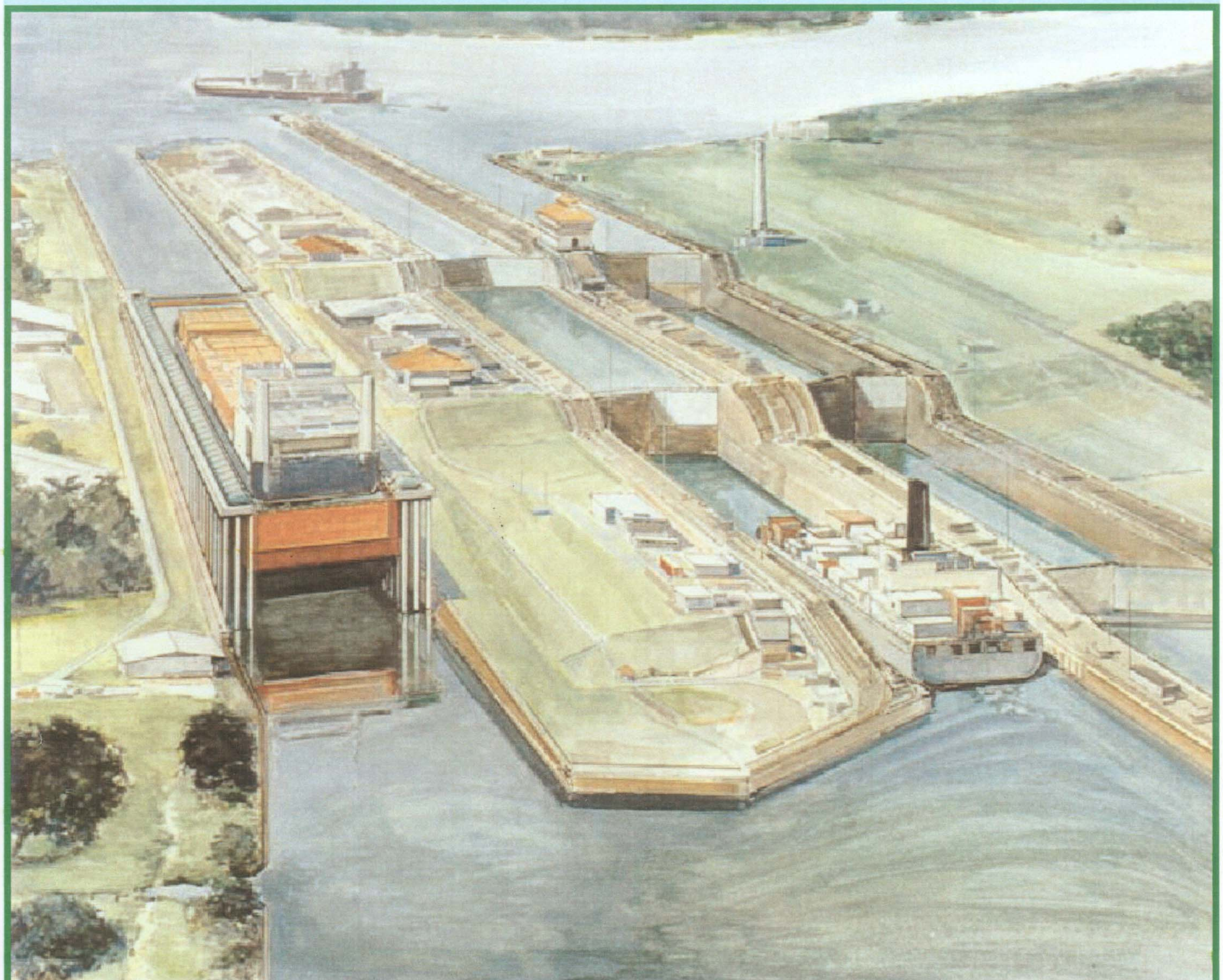


TDA Syncrolift® Study Progress Report

Phase I Results

February 2000

Executive Summary

Introduction

In March 1999 Syncrolift, Inc. began a $1.2M study to assess the feasibility of using Syncrolift shiplift technology to design a chamber-type shiplift that could be used to provide additional capacity in the Panama Canal. The lift would be designed to efficiently handle the smaller vessels, which use the same amount of water as large vessels – but pay far lower fees. This report covers the Phase I study results including: system design parameters, chamber sizing and selection, system performance analysis, hydrodynamic testing, wire rope testing, and saltwater mitigation measures.

Proposed Dimensions

The system principal dimensions are:

	Maximum Size Vessel	Chamber Interior	Chamber Gate Sections
Length (m)	192.0	198.1	242.0 (overall)
Beam (m)	25.3	26.5	28.3
Draft (m)	9.3	10.1	12.6

Projected Throughput

Based on data provided by the PCC for the years 1995 – 1998, the proposed system would be capable of servicing 49.2% of the vessels transiting the Canal while saving 70% of the water compared to the existing locks. Annual transits which could have been accommodated by such a lift ranged from 6,600 (47.0% - 1998) to 7,700 (51.7% - 1995). In order to maintain the PCC target Canal Waters Time (CWT) of 18-20 hours for smaller vessels, a practical limit for the system would be approximately 7,000 transits per year (47.0%).

Hydrodynamic Testing

Results from the hydrodynamic model tests conducted at the University of Michigan were in agreement with the full-scale measurements taken by the US Army Corp of Engineers in April-1999. Vessels entering at reasonable speeds are expected to generate a temporary 0.60 – 0.90m rise in water level (surcharge) at the closed end of the chamber as the entering vessel restricts the area for exiting water. The same phenomenon occurs as the vessel exits the chamber – the exiting vessel restricts the area for entering water, causing a temporary decrease in the chamber water level (drawdown). For the structural design of the chamber, both the surcharge and the drawdown can easily be accommodated within the design process. Phase II of the study will analyze the dynamic effects of vertical and horizontal accelerations on the chamber and the implications for the structural design.

Wire Rope Performance

Wire rope performance has been one of the primary design considerations since proposing a Syncrolift type chamber-lift for the Panama Canal. To resolve this issue, Syncrolift is working with Bridon, International to determine the fatigue performance of wire rope under these conditions by conducting full-scale rope tests. Bridon is using a specially designed rope that includes a plastic compound integrated into the rope during the manufacturing process. The plastic keeps the strands from fretting against one another as the rope is worked, and provides a better rope topography to reduce contact stresses and wear at the sheave groove. The result is a rope whose fatigue performance is outperforming traditional all-wire rope construction by a factor of five for smaller diameter ropes. While the results are extremely favorable, the length of time required for testing has also extended the overall program. Testing will continue with larger diameter ropes to confirm existing fatigue performance projections.

Saltwater Mitigation

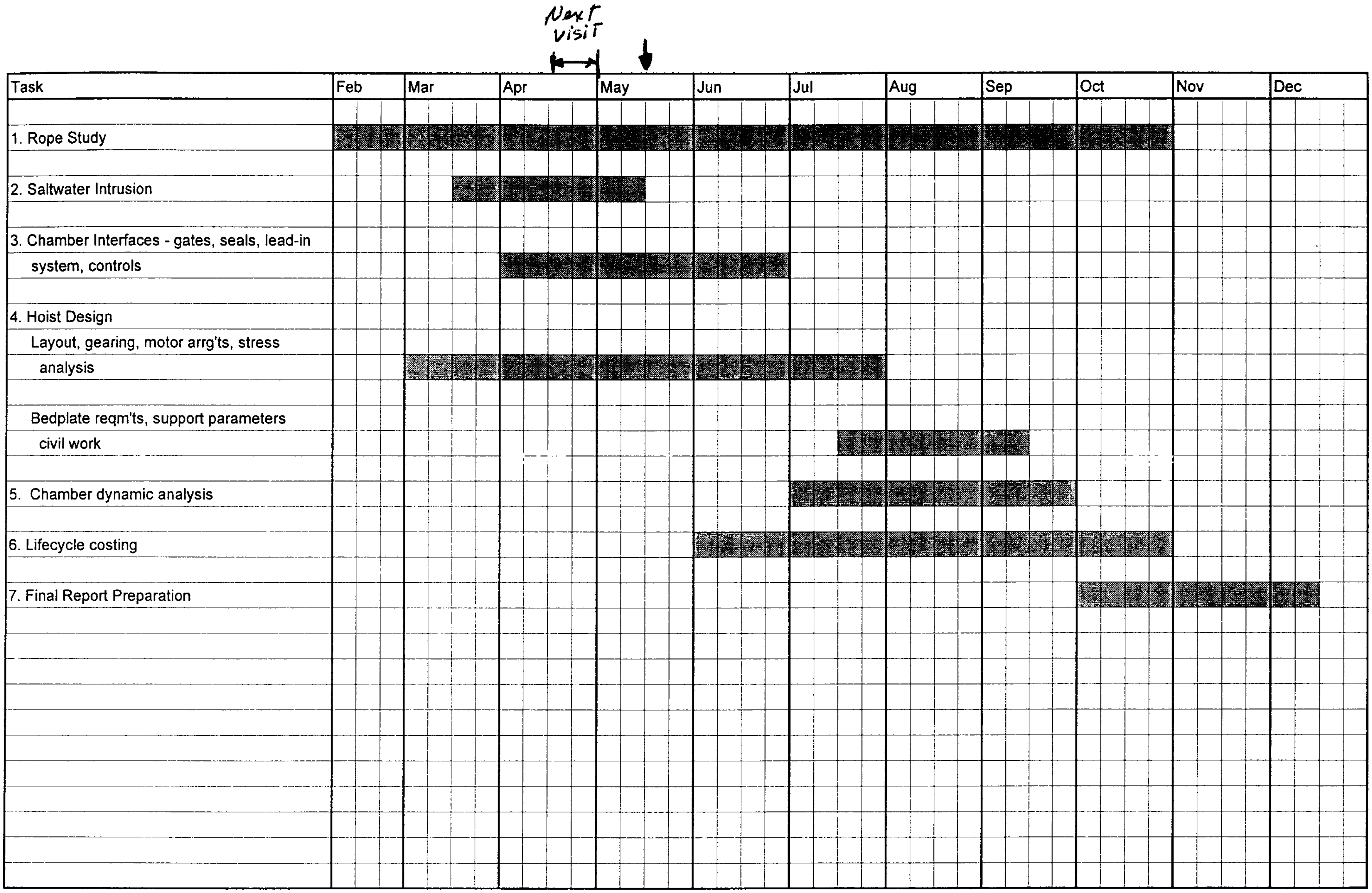
Another area of concern about adding Canal capacity is its effect on the salinity levels in Lake Gatun, which is the primary source of drinking water for most of Panama. A study by the US Army Corps of Engineers Waterways Experiments Station (WES) determined that a Syncrolift system, unmitigated, would raise the salinity of Lake Gatun beyond the allowable standards for drinking water within 5-7 years from the start of operations. To mitigate this unacceptable situation, a saltwater exchange system has been incorporated that will drain saltwater from the bottom of the chamber through ports located in the gate recesses, while freshwater flows in through entrance ports, or a partially opened gate, at the top. The saltwater would be removed without any intrusion into Lake Gatun or Gaillard Cut. Although some freshwater will be used during regular operations, the system still offers a 70% freshwater savings compared to the existing locks. The saltwater exchange system will be numerically modeled and validated during Phase II of the study.

Way Forward

Phase II of the study will continue through 2000, building on the results of Phase I with continued analysis of the chamber, including the gates and saltwater mitigation system, plus the preliminary design of the hoist. Syncrolift will also provide life-cycle cost estimates and work with a PCC-selected third party to review the civil foundation requirements and design. All work is expected to be complete by the end of 2000.

TDA-Syncrolift Study

Phase II Schedule



TDA SYNCROLIFT STUDY – PROGRESS REPORT
Phase I Results

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TDA SYNCROLIFT STUDY – PROGRESS REPORT
Phase I Results

General

Syncrolift Inc. was contracted in March 1999 to perform a $1.2M feasibility study examining the technical, operational, financial, and other critical aspects involving the use of a Syncrolift® type chamber-lift to provide additional capacity for small and medium size vessels transiting the Panama Canal.

The study is divided into two phases and will take approximately 2 years to complete. Phase I results are described below.

Goals and Objectives – Phase I

- Determine how many vessels could transit the Canal using a Syncrolift type chamber-lift designed within the limits of existing technology, although not necessarily within the limits of existing installations and equipment.

- Quantify vessel transit capacities (throughput), cycle times, and system performance for the proposed preliminary design.

- Conduct model tests to quantify the hydrodynamic forces and pressures exerted on the chamber during vessel entering and exiting operations, and reconcile the test results against field measurements obtained by the PCC.

- Conduct full-scale wire rope tests to establish reliable data for predicting fatigue performance.

- Describe features incorporated into the system to minimize saltwater intrusion into Lake Gatun. Address relevant issues and findings from PCC saltwater intrusion study conducted by the Waterways Experiments Station (WES) in Vicksburg, MS.

Data Collection and Analysis

The PCC provided historical transit data for fiscal years 1995 – 1998, with each year represented by the period from October 1 – September 30. The original data set did not include vessels under 300t for the years 1995 – 1997, which were appended via a later data supplement. Because the two data sets were drawn from different sources and the records did not include any unique identifiers for vessel transits or lockages, there was some duplication of records between the two data sets. Duplicates were removed by eliminating records for vessels with the same transit date, name, and vessel characteristics. It should also be noted that the data provided was a transit history and not a lockage history. There were no fields within the database allowing vessels from tandem lockages to be identified and grouped together. A breakdown of the database by vessel type is shown below.

Panama Canal Vessel Transits by Ship Type
1995 - 1998

Vessel Type	95	96	97	98	Total
Dry-bulk carrier	3,753	3,868	3,503	3,501	14,625
Refrigerated Cargo	2,580	2,505	2,449	2,074	9,608
Tanker	1,866	2,082	2,016	1,957	7,921
Full container ship	1,312	1,392	1,379	1,643	5,726
General Cargo	1,523	1,455	1,380	1,338	5,696
Yatch	873	875	901	765	3,414
Vehicle carrier	624	563	519	545	2,251
Fishing Vessel	375	423	424	425	1,647
Container/break-bulk ship	358	325	387	360	1,430
Passenger Ship	311	273	290	316	1,190
Roll-on/Roll-off	252	222	179	182	835
Liquid-gas carrier	236	181	188	191	796
Tug	149	176	198	194	717
Warship (displacement)	184	140	152	99	575
Other PC NET	96	73	104	134	407
Vehicle/Dry-bulk carrier	122	98	67	61	348
Barge, not self-propelled	88	64	65	79	296
Dry/liquid bulk carrier	37	46	57	33	173
Research vessel	36	45	31	43	155
Tank barge, not self-propelled	7	11	47	19	84
Supply ship	27	12	19	16	74
Factory ship	20	10	9	7	46
Dredge	8	12	10	15	45
Cable ship	3	6	3	10	22
Other displacement	2	5	3	5	15
Tank barge integrated	0	0	3	8	11
Barge carrier	1	2	2	3	8
Barge, self-propelled	0	0	5	3	8
Barge integrated	0	0	1	6	7
Tank barge, self-propelled	0	3	2	0	5
Totals	14,843	14,867	14,393	14,032	58,135

Design Parameters

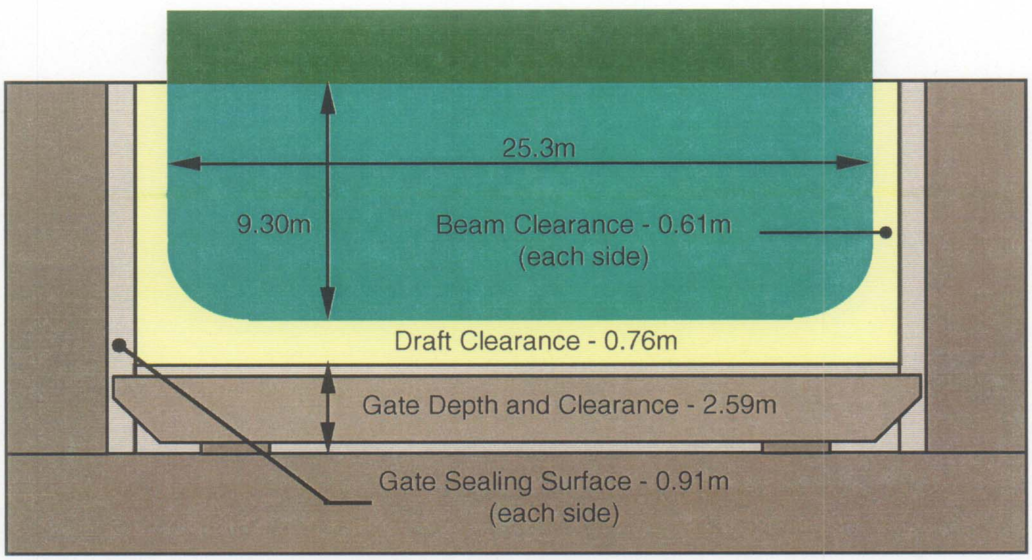
Principal design parameters and their selection methodology are listed below:

1. _Lift height_ – the only fixed parameter within the study, a maximum lift height of 29.4m was used for hoist design based on the total range of tides and lake elevations provided by the PCC. For the throughput analysis an average lift height

of 25.9m was used representing the average elevation of Lake Gatun above sea level.

2. *Lift rate* – 0.91m per minute reflects the average lift/lower rates for daily operations in the Canal. This parameter directly affects the power requirements for the motors used to operate the system.

3. *Unit Lift, tons per meter (tpm)* – The most critical element within the design, once the tpm is determined, all other parameters are adjusted to meet this constraint. The tpm is calculated by summing the saltwater volume, structure, and miscellaneous items for a standard unit length of structure. Because the ships will remain afloat, vessel size does not affect the calculation. The maximum tpm will be in the chamber ends, where there is additional depth for the gates to recess out of the way during operations, and additional beam for the gate sealing surfaces. Through an iterative process focusing primarily on hoist parameters (see item 4), a limit of 480 tpm has been calculated for the design based on the following factors:



Note: Diagram not to scale

a. *Maximum vessel size* – length – 192.0m, beam – 25.3m, draft – 9.30m, maximum vessel size was determined by analysis of the PCC transit database to select the principal vessel characteristics that would maximize system throughput. Selection methodology is described below in Chamber Sizing and Selection. (note: length is not critical because the chamber can be built to any length without affecting engineering feasibility).

b. *Vessel beam and draft clearance* – beam clearance – 0.61m on either side, draft clearance – 0.76m. Clearances based on existing limits used during Canal operations, selection methodology described below.

c. *Gate depth (thickness), sealing surfaces and clearances* – based on existing designs for flap gates of similar proportions, gate depth – 2.29m, sealing surfaces – 0.91m each side and bottom, bottom clearance 0.30m.

d. *Structural weight allowance* – 25% of the water weight, derived from previous estimates to satisfy bending, shear, and deflection requirements; confirmed through preliminary FEA modeling of chamber structure.

e. *Saltwater density allowance* – Factor of 1.0256 included in tpm calculation to account for saltwater environment.

f. *Lead-in system / miscellaneous allowance* – 20 tpm included for lead-in system and other miscellaneous items that may need to be placed on the chamber, based on previous Syncrolift lead-in installations for Panamax size vessels.

4. *Hoist Parameters* – Based on the 480 tpm lift, preliminary hoist calculations were performed to ensure that basic hoist design parameters would not exceed existing technology. The figures provided are preliminary, and subject to change as a result of the preliminary hoist design that will be done during Phase II of the feasibility study. The following factors were considered:

a. *Hoist drum diameter* – 3.75m – No special equipment or manufacturing processes required to turn drums to standard Syncrolift specifications.

b. *Torque at the drum* – 1.30 million lb-ft – Within existing gear capacities for hoist manufacturers.

c. *Motor hp requirements* – 125 hp – Within existing technology for AC synchronous motors.

d. *Other hoist parameters* :

i. *Wire rope diameter* – 76mm – Based on wire rope manufacturer specifications

ii. *Reeving system* – The hoist reeving is a six part system that includes three sheaves mounted on the chamber, and two sheaves mounted in a bedplate grouted to the pier. The reeving system determines how many bends the rope will perform during each lift/lower cycle, thereby directly affecting wire rope fatigue life.

iii. *Design factor (factor of safety)* – 5 – Same as other industrial equipment where movement of personnel is allowed.

Chamber Sizing and Selection

Based on the unit lift parameters described above, a program was created in Excel to analyze the PCC transit database and select the vessel principal characteristics (length, beam, and draft) that would maximize system throughput. For a matrix of beams and drafts, the program calculated the total transits, revenue, and tpm for every beam-draft combination. Within the beam-draft matrix, beam was incremented 0.15m for each case, and draft was incremented 0.076m. The optimum beam-draft configuration was calculated for 480 tpm with a chamber of unlimited length. The appropriate length was determined (192.0m) so that the highest percentage of vessels would be included without excessive chamber length.

Although the model specifies an optimum configuration, the recommendation is only an optimum for the data set that created it – looking at different time periods, or altering vessel beam and draft clearances yields a different optimum configuration (although the differences may be slight). As a stand alone business case, it should also be noted that the model was optimized for maximum throughput which may not yield the maximum revenue.

Model inputs, outputs, and sample results are shown below for a fixed vessel length of 192.0m.

Input Variables	Outputs (calculated for every beam-draft combination)
1. Vessel matrix range of beams and drafts 2. Vessel beam clearance (1.22m – total) 3. Vessel draft clearance (0.76m) 4. Structural weight allowance (25%)	1. Vessel beam and draft 2. Number of transits (as % of total) 3. Revenue ($ million) 4. Tons per meter (tpm)

Sample Results:

Inclusion %	Revenue ($ M)	Vessel Data		Tons per Meter
		Beam (m)	Draft (m)	
49.2%	341.4	25.3	9.3	479.9
49.1%	340.8	25.5	9.2	479.4
48.9%	347.3	25.6	9.1	479.0
48.9%	346.1	26.2	8.9	480.2

48.9%	340.1	26.1	8.9	477.8
48.8%	335.2	25.8	9.1	478.6
48.7%	345.1	25.3	9.2	476.9

The limiting beam and draft clearances play an important role in determining system throughput, and calculating the tpm. During the course of the analysis three cases were considered for vessel beam and draft limiting clearances:

I. Largest clearance – PCC recommended
Beam clearance – 1.52m either side Draft clearance – 1.52m

II. Medium clearance – Syncrolift suggested
Beam clearance – 0.91m either side Draft clearance – 1.52m

III. Least clearance – Current Canal operations
Beam clearance – 0.61m Draft clearance – 0.76m

The beam and draft clearances affect two areas:

1) the length of time required for vessels to maneuver because smaller clearances require slower vessel speeds to avoid squat and grounding

2) the pressures exerted on the chamber during maneuvering because the area available for water to enter or exit the chamber affects the water level within the chamber, and hence pressures on the structure

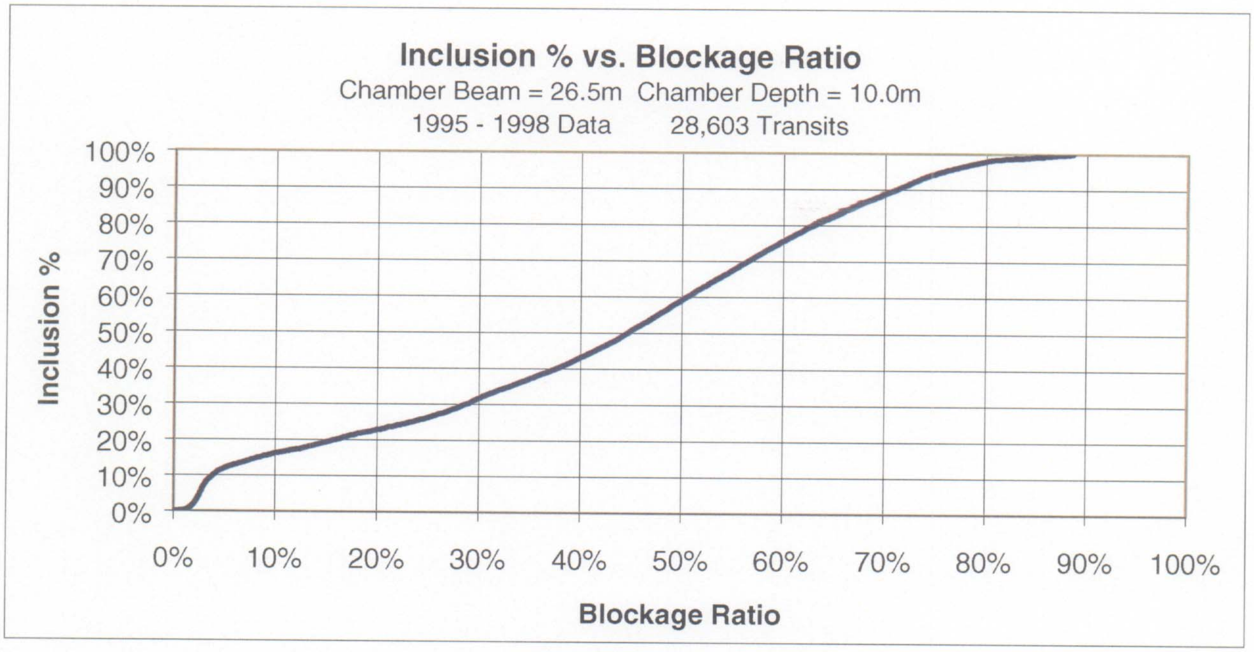
The issue of limiting clearances was analyzed using a quantifiable factor called the blockage ratio:

blockage ratio = (ship beam x ship draft) / (chamber beam x chamber draft)

For a chamber beam = 26.5m, and a chamber water depth = 10.0m the three clearance cases described above had the following blockage ratios:

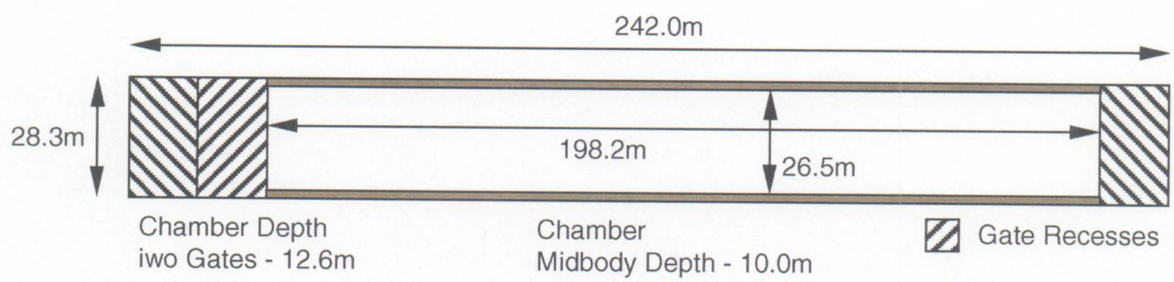
I. 75% II. 79% III. 88%

Because fewer than 0.5% of the transits (see graph below) would have the maximum blockage ratio of 88%, and the results of the model testing demonstrated that even the largest vessels would be able to enter and exit at reasonable speeds, the decision was made to use Case III (clearances for current Canal operations) as the allowable vessel clearances which yields a maximum inclusion of 49.2%. This percentage means that for the years 1995-1998, the Syncrolift system is sized to accommodate 49.2% of all vessels that went through the Panama Canal.

