	Y	S	3	0.05	0.50	0.50	5.71	0.10	0.45	1.50		6.80	
7/12/90	10:31	H	S	2	0.43	-0.05	0.43	83.37	-8.60	-0.05	-2.40		5.70	
7/12/90	11:13	Y	S	1	0.49	0.10	0.50	78.47	4.90	-0.05	-2.70		4.60	RPM 0 -> 0
7/12/90	11:57	H	S	1	0.45	0.25	0.51	60.95	1.80	0.00	-1.00		2.50	
7/12/90	12:35	Y	S	3	0.60	0.33	0.68	61.19	1.82	-0.13	0.00		1.70	
7/12/90	13:17	H	S	1	0.20	0.20	0.28	45.00	1.00	0.05	-1.00		0.90	North hit off of south wall rebound
7/12/90	14:03	Y	S	3	0.39	0.25	0.46	57.34	1.56	0.00	2.00		0.30	
7/12/90	14:48	H	S	2	0.35	0.23	0.42	56.69	1.52	0.06	-1.00		0.40	
7/12/90	15:34	Y	S	1	0.57	0.13	0.58	77.15	4.38	0.00	-2.10		0.90	
7/12/90	16:18	H	S	1	0.65	0.40	0.76	58.39	1.63	0.10	-2.40		2.50	
7/12/90	17:40	H	S	2	0.50	0.10	0.51	78.69	5.00	-0.35	-1.00		4.80	
7/12/90	18:15	Y	S	2	0.60	0.35	0.69	59.74	1.71	0.10	-2.00		7.70	
7/12/90	18:59	H	S	4	0.75	0.50	0.90	56.31	1.50	0.00	-2.00		8.40	
7/12/90	19:37	Y	S	2	0.50	0.00	0.50	89.99	5000.00	0.12	-1.50		9.80	
7/12/90	20:23	H	S	1	0.52	0.50	0.72	46.12	1.04	0.47	-1.00		10.10	

Date	Time	Ship	Dir.	# hit	V-Per.	V-Parel	V-Tot	Ap.Ang.	v-per	N(in.)	F(in.)	w(mph)	T(FT)	NOTES/ COMMENTS
					VELOCITY (FT/S)				v par	delta	delta			
		Position			NORTH & SOUTH					N	F	wind	tide	
7/12/90	22:19	Y	S	1	0.40	0.12	0.42	73.30	3.33	0.00	-2.00		12.20	All of N-wall not in picture
7/12/90	23:34	Y	S	2	0.43	0.10	0.44	76.91	4.30	-0.25	0.00		12.00	
7/13/90	6:53	Y	S	1	0.60	0.20	0.63	71.57	3.00	-0.30	-2.00		6.60	
7/13/90	7:32	H	S	1	0.60	0.10	0.61	80.54	6.00	-0.10	-2.50		7.70	
7/13/90	8:13	Y	S	1	0.30	0.00	0.30	89.98	3000.00	-0.40	-1.50		8.10	
7/13/90	9:00	H	S	1	0.47	0.45	0.65	46.25	1.04	0.42	-2.50		8.40	
7/13/90	9:47	Y	S	3	0.50	0.50	0.71	45.00	1.00	0.25	0.00		8.10	
7/13/90	10:34	H	S	2	0.25	0.50	0.56	26.57	0.50	0.50	-2.00		7.40	
7/13/90	11:11	Y	S	1	0.30	0.34	0.45	41.42	0.88	0.25	-1.70		6.40	
7/13/90	12:32	Y	S	1	0.61	0.50	0.79	50.66	1.22	0.10	-2.40		4.30	
7/13/90	13:18	H	S	1	0.50	0.00	0.50	89.99	5000.00	-0.25	-1.80		3.00	
7/13/90	14:02	Y	S	1	0.63	0.45	0.77	54.46	1.40	0.30	-1.00		1.60	
7/13/90	19:40	Y	S	3	0.05	0.50	0.50	5.71	0.10	0.38	-1.00		12.10	
7/13/90	20:35	H	S	3	0.95	0.51	1.08	61.77	1.86	-0.28	-1.00		11.70	
7/13/90	21:02	Y	S	2	0.50	0.45	0.67	48.01	1.11	0.00	-3.70		10.90	
7/13/90	22:23	Y	S	3	0.90	0.45	1.01	63.43	2.00	0.10	-2.50		9.60	
7/13/90	23:44	Y	S	2	0.50	0.40	0.64	51.34	1.25	0.10	-2.10		8.60	
7/14/90	1:00	Y	S	1	0.30	0.30	0.42	45.00	1.00	-0.10	-1.80		8.00	
7/14/90	5:31	Y	S	2	0.30	0.10	0.32	71.57	3.00	0.00	-2.00		3.10	
7/14/90	6:52	Y	S	2	0.50	0.50	0.71	45.00	1.00	0.05	-2.00		4.60	
7/14/90	7:31	H	S	1	0.75	0.10	0.76	82.41	7.50	-0.32	-2.50		5.40	
7/14/90	8:14	Y	S	1	0.63	0.22	0.67	70.75	2.86	-0.10	-1.80		6.20	
7/14/90	9:02	H	S	1	0.48	0.00	0.48	89.99	4800.00	-0.10	-2.00		7.30	
7/14/90	9:46	Y	S	2	0.05	0.43	0.43	6.63	0.12	0.65	0.00		7.80	
7/14/90	10:32	H	S	1	0.65	0.30	0.72	65.22	2.17	-0.25	-3.00		8.10	
7/14/90	11:11	Y	S	1	0.25	0.40	0.47	32.01	0.63	0.00	-2.70		7.90	
7/14/90	11:54	H	S	2	0.10	0.45	0.46	12.53	0.22	0.25	0.00		7.30	
7/14/90	12:33	Y	S	4	0.60	0.23	0.64	69.03	2.61	-0.10	2.10		6.40	
7/14/90	13:17	H	S	1	0.70	0.05	0.70	85.91	14.00	0.60	-2.00		5.50	
7/14/90	14:00	Y	S	4	0.50	1.00	1.12	26.57	0.50	0.58	0.00		4.50	
7/14/90	14:49	H	S	3	0.50	0.40	0.64	51.34	1.25	0.20	-2.50		3.80	
7/14/90	15:34	Y	S	2	0.49	0.10	0.50	78.47	4.90	-0.40	-2.50		3.30	RPM 0 -> 0
7/14/90	16:12	H	S	3	0.69	0.10	0.70	81.75	6.90	-0.10	-1.80		3.40	
7/14/90	17:36	H	S	1	0.50	0.08	0.51	80.91	6.25	-0.23	-2.20		4.30	
7/14/90	18:16	Y	S	1	0.35	0.51	0.62	34.46	0.69	0.45	-2.00		5.90	
7/14/90	19:38	Y	S	1	0.35	0.00	0.35	89.98	3500.00	0.28	-2.10		7.20	
7/14/90	20:23	H	S	1	0.52	0.10	0.53	79.11	5.20	-0.19	-1.80		9.70	
7/14/90	20:58	Y	S	1	0.33	0.30	0.45	47.73	1.10	0.10	-1.00		10.90	
7/14/90	21:43	H	S	1	0.63	0.25	0.68	68.36	2.52	-0.10	-2.30		11.60	
7/14/90	23:39	Y	S	1	0.25	0.10	0.27	68.20	2.50	-0.30	-2.00		11.80	

Date	Time	Ship	Dir.	# hit	V-Per.	V-Paral	V-Tot	Ap.Ang.	v-per	N(in.)	F(in.)	w(mph)	T(FT)	NOTES/ COMMENTS	
PE					VELOCITY (FT/S)				v par	delta	delta				
		Position			NORTH & SOUTH					N	F	wind	tide		
7/14/90	22:17	Y	S	2	0.51	0.00	0.51	89.99	5100.00	-0.05	-2.40		12.00	N-wall hit first	
7/15/90	6:56	Y	S	1	0.52	0.30	0.60	60.02	1.73	0.00	-3.20		2.50		
7/15/90	8:11	Y	S	2	0.48	0.15	0.50	72.65	3.20	-0.10	-2.10		4.40		
7/15/90	9:03	H	S	5	0.61	0.35	0.70	60.15	1.74	-0.20	2.50		5.40		
7/15/90	9:48	Y	S	1	0.42	0.00	0.42	89.99	4200.00	-0.10	-3.00		6.80		
7/15/90	10:32	H	S	4	0.50	0.50	0.71	45.00	1.00	0.25	-2.00		7.40		
7/15/90	11:16	Y	S	2	0.63	0.25	0.68	68.36	2.52	0.00	-3.60		7.90		
7/15/90	11:54	H	S	1	0.60	0.25	0.65	67.38	2.40	-0.35	-3.00		8.10		
7/16/90	18:12	Y	S	2	0.45	0.10	0.46	77.47	4.50	-0.10	-2.00		6.40		
7/16/90	18:52	H	N	1	0.50	-0.05	0.50	84.29	-10.00	5.00	0.00		7.20		
7/16/90	19:36	Y	N	1	0.50	0.38	0.63	52.77	1.32	8.00	-3.00		7.70		
7/16/90	20:28	H	N	3	0.60	0.10	0.61	80.54	6.00	4.50	6.00		9.40		
7/16/90	20:57	Y	S	2	0.53	0.55	0.76	43.94	0.96	0.00	-3.00		10.30		
7/16/90	22:18	Y	N	3	0.45	0.30	0.54	56.31	1.50	8.00	-2.00		11.40		
7/16/90	23:35	Y	S	3	0.70	0.50	0.86	54.46	1.40	-0.22	-3.50		11.60		
7/17/90	6:12	H	S	2	0.50	0.25	0.56	63.43	2.00	0.00	2.30		-0.50		
7/17/90	6:52	Y	N	4	0.10	0.63	0.64	9.02	0.16	4.80	7.80		-0.70	North wall not in picture	
7/17/90	7:32	H	N	4	0.52	0.10	0.53	79.11	5.20	10.20	3.00		-0.80		
7/17/90	8:12	Y	S	2	0.27	0.13	0.30	64.29	2.08	0.00	-1.50		-0.30		
7/17/90	9:02	H	S	1	0.58	0.33	0.67	60.36	1.76	-0.10	-1.00		0.50		
7/17/90	9:47	Y	N	4	0.50	0.62	0.80	38.88	0.81	7.80	7.20		1.00		
7/17/90	10:34	H	N	3	0.24	0.60	0.65	21.80	0.40	8.40	3.20		3.00		
7/17/90	11:11	Y	N	1	0.10	0.40	0.41	14.04	0.25	7.20	-2.20		4.50	North wall not in picture	
7/17/90	11:56	H	S	2	0.70	0.22	0.73	72.55	3.18	-0.40	-1.50		6.30		
7/17/90	12:36	Y	N	2	0.65	0.10	0.66	81.25	6.50	14.40	-3.00		6.90		
7/17/90	13:18	H	N	1	0.35	0.50	0.61	34.99	0.70	9.40	-2.00		8.80		
7/17/90	14:49	H	N	3	0.08	0.60	0.61	7.59	0.13	9.60	-1.00		9.30	N&S wall contact at = time	
7/17/90	15:34	Y	S	2	0.30	0.50	0.58	30.96	0.60	0.40	0.00		9.40		
7/17/90	16:13	H	S	2	0.26	0.37	0.45	35.10	0.70	0.10	-1.10		8.90		
7/17/90	16:53	Y	S	4	0.26	0.10	0.28	68.96	2.60	0.00	-1.00		8.50		
7/17/90	17:32	H	N	1	0.30	0.48	0.57	32.01	0.63	7.30	-1.00		8.10	No S-wall hit	
7/17/90	18:12	Y	N	1	0.60	0.50	0.78	50.19	1.20	12.50	-4.00		7.70		
7/17/90	18:52	H	N	1	0.18	0.35	0.39	27.22	0.51	6.00	0.00		7.50	N Wall not shown	
7/17/90	19:36	Y	N	2	0.10	0.40	0.41	14.04	0.25	5.00	-1.00		7.40	No S wall delta	
7/17/90	20:21	H	N	2	0.15	0.73	0.75	11.61	0.21	7.30	-2.80		7.10	Two N wall hits	
7/17/90	20:57	Y	N	1	0.51	0.75	0.91	34.22	0.68	9.60	-2.20		6.10	N-wall hit first	
7/17/90	22:22	Y	N	1	0.55	0.55	0.78	45.00	1.00	12.00	-2.00		4.00		
7/18/90	5:31	Y	N	1	0.30	0.51	0.59	30.47	0.59	6.50	-1.50		2.80		
7/18/90	7:31	H	N	2	0.10	0.60	0.61	9.46	0.17	5.00	-1.00		-1.20	North wall not in picture	
7/18/90	8:12	Y	N	2	0.20	0.50	0.54	21.80	0.40	9.00	-2.00		-1.80		

Date	Time	Ship	Dir.	# hit	V-Per.	V-Paral	V-Tot	Ap.Ang.	v-per	N(in.)	F(in.)	w(mph)	T(FT)	NOTES/ COMMENTS
					VELOCITY (FT/S)				v par	delta	delta			
		Position			NORTH & SOUTH					N	F	wind	tide	
7/18/90	9:02	H	N	3	0.30	0.51	0.59	30.47	0.59	6.50	1.00		-1.20	
7/18/90	9:47	Y	S	1	0.49	0.10	0.50	78.47	4.90	-0.15	-1.50		-0.60	RPM 20 -> 40
7/18/90	11:15	Y	N	4	0.05	0.50	0.50	5.71	0.10	6.10	1.00		1.90	
7/18/90	11:51	H	N	1	0.15	0.55	0.57	15.26	0.27	5.50	-1.50		3.40	
7/18/90	12:32	Y	N	1	0.10	0.51	0.52	11.09	0.20	7.50	-2.40		4.60	North wall not in picture
7/18/90	13:19	H	N	2	0.41	0.45	0.61	42.34	0.91	10.00	-1.50		6.70	
7/18/90	14:28	H	S	3	0.51	0.05	0.51	84.40	10.20	-0.45	-2.00		9.20	
7/18/90	15:31	Y	S	3	0.50	-0.03	0.50	86.57	-16.67	0.48	-1.00		10.10	
7/18/90	16:15	H	N	1	0.21	0.07	0.22	71.57	3.00	6.00	0.00		10.40	N Wall not shown
7/18/90	16:53	Y	S	1	0.60	0.05	0.60	85.24	12.00	-0.05	-3.00		10.20	
7/18/90	17:35	H	S	1	0.28	0.40	0.49	34.99	0.70	0.05	-1.00		9.90	
7/18/90	18:12	Y	N	1	0.02	0.75	0.75	1.53	0.03	5.00	-1.00		9.30	same time
7/18/90	18:50	H	N	1	0.62	-0.10	0.63	80.84	-6.20	6.00	-1.00		8.90	
7/18/90	19:38	Y	N	1	0.32	0.22	0.39	55.49	1.45	6.10	-2.00		8.30	
7/18/90	20:24	H	S	2	0.50	0.05	0.50	84.29	10.00	-0.05	-2.50		8.10	
7/18/90	21:00	Y	S	1	0.77	0.10	0.78	82.60	7.70	-0.30	-3.50		8.20	
7/18/90	22:18	Y	S	1	0.51	0.48	0.70	46.74	1.06	0.10	-2.00		8.40	N-wall hit first
7/18/90	23:31	Y	S	1	0.61	0.45	0.76	53.58	1.36	-0.20	-3.00		8.70	
7/18/90	10;33	H	S	2	0.35	0.05	0.35	81.87	7.00	-0.19	0.00		0.30	
7/18/90	14;02	Y	S	1	0.50	0.55	0.74	42.27	0.91	0.00	-2.50		8.30	