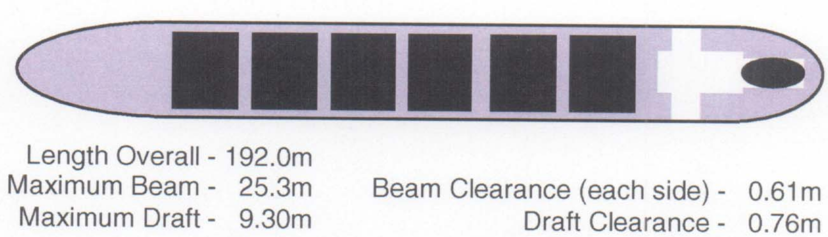


Based on the discussion above, the system parameters and yearly transits by ship type are summarized below.

Chamber Dimensions



Max Vessel Dimensions



Syncrolift Vessel Transits by Ship Type
1995 - 1998

Vessel Type	95	96	97	98	Total
Refrigerated Cargo	2,550	2,478	2,413	2,047	9,488
General Cargo	1,212	1,097	1,042	1,044	4,395
Yatch	873	875	901	765	3,414
Tanker	627	620	621	631	2,499
Dry-bulk carrier	639	562	551	499	2,251
Fishing Vessel	375	423	424	425	1,647
Full container ship	262	206	130	183	781
Tug	145	173	188	184	690
Warship (displacement)	166	125	138	89	518
Container/break-bulk ship	146	121	137	97	501
Passenger Ship	130	118	98	146	492
Liquid-gas carrier	122	83	94	118	417
Other PC NET	81	59	97	119	356
Roll-on/Roll-off	131	93	69	62	355
Barge, not self-propelled	65	50	56	59	230
Research vessel	36	45	31	43	155
Vehicle carrier	43	27	8	2	80
Supply ship	27	12	19	16	74
Tank barge, not self-propelled	1	8	42	13	64
Vehicle/Dry-bulk carrier	17	11	15	12	55
Factory ship	20	10	9	7	46
Dredge	8	12	9	15	44
Cable ship	3	6	3	10	22
Other displacement	2	5	3	5	15
Barge, self-propelled	0	0	5	3	8
Tank barge, self-propelled	0	2	2	0	4
Barge integrated	0	0	0	2	2
Dry/liquid bulk carrier	0	0	0	0	0
Barge carrier	0	0	0	0	0
Tank barge integrated	0	0	0	0	0
Totals	7,681	7,221	7,105	6,596	28,603
% of Annual Transits	51.7%	48.6%	49.4%	47.0%	49.2%

System Performance

System Performance Analysis

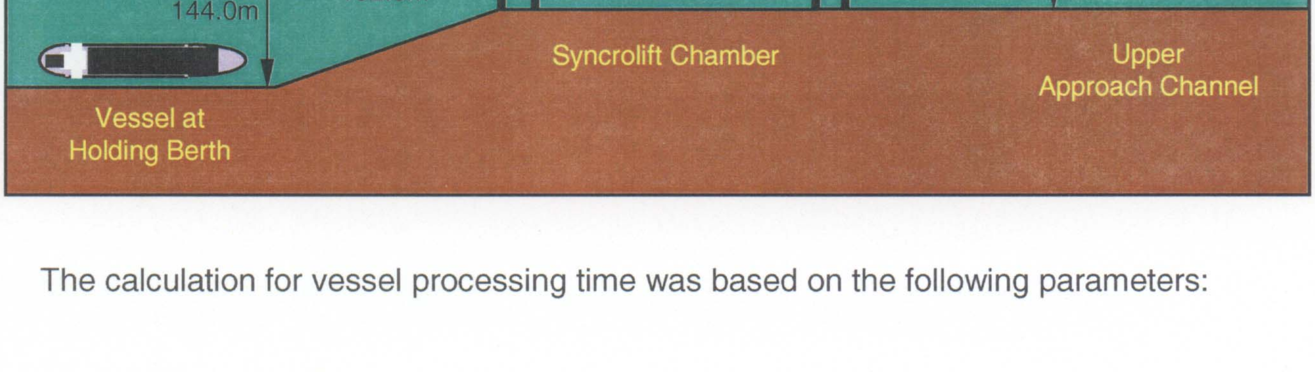
To evaluate the Syncrolift system performance, a comprehensive computer model was designed to simulate the operation of a complete transit lane using one Syncrolift chamber type lift at each end. The model results were calculated for each year using real ship data extracted from the PCC transit database.

The model is divided into two modules. The first module uses the vessel's principal characteristics and the Syncrolift's operational parameters to calculate a processing time for each vessel. The processing time starts with the vessel maneuvering from a holding berth and ends with vessel departure, including full exit and clearance from the Syncrolift so the next vessel can enter the chamber. An allowance for saltwater mitigation measures is calculated as part of the processing time during the lift phase. No saltwater mitigation measures are required for vessels being lowered to the sea. The second module uses the processing time, along with other inputs including: transit direction, arrival time, random system outages, and semi-planned outages, to simulate operation of the Syncrolift system. The second module produces a performance record for each vessel showing vessel wait time and Canal Waters Time (CWT) – the time required to pass through the whole system; two Syncrolifts, Gaillard Cut and across Lake Gatun. The second module also produces system performance results including: system utilization, system wait time, empty moves required, tandem moves performed, maximum service and wait times, freshwater saved versus lockage operations, and annual average CWT. For the smaller vessels targeted to use the Syncrolift system, the PCC promotes a CWT time of 18-20 hours. The results can also be compiled by month to assess system performance throughout the year.

The modules and their specific inputs are described in more detail below.

MODULE I – VESSEL PROCESSING TIME

The configuration used for calculating the vessel processing is shown below.



The calculation for vessel processing time was based on the following parameters:

1. *Syncrolift System Channel Layouts* – Because the actual sites and layouts have not been selected, simple channel layouts were assumed to provide a baseline for the calculations. Revised lengths and widths can be easily incorporated into the program and new results calculated.

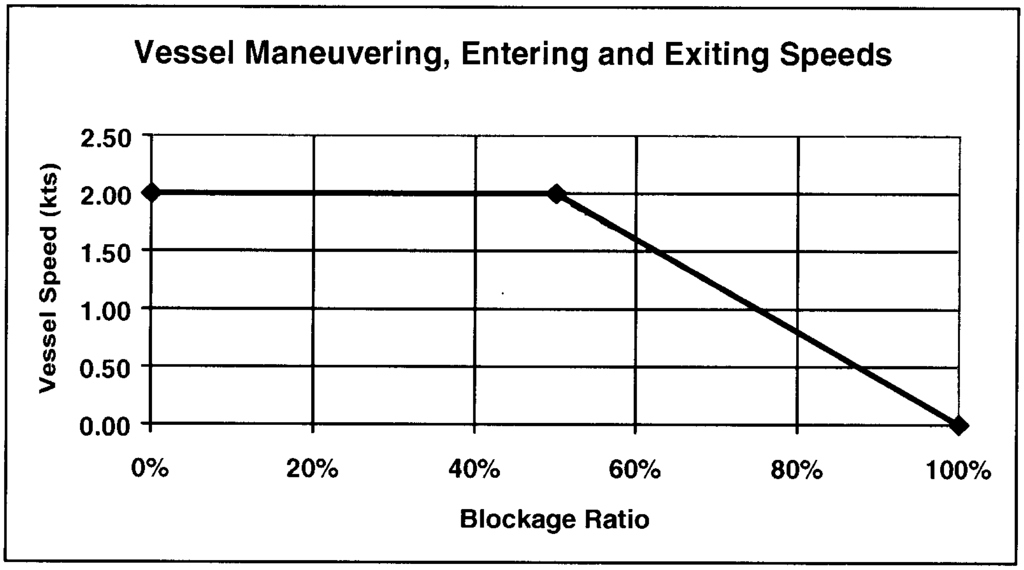
   a) *Approach Channel Length* – 192.0m, it was assumed that the holding berths for the vessels would be located one ship length (maximum size vessel) from the entrance of the chamber so vessels could maneuver into the center of the channel and enter the Syncrolift.

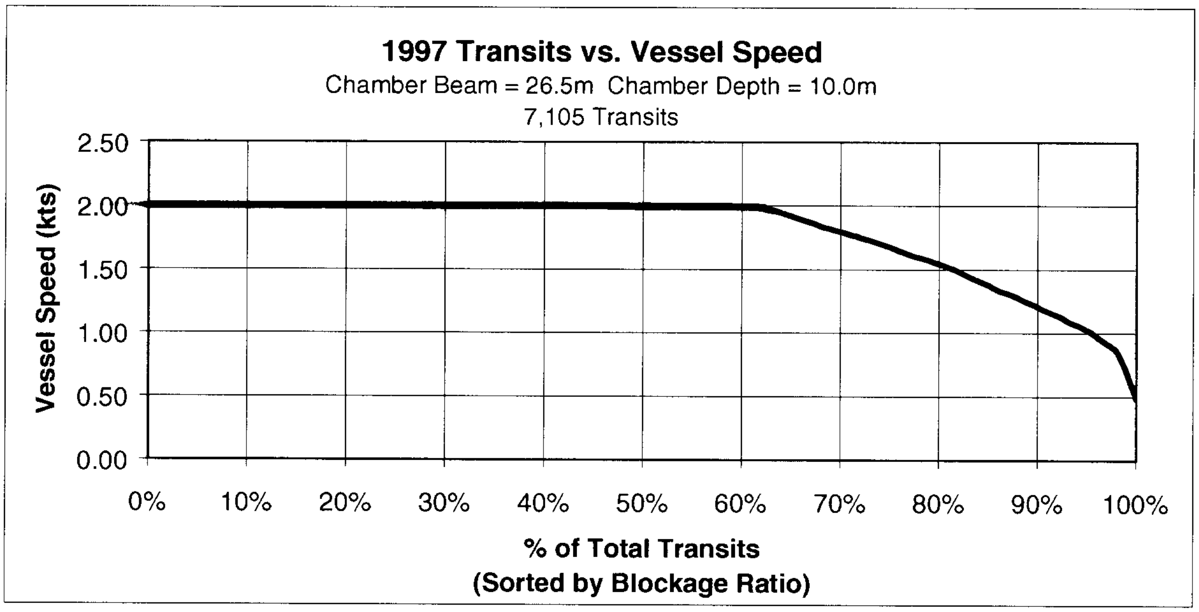
   b) *Approach Channel Width* – 144.0m, the channel was sized to allow operations with two maximum size vessels, one at the holding berth and one exiting the chamber. The width was calculated based on PCC requirements for 2.8 times the maximum beam plus 73.1m to allow for the slope of the channel banks.

2. *Gate Operations* – Based on existing literature and designs, gates of similar size and proportion require approximately 5 minutes to open. For the purposes of the model, this was translated into a linear speed of 6.7cm/s. The length of time to open the gate is then calculated based on the gate geometry rotated through 90 degrees. To account for the fact that the gates will not be opened strictly in series or in parallel, a factor of 1.5 was used to allow the first gate to open half-way, at which time the second gate would start to open or close. Therefore the time allowed to open and close the two gates (at either the top or the bottom) is approximately 7.5 minutes.

3. *Maneuvering, Entering and Exiting Speeds* – The vessel's operational speed in the system can be affected by many factors including: vessel size and power, wind, weather, pilot experience, etc. Rather than trying to account for the myriad variables that affect vessel speed, a simple algorithm was used based on the blockage ratio. The maximum speed used for any vessel was two knots up to a 50% blockage ratio. At a 50% blockage ratio, the vessel entrance area equals the water exit area so water is allowed to flow freely without buildup inside the chamber. At blockage ratios higher than 50%, water flow becomes restricted and additional vessel power is required to move at the same speed. So for blockage ratios of 50% - 100% a linear decrease of vessel speed to zero is assumed. The graph used for calculating vessel speed and an example graph showing the speeds used for 1997 are shown below. As can be seen from the 1997 graph, over 60% of the vessels are traveling at the maximum speed – 2 knots, while less than 5% of the vessels are moving at speeds less than 1 knot. The vessels with the maximum blockage ratio – 88% are operating at 0.48 knot.

   When compared to actual vessel speeds as measured by the U.S. Army Corps of Engineers, Pittsburgh District, the proposed method produces comparable, even conservative, results for use in the model. The speeds measured by the Corps ranged from 0.67 knots to 2.75 knots across the sill for vessels entering the locks, and 0.55 knots to 2.76 knots across the sill for vessels exiting the locks.





After the vessel maneuvering, entering, and exiting speed has been determined, the time required for each operation is calculated by multiplying the distance traveled by the speed. The following definitions were used for vessel operations:

Maneuver – Move laterally from the holding berth into the center of the channel (½ channel width – 72.0m), and move forward to chamber entrance, 192.0m.

Enter – Move forward from chamber entrance until the stern has cleared both downstream gates plus ½ clearance length (3.0m) into the chamber.

Exit – Move ½ clearance length (3.0m), then over the two upstream gates and down the approach channel (192.0m) until the stern is clear of the vessel holding berth.

4. *Lift and Lower Times* – As stated in the Design Parameters section, a lift speed comparable to the existing locks of 0.91m/min was used over a distance of 25.9m resulting in a lift or lower time of 28 minutes.

5. *Sealing Operations at the Upper Pool* – When the chamber reaches the upper pool it will have to seal against the dam face. The space between the chamber and the channel will have to be flooded before the gates can be opened, and it will have to be emptied and the seal released before the chamber can be lowered. Five minutes has been allowed in each lift and lower cycle to accomplish this task. For the lift cycle the steps would include sealing, filling the void space, and equalizing the water levels. For the lower cycle it would include draining the void space and disengaging the seal. Because there are no vessels to contend with in the void space, turbulence created by rapid filling and emptying is inconsequential.

6. *Saltwater Mitigation Measures* – As a result of the saltwater intrusion study done by the Waterways Experiments Station (WES) in Vicksburg, MS, it was deemed necessary to incorporate saltwater mitigation measure into the Syncrolift operations to avoid raising the salinity levels in Lake Gatun. The method selected for saltwater mitigation is to exchange the saltwater with freshwater by draining saltwater from the bottom of the chamber while filling with freshwater at the top. The drains will be located at points to be determined in the gate recesses at the chamber ends. They will be sized for a discharge rate of approximately 56.6m^3 per second. For the purpose of the model, 8 ports with a discharge area of 4.41m^2 discharging 60.5m^3 per second were used. The discharge rate is not important provided the inflow of freshwater does not exceed a rate 0f 1.83 m/s (3.6 knots) – a preliminary recommendation made by WES to be validated through testing.

   For the freshwater exchange a water entrance area of 40.41m^2 is used. This entrance area can be provided by designing sluice gates into the top of the upstream chamber flap gate, or by opening the upstream chamber gate until the upper edge is 1.5m below the water surface. This arrangement produces a freshwater inflow velocity of 1.49m/s (almost 20% below the WES recommendation), and an average exchange time of 14.1 minutes.

   The saltwater exchange time is determined for each vessel by the following equation:

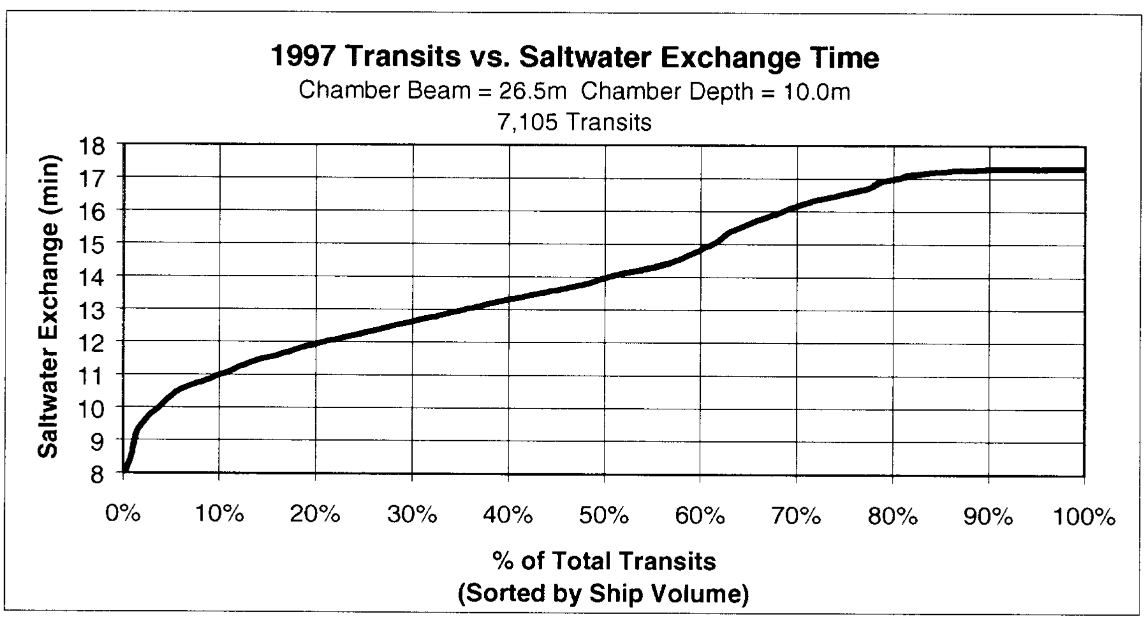
   saltwater exchange time = (chamber volume – ship volume) / drainage rate

   For the current design, the chamber volume is 62,774 m^3 – this figure excludes the volume between the two downstream chamber gates which do not open during operations at the upper pool. The ship volume is calculated by multiplying length, beam and draft by the block coefficient according to vessel type. The block coefficients were drawn from naval architecture industry publications. A table of the block coefficients used is shown below.

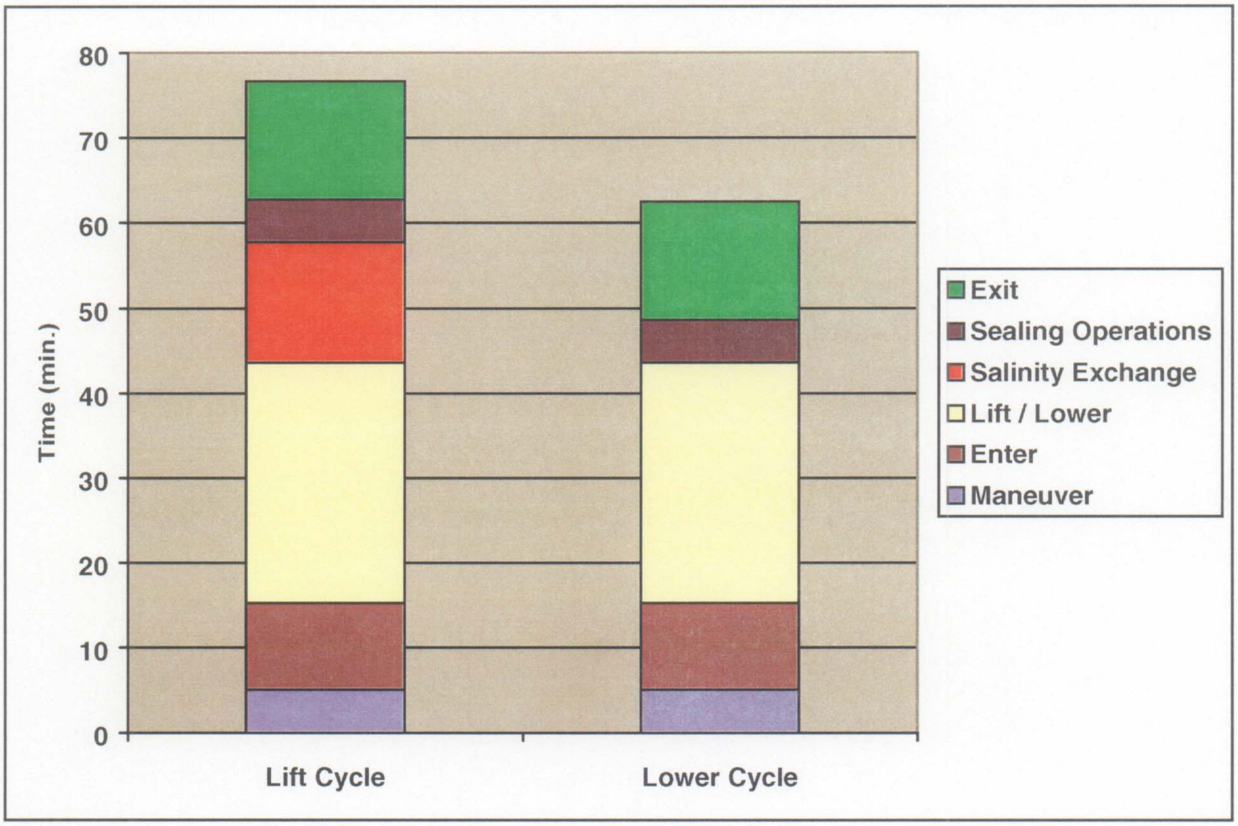
Block Coefficients Used to Calculate Ship Volume

Vessel Type	Cb	Vessel Type	Cb
Dry-Bulk Carrier	0.84	Roll-on/Roll-off	0.75
Tanker	0.84	Container/Breakbulk Ship	0.70
Barge Integrated	0.80	Liquid-gas Carrier	0.70
Barge, not self-propelled	0.80	Other Displacement	0.70
Barge, self-propelled	0.80	Full Container Ship	0.65
Dry/Liquid Bulk Carrier	0.80	Passenger Ship	0.64
Refrigerated Cargo	0.80	Cable Ship	0.60
Tank Barge Integrated	0.80	Fishing Vessel	0.60
Tank Barge, not self-propelled	0.80	Other PC Net	0.60
Tank Barge, self-propelled	0.80	Research Vessel	0.60
Vehicle Carrier	0.80	Supply Ship	0.60
Vehicle/Dry-bulk Carrier	0.80	Tug	0.59
Barge Carrier	0.75	Dredge	0.58
Factory Ship	0.75	Yacht	0.57
General Cargo	0.75	Warship (displacement)	0.55

The graph below shows the saltwater exchange times used in the 1997 throughput analysis.



Using the information above, the model calculates a processing time for each vessel by summing the components for each lift or lower cycle. The model also calculates the time required to perform an empty move, which is used by the second module during the operations simulation. Average lift and lower cycle times for 1997 are shown below.



MODULE II – SYNCROLIFT SIMULATIONS

The computer model's second module simulates the operation of a full transit lane with one Syncrolift at either end. The simulation uses actual ships and arrival data extracted from the PCC transit database, plus the Syncrolift processing time calculated from module I, to determine system performance. Because the data provided only had an arrival day, each vessel was assigned a random arrival time within that 24-hour period.

Because vessel processing times are based on available information and best estimates, a number of key parameters were graphed against a range of process times. These graphs help to assess the sensitivity of parameters that affect vessel processing times. As a numerical exercise within the model, processing times were changed uniformly for all vessels. These incremental changes would reflect actual changes to factors such as lift/lower times, gate open/close times, or longer vessel maneuvering, entering and exiting periods.

The simulation results are based on the following operational parameters:

1. *Service schedule* – Decisions for operating the Syncrolift were based on a calculation for quickest time into service. Based on each vessel's arrival time, the model determined the fastest time into service and selected that vessel. Examples of the program logic are illustrated below.

   Example 1 – The time is 12:00 and the chamber is at the upper pool. Vessel A has arrived at the lower pool at 11:30. To transit Vessel A, the chamber would have to move empty to the lower pool (44 minutes). Therefore the service time for Vessel A would be 12:44.

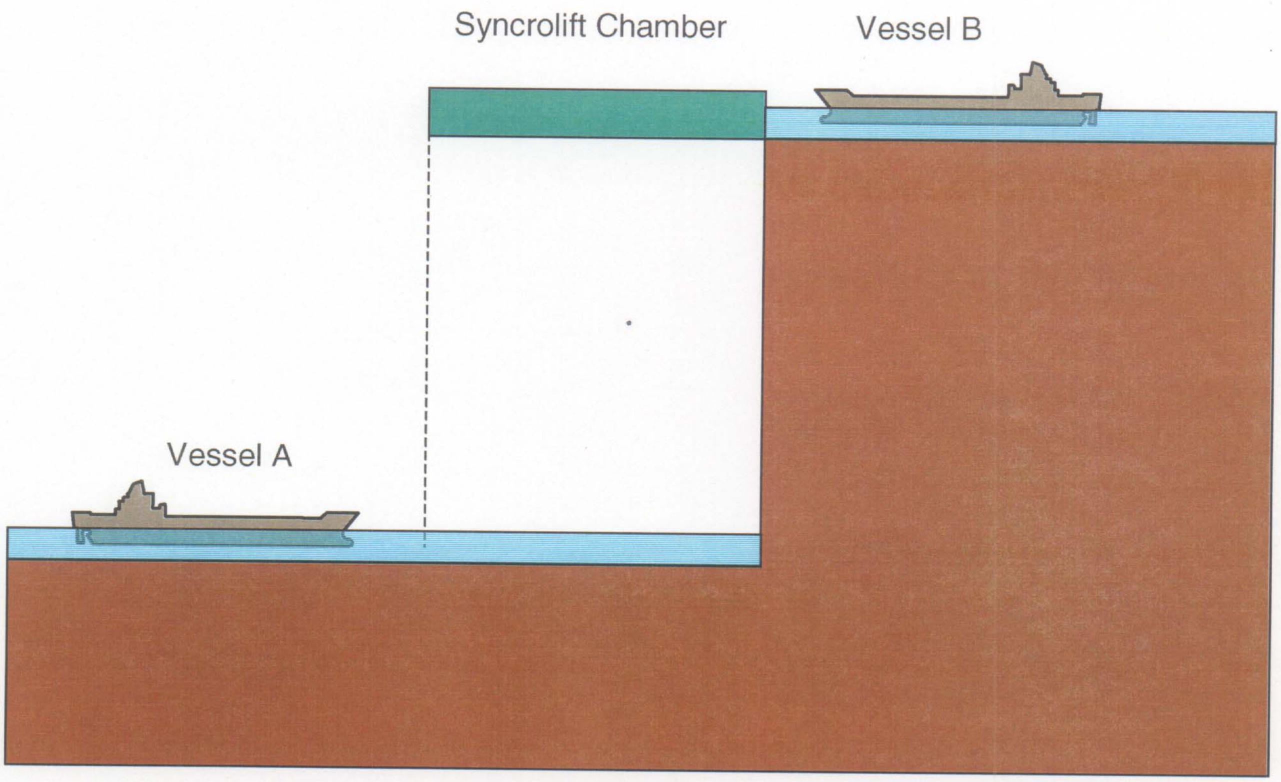
   Vessel B will arrive at the upper pool at 12:40. Because the chamber is already at the upper pool, no empty move would be required and the potential service time for Vessel B would be 12:40.