7/18/90	6;51	Y	N	7	0.35	0.28	0.45	51.34	1.25	-1.00	5.00		0.40	
7/19/90	5:31	Y	N	1	0.48	0.45	0.66	46.85	1.07	6.20	-3.00		4.20	
7/19/90	6:12	H	N	1	0.45	0.10	0.46	77.47	4.50	5.50	-1.00		1.60	
7/19/90	6:50	Y	N	1	0.42	0.25	0.49	59.24	1.68	6.00	-2.00		0.30	
7/19/90	7:32	H	S	2	0.20	0.15	0.25	53.13	1.33	0.00	0.00		-0.80	
7/19/90	8:13	Y	S	1	0.41	0.10	0.42	76.29	4.10	-0.22	-2.00		-1.10	
7/19/90	9:02	H	N	3	0.10	0.50	0.51	11.31	0.20	4.50	-2.00		-2.50	North wall not in picture
7/19/90	9:47	Y	N	3	0.05	0.49	0.49	5.83	0.10	5.20	-1.00		-1.80	Energy is transferred between piles
7/19/90	10:33	H	S	1	0.21	0.05	0.22	76.61	4.20	-0.20	0.00		-1.40	
7/19/90	11:14	Y	N	4	0.08	0.50	0.51	9.09	0.16	7.50	1.50		-0.40	N&S wall contact at = time
7/19/90	11:58	H	N	1	0.15	0.41	0.44	20.10	0.37	7.00	-1.50		0.60	
7/19/90	12:34	Y	N	2	0.15	0.55	0.57	15.26	0.27	8.00	-3.50		2.60	No south wall delta
7/19/90	13:18	H	N	3	0.40	0.61	0.73	33.25	0.66	7.90	-1.00		4.40	All of N-wall not in picture
7/19/90	14:10	Y	N	3	0.48	0.55	0.73	41.11	0.87	9.00	1.00		7.10	
7/19/90	14:48	H	S	1	0.60	0.49	0.77	50.76	1.22	0.00	-2.50		8.50	
9/5/90	14:51	H	S	1	0.65	0.52	0.83	51.34	1.25	0.51	-1.50		7.60	
9/5/90	16:13	H	S	3	0.20	0.65	0.68	17.10	0.31	0.85	0.00		4.30	
9/5/90	16:13	H	N	1	0.70	0.20	0.73	74.05	3.50	3.00	-1.50		4.30	
9/5/90	17:38	H	S	2	0.75	0.51	0.91	55.78	1.47		-2.00		1.90	
9/5/90	18:55	H	S	1	0.95	0.10	0.96	83.99	9.50	0.00	-4.50		0.90	

Date	Time	Ship	Dir.	# hit	V-Per.	V-Paral	V-Tot	Ap.Ang.	v-per	N(in.)	F(in.)	w(mph)	T(FT)	NOTES/ COMMENTS
					VELOCITY (FT/S)				v par	delta	delta			
		Position			NORTH & SOUTH					N	F	wind	tide	
9/5/90	20:20	H	S	3	0.41	0.50	0.65	39.35	0.82	0.00	-1.00		1.80	
9/6/90	1:22	H	N	6	0.15	0.51	0.53	16.39	0.29	-1.00	2.00		8.20	
9/6/90	1:22	H	S	1	0.65	0.20	0.68	72.90	3.25	0.00	-2.00		8.20	
9/6/90	2:54	H	S	1	0.57	0.40	0.70	54.94	1.43	0.30	2.50		8.30	
9/6/90	7:34	H	S	4	0.52	0.65	0.83	38.66	0.80		-1.00		-0.20	
9/6/90	9:04	H	S	4	0.30	0.55	0.63	28.61	0.55		-1.00		0.50	
9/6/90	10:35	H	N	3	0.10	0.60	0.61	9.46	0.17	1.00	0.00		3.00	North wall not in picture
9/6/90	10:35	H	S	1	0.85	0.10	0.86	83.29	8.50	0.15	-2.00		3.00	
9/6/90	11:59	H	S	1	0.50	0.25	0.56	63.43	2.00	0.00	-1.00		6.20	
2/1/91	15:32	Y	S	1	0.51	0.27	0.58	62.10	1.89	0.00	-2.00	S 9.0	7.60	
2/1/91	16:17	T	S	1	0.90	0.40	0.98	66.04	2.25	0.00	-3.00	S 9.0	8.60	
2/1/91	16:50	Y	N	1	0.52	0.28	0.59	61.70	1.86	3.00	-3.00	S 9.0	9.30	
2/1/91	17:36	T	N	1	0.40	0.00	0.40	89.99	4000.00	1.00	0.00	S 9.0	10.20	All of N-wall not shown
2/1/91	18:22	Y	N	5	0.49	0.10	0.50	78.47	4.90	-2.50	3.00	S 8.2	10.30	RPM 0 -> 0
2/1/91	19:02	T	S	1	0.51	0.30	0.59	59.53	1.70	0.00		S 8.2	9.80	2 cameras back & working fine
2/1/91	19:37	Y	S	1	0.40	0.37	0.54	47.23	1.08	0.00	-1.50	S 8.2	9.20	
2/1/91	20:26	T	N	1	0.50	0.10	0.51	78.69	5.00	3.00		S 9.0	7.90	
2/1/91	20:58	Y	S	1	0.40	0.05	0.40	82.87	8.00	0.00	-1.00	S 9.0	6.20	
2/1/91	22:19	T	S	1	0.35	0.25	0.43	54.46	1.40	0.00	-0.50	S 7.0	3.90	
2/2/91	5:33	Y	S	1	0.50	0.35	0.61	55.01	1.43	0.00	-2.00	S 9.0	10.34	
2/2/91	6:51	Y	S	1	0.15	0.35	0.38	23.20	0.43	0.35		S 9.0	12.50	
2/2/91	8:13	Y	S	1	0.50	0.15	0.52	73.30	3.33	0.00	-2.00	S 9.0	12.30	
2/2/91	9:07	T	N	3	0.51	0.50	0.71	45.57	1.02	2.00	-1.00	S 16.5	10.80	
2/2/91	9:46	Y	N	8	0.65	0.50	0.82	52.43	1.30	-3.00	6.00	S 17.0	9.20	
2/2/91	10:34	T	N	1	0.00	0.35	0.35	0.00	0.00	1.00	-1.00	S 17.5	7.70	
2/2/91	11:13	Y	S	1	0.41	0.10	0.42	76.29	4.10	0.60	-1.00	S 17.5	5.70	
2/2/91	12:31	Y	N	1	0.51	0.60	0.79	40.36	0.85	3.00	-2.00	S 10.0	3.80	
2/2/91	14:04	Y	N	5	0.50	0.52	0.72	43.88	0.96	-2.80	5.50	S 16.0	3.40	
2/2/91	14:52	T	N	5	0.45	0.00	0.45	89.99	4500.00	0.00	1.00	S 16.0	4.30	
2/2/91	15:32	Y	N	5	0.60	0.50	0.78	50.19	1.20	1.00	0.00	S 16.0	5.00	
2/2/91	16:16	T	N	1	0.40	0.55	0.68	36.03	0.73	3.00	0.00	S 17.5	6.60	
2/2/91	17:37	T	N	6	0.35	0.35	0.49	45.00	1.00	0.00	1.00	S 17.5	8.70	
2/2/91	18:13	Y	N	7	0.50	0.55	0.74	42.27	0.91	2.00	-1.00	S 16.0	9.40	
2/2/91	18:56	T	N	9	0.50	0.50	0.71	45.00	1.00	3.50	-1.50	S 16.0	9.80	
2/2/91	19:37	Y	N	1	0.50	0.50	0.71	45.00	1.00	2.00	-1.00	S 16.0	9.70	
2/2/91	20:55	T	N	1	0.30	0.15	0.34	63.43	2.00	2.80	-1.00	S 9.0	8.40	
2/2/91	22:17	Y	N	1	0.50	0.15	0.52	73.30	3.33	1.50	0.00	S 6.0	5.60	