   Based on fastest time into service, the model selects Vessel B for transit. (12:40 – Vessel B vs. 12:44 – Vessel A) (No empty move required.)

   Example 2 – The time is 12:00 and the chamber is at the upper pool. For Vessel A the situation is the same, waiting since 11:30 the chamber would have to make an empty move (44 minutes) and service Vessel A at 12:44.

   Vessel B will arrive at the upper pool at 12:50, no empty move is required and the service time for Vessel B would be 12:50.

   Based on fastest time into service, the model selects Vessel A for transit. (12:44 – Vessel A vs. 12:50 – Vessel B) (1 empty move required.)



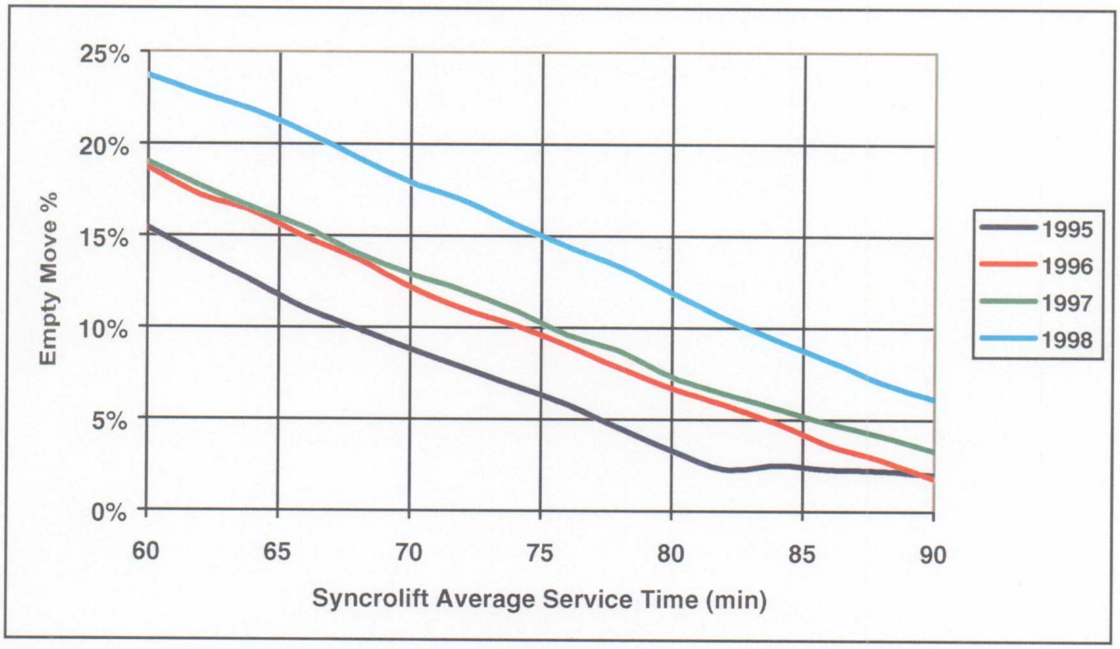
Vessel A	Example 1	Vessel B
12:00	Time Now	12:00
11:30	Vessel Arrival Time	12:40
0:44	Syncrolift Empty Move	0:00
12:44	Potential Service Time	12:40
	Selection ⟶	**Vessel B**

Vessel A	Example 2	Vessel B
12:00	Time Now	12:00
11:30	Vessel Arrival Time	12:50
0:44	Syncrolift Empty Move	0:00
12:44	Potential Service Time	12:50
Vessel A	⟵ Selection	

2. *Empty Moves* – During slower periods where there were no vessels on queue at one or both locations (upper and lower pools), the chamber was moved empty to deliver service wherever it was required. The decision to perform an empty move was

determined by the service schedule calculation for the quickest time into service. As vessel traffic, or vessel processing times increased, the number of empty moves required decreased. For the purposes of calculating system utilization, empty moves are not included. Empty moves for varying process times are shown below.

Syncrolift Service Time vs. Empty Moves
1995-98 w/ Random Outages



3. *Random Outages and Semi-Scheduled Maintenance* – To reflect actual operating conditions, a random set of breakdowns and semi-planned outages were included in the simulation based on Syncrolift experience with similar equipment. The types of outages included were broken down into three categories:

   a) *Semi-planned Outage* – 12 hour outages occurring randomly on a quarterly basis (48 hours total). These outages reflect a situation where a something has occurred that will not stop the lift, but will require attention in the short term.

   b) *Nuisance Mechanical Outage* – 4 hour outages averaging one incident every three months (16 hours total), occurring randomly throughout the year. These outages reflect situations that may occur when, for example, a brake pawl is stuck in a ratchet tooth, or some other piece of mechanical equipment is not functioning properly, but has not failed.

   c) *Nuisance Electrical Outage* – 2 hour outages averaging one incident per week, (106 hours), occurring randomly throughout the year. These outages reflect situations that may occur when, for example, a wire comes loose in an electrical panel.

Based on the criteria above, the random breakdown hours were distributed on a monthly basis as shown below.

Month	Hours Down	Month	Hours Down
October	12	April	10
November	16	May	10
December	20	June	16
January	14	July	18
February	16	August	8
March	18	September	12

Total Down Hours = 170 – approximately 1.9% lane unavailability

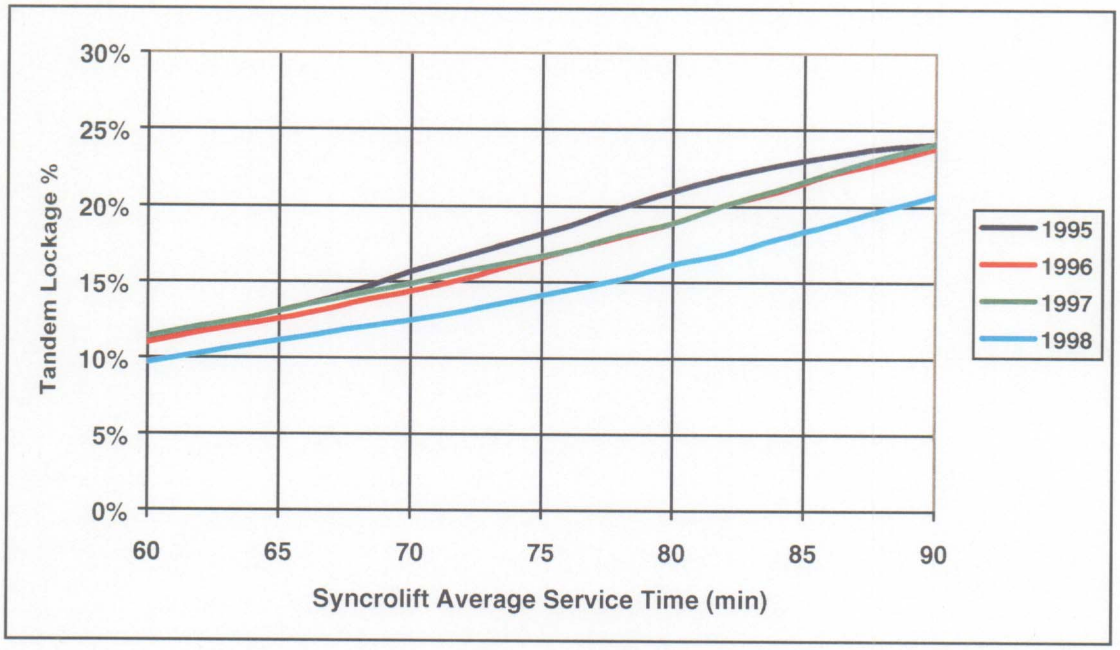
The system throughputs and model results do not reflect a one-week annual maintenance camp where vessels would be rerouted through the locks. For the outages included in the simulation, vessels are held and wait times increased until the outage is complete. The one-week maintenance camp would contribute 168 hours of additional downtime, resulting in an overall lane availability of 96.1%. On average, this would result in the loss of 118 transits per year – assuming the maintenance camp is scheduled for a seasonal slow period (August – November) where the transit traffic is 85% of the annual average.

Year	Average Weekly Transits	Transits Lost (85%)
1995	148	126
1996	139	118
1997	138	117
1998	128	109
Total '95 – '98	138	118

3. *Tandem moves* – Vessels were allowed to transit in tandem (or in very rare cases triplet) as long as there was 25m clearance between vessels. For example, rather than a single vessel length of 192m, two vessels could transit in tandem if their combined length was less than 167m (or for triplets, a combined length of less than

142m). Tandems were determined by searching the vessel queue in order of arrival to see if there were eligible vessels. For processing times averaging 70 min. (typical design time) the tandem transits ranged from 12.5% - 16.2% of the total transits, and had a significant impact on the average CWT. When a tandem transit was feasible, the processing time was modified for both vessels to allow the second vessel to enter and exit the chamber behind the first. The number of tandem transits for varying process times is shown below.

Syncrolift Service Time vs. Tandem Lockages
1995-98 w/ Random Outages



4. *Canal Waters Time (CWT)* – The CWT for the system was calculated by summing the following components:

   a) *Lower pool wait time* – time spent from arrival until transit service time

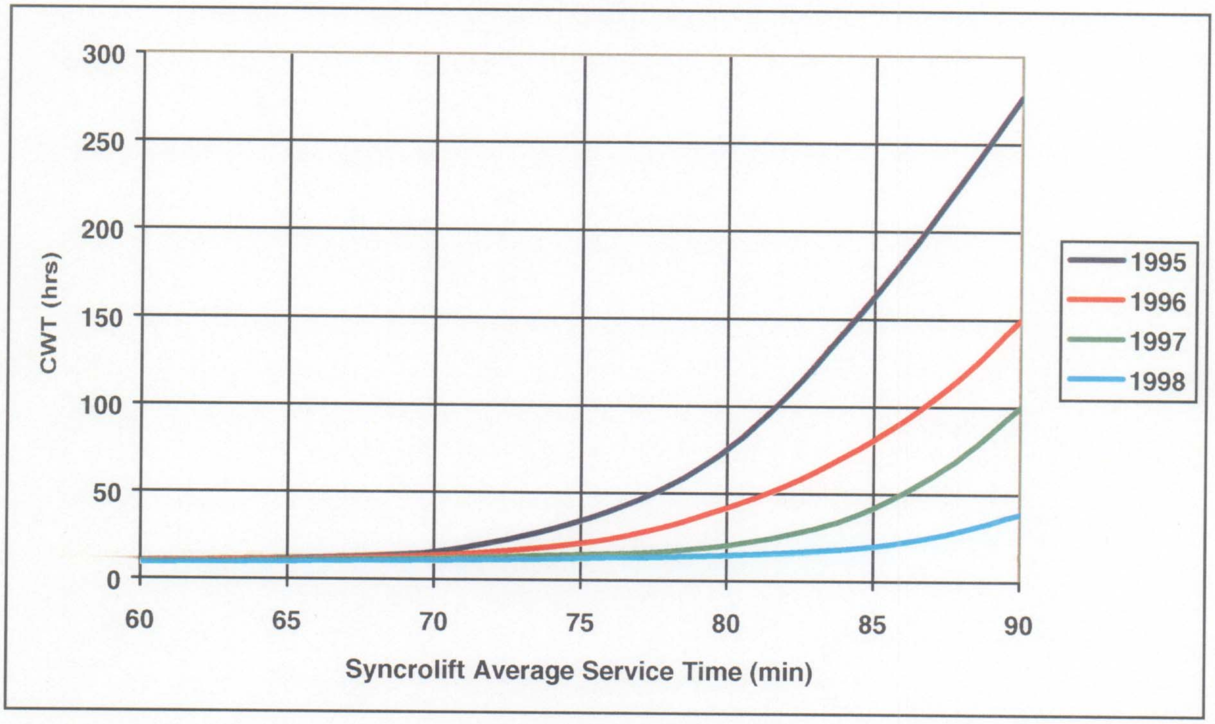
   b) *Processing time* – one lift (including saltwater mitigation) and one lower

   c) *Crossing Lake Gatun and Gaillard Cut* – 4 hours, 3.5 hours to cross Gatun and Gaillard Cut (per PCC data), plus 0.5 hours for arrival processing time – vessel is already in the system, but not at the holding berth or in the queue.

   d) *Upper pool wait time* – because the vessels crossing Lake Gatun and Gaillard Cut are spaced approximately 140 minutes apart, the wait times for the upper pool are greatly reduced. In actuality, the wait times are dependent on the average processing times for each vessel – for an average processing time of 68 minutes, the average wait time at the upper pool was 35 minutes. If the average processing time rises to 88 minutes, the average wait at the upper pool also rises, to 74 minutes. For the purposes of these analyses, an average wait time of 45 minutes was used at the upper pool.

Model results for CWT versus average processing time are shown below.

Syncrolift Service Time vs. CWT
1995 – 1998 w/ Tandem Lockages and Random Outages



Chamber Dimensions

	Max Vessel	Chamber Interior
Length	192.0	198.1
Beam	25.3	26.5
Draft	9.3	10.0

Total Transits - Vessels

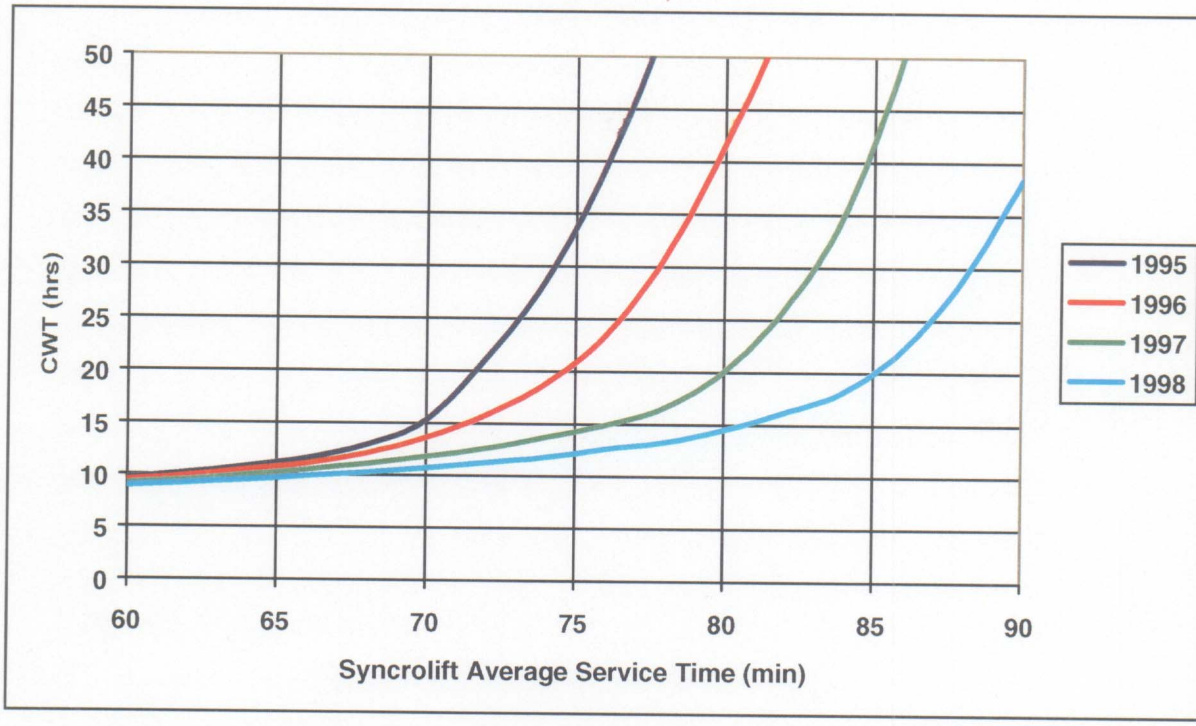
	NB	SB	Total
1995	3,802	3,879	7,681
1996	3,545	3,676	7,221
1997	3,452	3,653	7,105
1998	3,259	3,337	6,596

Total Transits - %

	NB	SB	Inclusion
1995	49.5%	50.5%	51.7%
1996	49.1%	50.9%	48.6%
1997	48.6%	51.4%	49.4%
1998	49.4%	50.6%	47.0%

Because the PCC CWT goal for smaller vessels is 18-20 hours, the graph above is repeated below with the y-scale maximum reduced from 300 to 50.

Syncrolift Service Time vs. CWT
1995 – 1998 w/ Tandem Lockages and Random Outages



SYNCROLIFT SIMULATIONS RESULTS

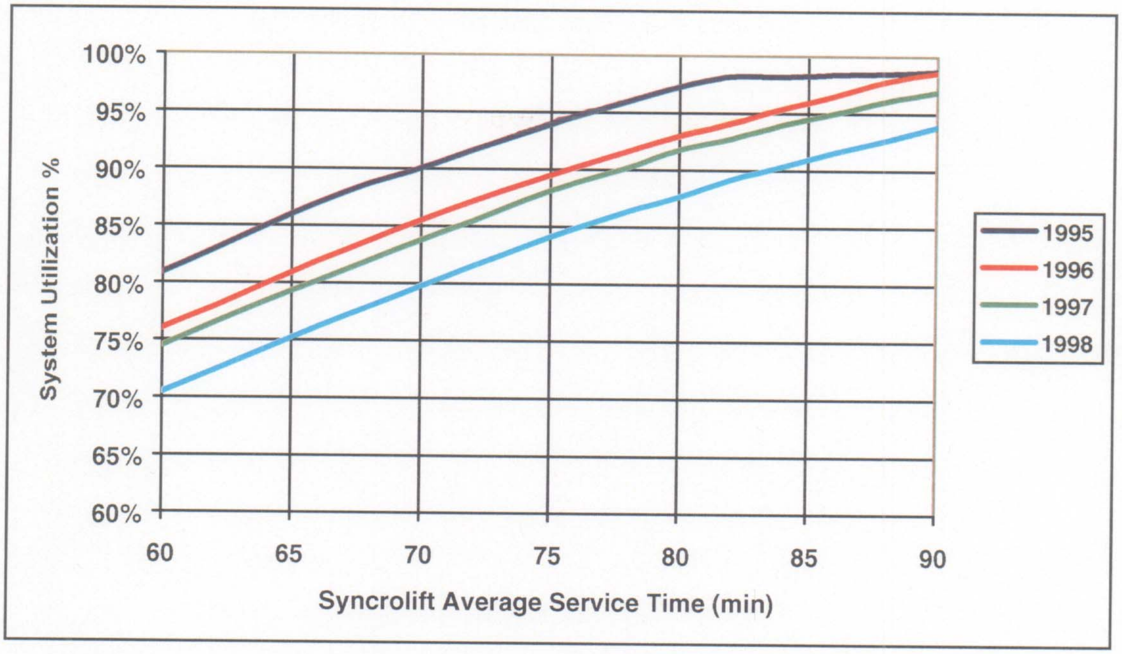
In addition to the graphs and results shown above, the simulation model also tracked other important factors such as system utilization, water savings compared to traditional locks, and the CWT results and empty moves by month. These results are shown below.

System Utilization – The system utilization was calculated by dividing the time in use by the total time according to the following definitions:

> Time in use – time spent transiting vessels, excludes empty moves
>
> Total time – Total time to process all vessels, excluding downtime due to random outages and semi-planned maintenance

Based on PCC experience, the recommended limit for practical system utilization is 85%. For the Syncrolift system, the utilization is within 85% for the for the 70 minute design times of 1996 – 1998. For 1995 where the design time is 71 minutes, the system utilization exceeds 90%. The system utilization for varying process times is shown below.

Syncrolift Service Time vs. System Utilization
1995 – 1998 w/ Tandem Lockages and Random Outages

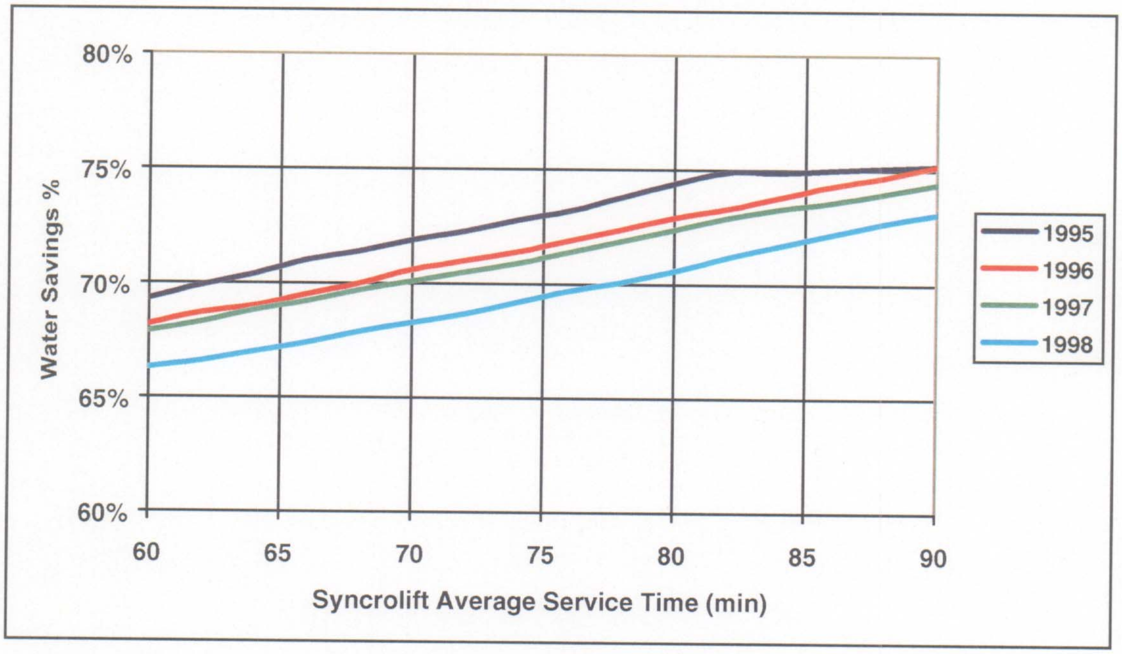


<u>Water Savings</u> – In the early stages of development, one of the primary features of the Syncrolift system was the fact that it could accomplish the 25.9m lift in one step, and its freshwater use would be virtually zero. However, the results of the saltwater intrusion studies revealed that the undiluted seawater contained in the chamber would have a negative impact on the salinity levels in Lake Gatun. The best way to mitigate this effect would be to exchange the seawater with freshwater, preventing the release of saltwater into Lake Gatun.

Although this has an obvious impact on the proposed 100% water savings, volumetrically the chamber is approximately 50% of a full-size lock, and the saltwater exchange is only required for the lift portion of the transit. This results in water savings between 65% - 75%, a significant figure that exceeds the best savings achievable through different water recycling methods.

The model calculates water savings by tracking total water used for each transit and dividing the total by the same number of lockages (transits – tandem moves) using 52 million gallons of freshwater each.

Syncrolift Service Time vs. Water Savings Compared to Typical Lock
1995 – 1998 w/ Tandem Lockages and Random Outages

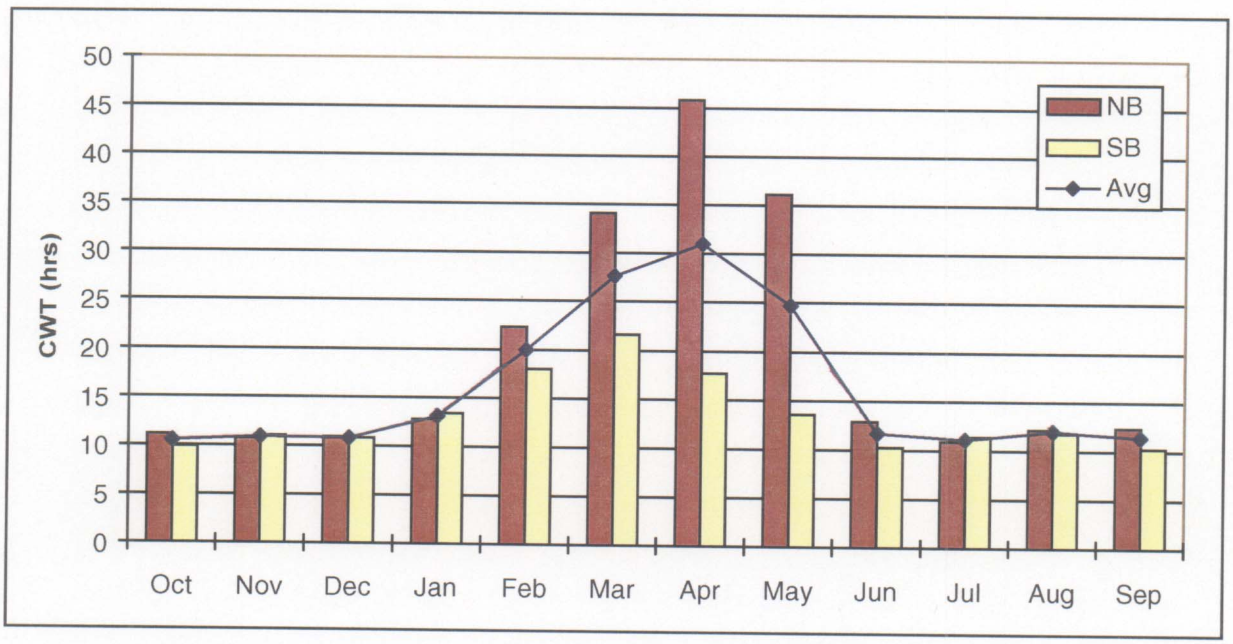


System Performance by Month – While annual averages are useful for comparing performance across years and to existing systems, the PCC was also interested in how the system performed throughout the year. In particular, how did the system perform during the peak season (December – July) when the average weekly transits may exceed the annual weekly average by 30% - 40%. The Syncrolift performance figures for the design process time by month are summarized below.

1995 Syncrolift Performance by Month

71 Min. Average Service Time (Design)

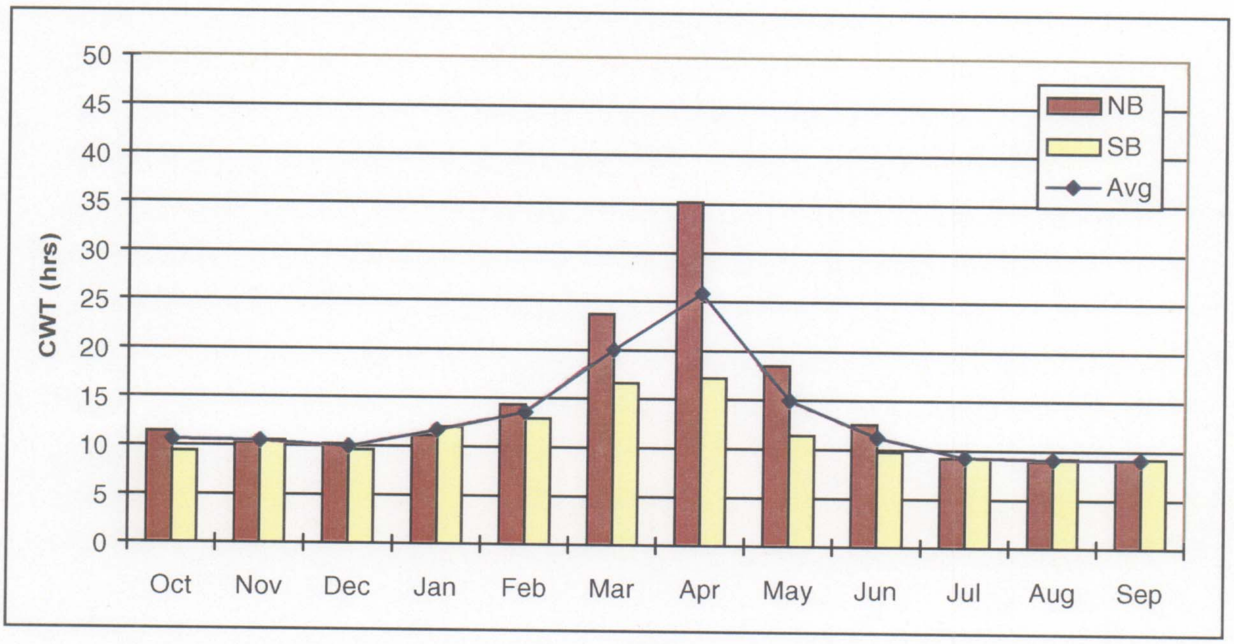
Month	NB Transits	SB Transits	Total Transits	NB CWT	SB CWT	Avg CWT	Empty Moves	Down Hours
Oct	312	280	592	11.1	9.9	10.5	73	12
Nov	293	284	577	10.7	11.0	10.9	88	16
Dec	286	300	586	10.9	10.8	10.8	76	20
Jan	300	348	648	12.8	13.4	13.1	53	14
Feb	348	387	735	22.3	18.0	20.0	7	16
Mar	369	399	768	34.1	21.6	27.6	0	18
Apr	360	400	760	45.8	17.7	31.0	5	10
May	337	345	682	36.1	13.6	24.7	22	10
Jun	310	287	597	12.9	10.3	11.7	81	16
Jul	298	278	576	10.9	11.4	11.1	69	18
Aug	291	298	589	12.2	11.8	12.0	72	8
Sep	298	273	571	12.4	10.3	11.4	86	12
Total	3,802	3,879	7,681	20.3	13.8	17.0	632	170
							Monthly Avg.	14.2



1996 Syncrolift Performance by Month

70 Min. Average Service Time (Design)

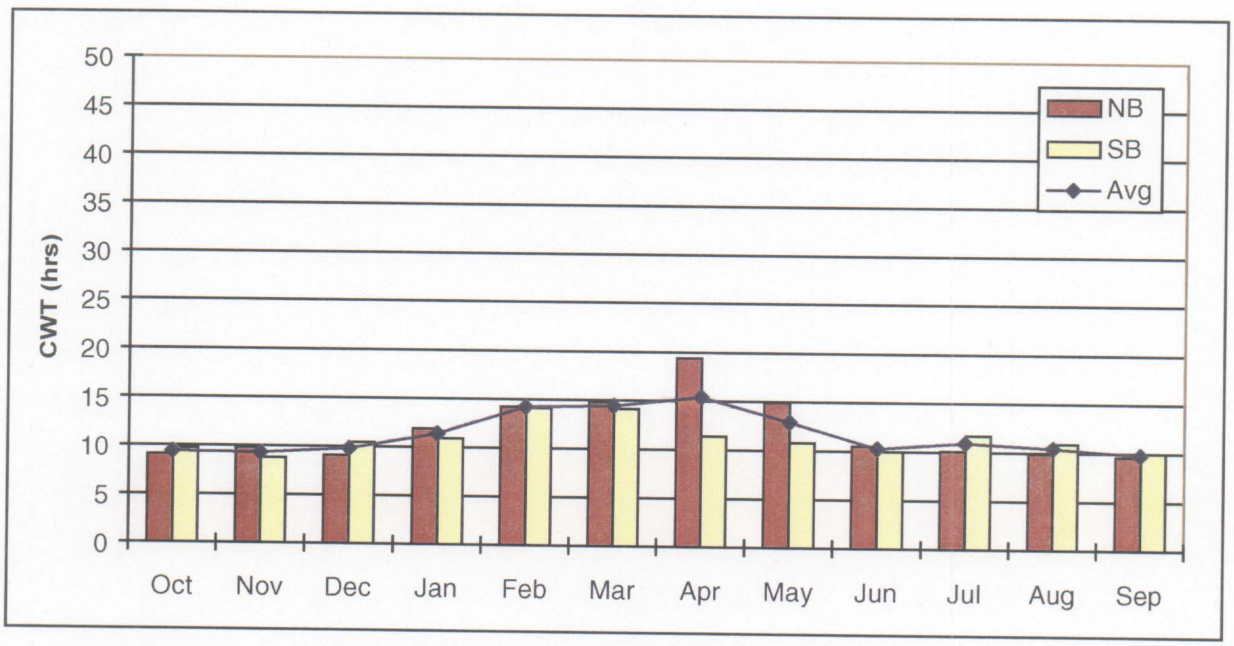
Month	NB Transits	SB Transits	Total Transits	NB CWT	SB CWT	Avg CWT	Empty Moves	Down Hours
Oct	300	240	540	11.4	9.4	10.5	96	12
Nov	278	269	547	10.3	10.5	10.4	101	16
Dec	282	295	577	10.2	9.6	9.9	70	20
Jan	273	335	608	11.1	12.0	11.6	68	14
Feb	316	391	707	14.3	12.9	13.5	33	16
Mar	358	392	750	23.7	16.6	20.0	13	18
Apr	371	407	778	35.2	17.2	25.8	4	10
May	306	323	629	18.5	11.4	14.9	71	10
Jun	298	282	580	12.6	9.8	11.2	87	16
Jul	270	251	521	9.2	9.2	9.2	99	18
Aug	250	261	511	9.0	9.2	9.1	123	8
Sep	243	230	473	9.1	9.2	9.1	117	12
Total	3,545	3,676	7,221	15.4	11.9	13.6	882	170
							Monthly Avg.	14.2



1997 Syncrolift Performance by Month

70 Min. Average Service Time (Design)

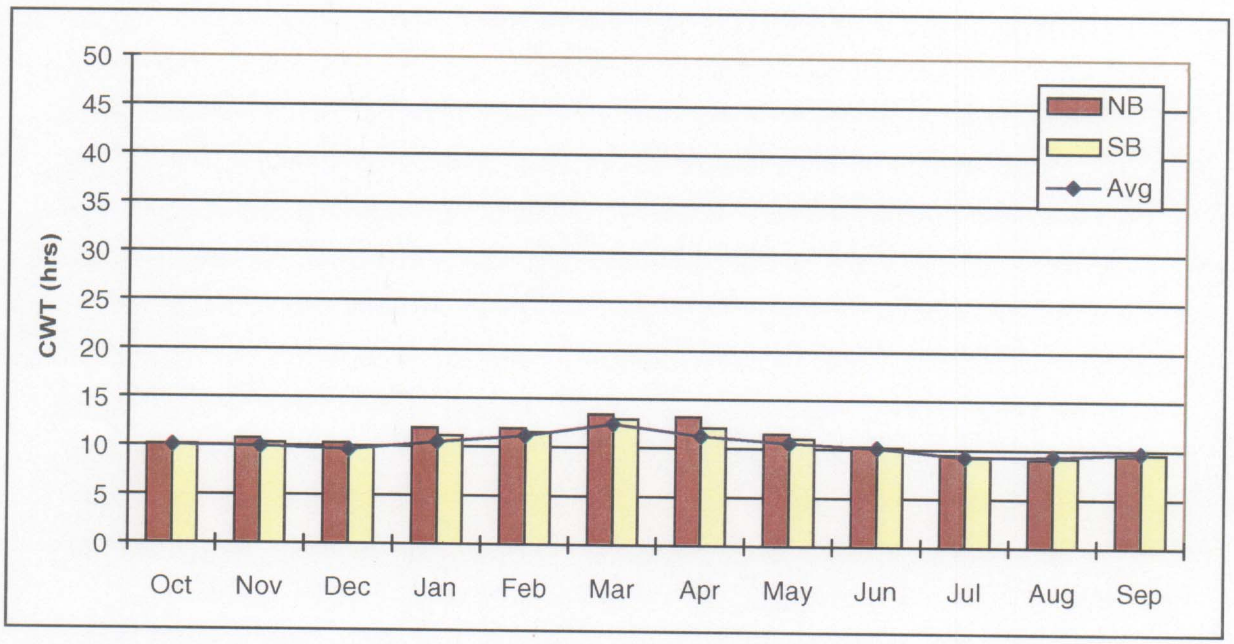
Month	NB Transits	SB Transits	Total Transits	NB CWT	SB CWT	Avg CWT	Empty Moves	Down Hours
Oct	257	224	481	9.1	9.7	9.4	106	12
Nov	244	240	484	9.8	8.8	9.3	104	16
Dec	255	323	578	9.1	10.4	9.8	98	20
Jan	298	360	658	11.9	10.9	11.4	67	14
Feb	299	399	698	14.2	14.1	14.2	39	16
Mar	313	396	709	14.8	14.1	14.4	36	18
Apr	353	350	703	19.4	11.4	15.4	50	10
May	348	338	686	14.9	10.8	12.9	52	10
Jun	287	284	571	10.5	10.0	10.3	90	16
Jul	283	248	531	10.1	11.7	10.9	92	18
Aug	264	248	512	9.9	10.9	10.4	88	8
Sep	251	243	494	9.6	10.0	9.8	96	12
Total	3,452	3,653	7,105	12.3	11.3	11.8	918	170
							Monthly Avg.	14.2



1998 Syncrolift Performance by Month

70 Min. Average Service Time (Design)

Month	NB Transits	SB Transits	Total Transits	NB CWT	SB CWT	Avg CWT	Empty Moves	Down Hours
Oct	262	242	504	10.1	10.0	10.1	110	12
Nov	272	258	530	10.7	9.9	10.3	108	16
Dec	267	281	548	10.3	9.6	10.0	104	20
Jan	271	320	591	11.9	10.4	11.1	91	14
Feb	297	310	607	11.9	11.1	11.5	95	16
Mar	321	362	683	13.4	12.4	12.9	43	18
Apr	294	364	658	13.2	11.2	12.1	89	10
May	314	285	599	11.5	10.5	11.0	87	10
Jun	258	272	530	10.3	10.1	10.2	95	16
Jul	272	235	507	9.5	9.2	9.3	107	18
Aug	207	210	417	9.1	9.3	9.2	117	8
Sep	224	198	422	9.5	9.7	9.6	137	12
Total	3,259	3,337	6,596	11.1	10.4	10.7	1,183	170
							Monthly Avg.	14.2



Model Testing

SIMULATION MODEL CONCLUSIONS

Based on the simulation model results, the Syncrolift is a practical, efficient system for adding capacity to the Panama Canal with significant savings in water usage. Designed to handle 49.2% of existing Canal traffic, operational limits would reduce this figure to about 47%, or a maximum of 7,000 transits per year, in order to maintain the PCC CWT service target of 18-20 hours throughout the year. The 47% figure reflects unplanned outages and semi-planned maintenance, as well as the loss of 118 transits during the one-week shutdown for regularly scheduled annual maintenance.

While the system is robust enough to handle processing time increases without significant impacts to capacity, portions of the processing time rely on assumptions which are yet to be determined – but may have a significant impact on the overall processing time, for example:

a) Approach Channels – The geometry of the approach channels impacts the time required for maneuvering, entering and exiting the chamber. Because the system efficiency relies on two-way operations, the design and location of the holding berths and passing channels is an important parameter for calculating throughput. Until specific sites are determined, the approach channels will not receive any further attention during the study.

b) Saltwater Mitigation – The time requirements for the saltwater mitigation measures are based on WES recommendations that will be validated during Phase II of the study. Although WES created preliminary saltwater intrusion models for Lake Gatun, given the size and complexity of the system, it is possible that the measures incorporated into the design may not be required, or are required on a part-time basis only.

Hydrodynamic Model Testing Program

Syncrolift Inc. contracted the University of Michigan to conduct unpowered hydrodynamic model tests to measure the forces and pressures exerted on the chamber walls and floor during vessel entry and exit operations. The tests also measured hydrodynamic flows and vessel drag at varying beam and draft clearances to assess the operational feasibility of each configuration. The tests were not intended to be a final evaluation of vessel hydrodynamic performance for each configuration, but were to be used as a comparative tool for selecting a final configuration to be evaluated further at a later date.

The results of the model tests were also compared to full-scale measurements taken by the U.S. Army Corps of Engineers, Pittsburgh District on April 22 – 29, 1999 to ensure that the model results reflected actual conditions for vessel operations in a restricted waterway.

Three principal clearance cases were tested:

	I. Largest Clearance PCC Recommended	II. Medium Clearance Syncrolift Suggested	III. Least Clearance Current Canal Operations
Beam Clearance (each side)	1.52m	0.91m	0.61m
Draft Clearance	1.52m	1.52m	0.76m
Blockage Ratio (at design draft)	74%	78%	86%

Each configuration was tested at three drafts, the design draft ±1 foot full-scale (±0.30m), over a range of speeds from 0.5 – 2.5 knots (full-scale) by 0.5 knot increments. This matrix provided data for a range of blockage ratios and operating speeds to assess the operational feasibility of each configuration. To perform the tests, the University of Michigan used one ship model and three different chambers, which resulted in three different scaling ratios.

At the time the model testing was being contracted, the optimum vessel was based on the 1998 data using the Syncrolift suggested clearances. Since that time the proportions of the maximum sized vessel have changed slightly with the vessel becoming wider and deeper. The change in size was due to additional data supplied by the PCC, and a decision to use the minimum clearances – which would represent a very small portion of the proposed transits. Because each configuration was tested through a range of speeds and blockage ratios, testing for the new configuration is not required.

The test matrix, chamber dimensions, and vessel dimensions are shown below.

University of Michigan Test Program

		Case I Max. Clearance			Case II Med. Clearance			Case III Min. Clearance		
Hull Form Blockage Ratios		72%	74%	77%	76%	78%	81%	83%	86%	89%
Draft Conditions		7.9	8.2	8.5	7.9	8.2	8.5	8.5	8.8	9.1
Speeds	0.5 kts									
	1.0 kts									
	1.5 kts									
	2.0 kts									
	2.5 kts									

Note: Shaded cells were not tested

	Chamber	Case I	Case II	Case III
Scale Ratio		29.8	31.4	32.2
Length (m)	232.6	154.8	162.8	166.7
Beam (m)	25.8	22.7	23.9	24.5
Design Draft (m)	9.75	8.23	8.23	8.84

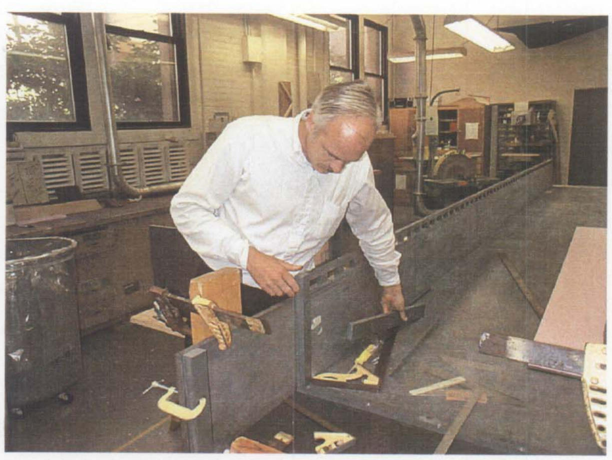
Tests were conducted for both entering and exiting conditions to measure the water surcharge (increased water depth) and drawdown (decreased water depth) during vessel operations. Because the system is open to the atmosphere, the only pressure changes exerted on the chamber surfaces are due to changes in water depth. A few powered tests were also conducted for each configuration at the design draft.

While the program was being set-up in the test tank on North Campus, the voltage output of the multi-turn potentiometer used to calibrate model speed was inadvertently offset by a factor of 0.734. This resulted in the program being unwittingly conducted for model speeds that were 73.4% of the desired test speed. The offset does not affect the validity of the data, but it does change the scale of the results plots. Therefore, the test results now reflect the following full-scale speeds:

Desired Test Speed	Actual Test Speed
0.5 kts	0.37 kts
1.0 kts	0.73 kts
1.5 kts	1.10 kts
2.0 kts	1.47 kts
2.5 kts	1.84 kts

MODEL CONSTRUCTION

The model was constructed from black PVC according to drawings provided by Syncrolift. The tests simulated entry and exit at the upper level, so the upstream gate was fixed open for vessel entry and exit, while the downstream gate was fixed closed. To accommodate the three different scale ratios, the model was built in sections – one parallel midbody plus inserts to change the width, and three pairs of gate ends to change the length. Each

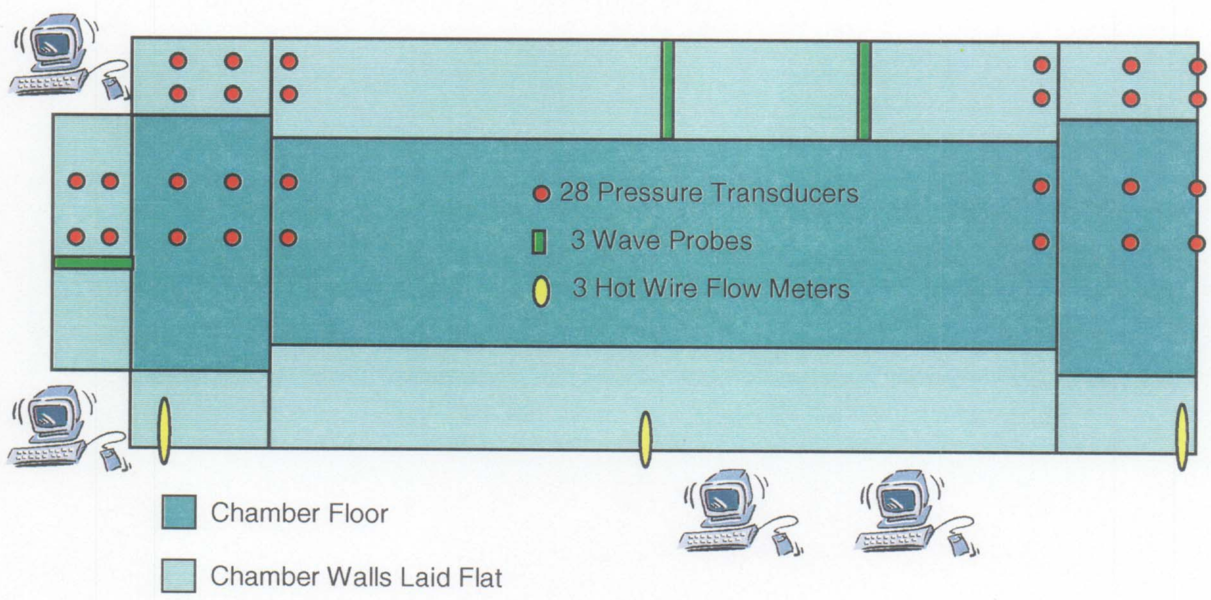


configuration consisted of the midbody with an insert, plus the appropriate gate ends to provide the correct scale ratio. The PVC was hand sanded to provide a rough surface to stimulate turbulent flow during testing. A smooth surface would allow laminar flow around the vessel and across the chamber and would not reflect actual full-scale operating conditions. The model also included overflow ports at the design water height to provide additional area for water inflow and egress. The majority of the tests were conducted with the ports covered so that the maximum pressures would be recorded. Some test were conducted during the largest clearance case with open ports to evaluate their impact on operations.

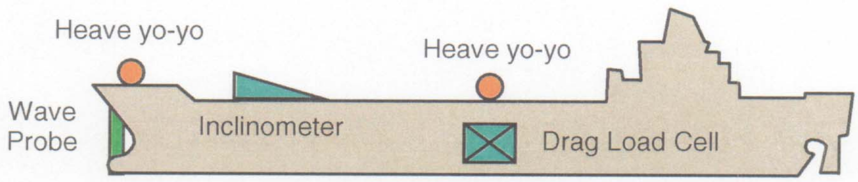
INSTRUMENTATION

The chamber was instrumented throughout its length with various probes and gauges to measure water flows and pressure changes during each test. Water pressure was measured using pressure transducers that mounted flush into the chamber walls and floor. There were also three wave probes placed at different points in the chamber to measure water height. Flow meters were used at three locations to measure water velocity along the primary flow axis (longitudinal). Because the most interest was in pressure and flow changes in the gate ends where the chamber changes shape, the majority of the instrumentation was concentrated in these areas. The ship model was also instrumented to measure drag, heave and pitch during the tests, but was restrained along the roll and yaw axes. A wave probe was mounted on the bow of the vessel to measure wave height. A summary of the instrumentation is shown below.

Chamber Instrumentation



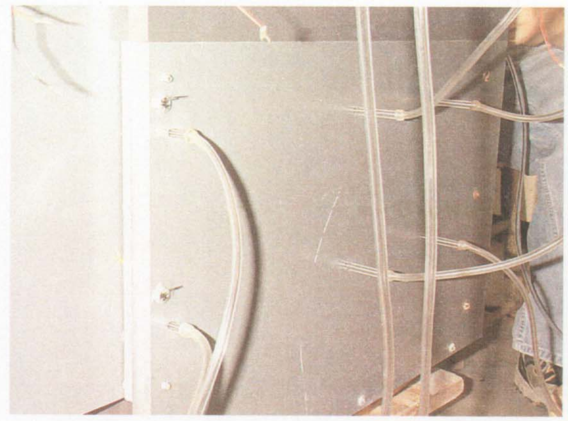
Vessel Instrumentation



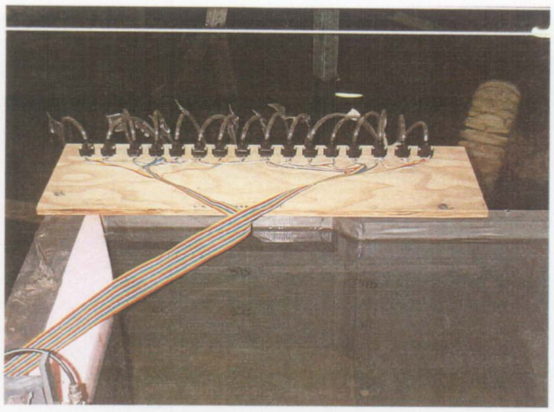
The system was operated using four computers networked together. Three computers were used to collect and analyze data, while the fourth computer was programmed to run the model up and down the chamber. Data was collected at a rate of 10 points per second, with 1,500 – 2,000 points taken for each test depending on vessel speed. Data was collected on 42 channels, 39 data inputs plus one position channel fed to each of the three data computers.

Photos of the instrumentation and model set-up are shown below.

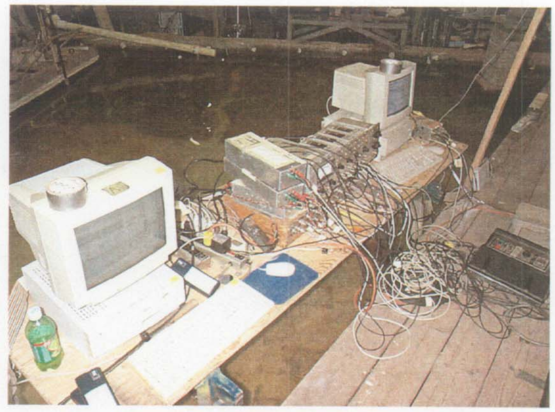
Model gate with transducer board mounted on the side.



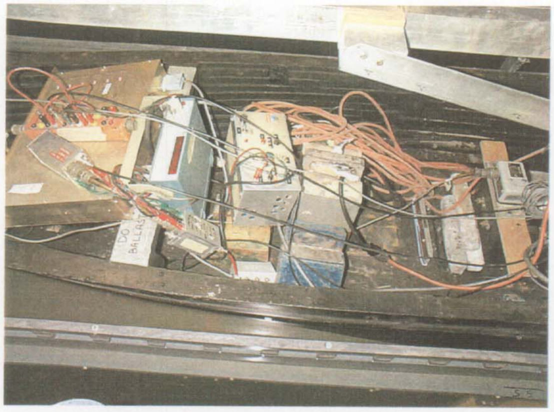
Gate exterior with hoses from transducer probes to transducer board.



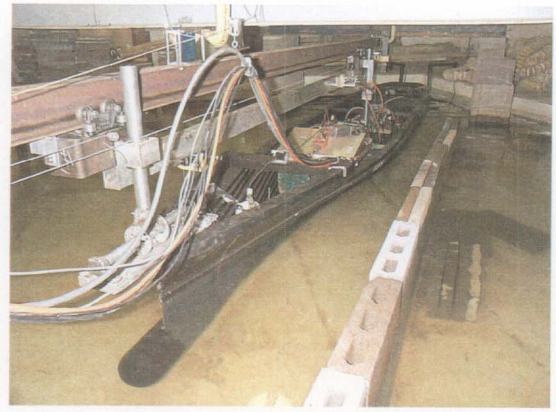
Transducer board mounted on the chamber in the model test tank.



University of Michigan cable channel.



Model instrumentation.



Model in the test tank prepared to conduct entrance test.

MODEL TEST RESULTS

The analysis and presentation of model test results for this report will focus on the feasibility study's primary objective – determining the forces and pressures exerted on the chamber during vessel entering and exiting operations.