2/2/91	23:33	Y	N	1	0.50	0.50	0.71	45.00	1.00	1.00	0.00	S 5.0	3.10	
2/3/91	6:53	Y	S	1	0.45	0.00	0.45	89.99	4500.00	-0.15	-1.00	S 5.1	12.20	
2/3/91	9:47	Y	S	1	0.75	0.20	0.78	75.07	3.75	0.00	-2.00	S 8.0	10.50	

Date	Time	Ship	Dir.	# hit	V-Per.	V-Paral	V-Tot	Ap.Ang.	v-per	N(in.)	F(in.)	w(mph)	T(FT)	NOTES/ COMMENTS
					VELOCITY (FT/S)				v par	delta	delta			
		Position			NORTH & SOUTH					N	F	wind	tide	
2/3/91	10:34	T	S	1	0.70	0.65	0.96	47.12	1.08	0.65	-2.50	S 8.0	8.80	
2/3/91	11:12	Y	S	1	0.25	0.60	0.65	22.62	0.42	0.60	-1.00	S 10.0	7.50	
2/3/91	12:05	T	S	1	0.40	0.45	0.60	41.63	0.89	0.40	-1.00	S 13.0	5.70	
2/3/91	14:48	T	N	5	0.40	0.50	0.64	38.66	0.80	0.00	-1.50	S 14.8	2.70	
2/3/91	19:36	Y	N	1	0.40	0.15	0.43	69.44	2.67	1.50		S 15.8	8.90	All of N-wall not shown
2/3/91	20:24	T	N	1	0.30	0.10	0.32	71.57	3.00	1.00		S 13.0	9.40	
2/12/91	19:38	Y	S	1	0.47	0.24	0.53	62.95	1.96	0.15		-	0.00	
2/12/91	20:59	Y	S	1	0.51	0.40	0.65	51.89	1.28	0.00		-	0.00	
2/12/91	22:18	Y	N	1	0.51	0.45	0.68	48.58	1.13	2.00		-	2.10	
2/13/91	5:33	Y	N	2	0.77	0.32	0.83	67.43	2.41	4.00		S 2.0	11.60	
2/13/91	6:15	T	N	3 to 5	0.35	0.10	0.36	74.05	3.50	2.00		S 2.0	11.20	
2/13/91	6:53	Y	S	1	0.15	0.50	0.52	16.70	0.30	0.55		S 2.0	10.60	N Wall not shown
2/13/91	7:36	T	N	1	0.27	0.10	0.29	69.68	2.70	1.50	-0.50	S 2.0	9.70	
2/13/91	8:14	Y	S	5	0.10	0.45	0.46	12.53	0.22	0.00	1.50	S 2.0	8.70	North wall not in picture
2/13/91	9:05	T	N	1	0.30	0.15	0.34	63.43	2.00	2.00	-1.00	S 2.0	7.10	
2/13/91	9:48	Y	N	1	0.45	0.00	0.45	89.99	4500.00	2.00	-1.00	S 2.0	6.70	
2/13/91	10:11	T	N	4 to 6	0.15	0.40	0.43	20.56	0.38	0.00	1.00	S 0.04	6.40	South hit off north wall rebound
2/13/91	11:12	Y	N	3	0.50	0.15	0.52	73.30	3.33	2.70	-1.00	S 1.0	6.60	
2/13/91	12:32	Y	S	1	0.22	0.17	0.28	52.31	1.29	0.10	-2.00	S 5.5	7.70	
2/13/91	13:21	T	S	4	0.51	0.61	0.80	39.90	0.84		-	S 5.8	8.70	
2/13/91	14:02	Y	N	7	0.50	0.50	0.71	45.00	1.00	5.50	-3.00	S 7.8	9.30	
2/13/91	14:50	T	N	5	0.43	0.35	0.55	50.86	1.23	1.00	2.00	S 7.8	9.90	
2/13/91	15:34	Y	N	5	0.40	0.40	0.57	45.00	1.00	0.80	3.00	S 7.8	10.00	
2/13/91	16:16	T	N	1	0.45	0.40	0.60	48.37	1.13	3.00	0.00	S 7.8	9.50	
2/13/91	16:52	Y	N	5	0.30	0.18	0.35	59.04	1.67	2.10	2.50	S 7.8	8.70	
2/13/91	17:34	T	N	1	0.55	0.05	0.55	84.81	11.00	2.50	-1.00	S 7.8	8.00	
2/13/91	18:12	Y	N	4	0.50	0.25	0.56	63.43	2.00	0.00	3.00	S 7.8	6.40	
2/13/91	23:37	Y	N	1	0.27	0.11	0.29	67.83	2.45	1.00	-	S 5.2	0.00	
2/14/91	5:32	Y	S	1	0.50	0.25	0.56	63.43	2.00	0.10		5.40	11.90	
2/14/91	7:35	T	S	1	0.40	0.21	0.45	62.30	1.90	0.10	-2.00	3.40	10.00	
2/14/91	8:12	Y	S	6	0.35	0.50	0.61	34.99	0.70	0.00	1.50	3.40	8.70	
2/14/91	9:06	T	N	1	0.51	0.10	0.52	78.91	5.10	2.70	-1.00	3.40	7.70	
2/14/91	9:46	Y	S	2	0.50	0.10	0.51	78.69	5.00	0.00	-1.00	3.40	6.50	
2/14/91	10:36	T	N	1	0.35	0.00	0.35	89.98	3500.00	1.00	0.00	3.40	5.80	All of N-wall not in picture
2/14/91	11:11	Y	N	1	0.45	0.10	0.46	77.47	4.50	2.00	-1.00	6.00	5.50	
2/14/91	12:32	Y	S	1	0.75	0.50	0.90	56.31	1.50	0.00	-2.70	6.00	6.40	
2/14/91	13:22	T	S	1	0.15	0.25	0.29	30.96	0.60	0.10	0.00	6.00	7.70	North wall hit off south wall rebound
2/14/91	14:02	Y	N	1	0.48	0.38	0.61	51.63	1.26	2.50	-1.00	6.00	8.10	RPM -60 -> -40 RPM second # =
2/14/91	14:53	T	N	1	0.50	0.05	0.50	84.29	10.00	1.10	-0.50	6.00	9.40	
2/14/91	15:35	Y	N	1	0.62	0.11	0.63	79.94	5.64	3.00	-1.00	6.00	9.90	

Date	Time	Ship	Dir.	# hit	V-Per.	V-Paral	V-Tot	Ap.Ang.	v-per	N(in.)	F(in.)	w(mph)	T(FT)	NOTES/ COMMENTS
					VELOCITY (FT/S)				v par	delta	delta			
		Position			NORTH & SOUTH					N	F	wind	tide	
2/14/91	16:16	T	S	7	0.27	0.40	0.48	34.02	0.68	0.00	2.00	6.00	10.10	
2/14/91	16:54	Y	N	2	0.41	0.52	0.66	38.25	0.79	1.00	-1.00	6.00	9.50	
2/14/91	17:36	T	S	6	0.50	0.50	0.71	45.00	1.00	0.00	0.00	2.40	8.40	
2/14/91	18:21	Y	N	4	0.35	0.45	0.57	37.87	0.78	1.50		2.40	7.60	
2/14/91	18:56	T	S	1	0.55	0.41	0.69	53.30	1.34	0.00		2.40	5.30	
2/14/91	19:43	Y	S	1	0.50	0.55	0.74	42.27	0.91	0.45		2.40	2.70	
2/14/91	20:25	T	S	1	0.60	0.31	0.68	62.68	1.94	0.00		2.40	0.20	
2/14/91	23:34	Y	S	1	0.40	0.10	0.41	75.96	4.00	0.00		2.40	1.50	
2/15/91	5:31	Y	N	1	0.60	0.25	0.65	67.38	2.40	2.80		3.80	12.00	
2/15/91	6:16	T	N	1	0.40	0.18	0.44	65.77	2.22	2.60		3.80	11.40	
2/15/91	6:52	Y	S	1	0.51	0.22	0.56	66.67	2.32	0.00		3.80	10.30	
2/15/91	7:36	T	N	9	0.40	0.42	0.58	43.60	0.95	-1.80	2.50	3.80	9.20	
2/15/91	8:13	Y	N	2	0.50	0.41	0.65	50.65	1.22	2.00	-1.00	3.80	6.90	
2/15/91	9:09	T	S	3	0.31	0.45	0.55	34.56	0.69	0.00	-1.00	4.90	5.40	
2/15/91	9:50	Y	S	2	0.07	0.42	0.43	9.46	0.17	0.41	-0.80	8.00	5.00	
2/15/91	10:37	T	N	1	0.45	0.00	0.45	89.99	4500.00	1.00	-1.00	8.00	4.70	
2/15/91	11:14	Y	S	1	0.77	0.50	0.92	57.00	1.54	0.00	-2.00	4.00	4.60	
2/15/91	12:00	T	S	1	0.50	0.40	0.64	51.34	1.25	0.00	-1.00	4.00	4.80	
2/15/91	12:32	Y	N	1	0.30	0.41	0.51	36.19	0.73	1.80	-0.50	4.00	5.20	
2/15/91	13:21	T	N	1	0.50	0.60	0.78	39.81	0.83	2.00	-0.50	4.00	6.00	
2/15/91	14:05	Y	N	4	0.01	0.30	0.30	1.91	0.03	0.00	0.00	4.00	7.10	Hits S wall, then deflex both walls at
2/15/91	14:53	T	S	2	0.40	0.45	0.60	41.63	0.89	0.20	-1.00	4.00	7.90	
2/22/91	5:33	Y	S	1	0.10	0.38	0.39	14.74	0.26	0.40		2.80	8.20	North wall not in picture
2/22/91	6:16		N	1	0.30	0.35	0.46	40.60	0.86	1.00		2.80	8.90	
2/22/91	6:53	Y	S	1	0.55	0.38	0.67	55.36	1.45	0.00		2.80	9.50	
2/22/91	7:35		S	5	0.35	0.45	0.57	37.87	0.78	0.40	1.00	2.80	10.10	
2/22/91	8:14	Y	S	1	0.30	0.45	0.54	33.69	0.67	0.25	-2.00	2.80	10.70	
2/22/91	9:07		N	2	0.50	0.12	0.51	76.50	4.17	2.80	-1.00	2.80	10.90	
2/22/91	9:48	Y	N	1	0.49	0.45	0.67	47.44	1.09	1.00	-0.50	2.80	11.10	RPM 0 -> 0
2/22/91	10:36		N	1	0.41	0.00	0.41	89.99	4100.00	3.00	-1.00	2.80	10.50	
2/22/91	11:13	Y	N	1	0.51	0.22	0.56	66.67	2.32	2.50	-1.50	2.80	9.50	
2/22/91	11:55		S	2	0.15	0.45	0.47	18.43	0.33	0.30	0.00	4.10	8.50	
2/22/91	12:36	Y	S	6	0.47	0.11	0.48	76.83	4.27	0.00	-2.10	4.10	6.80	
2/22/91	13:21		N	1	0.48	0.35	0.59	53.90	1.37	2.70	-0.50	4.10	5.10	RPM 0 -> 0
2/22/91	14:06	Y	S	1	0.35	0.25	0.43	54.46	1.40	0.00	-0.80	5.50	3.70	
2/22/91	14:54		N	1	0.35	0.25	0.43	54.46	1.40	1.50	0.00	5.50	1.40	
2/22/91	15:31	Y	S	1	0.50	0.45	0.67	48.01	1.11	0.10	-0.80	5.50	0.80	
2/22/91	16:16		N	1	0.25	0.40	0.47	32.01	0.63	1.00	0.00	0.90	0.30	
2/22/91	16:54	Y	N	7	0.20	0.20	0.28	45.00	1.00	-1.00	1.50	0.90	-0.30	
2/22/91	17:40		S	1	0.28	0.23	0.36	50.60	1.22	0.10	-0.50	0.90	0.00	

Date	Time	Ship	Dir.	# hit	V-Per.	V-Paral	V-Tot	Ap.Ang.	v-per	N(in.)	F(in.)	w(mph)	T(FT)	NOTES/ COMMENTS
						VELOCITY (FT/S)			v par	delta	delta			
			Position			NORTH & SOUTH				N	F	wind	tide	
2/22/91	18:13	Y	S	1	0.50	0.25	0.56	63.43	2.00	0.20		0.90	0.80	
2/22/91	19:00		N	5	0.40	0.25	0.47	57.99	1.60	2.00		0.90	2.00	
2/22/91	19:38	Y	N	4	0.10	0.25	0.27	21.80	0.40	1.00		0.90	2.60	No S wall delta
2/22/91	20:25		N	1	0.37	0.15	0.40	67.93	2.47	1.80		0.90	3.00	
2/22/91	20:58	Y			0.00	0.40	0.40	0.00	0.00	0.38		0.90	4.20	1st hit along N-wall then rides along
2/22/91	22:19	Y	N	1	0.10	0.34	0.35	16.39	0.29	0.50		0.90	6.20	
2/23/91	5:33	Y	N	1	0.45	0.40	0.60	48.37	1.13	3.00		7.00	8.30	
2/23/91	6:54	Y	N	1	0.15	0.30	0.34	26.57	0.50	2.00	0.00	5.20	8.80	N-wall hit during S-wall rebound
2/23/91	8:17	Y	S	9	0.24	0.25	0.35	43.83	0.96	0.00	3.00	5.20	9.60	
2/23/91	8:55	Y	N	1	0.30	0.05	0.30	80.54	6.00	3.00	-1.00	5.20	10.20	N-SIDE HIT ALONG SIDE OF SHIP
2/23/91	9:17		S	6	0.25	0.35	0.43	35.54	0.71	0.00	1.50	5.20	10.40	
2/23/91	9:50	Y	N	1	0.50	0.20	0.54	68.20	2.50	3.00	-2.00	5.20	10.50	
2/23/91	10:41		S	9	0.40	0.10	0.41	75.96	4.00		1.00	5.20	10.70	
2/23/91	11:14	Y	N	1	0.50	0.40	0.64	51.34	1.25	3.10	-1.00	5.20	10.20	
2/23/91	12:14				0.30	0.35	0.46	40.60	0.86	0.45	-1.00	5.20	8.70	
2/23/91	12:40	Y	S	1	0.30	0.40	0.50	36.87	0.75	0.25	-0.50	5.20	7.90	
2/23/91	13:31		S	1	0.50	0.05	0.50	84.29	10.00	0.00	-0.50	5.20	5.70	
2/23/91	14:04	Y	S	1	0.30	0.45	0.54	33.69	0.67	0.15	-1.00	5.20	4.90	
2/23/91	15:33	Y	S	1	0.40	0.40	0.57	45.00	1.00	0.40	-0.50	5.20	1.70	
2/23/91	16:17		N	1	0.28	-0.21	0.35	53.13	-1.33	0.80	0.00	7.60	1.00	
2/23/91	16:56	Y	S	1	0.45	0.00	0.45	89.99	4500.00	-0.20	-1.00	7.60	-0.10	
2/23/91	17:40		S	1	0.51	0.38	0.64	53.31	1.34	0.00	-1.00	7.60	-0.50	
2/23/91	18:17	Y	S	1	0.50	0.10	0.51	78.69	5.00	0.00		7.60	-0.60	
2/23/91	19:00		S	1	0.45	0.50	0.67	41.99	0.90	0.25		7.60	-0.30	
2/23/91	19:44	Y	S	1	0.50	0.35	0.61	55.01	1.43	0.20		7.60	0.40	N-wall seems to be hit first
2/23/91	21:00	Y	N	5	0.55	0.47	0.72	49.48	1.17	2.50		7.60	2.30	
2/23/91	22:21	Y	N	1	0.40	0.00	0.40	89.99	4000.00	2.00		3.10	4.00	
2/23/91	23:46	Y	N	1	0.65	0.25	0.70	68.96	2.60	3.50		3.10	6.20	