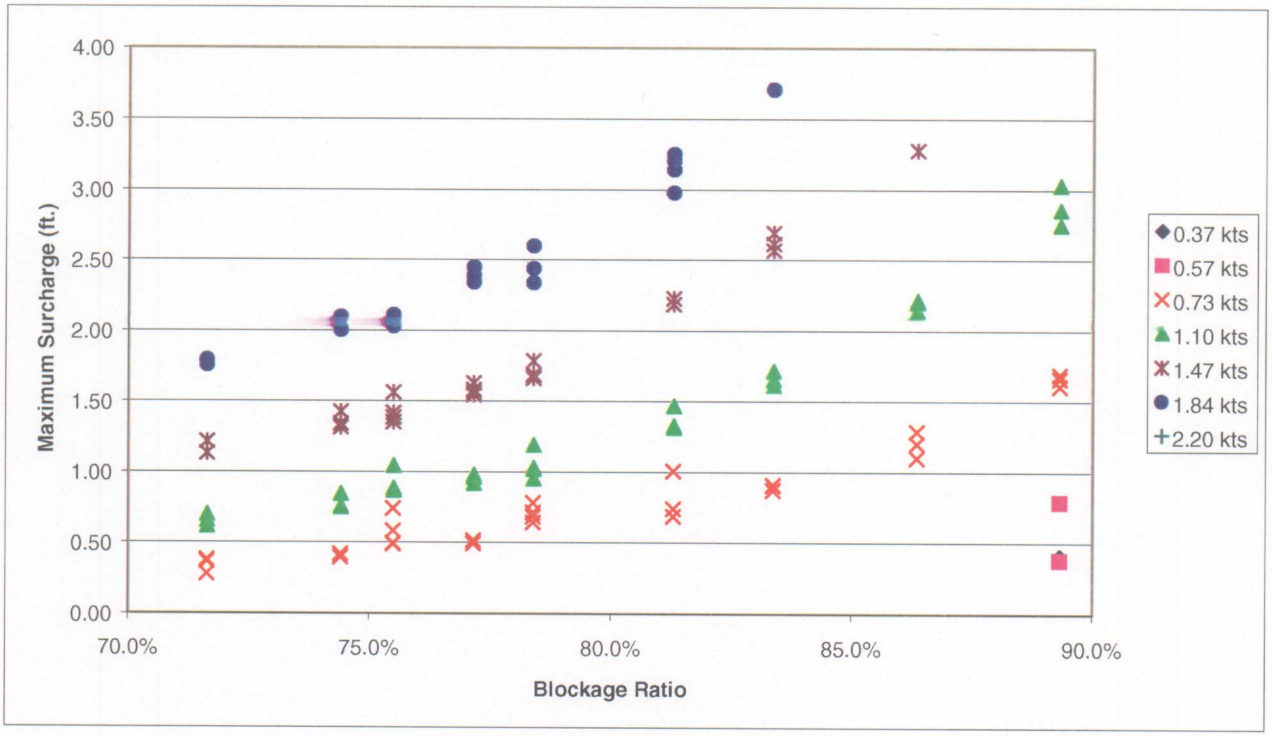
Because it is an open system, pressure changes on the chamber are measured as changes in water height within the chamber. During vessel entering operations, the water level rises (surcharge) after the bow has crossed the chamber sill and restricted the area available for water to exit. During vessel exiting operations, the water level lowers (drawdown) because the exiting volume of the vessel cannot be replaced quickly enough through the limited area available for water entrance. For the chamber design, the surcharge is more important because it will put additional load on the hoists and chamber, whereas the drawdowns are reducing the loads on the hoists and chamber. The drawdowns, however, affect the hydrodynamic performance of the vessel and play a role in determining the limiting speeds for exiting operations.

To determine the magnitude of these effects, the peak pressures were graphed at different speeds and blockage ratios. The uniform shape of the chamber and vessel helped to provide consistent results that lend themselves easily to a predictive model for forecasting results. As was found in the full-scale measurements taken by the US Army Corps of Engineers, Pittsburgh District, the vessels entering follow the model more consistently than the vessels exiting, which had a wider variance in the results. Typical graphs for different scenarios are shown below; a complete set of graph results are included as Appendix A.

Entering Condition – Surcharge Results

For vessels entering the chamber, the maximum surcharge was graphed against blockage ratios at varying speeds. (See below) Although conditions were tested that created surcharges of 3-4 feet, these were for the vessels with the highest blockage ratios traveling at a constant speeds of 1.5 – 2.0 knots. Although it is not a problem for the chamber design, vessels of this size are expected to enter the chamber at slower speeds. An increase in static pressure of 10%-12% (3.75 ft surcharge / 32 foot depth) can be accommodated within the design of the chamber structure. For the throughput model, vessels of this size were limited to speeds of 0.48 – 0.80 knot.

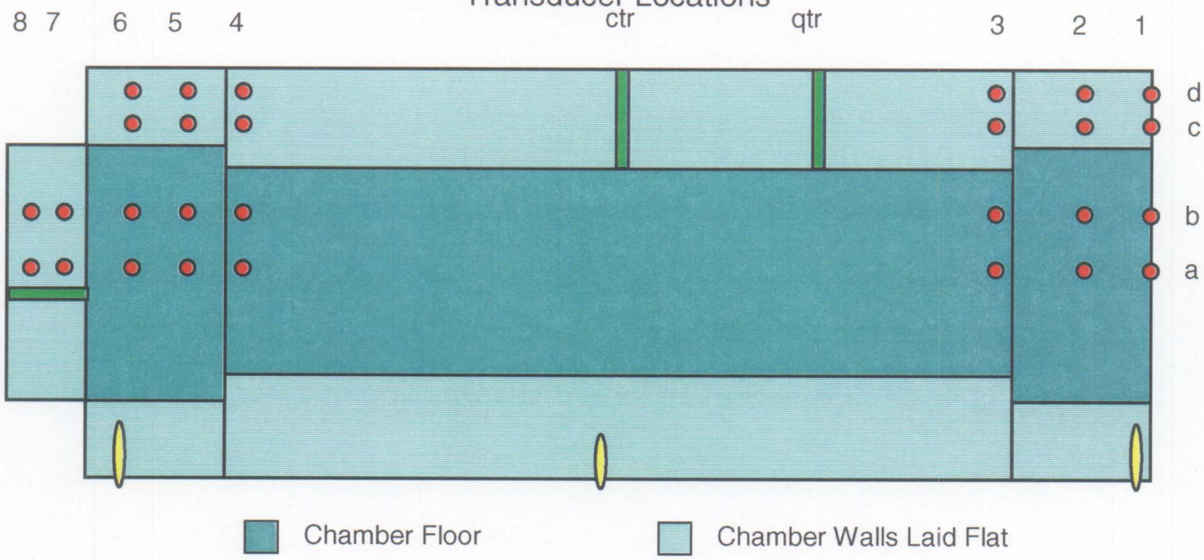
Blockage Ratio vs. Maximum Surcharge
Cases I, II, and III



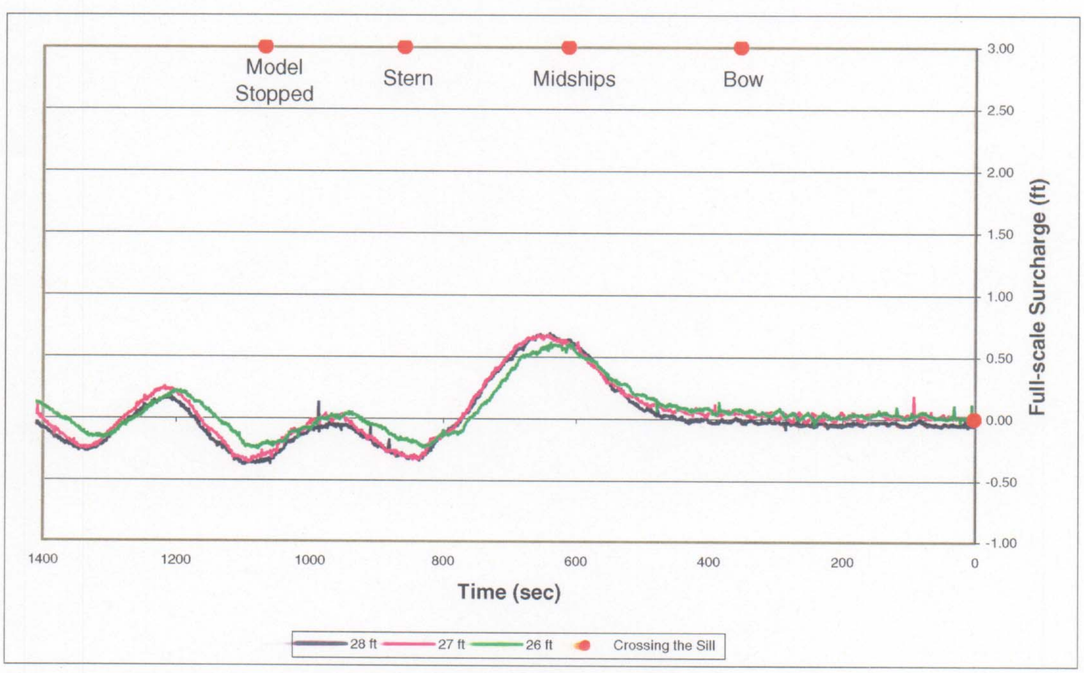
By graphing the pressures against time it was determined that the peak pressures occurred shortly after the model's midships crossed the sill. As the clearances decreased, the peak pressure occurred later in the test, and the pressure increase lasted for a longer length of time. The sample graphs that follow represent transducer 5a, located on the chamber centerline in the gate recess of the closed end, where the highest pressures were typically measured. The sample graphs are for full-scale speeds of 1.10 knots to allow comparison for different drafts within graphs and for different clearance cases between graphs. The three graphs show individually for each clearance case how the peak pressure increased as draft increased (thereby increasing the blockage ratio), and how the peak pressures increased as the clearances were reduced (again reflecting an increase in blockage ratio).

Following the 1.10 knot graphs is a similar graph for the scale ratio 29.8 at a speed of 1.84 knots. This graph is provided to include the series of tests which were done at a blockage ratio of 41% and show that for blockage ratio's of less than 50%, the surcharge, even at higher speeds is minimal.

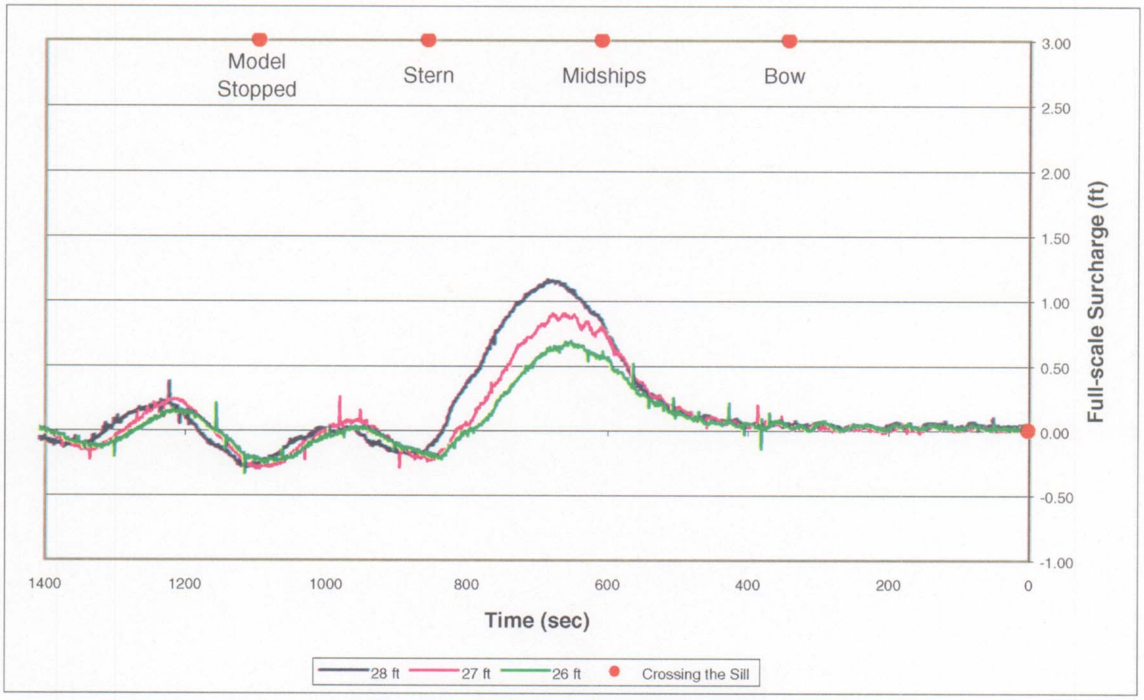
Transducer Locations



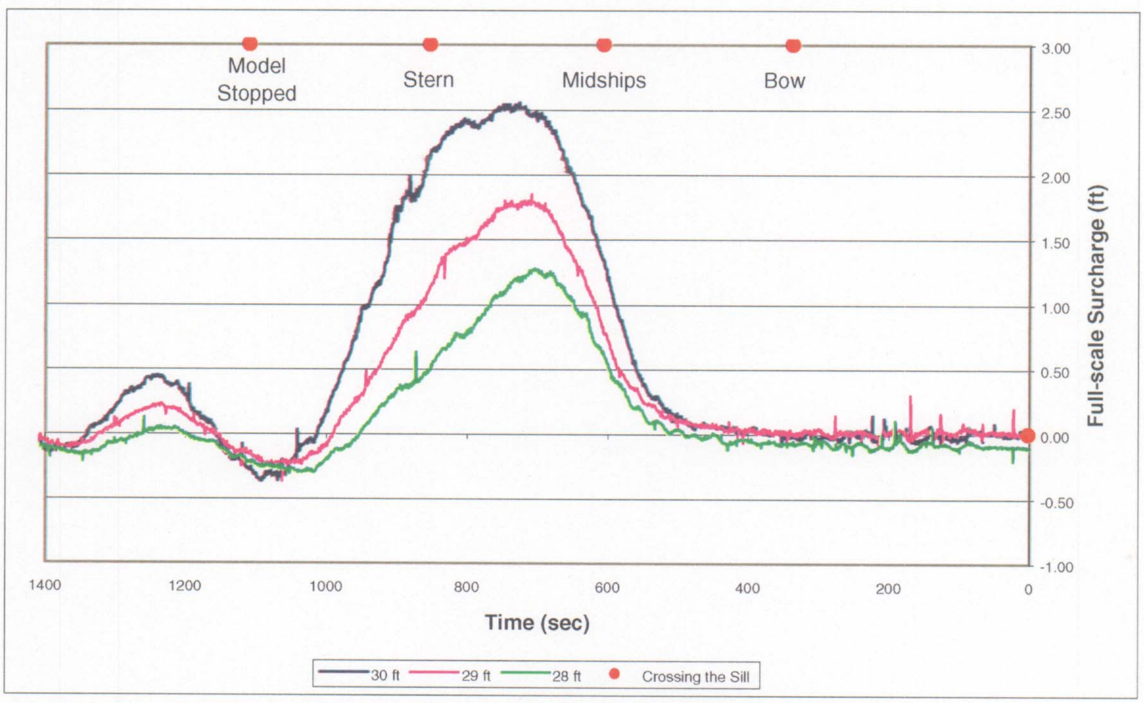
Water Surcharge – Entering Condition, 1.10 knots
Case I – Largest Clearance, Scale 29.8



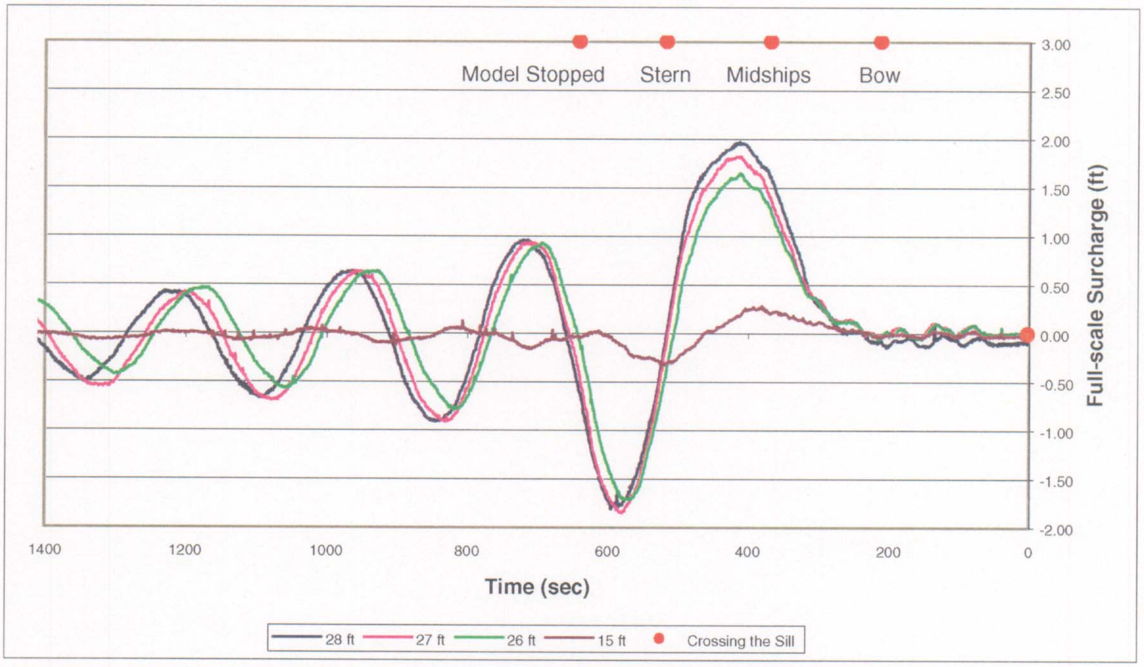
Water Surcharge – Entering Condition, 1.10 knots
Case II – Medium Clearance, Scale 31.4



Water Surcharge – Entering Condition, 1.10 knots
Case III – Least Clearance, Scale 32.2

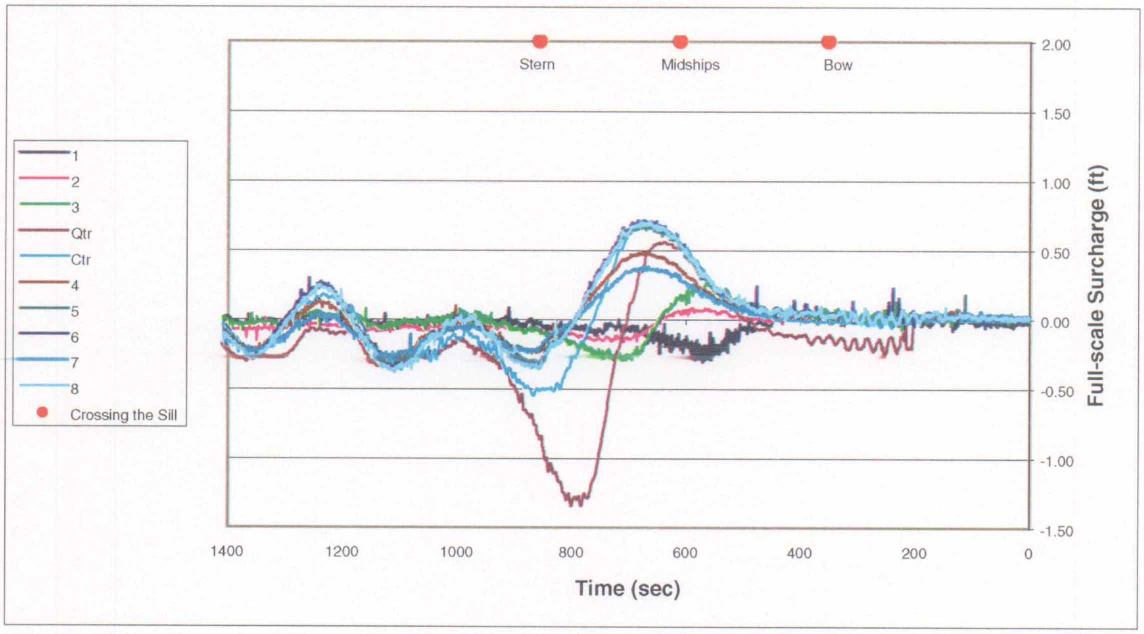


Water Surcharge – Entering Condition, 1.84 knots
Case I – Largest Clearance, Scale 29.8

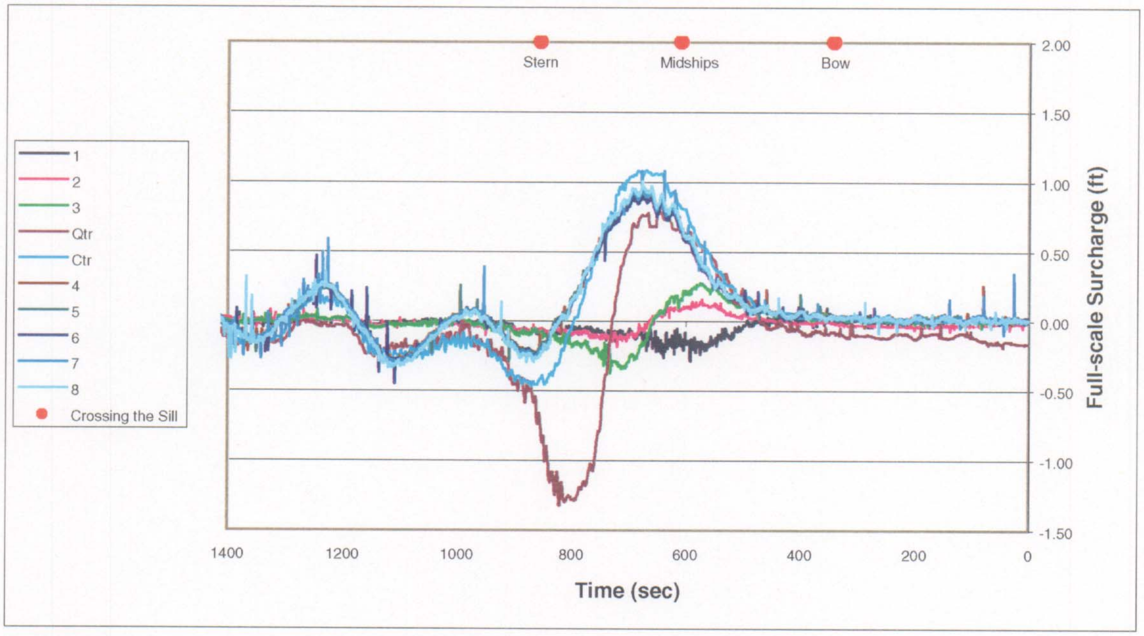


By graphing the centerline pressure sensors against time, it is possible to determine what the water surface is doing at any given time as the vessel enters the chamber, and how this is affected by changes in clearances. The following three graphs show the centerline sensors for the three design clearance cases. The graphs show that at the largest clearance the water gradually flows from the back of the chamber to the front, while at the tightest clearance there is a virtual step along the side of the vessel where the water level switches abruptly from a surcharge to a drawdown.

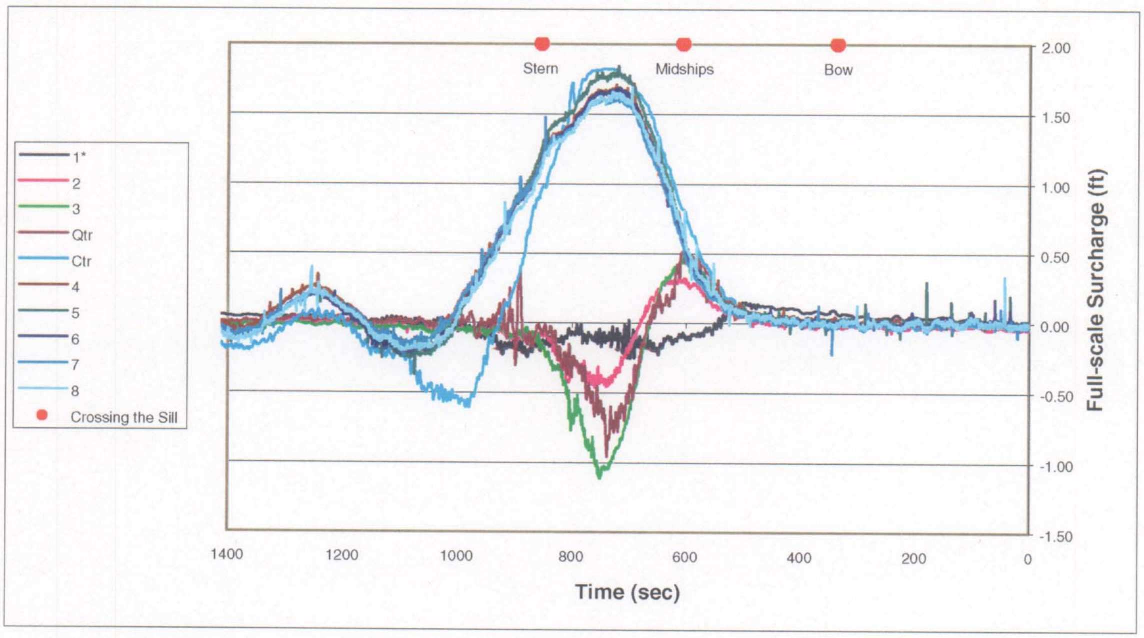
Water Surcharge – Entering Condition, 1.10 knots
Case I – Largest Clearance, Scale 29.8, Draft – 27 ft.



Water Surcharge – Entering Condition, 1.10 knots
Case II – Medium Clearance, Scale 31.4, Draft – 27 ft.



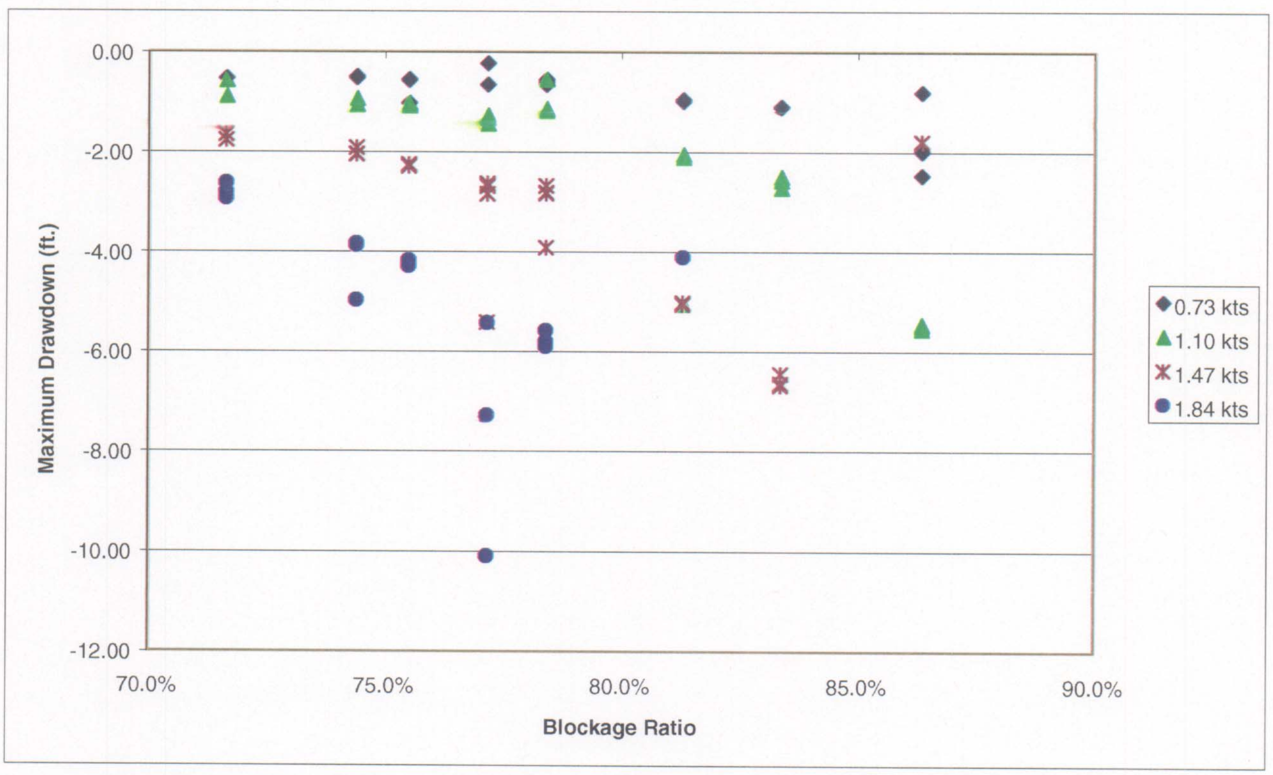
Water Surcharge – Entering Condition, 1.10 knots
Case III – Least Clearance, Scale 32.2, Draft – 29 ft.