2/25/91	5:33	Y	N	1	0.50	0.15	0.52	73.30	3.33	3.00	-1.80		10.30	N-wall hit first
2/25/91	6:18		N	1	0.80	0.32	0.86	68.20	2.50	4.00			8.80	
2/25/91	6:53	Y	N	1	0.65	0.00	0.65	89.99	6500.00	1.50	-0.50		8.20	
2/25/91	7:38		S	4	0.80	0.38	0.89	64.59	2.11	0.00	0.00		7.70	
2/25/91	8:14	Y	N	6	0.15	0.47	0.49	17.70	0.32	0.50	0.50		7.40	No north wall hit
2/25/91	9:06		S	1	1.00	0.43	1.09	66.73	2.33	0.00	-2.00		7.50	
2/25/91	9:49	Y	S	1	0.98	0.50	1.10	62.97	1.96	0.00	-3.00		7.80	
2/25/91	10:36		S	1	0.70	0.90	1.14	37.87	0.78	0.50	-1.00		8.60	
2/25/91	11:16	Y	S	1	0.90	0.40	0.98	66.04	2.25	0.00	-1.50		9.30	
2/25/91	11:57		N	1	0.51	0.43	0.67	49.86	1.19	3.00	-2.00		9.90	
2/25/91	12:36	Y	S	5	0.52	0.00	0.52	89.99	5200.00	0.00	3.00		10.00	
2/25/91	13:21		S	2	0.53	0.35	0.64	56.56	1.51	0.00	-1.50		10.30	

Date	Time	Ship	Dir.	# hit	V-Per.	V-Paral	V-Tot	Ap.Ang.	v-per	N(in.)	F(in.)	w(mph)	T(FT)	NOTES/ COMMENTS
					VELOCITY (FT/S)				v par	delta	delta			
		Position			NORTH & SOUTH					N	F	wind	tide	
2/25/91	14:03	Y	S	5	0.50	-0.30	0.58	59.04	-1.67	0.00	-0.50		9.90	
2/25/91	14:57		N	1	0.51	0.48	0.70	46.74	1.06	2.30	0.00		9.00	
2/25/91	15:39	Y	S	1	0.52	0.40	0.66	52.43	1.30	0.00	-2.10		8.20	
2/25/91	16:20		S	1	0.45	0.50	0.67	41.99	0.90	0.35	-1.00		6.70	
2/25/91	16:53	Y	S	1	0.50	0.15	0.52	73.30	3.33	0.00	-1.00		5.30	N-wall hit first
2/25/91	17:41		N	1	0.50	0.10	0.51	78.69	5.00	3.00	-1.00		4.40	
2/25/91	18:10	Y	S	1	0.51	0.50	0.71	45.57	1.02	0.00	-1.00		3.10	
2/25/91	18:59		N	1	0.05	0.10	0.11	26.57	0.50	1.00	0.00		2.00	gains movement)
2/25/91	19:37	Y	S	1	0.43	0.15	0.46	70.77	2.87	0.35			1.20	
2/25/91	20:28		S	1	0.50	0.10	0.51	78.69	5.00	0.00			-1.00	
2/25/91	21:09	Y	N	1	0.05	0.80	0.80	3.58	0.06	1.00			-0.70	
2/25/91	22:18	Y	N	5	0.85	0.31	0.90	69.96	2.74	1.00			1.30	
2/25/91	23:36	Y	N	9	0.35	0.35	0.49	45.00	1.00	-1.00	1.50		4.40	
2/26/91	5:31	Y	S	1	0.40	0.25	0.47	57.99	1.60				11.90	
2/26/91	6:14	T	S	1	0.60	0.35	0.69	59.74	1.71	0.00			10.00	
2/26/91	6:53	Y	N	1	0.42	0.15	0.45	70.35	2.80	2.00	-0.80		8.90	
2/26/91	7:33	T	S	1	0.15	0.47	0.49	17.70	0.32	0.45	-1.00		7.80	
2/26/91	8:14	Y	S	1	0.45	0.20	0.49	66.04	2.25	0.00	-1.00		7.10	
2/26/91	9:06	T	S	1	0.60	0.28	0.66	64.98	2.14	0.00	-1.50		6.50	
2/26/91	9:50	Y	N	1	0.50	0.35	0.61	55.01	1.43	2.00	-0.80		6.50	
2/26/91	10:33	T	N	6	0.25	0.40	0.47	32.01	0.63	0.00	1.00		6.90	
2/26/91	11:16	Y	S	1	0.48	0.35	0.59	53.90	1.37	0.10	-1.50		7.80	RPM -50 -> -20 =2 sec. after
2/26/91	11:55	T	S	1	0.41	0.38	0.56	47.17	1.08	0.15	-1.00		8.40	
2/26/91	12:35	Y	S	1	0.55	0.70	0.89	38.16	0.79	0.70	-3.00		9.20	
2/26/91	13:18	T	N	1	0.50	0.31	0.59	58.20	1.61	2.80	-1.00		10.00	
2/26/91	14:04	Y	N	1	0.70	0.27	0.75	68.91	2.59	3.50	-1.00		10.30	
2/26/91	14:47	T	S	1	0.55	0.50	0.74	47.73	1.10	0.10	-1.00		10.10	
2/26/91	15:35	Y	S	1	0.35	0.55	0.65	32.47	0.64	0.65	-1.00		9.20	
2/26/91	16:13	T	N	1	0.81	0.22	0.84	74.80	3.68	4.00	-1.50		8.10	
2/26/91	16:53	Y	N	1	0.53	0.25	0.59	64.75	2.12	3.50	-1.50		6.70	
2/26/91	17:36	T	S	1	0.45	0.61	0.76	36.42	0.74	0.87	-1.00		5.10	
2/26/91	18:12	Y	N	1	0.61	1.10	1.26	29.01	0.55	1.80	-0.50		3.90	
2/26/91	18:55	T	N	1	0.50	0.45	0.67	48.01	1.11	2.00			1.90	
2/26/91	19:37	Y	S	1	0.70	0.50	0.86	54.46	1.40	0.00			-0.71	
7/16/90	9:47	Y	N	2	0.65	0.25	0.70	68.96	2.60	9.60	-3.00		4.40	
7/16/90	10:34	H	N	1	0.45	0.05	0.45	83.66	9.00	8.40	-2.10		5.80	
7/16/90	11:14	Y	S	1	0.10	0.60	0.61	9.46	0.17	0.50	-2.00		6.80	North wall not in picture
7/16/90	11:56	H	N	2	0.40	0.50	0.64	38.66	0.80	7.80	-1.00		7.30	
7/16/90	12:32	Y	S	1	0.60	0.30	0.67	63.43	2.00	0.00	-4.00		8.10	
7/16/90	13:18	H	S	1	0.25	0.25	0.35	45.00	1.00	-0.10	-2.00		8.50	

Date	Time	Ship	Dir.	# hit	V-Per.	V-Paral	V-Tot	Ap.Ang.	v-per	N(in.)	F(in.)	w(mph)	T(FT)	NOTES/ COMMENTS	
						VELOCITY (FT/S)			v par	delta	delta				
			Position			NORTH & SOUTH				N	F	wind	tide		
7/16/90	14:01	Y	N	3	0.40	0.55	0.68	36.03	0.73	6.80	-2.00		8.30		
7/16/90	14:47	H	N	2	0.45	0.25	0.51	60.95	1.80	6.00	-3.00		8.10	All of N-wall not shown	
7/16/90	15:31	Y	S	1	0.45	0.35	0.57	52.13	1.29	0.00	-1.00		7.70		
7/16/90	16:13	H	S	3	0.42	0.33	0.53	51.84	1.27	0.10	-2.00		7.00	Rebound hit on N-wall, S-wall contact	
7/16/90	16:52	Y	S	1	0.30	0.35	0.46	40.60	0.86	0.00	-1.00		6.80		
7/16/90	17:35	H	N	2	0.40	0.51	0.65	38.11	0.78	3.20	0.00		6.50	All of N-wall not in picture	
9/19/90	12:05	H	S	3	0.47	0.33	0.57	54.93	1.42		-0.70		7.50		
9/19/90	13:39	H	S	2	0.85	0.25	0.89	73.61	3.40		-2.90		8.30		
9/19/90	15:17	H	S	1	1.00	0.20	1.02	78.69	5.00		-3.10		6.30		
9/19/90	16:58	H	S	1	0.90	0.00	0.90	89.99	9000.00		-2.90		3.30		
9/19/90	18:25	H	S	1	0.50	0.10	0.51	78.69	5.00		-2.50		1.00		

APPENDIX H

DATA SET OF 102 HIGH DEFLECTION EVENTS

					VELOCITY (FT/S)					DELTA	DELTA			
		Position						appr	V-per	N	F	wind	tide	
Date	Time	Ship	Dir.	# hit	V-Per.	V-Paral	V-Total	ang	V-Par	N(in.)	F(in.)	mph	ft	NOTES/ COMMENTS
7/20/90	6:54	Y	S	1	0.70	0.30	0.76	66.80	2.33	3.50	-1.50		2.60	
7/20/90	14:49	H	N	1	0.65	0.65	0.92	45.00	1.00	8.30	-5.20		8.10	
7/20/90	16:21	H	S	1	0.50	0.50	0.71	45.00	1.00	4.00	-2.50		8.80	
7/20/90	17:47	H	S	1	0.55	0.27	0.61	63.85	2.04	4.50	-3.50		11.70	
7/20/90	17:53	Y	S	1	0.51	0.28	0.58	61.23	1.82	3.70	-1.50		10.40	
7/20/90	21:47	H	N	2	0.45	0.75	0.87	30.96	0.60	7.00	-3.00		8.10	
7/20/90	22:22	Y	N	1	0.73	0.15	0.75	78.39	4.87	8.00	-2.50		7.70	
7/21/90	7:33	H	N	1	0.71	0.42	0.82	59.39	1.69	7.10	-3.00		3.50	34 Tot. landings looked at
7/21/90	16:13	H	N	1	0.54	0.50	0.74	47.20	1.08	7.00	-3.00		8.40	
7/21/90	16:53	Y	N	1	0.53	0.10	0.54	79.32	5.30	8.30	-3.00		10.70	
7/21/90	17:44	H	S	1	0.50	0.48	0.69	46.17	1.04	4.00	-2.50		11.80	
7/21/90	18:15	Y	N	1	0.70	0.50	0.86	54.46	1.40	7.50	-2.10		12.20	
7/22/90	14:57	H	N	1	0.50	0.20	0.54	68.20	2.50	7.00	-2.50		4.50	38 Tot. landings looked at
7/22/90	15:41	Y	S	1	0.62	0.00	0.62	89.99	6200.00	3.50	-1.50		5.90	
7/22/90	17:05	Y	S	1	0.53	0.20	0.57	69.33	2.65	3.50	-2.20		9.80	
7/22/90	17:52	H	S	1	0.55	0.05	0.55	84.81	11.00	4.00	-3.00		11.00	
7/22/90	18:27	Y	N	1	0.53	0.20	0.57	69.33	2.65	7.10	-2.00		12.30	
7/22/90	19:42	Y	N	1	0.55	0.40	0.68	53.97	1.38	7.10	-2.00		12.30	
7/22/90	20:57	Y	S	1	0.81	0.35	0.88	66.63	2.31	4.00	-3.00		11.80	
7/23/90	17:41	H	S	1	0.75	0.22	0.78	73.65	3.41	3.50	-3.00		9.50	
7/23/90	18:13	Y	S	1	0.57	0.35	0.67	58.45	1.63	4.00	-2.00		10.80	
7/23/90	20:57	Y	N	1	1.90	0.50	1.96	75.26	3.80	13.30	-6.50		11.50	
7/23/90	23:31	Y	N	1	0.76	0.60	0.97	51.71	1.27	8.50	-5.00		6.70	
7/24/90	7:32	H	N	5	1.00	0.30	1.04	73.30	3.33	4.00	8.00		8.90	
7/24/90	9:47	Y	N	1	0.71	0.73	1.02	44.20	0.97	8.00	-3.50		4.40	
7/24/90	16:55	Y	N	1	0.56	0.10	0.57	79.88	5.60	7.50	-3.50		6.90	
7/24/90	20:58	Y	N	1	0.95	0.80	1.24	49.90	1.19	10.50	-6.50		12.20	
7/24/90	20:58	Y	S	1	0.30	0.20	0.36	56.31	1.50	-6.00	-3.00		12.20	Rebound off N-wall "still in contact
7/25/90	10:31	H	N	1	0.50	0.50	0.71	45.00	1.00	9.00	-3.00		4.70	48 Tot landings looked at
7/25/90	17:36	H	S	1	0.78	0.55	0.95	54.81	1.42	4.00	-4.00		7.20	
7/25/90	18:54	H	S	1	0.76	0.10	0.77	82.50	7.60	4.90	-2.70		10.20	
7/25/90	23:33	Y	N	1	0.60	0.00	0.60	89.99	6000.00	7.00	-2.00		7.10	
7/26/90	6:12	H	S	1	0.75	0.27	0.80	70.20	2.78	3.50	-4.00		-	
7/26/90	18:14	Y	N	3	0.85	0.10	0.86	83.29	8.50	8.10	1.00		7.50	
7/26/90	20:56	Y	S	1	0.85	0.25	0.89	73.61	3.40	4.10	-2.00		11.60	
7/26/90	22:17	Y	N	1	1.20	0.51	1.30	66.97	2.35	9.60	-4.50		10.70	
7/26/90	23:35	Y	N	1	1.10	0.43	1.18	68.65	2.56	9.20	-4.00		8.70	
7/27/90	8:12	Y	S	1	0.45	0.13	0.47	73.89	3.46	-3.20	-2.00		7.50	In contact w/ N-wall during impact
7/27/90	12:35	Y	N	1	0.65	0.10	0.66	81.25	6.50	7.20	-2.80		5.50	36 Tot. landings looked at
7/27/90	19:40	Y	N	1	0.70	0.10	0.71	81.87	7.00	7.30	-4.00		9.50	
7/27/90	20:58	Y	S	1	0.95	0.30	1.00	72.47	3.17	4.50	-2.50		11.00	
7/28/90	18:17	Y	S	1	0.73	0.10	0.74	82.20	7.30	3.50	-1.50		6.20	

					VELOCITY (FT/S)					DELTA	DELTA			
			Position					appr	V-per	N	F	wind	tide	
Date	Time	Ship	Dir.	# hit	V-Per.	V-Paral	V-Total	ang	V-Par	N(in.)	F(in.)	mph	ft	NOTES/ COMMENTS
7/28/90	18:54	H	N	1	0.65	0.05	0.65	85.60	13.00	8.50	-3.00		7.50	
7/28/90	19:38	Y	S	1	0.90	0.25	0.93	74.48	3.60	4.00	-2.50		8.40	
7/28/90	20:22	H	N	3	0.55	0.55	0.78	45.00	1.00	7.50	-3.00		10.70	
7/29/90	10:32	H	S	1	0.70	0.05	0.70	85.91	14.00	3.30	-1.50		6.80	44 Tot. landings looked at
7/29/90	15:39	Y	N	1	0.57	0.45	0.73	51.71	1.27	8.50	-2.50		6.40	
7/30/90	15:34	Y	N	1	0.57	0.10	0.58	80.05	5.70	8.00	-3.00		6.40	
7/30/90	18:13	Y	N	1	0.31	0.65	0.72	25.50	0.48	8.00	-3.00		6.50	In contact w/ S-wall. Hit on reboun