Exiting Condition – Drawdown Results

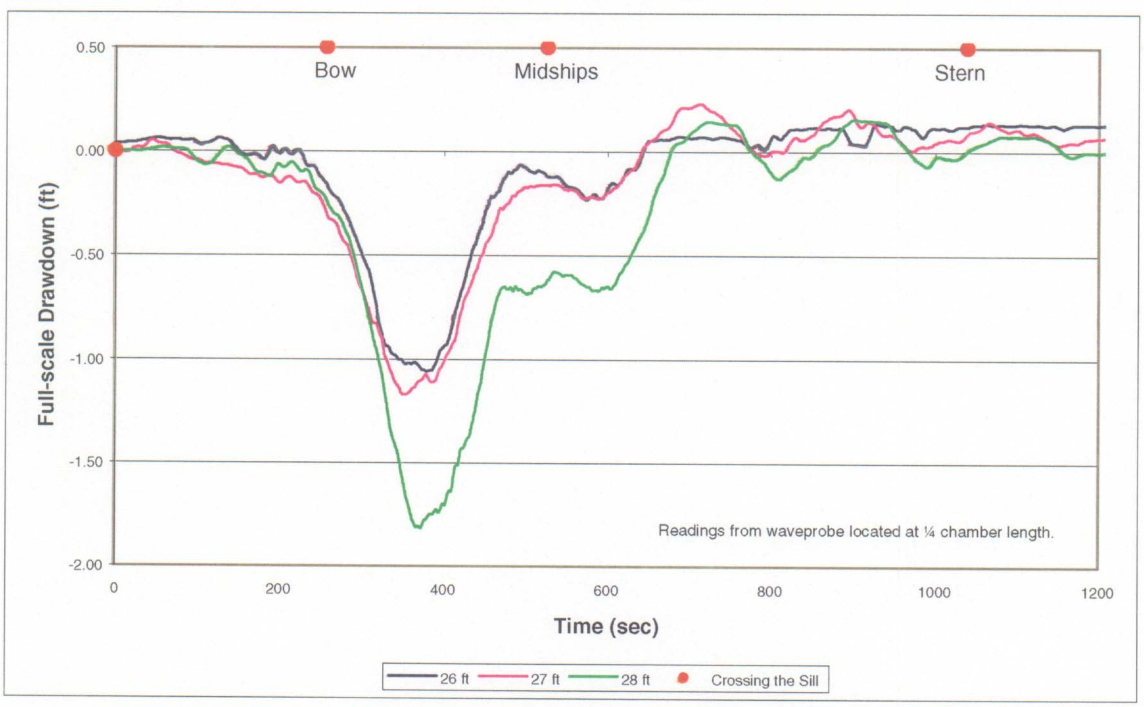
The graphs of drawdown during vessel exit operations are similar to the surcharge graphs for entering operations; both show a relationship between blockage ratio, exit speed and magnitude of the peak drawdown or surcharge. As blockage ratio increases, drawdown also increases because there is less area for the water to enter the chamber and replenish the volume of the exiting vessel. As was the case for the full-scale measurements taken in the Panama Canal, the data for the exit graphs shows more dispersion than the data for the entrance graphs. This is because the maximum drawdown is a more localized phenomenon than maximum surcharge. While the maximum surcharge was routinely at the closed end of the chamber with several sensors reading near maximum values, the maximum drawdown can occur anywhere from mid-chamber to the front sill and is highly dependent on vessel speed and position. Typical graphs of drawdown are shown below for the different clearance cases, more graphs are included in Appendix A.

Blockage Ratio vs. Maximum Drawdown
Cases I, II, and III

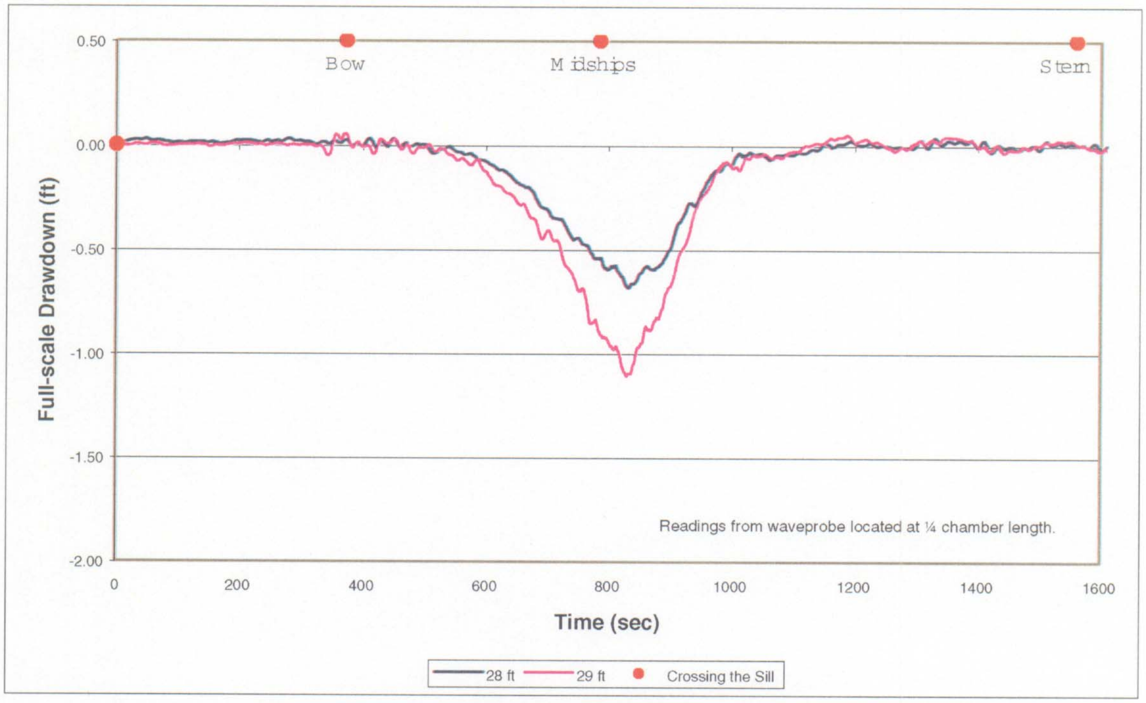


Water Drawdown – Exiting Condition, 1.10 knots
Case I – Largest Clearance, Scale 29.8

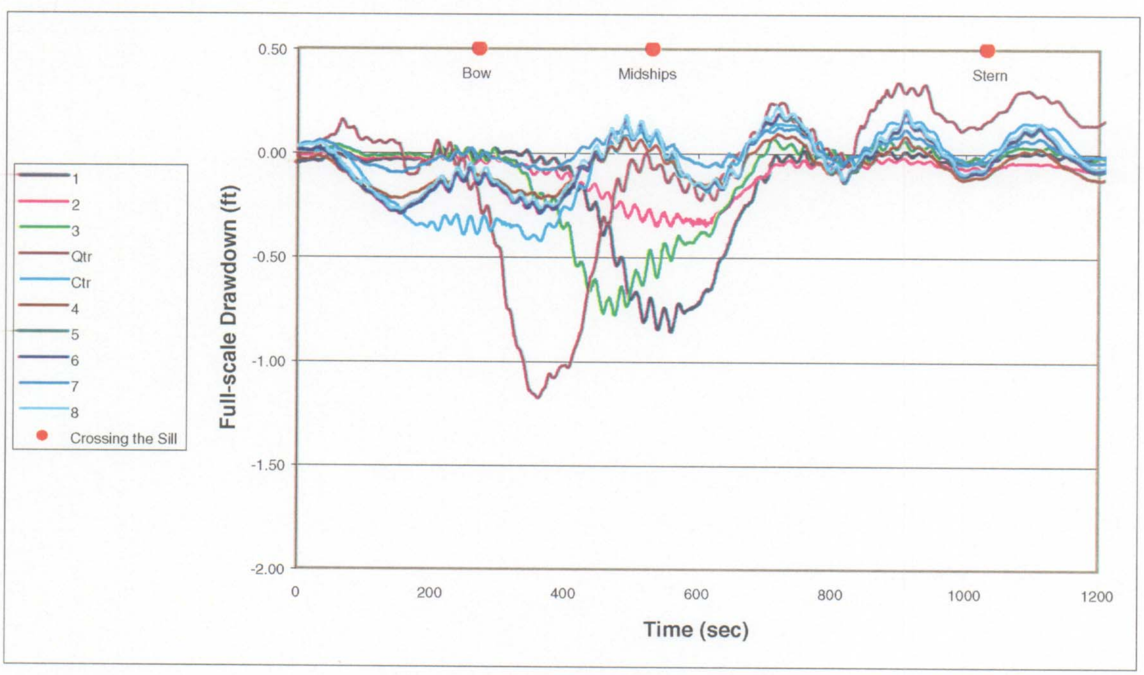
Water Drawdown – Exiting Condition, 1.10 knots
Case II – Medium Clearance, Scale 31.4



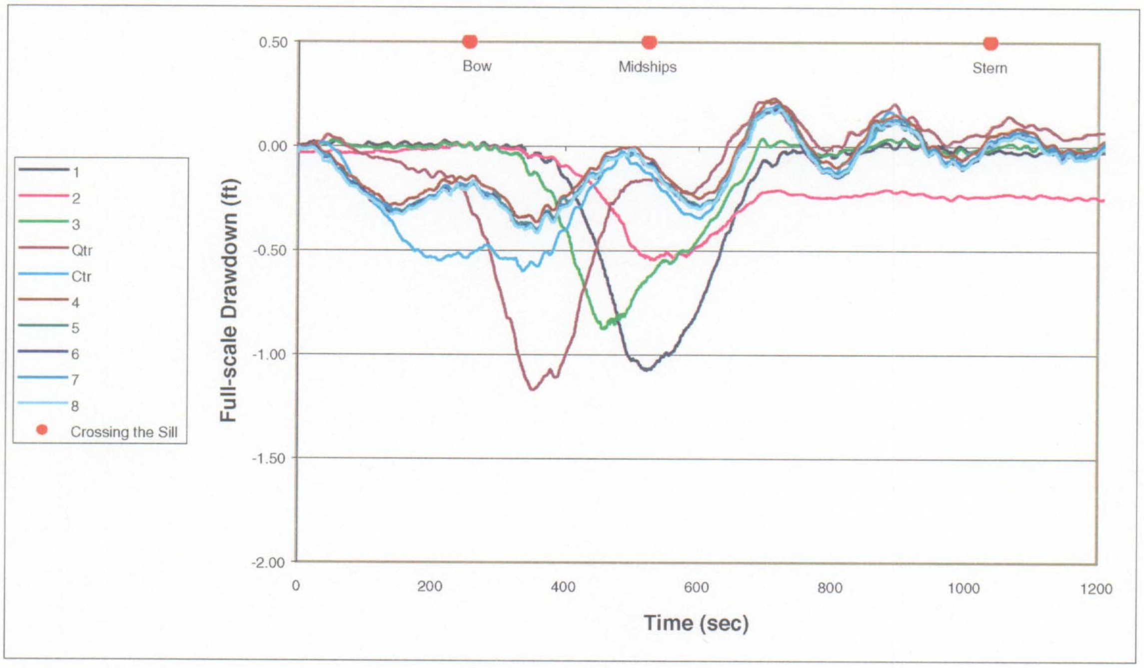
Water Drawdown – Exiting Condition, 0.73 knots
Case III – Least Clearance, Scale 32.2



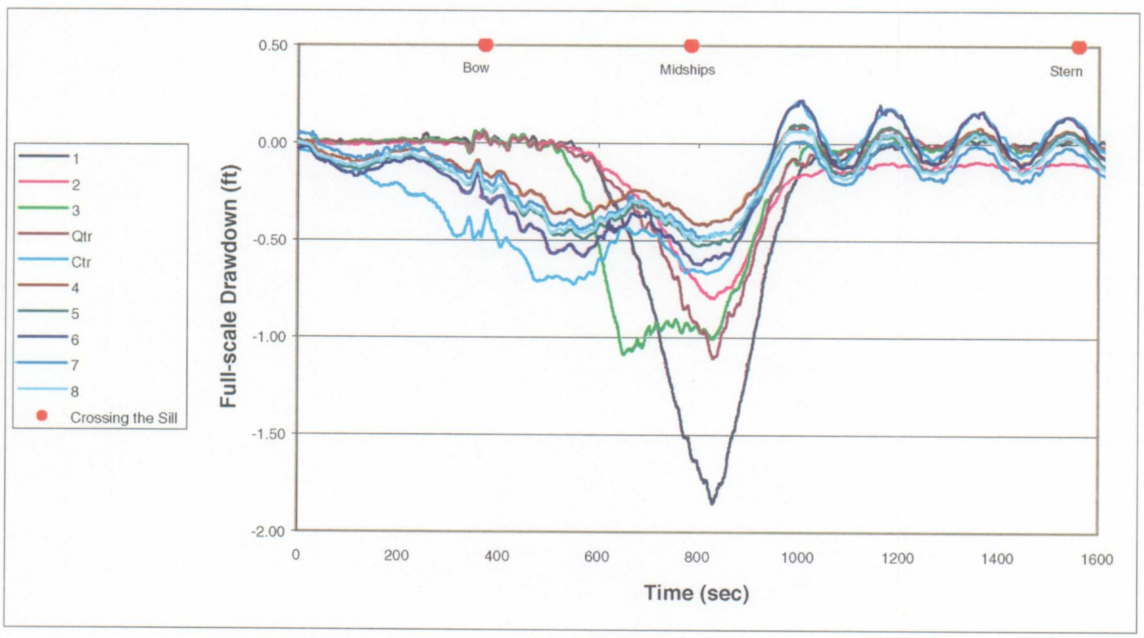
Water Drawdown – Exiting Condition, 1.10 knots
Case I – Largest Clearance, Scale 29.8, Draft – 27 ft.



Water Drawdown – Exiting Condition, 1.10 knots
Case II – Medium Clearance, Scale 31.4, Draft – 27 ft.



Water Drawdown – Exiting Condition, 0.73 knots
Case III – Medium Clearance, Scale 32.2, Draft – 29 ft.



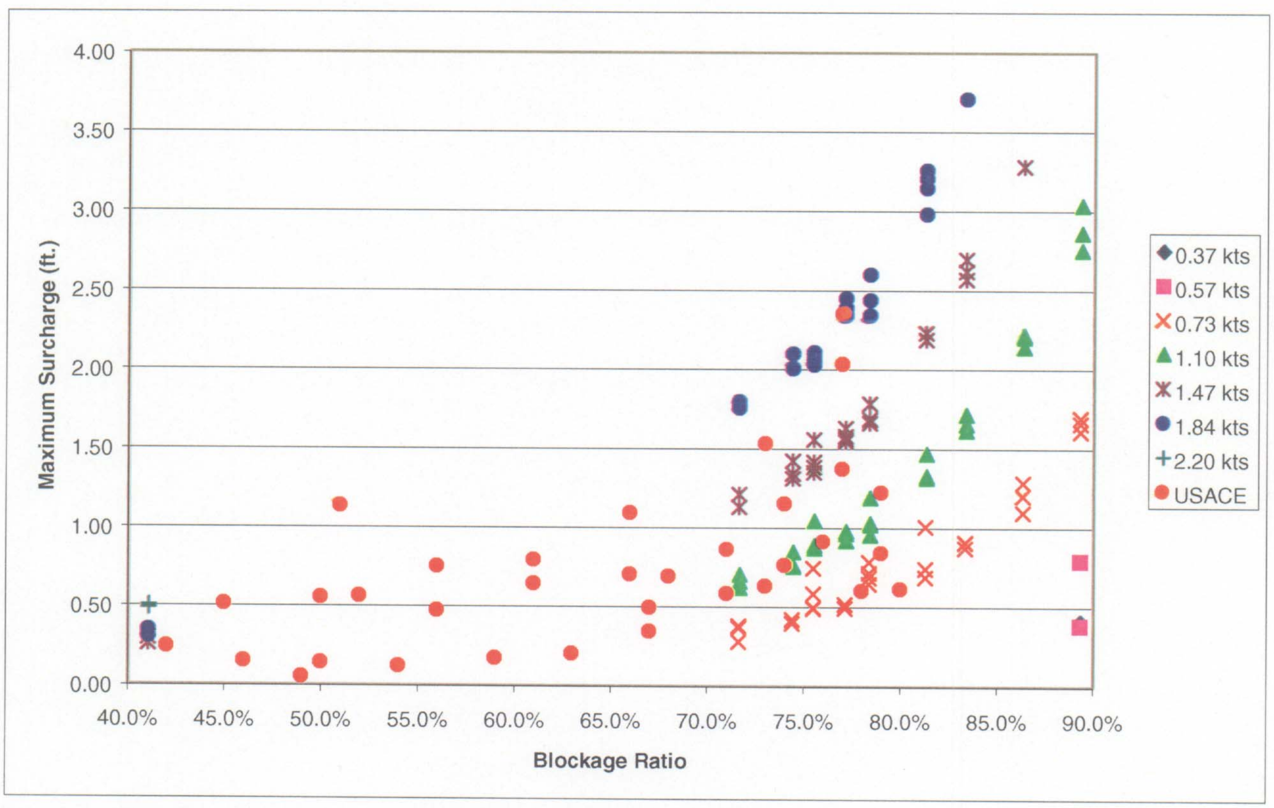
Correlation to US Army Corps of Engineers – Pittsburgh District Full-Scale Measurements

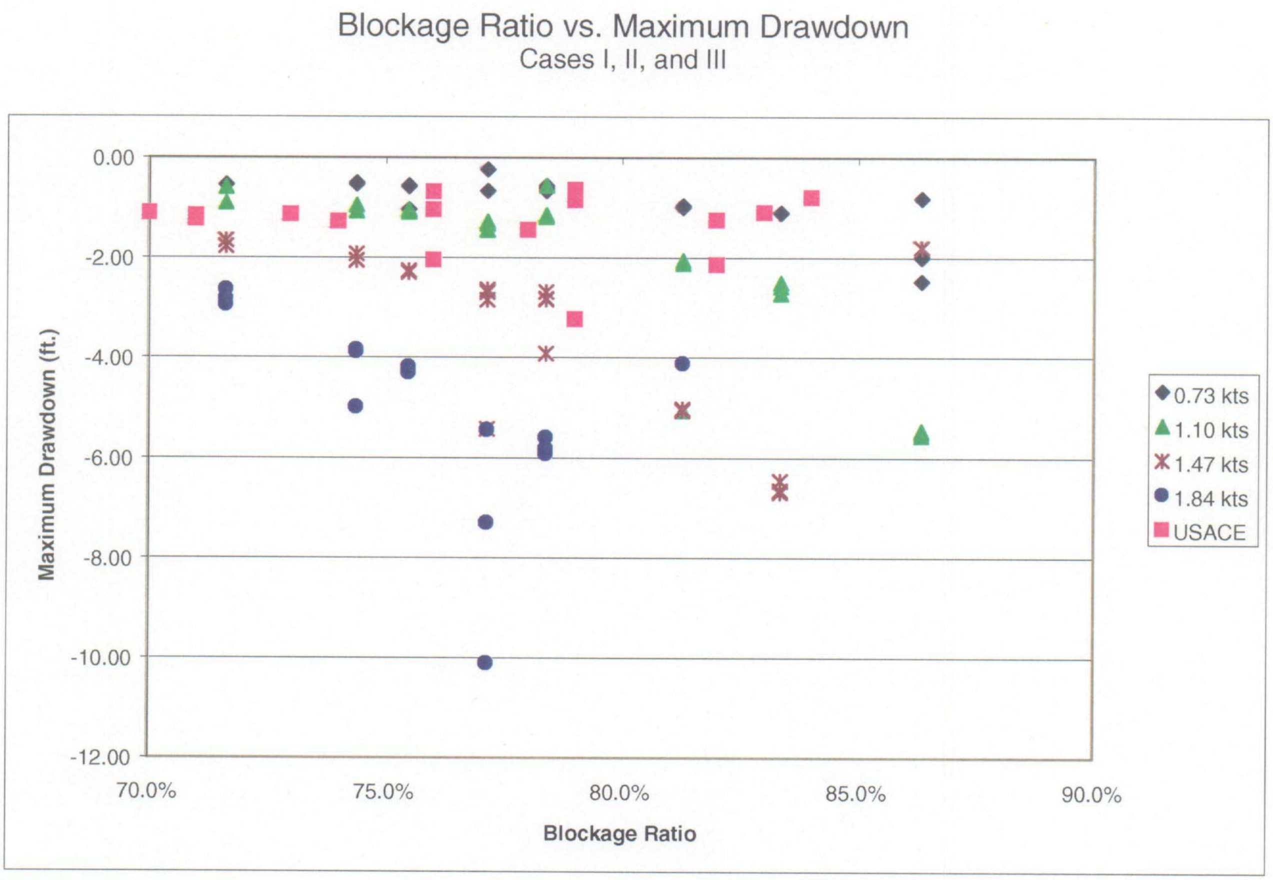
As part of the validation of the model testing, the model results were compared to full-scales measurements taken by the USACE-Pittsburgh District in April-1999. As the graphs below show, the measurements from both tests exhibit a very strong correlation. For surcharge, the full-scale results fall right in line with the general curves of model test data for blockage ratios between 40% and 70%. For the drawdown results, the full-scale tests fall within the scatter of model test data, although the magnitude of the drawdown is generally smaller than the model test results.

While the two sets of measurements are in general agreement regarding the magnitude of the surcharges and drawdowns, it should be noted that the model tests were unpowered. Therefore, the effects of propwash, and propeller circulation are not reflected, and the model tests were conducted at constant speeds with controlled accelerations and decelerations to deliver a constant speed across the sill. In the full-scale measurements the speed of the vessel changes as it enters or exits the locks and the vessel moves between deep and shallow water.

Blockage Ratio vs. Maximum Surcharge

Cases I, II, and III



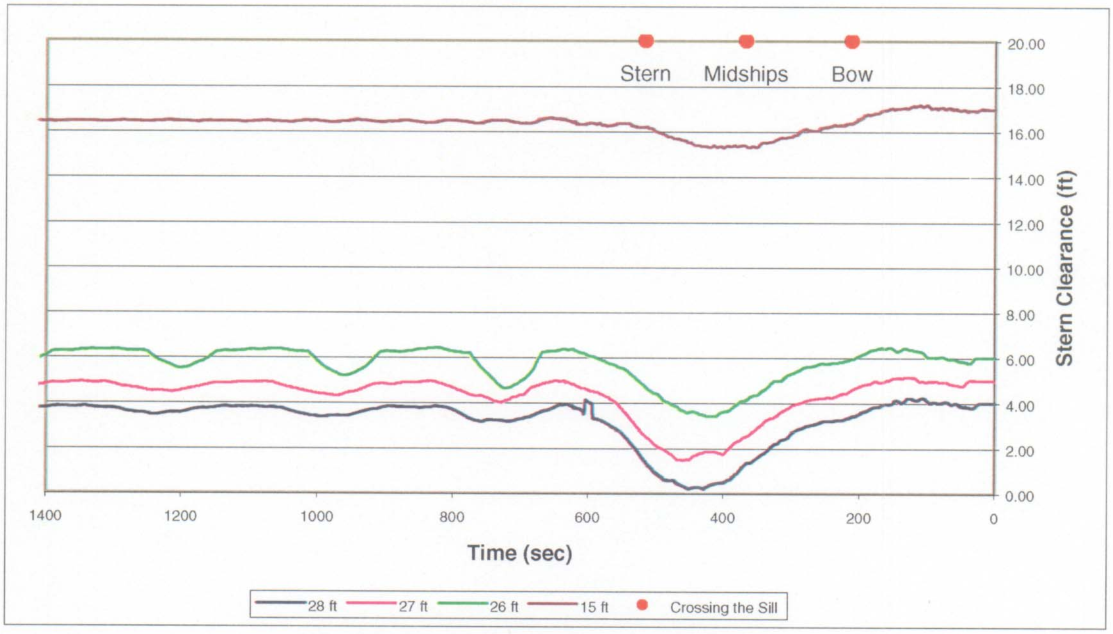


Heave Results and Stern Clearance

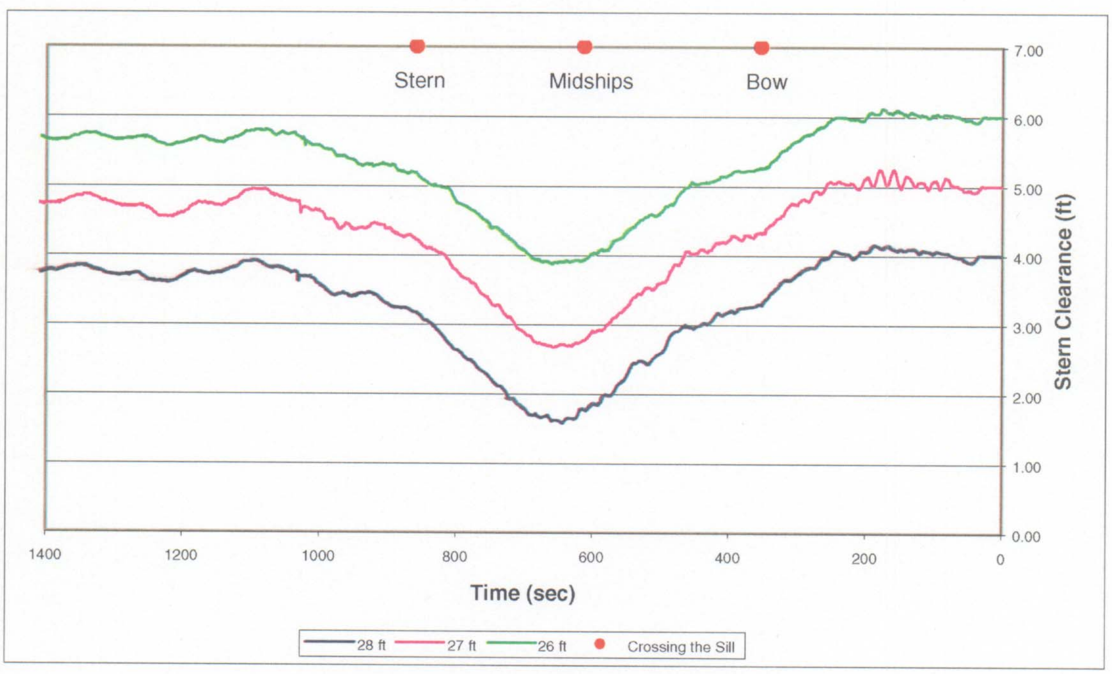
Another area of interest is the hydrodynamic performance of the vessel in a restricted waterway. Because the model tests were unpowered, the results are not a true reflection of what would happen under normal operating conditions – where the propeller circulation and propwash influence vessel pitch and squat. However, to provide a general indication, the model results are graphed below. Where available, the propeller wash was graphed, generally causing more noise in the data and marginally reducing the stern clearance.