7/30/90	20:23	H	S	1	0.85	0.58	1.03	55.69	1.47	4.20	-2.50		8.90	
7/30/90	20:59	Y	S	1	0.70	0.45	0.83	57.26	1.56	6.00	-3.00		9.90	N-wall hit dur S-wall contact
7/31/90	6:12	H	N	1	0.95	0.51	1.08	61.77	1.86	9.30	-4.00		1.10	31 Tot hits looked at
7/31/90	7:15	H	S	1	0.35	0.51	0.62	34.46	0.69	4.00	-2.00		0.90	
7/31/90	9:47	Y	N	1	0.75	0.00	0.75	89.99	7500.00	7.30	-3.00		2.60	
7/31/90	18:18	Y	N	4	0.58	0.00	0.58	89.99	5800.00	7.80	2.50		7.70	
7/31/90	18:56	H	N	1	0.95	0.10	0.96	83.99	9.50	9.10	-4.00		7.70	
7/31/90	19:38	Y	S	1	0.75	0.42	0.86	60.75	1.79	5.00	-3.00		7.90	
7/31/90	22:16	Y	S	1	0.68	0.50	0.84	53.67	1.36	4.00	-1.50		8.90	
8/1/90	11:58	H	N	1	0.52	0.00	0.52	89.99	5200.00	7.50	-3.00		4.90	
8/1/90	17:00	Y	S	1	0.65	0.50	0.82	52.43	1.30	3.50	-2.00		9.80	
8/1/90	20:56	Y	N	1	0.75	0.00	0.75	89.99	7500.00	8.50	-2.80		7.90	
8/1/90	22:18	Y	N	1	0.80	0.15	0.81	79.38	5.33	4.30	-3.50		8.10	
8/2/90	5:32	Y	N	1	0.55	0.00	0.55	89.99	5500.00	7.00	-2.00		4.00	36 Tot. landings looked at
8/2/90	11:53	H	N	1	0.85	0.45	0.96	62.10	1.89	8.10	-3.00		3.00	
8/14/90	10:35	H	N	1	0.95	0.55	1.10	59.93	1.73	10.80	-5.50		6.40	
8/14/90	12:37	Y	S	1	0.85	0.10	0.86	83.29	8.50	4.00	-3.00		8.80	
8/14/90	14:05	Y	N	1	0.80	0.50	0.94	57.99	1.60	10.00	-5.00		8.20	
8/14/90	20:56	Y	S	1	0.80	1.00	1.28	38.66	0.80	6.00	-3.00		10.00	
8/14/90	22:18	Y	S	1	1.10	0.40	1.17	70.02	2.75	4.80	-2.00		10.60	
8/15/90	19:36	Y	S	1	1.20	0.30	1.24	75.96	4.00	5.00	-4.00		8.10	36 Tot. landings looked at
10/8/90	18:14	Y	S	1	1.00	0.75	1.25	53.13	1.33	5.00	-4.00		5.20	48 Tot. landings looked at
10/9/90	8:12	Y	S	1	0.75	0.50	0.90	56.31	1.50	5.50	-3.50		7.80	
10/9/90	17:00	Y	S	1	0.51	0.00	0.51	89.99	5100.00	4.00	-1.50		7.90	
10/20/90	9:06	T	S	1	0.90	0.30	0.95	71.57	3.00	5.50	-1.50		3.10	
10/21/90	9:05	T	S	1	0.51	0.42	0.66	50.53	1.21	6.00	-3.00		2.70	
10/21/90	18:12	Y	S	1	0.63	0.00	0.63	89.99	6300.00	4.00	-1.00		3.50	
10/21/90	19:51	Y	S	1	0.95	0.10	0.96	83.99	9.50	5.00	-2.50		1.10	35 Tot. landings looked at
10/24/90	9:05	T	S	1	0.85	0.20	0.87	76.76	4.25	6.00	-2.50		3.30	20Tot. landings looked at
10/26/90	8:11	Y	S	1	0.55	0.21	0.59	69.10	2.62	4.10	-2.00		5.90	27 Tot. landings looked at
10/26/90	10:26	T	S	1	0.50	0.35	0.61	55.01	1.43	4.00	-2.50		4.30	
10/28/90	12:15	Y	S	1	0.70	0.50	0.86	54.46	1.40	4.50	-2.00		3.80	
10/30/90	10:46	Y	S	1	0.80	0.50	0.94	57.99	1.60	4.50	-2.00		7.80	33 Tot. landings looked at
10/30/90	12:55	T	S	1	0.90	0.50	1.03	60.95	1.80	5.00	-2.00		3.50	
10/30/90	14:59	T	S	1	0.90	0.55	1.05	58.57	1.64	6.00	-4.00		3.00	

					VELOCITY (FT/S)					DELTA	DELTA			
			Position					appr	V-per	N	F	wind	tide	
Date	Time	Ship	Dir.	# hit	V-Per.	V-Paral	V-Total	ang	V-Par	N(in.)	F(in.)	mph	ft	NOTES/ COMMENTS
10/30/90	16:32	Y	S	1	1.00	0.20	1.02	78.69	5.00	5.00	-1.50		2.00	
10/31/90	13:30	Y	S	1	0.75	0.60	0.96	51.34	1.25	5.50	-2.00		4.00	31 Tot. landings looked at
11/4/90	15:02	Y	S	1	0.95	0.20	0.97	78.11	4.75	5.00	-3.50		7.00	25 Tot. landings looked at
11/9/90	8:14	Y	S	1	0.75	0.45	0.87	59.04	1.67	5.00	-1.00		4.00	9 Tot. hits looked at
11/9/90	9:08	T	S	1	1.00	0.50	1.12	63.43	2.00	6.00	-1.50		4.50	Then tape went blank
11/9/90	10:37	Y	S	1	0.75	0.50	0.90	56.31	1.50	5.50	-3.00		3.20	
11/17/90	9:47	T	S	2	0.60	0.00	0.60	89.99	6000.00	4.00	-1.00		7.50	32 Tot. hits looked at
12/1/90	15:32	Y	S	1	1.00	0.45	1.10	65.77	2.22	4.00	-2.00		1.10	10 Tot. landings looked at
12/3/90	14:04	Y	S	1	0.70	0.40	0.81	60.26	1.75	4.00	-1.00		8.50	12/2 - 12/3
12/3/90	14:51	T	S	1	0.90	0.20	0.92	77.47	4.50	4.00	-1.00		6.80	11 Tot. landings looked at
12/11/90	12:32	Y	N	1	1.10	0.15	1.11	82.23	7.33	5.00	-2.00		2.30	10 Tot. landings looked at
12/14/90	5:34	Y	S	1	0.65	0.00	0.65	89.99	6500.00	5.00	-1.00		4.30	25 Tot. hits looked at
12/14/90	6:53	Y	S	1	0.65	0.50	0.82	52.43	1.30	5.00	0.00		6.30	
12/15/90	14:02	Y	N	1	0.90	0.20	0.92	77.47	4.50	5.00	-2.00		4.40	
1/25/91	13:20	Y	N	1	1.00	0.30	1.04	73.30	3.33	6.00	-2.00		10.30	Video back not working at end
1/25/91	14:04	Y	S	1	1.00	0.50	1.12	63.43	2.00	3.50	-2.00		7.70	
1/27/91	13:19	T	N	1	1.40	0.25	1.42	79.88	5.60	7.50	-3.00		11.20	
2/18/91	16:53	Y	N	8	0.91	0.48	1.03	62.19	1.90		4.50		9.80	
2/19/91	13:21	T	N	9	1.20	0.20	1.22	80.54	6.00	-6.00	7.00			