It should be noted that the two data channels used to measure vessel motion (yo-yo pots on the bow and at the thrust bearing midships) also experienced the most difficulties during testing. These problems have been noted where appropriate on the graphs.

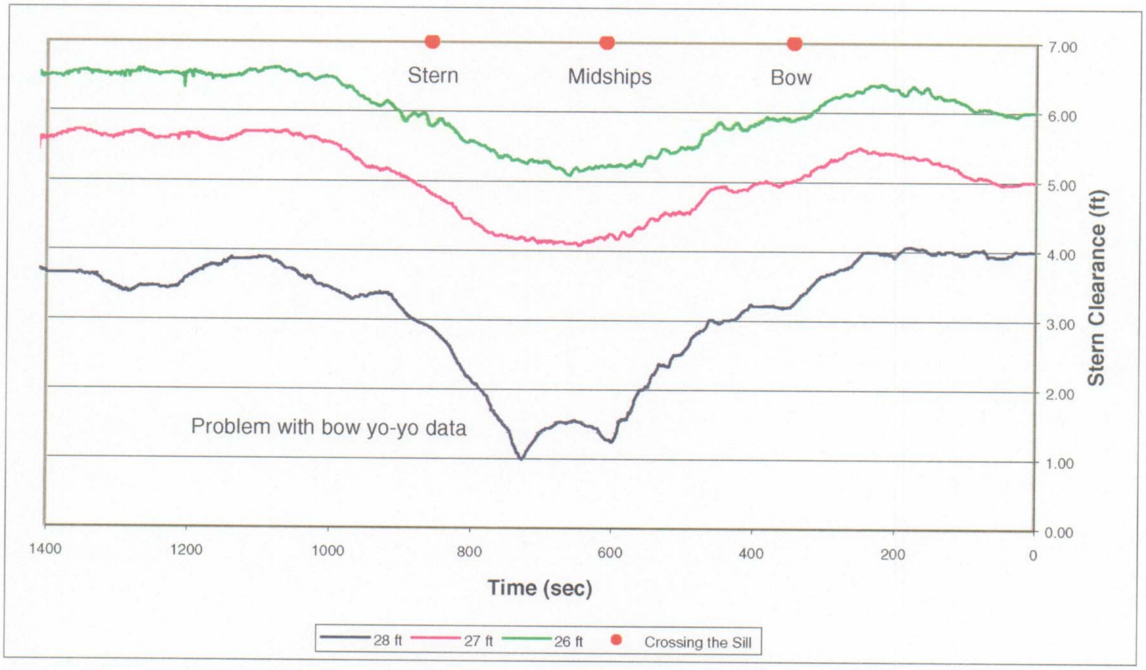
Stern Clearance – Entering Condition, 1.84 knots
Case I – Largest Clearance, Scale 29.8



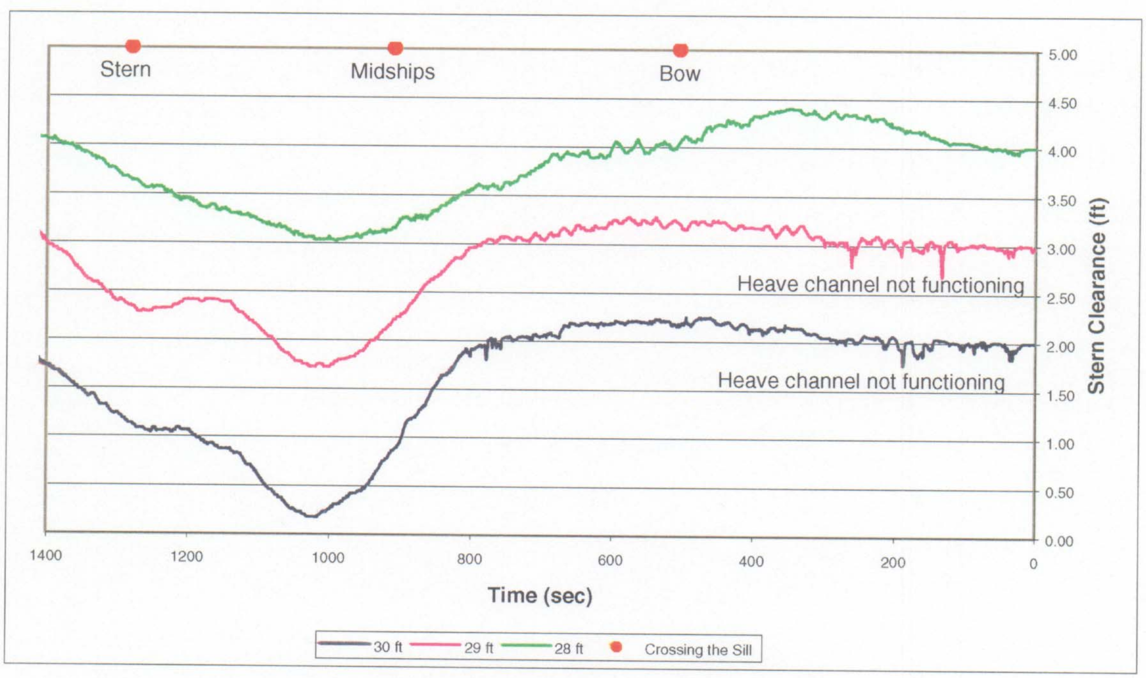
Stern Clearance – Entering Condition, 1.10 knots
Case I – Largest Clearance, Scale 29.8



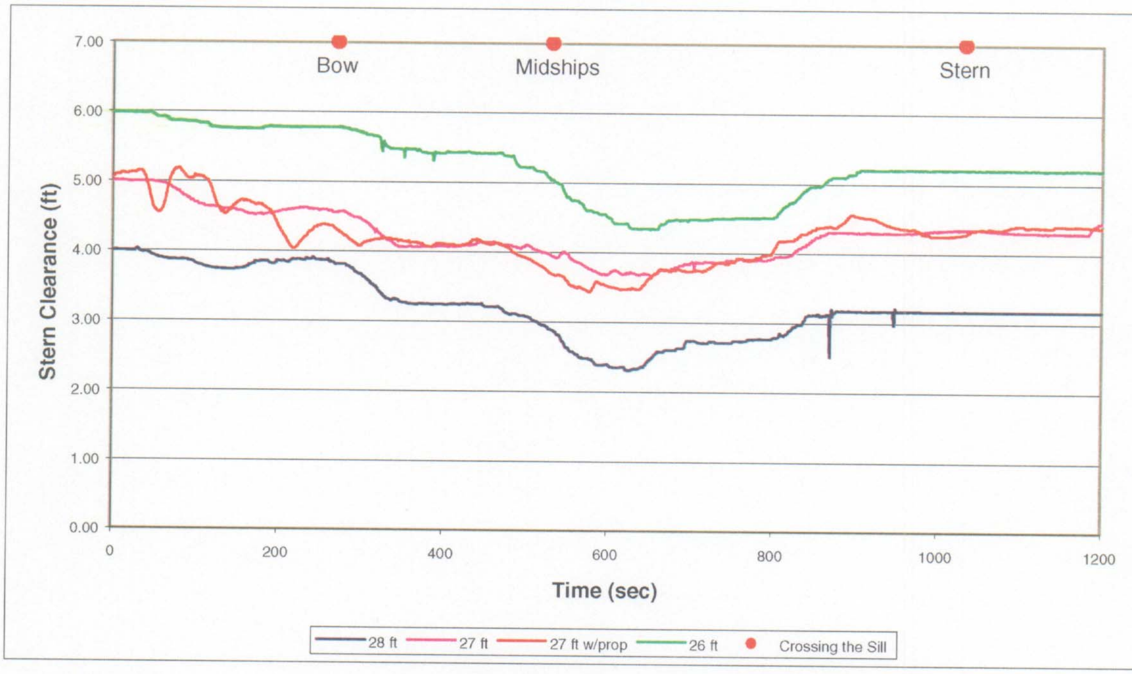
Stern Clearance – Entering Condition, 1.10 knots
Case II – Medium Clearance, Scale 31.4



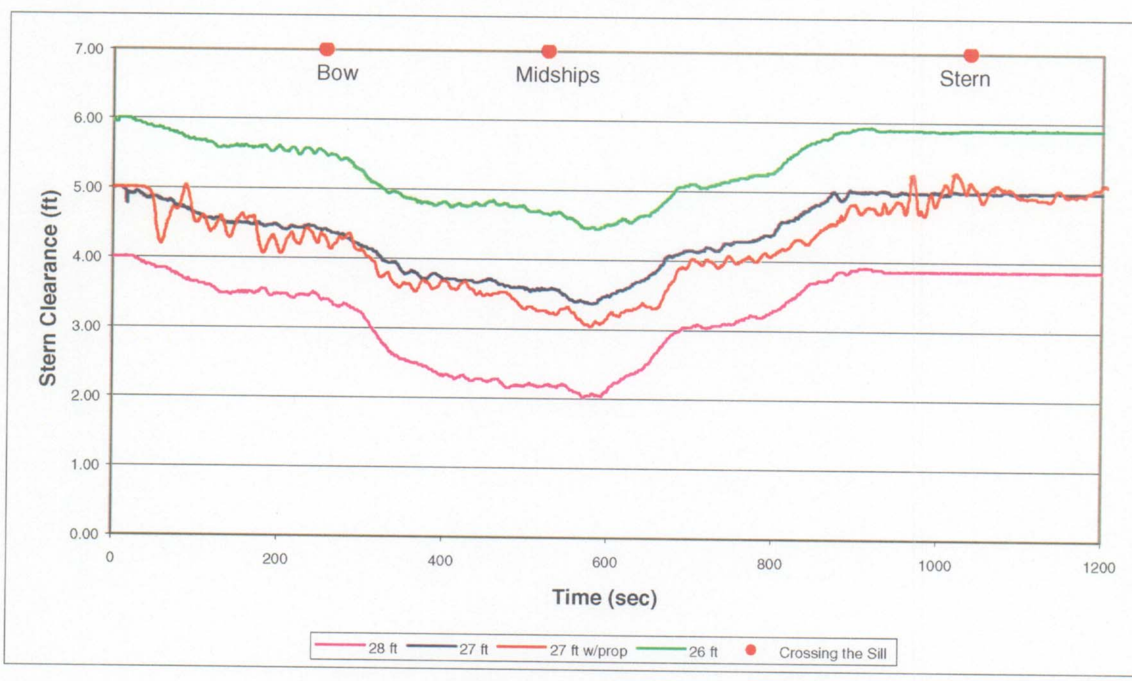
Stern Clearance – Entering Condition, 0.73 knots
Case III – Least Clearance, Scale 32.2



Stern Clearance – Exiting Condition, 1.10 knots
Case I – Largest Clearance, Scale 29.8

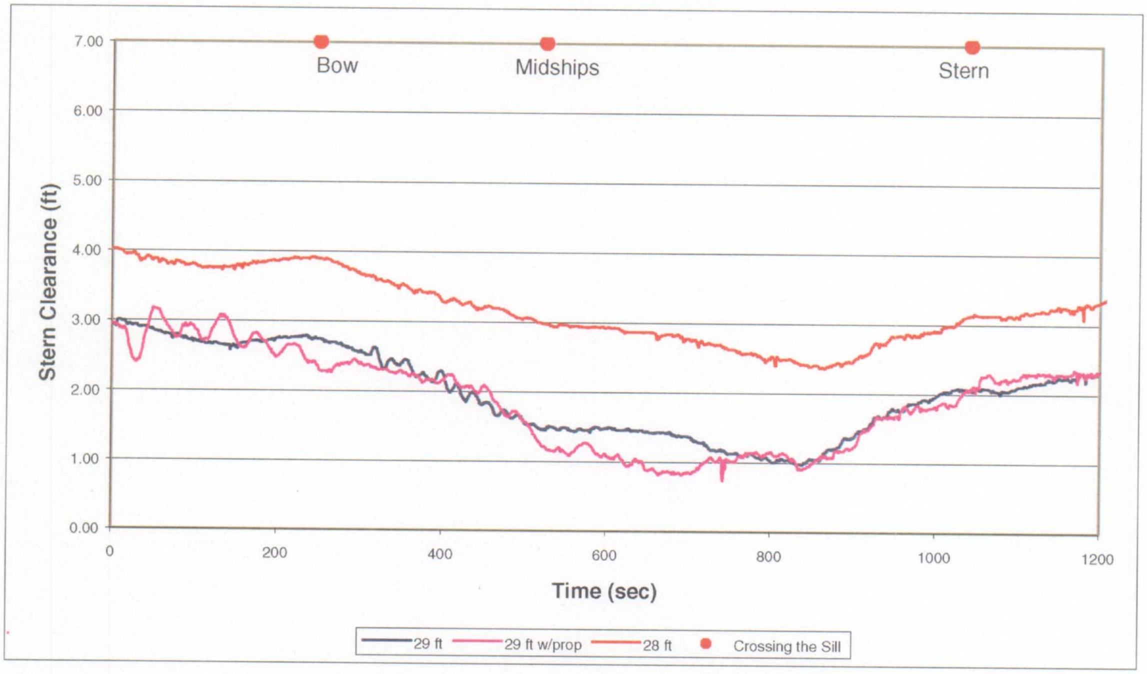


Stern Clearance – Exiting Condition, 1.10 knots
Case II – Medium Clearance, Scale 31.4



Saltwater Intrusion

Stern Clearance – Exiting Condition, 1.10 knots
Case III – Least Clearance, Scale 32.2



Saltwater Intrusion Analysis

The PCC contracted the US Army Corps of Engineers Waterways Experiments Station (WES) to analyze how adding Canal capacity would affect the salinity of Lake Gatun, which is the freshwater source for most of Panama. The study by WES reviewed traditional locks, locks with holding ponds for water re-use, and a Syncrolift system. Any system proposed by Syncrolift needed to address and incorporate the findings from the WES study.

One of the primary advantages of the Syncrolift system is the ability to transit the 25.9m elevation change in one step, thereby eliminating the maneuvering time required for moving between locks in a multi-step system. Unfortunately, transiting the 25.9m in one step also means that the Syncrolift chamber will deliver undiluted saltwater directly into Lake Gatun and/or Gaillard Cut.

A series of computations performed by WES calculated the final salinity of Lake Gatun under different operating scenarios. The computations considered the amount of saltwater delivered into Lake Gatun by the Syncrolift and ongoing Canal operations, and the historical freshwater inflows into Lake Gatun which would dilute the saltwater and reduce the overall salinity. The results of the different scenarios are shown below. As a reference point, the salinity limit for drinking water is 0.250 parts per thousand (ppt).

Scenario	Final Lake Gatun Salinity	Reaches Equilibrium
1. 38 lockages per day, conventional lock operations, no Syncrolift	0.030 ppt	5 years
2. 38 lockages per day, conventional lock operations, 20 lockages/day on Syncrolift w/ 35 ppt in chamber (standard seawater)	1.750 ppt	7 years
3. 38 lockages per day, conventional lock operations, 20 lockages/day on Syncrolift w/ 4.5 ppt in chamber	0.250 ppt	7 years
4. 38 lockages per day, conventional lock operations, 20 lockages/day on Syncrolift w/ 0.300 ppt in chamber	0.042 ppt	6 years

Testing of the seawater outside the lower pool gates measured an average salinity of 10 ppt. So for example, Case 3 – with saltwater of 4.5 ppt in the chamber, would require 55% of the saltwater to be captured and removed to keep the salinity levels of Lake Gatun within drinking water standards. However, with the current salinity of Lake Gatun being virtually zero, and 0.250 ppt being technically drinkable but highly undesirable, the PCC felt that a salinity increase to 0.250 ppt would be unacceptable. Case 4 was created which allows a 40% increase in salinity over existing levels, from 0.030 ppt to 0.042 ppt, but still remains well below the 0.250 ppt drinking water limit. To achieve a 0.300 ppt salinity in the chamber for Case 4, 97% of the saltwater would have to be captured and removed.

One method considered for resolving the issue was a saltwater sump built directly in front of the Syncrolift gates at the upper pool. When the chamber is at the upper pool and the gates open, the saltwater would flow out of the chamber and into the sump where it could then be drained from the system. However, there are two factors which make the sump solution undesirable:

1) the size of the sump required to capture such a large volume of saltwater would significantly increase the cost and construction requirements

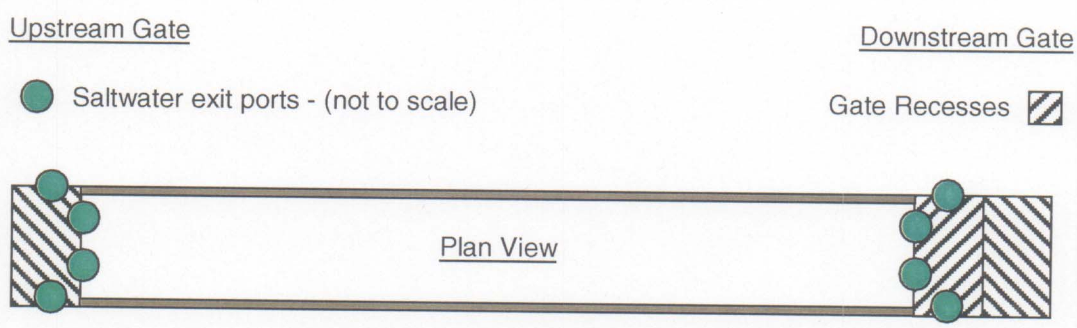
2) the freshwater required to operate the system would exceed the amount of freshwater used if the ships were passed through the existing locks. This is due to the mixing that occurs at the freshwater/saltwater interface, creating a much larger volume of diluted saltwater solution that needs to be drained and replaced with freshwater.

In order to be feasible, a more efficient system for capturing the saltwater was devised.

The new system takes advantage of the density differences between saltwater and freshwater, and uses the gate recesses in the chamber as natural sumps for draining the saltwater. Four drain ports are located in the gate recesses at each end of the chamber. After the chamber is sealed at the upper pool, the drain ports are opened followed by the upstream chamber gate. The gate is lowered until the upper surface of the gate is 1.5m below the water surface and stopped. As saltwater drains out the bottom of the chamber, it is replaced by freshwater flowing in over the top of the gate. Because of the density difference of saltwater and freshwater the mixing is minimized, and no saltwater is released from the chamber.

The ports and gate opening are sized to control the inflow of freshwater so the vessel in the chamber is not disturbed. The inflow area created by partially opening the upstream gate can also be achieved by designing sluice ports into the top of the gate. The saltwater mitigation system will be modeled numerically and tested during Phase II of the study.

Although some freshwater will be used to operate the system, it will still generate a savings of 65%-75% compared to the existing locks. The savings is a result of the chambers smaller size, approximately 50% of the size of the existing locks, and the fact that freshwater is required only during the lift portion of the transit. For the lowering cycle, the flow of saltwater at sea level is irrelevant. A graph of the freshwater savings is shown on page 22 in the discussion of simulation model results. A sketch of the system is shown below.



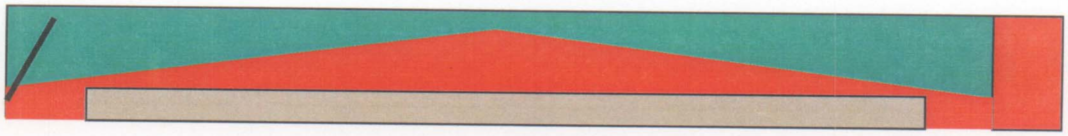
Saltwater Outflow

Number of exit ports	8
Port diameter (m)	0.84
Exit area (sq m)	4.41
Depth of Ports - center (m)	10.59
Discharge Velocity (m/s)	13.69
Discharge Rate (cu. m/s)	60.46
Avg. Exchange Time (min)	14.1

Freshwater Inflow

Gate Weir Depth (m)	1.52
Entrance Area (sq. m)	40.41
Water Entrance Velocity (m/s)	1.49

Elevation View



Proposed Operational Procedure

- Start with chamber sealed and water levels equalized
- Open drain ports – to be determined whether all at once, or progressively
- Open upstream gate so that the upper edge is 1.5m below the water surface (this can also be accomplished by designing sluice ports into the upper edge of the gate)
- Complete saltwater exchange without exceeding water inflow velocity of 1.83 mps

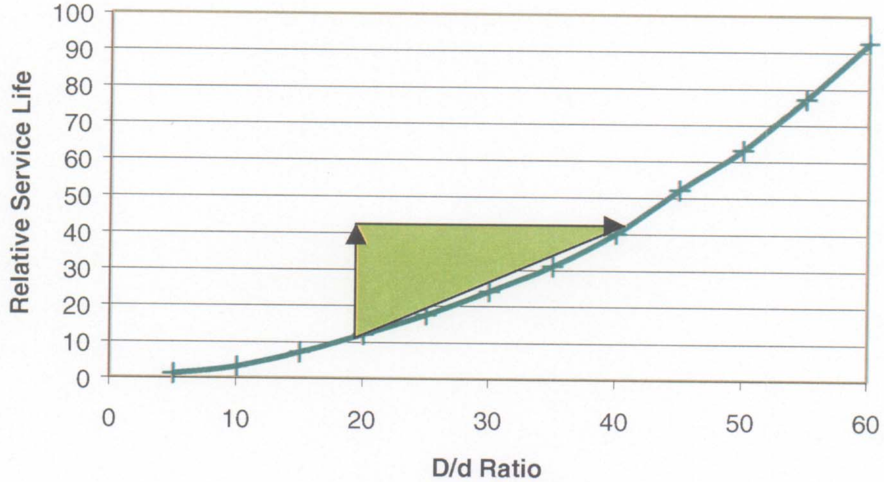
Wire Rope Study

One of the primary design considerations since proposing a Syncrolift type chamber-lift for the Panama Canal has been the performance of the wire rope. For a typical Syncrolift application, a shiplift may perform 200-300 cycles per year (although some installations have completed over 2,000 dockings in one year). By comparison, the lift proposed for the Panama Canal will cycle 7,000 times annually, operating 24 hours a day, 7 days a week. To make the operation practical, and to reduce downtime, the wire rope needs to have a minimum service life of 7 years.

To ensure the selection of a wire rope with the appropriate characteristics and performance, Syncrolift engaged the services of Bridon International, a world leader in the design, manufacture and supply of wire rope, to recommend the best type of rope construction. Under ordinary circumstances, fatigue life estimates for large diameter wire ropes are determined theoretically by extrapolating from the results of much smaller diameter ropes, which are easier to handle and test. Because the fatigue life plays such a critical role in this application, Bridon agreed that the best solution was to conduct full-scale (or as close to full-scale as practical) fatigue tests to validate performance.

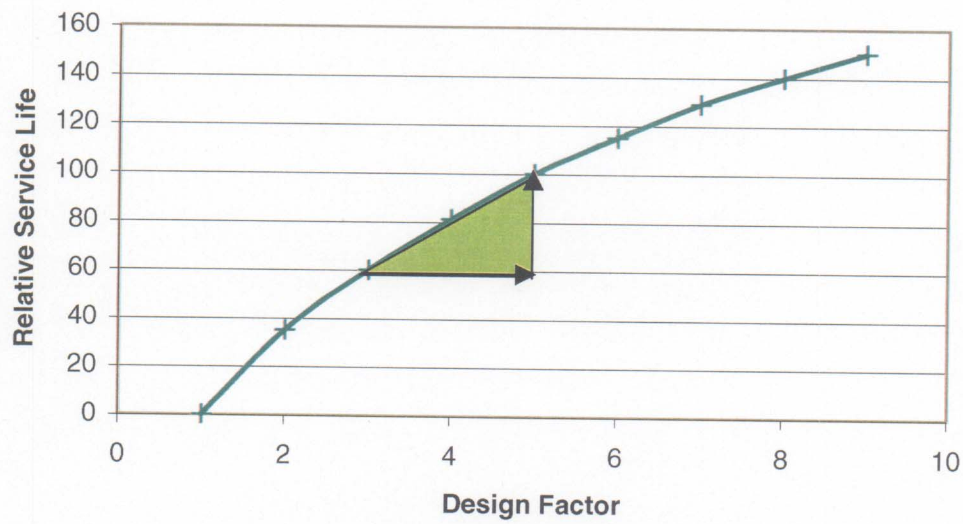
In addition to the construction of the rope itself, there are other design parameters that affect the rope fatigue life. Two of these factors are the D/d ratio – the ratio of the sheave diameter to the rope diameter, and the design factor – commonly referred to as the factor of safety. The D/d ratio is a measure of the bending radius the rope will see during operation. The smaller the D/d ratio, the tighter the bend. Tighter bends produce more stress on the rope which in turn reduces rope life. On a typical Syncrolift, where rope fatigue is usually not an issue, the D/d ratio is between 20-30. For the Panama Canal, the D/d ratio has nearly doubled to 40-50. The general impact of D/d ratio on rope life is shown below.

Wire Rope D/d Ratio vs. Relative Service Life



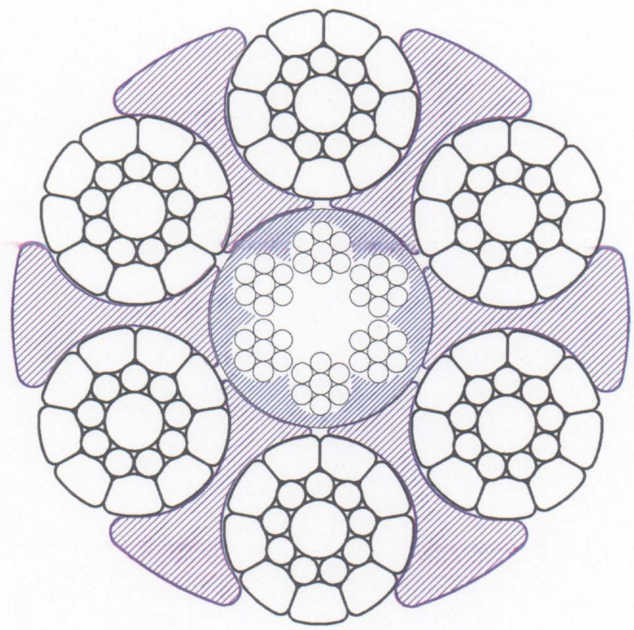
Formerly called the factor of safety, the design factor is specified by regulatory agencies based on the type of service the equipment will provide. For a typical Syncrolift shiplift, a design factor of three is standard. For the Panama Canal, however, a design factor of five will be used in accordance with other industrial machines and applications that are allowed to transport personnel. The impact of design factor on rope service life is shown on the graph below.

Design Factor vs. Relative Service Life

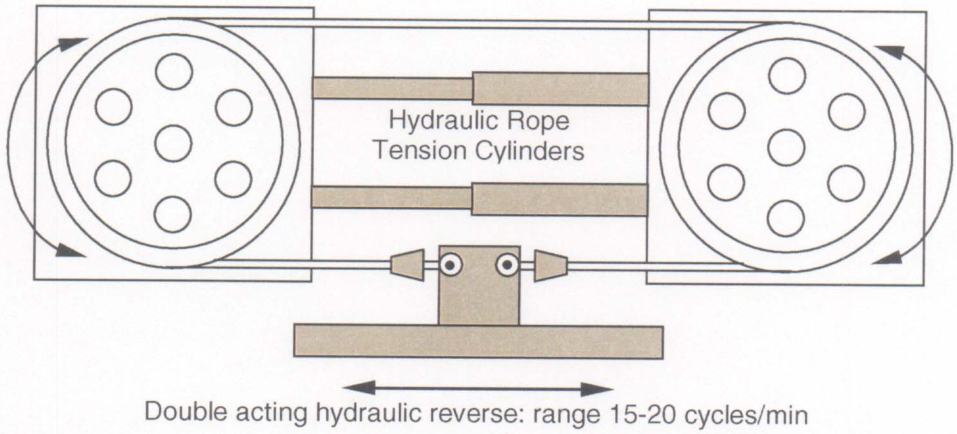


Taking these revised design factors into account, Bridon began the project with a preliminary database study of existing ropes and fatigue performance to determine the best type of rope construction for this application. It became apparent early on that a standard all-wire rope construction would not be able to withstand the rigorous demands of this application while providing the required fatigue performance unless an enormous drum and sheave diameter were used. An alternative to all-wire construction is a rope with a specially engineered plastic covered core. The plastic covered core prevents the strands from fretting against one another as the rope is worked, thereby extending the working life of the rope. Bridon has taken this design one-step further, with a special rope referred to as "Zebra" rope, which has plastic filler not only at the core, but also in the outer layer as well. By including the filler on the outer layer, the fretting of strands against one another is further reduced, and there is a smoother rope topography. The smoother topography reduces the contact stresses and wear at the sheave groove, and provides a smoother bending action at the sheave which will reflect in a reduction of the high-frequency stress ripples during lift/lower operations. A cross-sectional diagram of the rope is shown below.

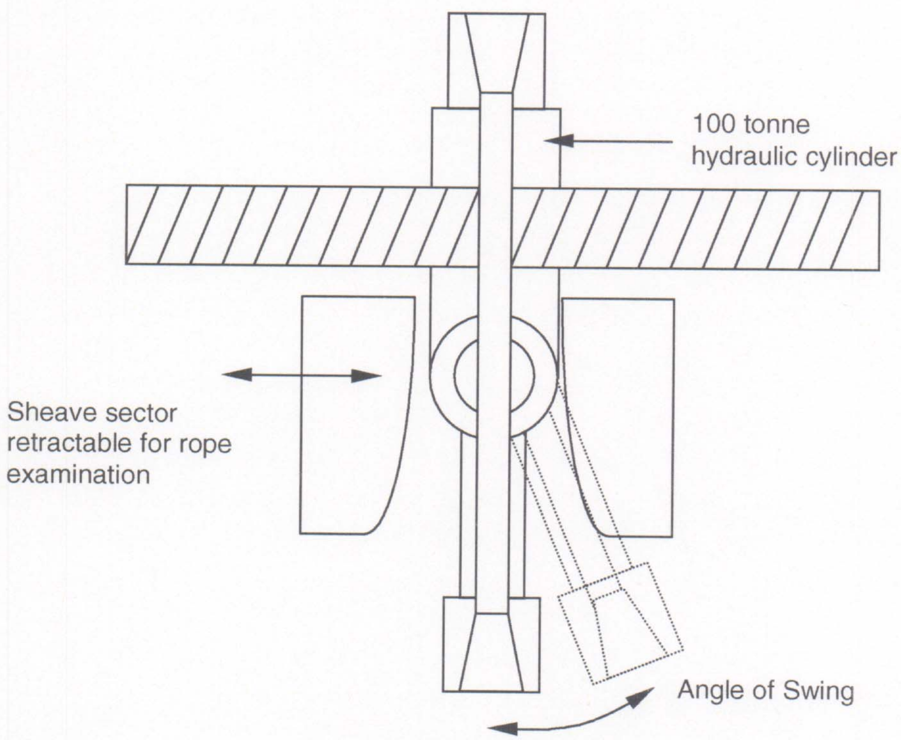
Bridon's "Zebra" Rope



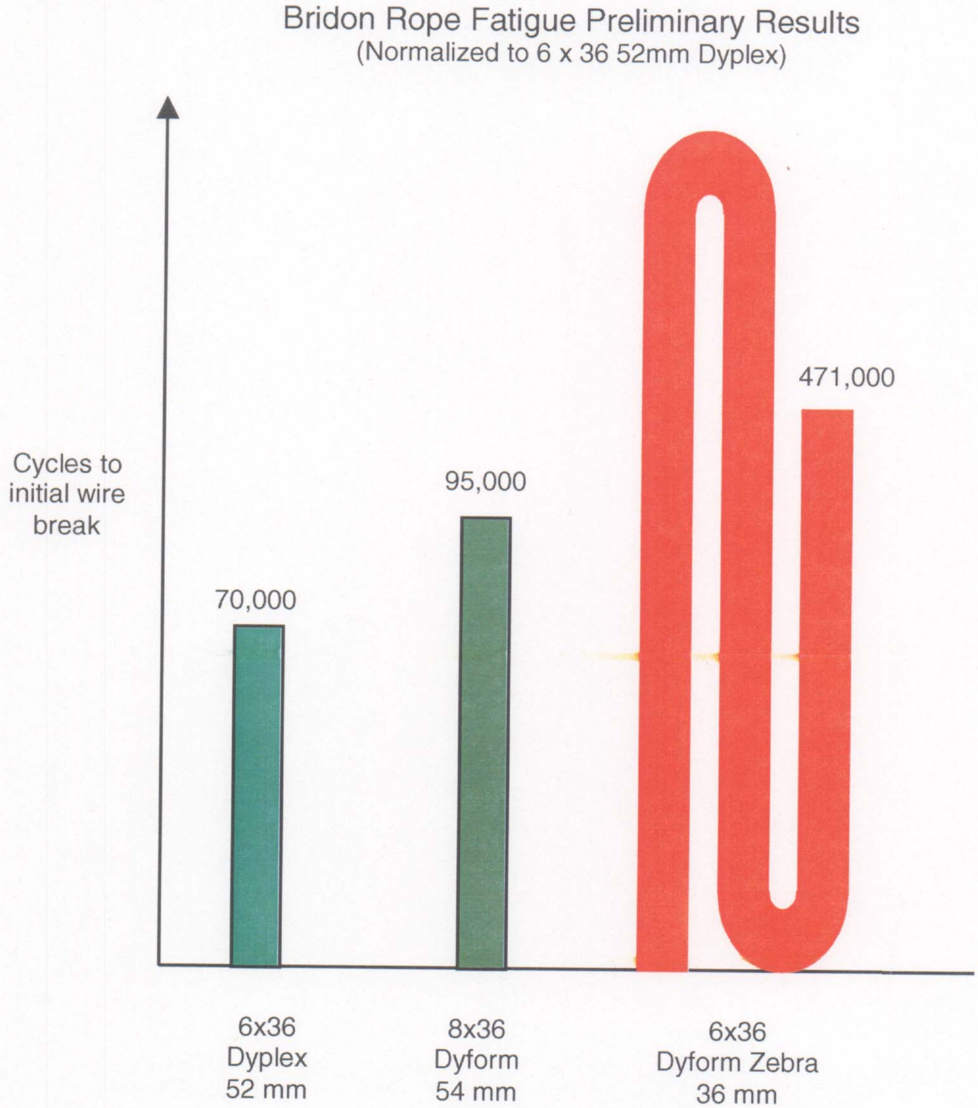
The rope tests are being carried out in two phases on two different types of machines. The first phase uses a conventional two-pulley type, 50-ton machine (see diagram below). The 50-ton machine tests a single rope sample (length about 7m) reeved around the sheaves and terminated at an intervening platform which is hydraulically actuated to provide a reciprocating action. One of the sheaves is hydraulically movable to apply and maintain a pre-set tension of up to 25 tons in each leg of the rope. Sheaves up to 1.25m can be accommodated. The speed of the reciprocating actuator is load dependent, but typically operates in the range of 15-20 cycles/minute. Because of the limitations on the sheave diameter, this machine is used for the initial sorting tests to determine the best types of construction for this application.



The full-scale testing will be done on a specially designed 100-ton capacity machine developed for testing larger ropes under a realistic working tension. The machine is based on a pendulum principle so that only a small length of rope is required (see diagram below). One end of the sample is anchored to the bottom of the pendulum, then taken over a fixed bending shoe (representing a segment of a sheave) and through a hollow loading cylinder to the upper termination. After the rope has been tensioned, the lower end of the pendulum is cycled back and forth (30 cycles/min), causing the rope to bend on and off the grooved profile of the shoe. There is also a retractable shoe on the opposite side which can be engaged if testing of reverse bending is required. For the 100-ton machine, rope diameters of 63mm and sheave diameters of 4m can be accommodated.



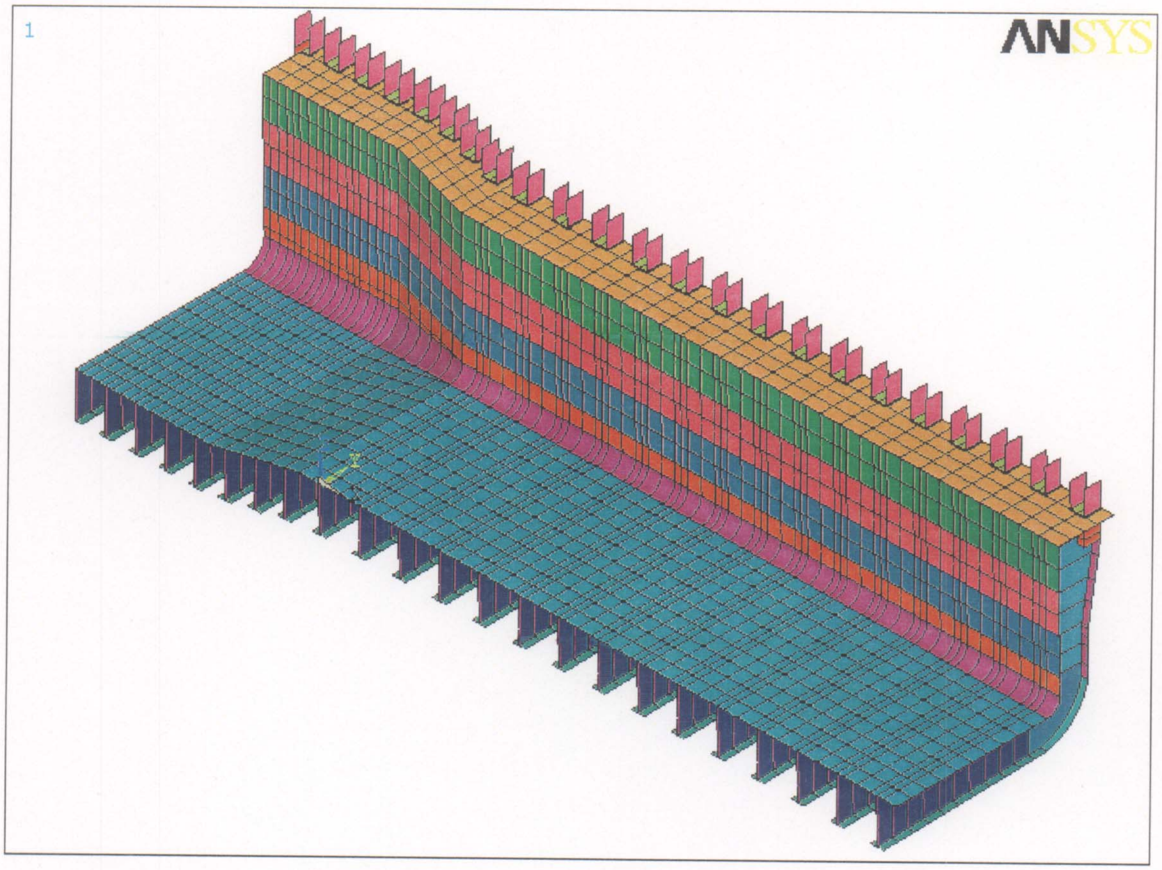
So far, as the graph below shows, the testing of the zebra rope on the 50-ton capacity machine has exceeded all expectations for fatigue performance. While it is expected that this five-fold advance in fatigue life will be reduced as the rope diameter increases, it will still provide a significant advance in performance over other products.

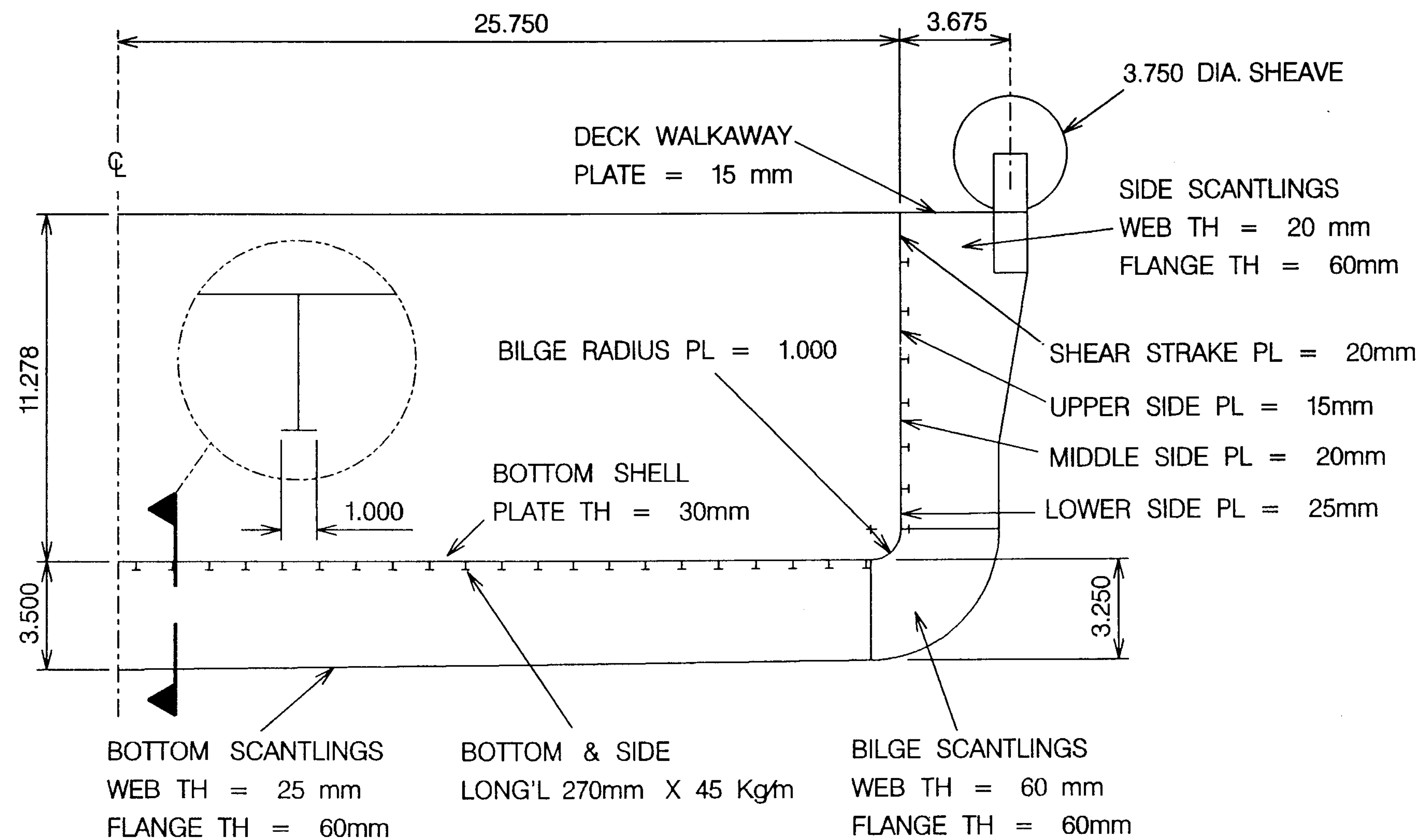


Although testing is behind schedule due to the extraordinary performance of the zebra rope, the preliminary results show that a 7-plus year rope life should be well within reach using zebra rope. Bridon will continue testing to confirm and finalize the fatigue performance results on larger diameter samples in the 100-ton capacity machine.

Preliminary Chamber Framing Design

As part of the preliminary design process, a static Finite Element Analysis (FEA) model was done to confirm the weight estimate for the chamber, which plays a critical role in determining throughput. The model results calculated the chamber weight to be 16-19% of the water weight, well within the current estimate of 25%. Phase II of the study will analyze the chamber under dynamic conditions and adjust the structure accordingly. A picture of the computer model is shown below, and the preliminary structural layout and framing is shown on the following page.





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Conclusions

Based on the progress to date, the Syncrolift system is an effective means of providing additional capacity for the Panama Canal. Sized to handle almost 50% of the existing traffic, the Syncrolift system is nearly equivalent to adding another full-size lane, but with a shallower draft that would not be affected by el Niños, or other conditions where freshwater is in short supply. Despite the freshwater usage for mitigating saltwater intrusion, the Syncrolift system is still the most effective alternative for conserving freshwater, offering a 70% savings over the existing locks.

To confirm the Syncrolift system as a practical alternative to traditional locks, there are several assumptions from Phase I that should be validated through further study.

1. Approach Channels – Because the Syncrolift system depends on two-way operations for its efficiency, the channel layouts and operating procedures should be considered and discussed to realistically determine their impact on vessel processing times, and to ensure practical implementation.

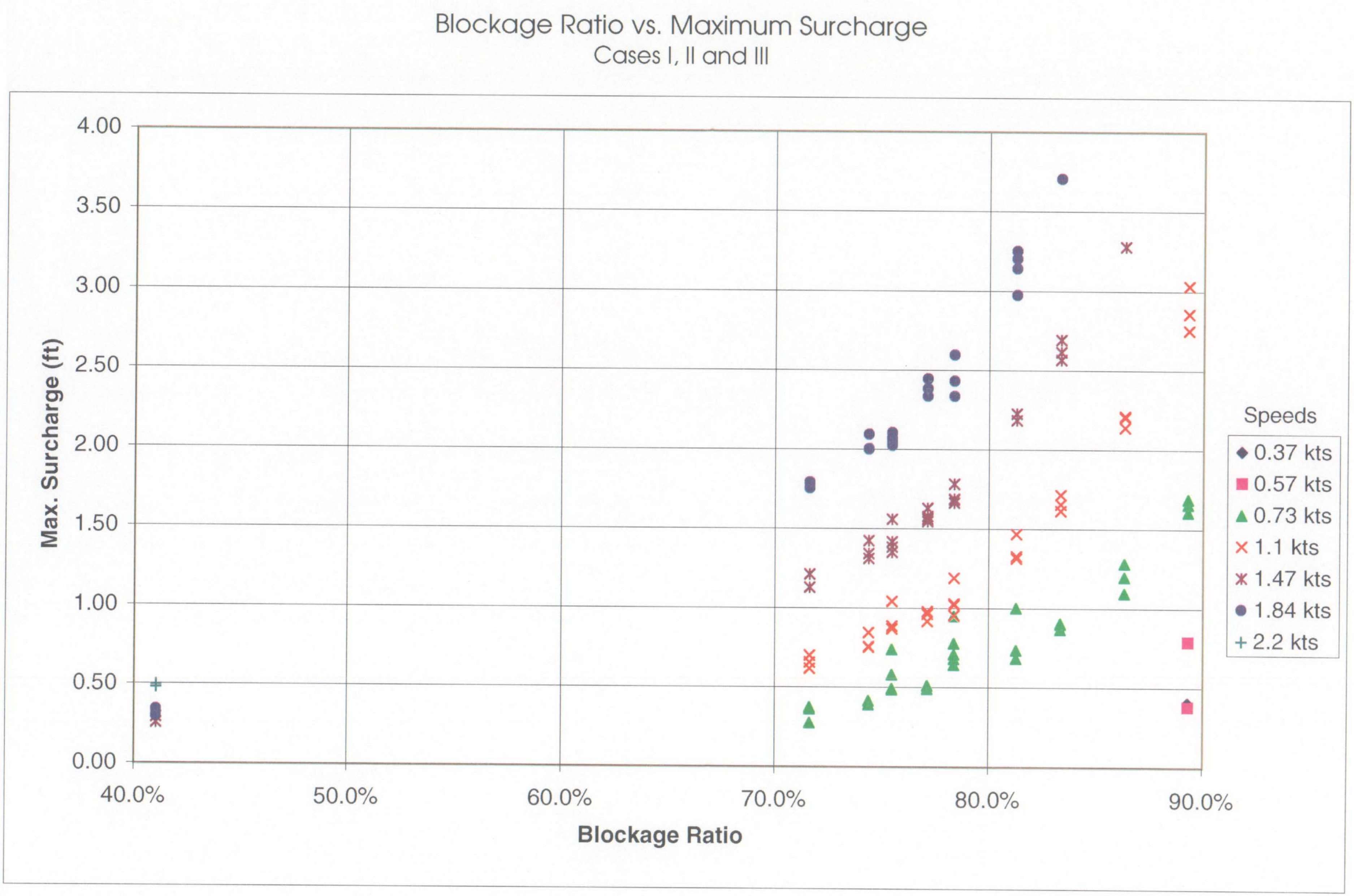
2. Saltwater Intrusion – The saltwater mitigation system should be modeled to determine the effect on processing times and validate freshwater usage assumptions. This will be done during Phase II of the study.

3. Lift/Lower Times – The current model lifts and lowers at the same speed. Further investigations should determine if the system can lower at a faster rate, and the associated impact on vessel processing times.

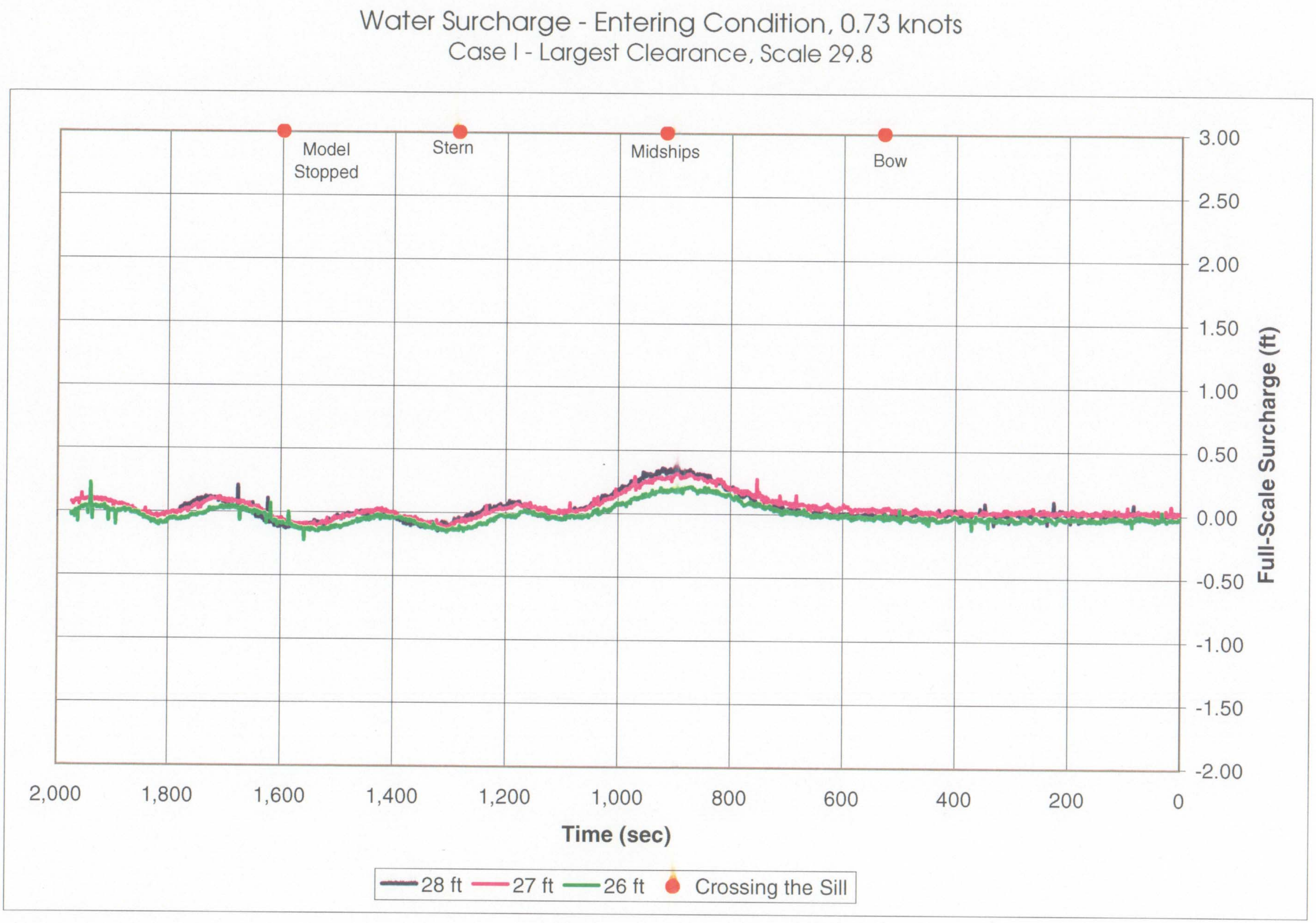
Phase II of the study will provide information regarding lifecycle costs and civil requirements, plus additional work on the design of the hoists, chamber, and gates. Once complete, there should be sufficient information to conclusively determine the feasibility, and viability, of proceeding with a Syncrolift system design to provide additional capacity to the Panama Canal.

APPENDIX A

Appendix Table of Contents

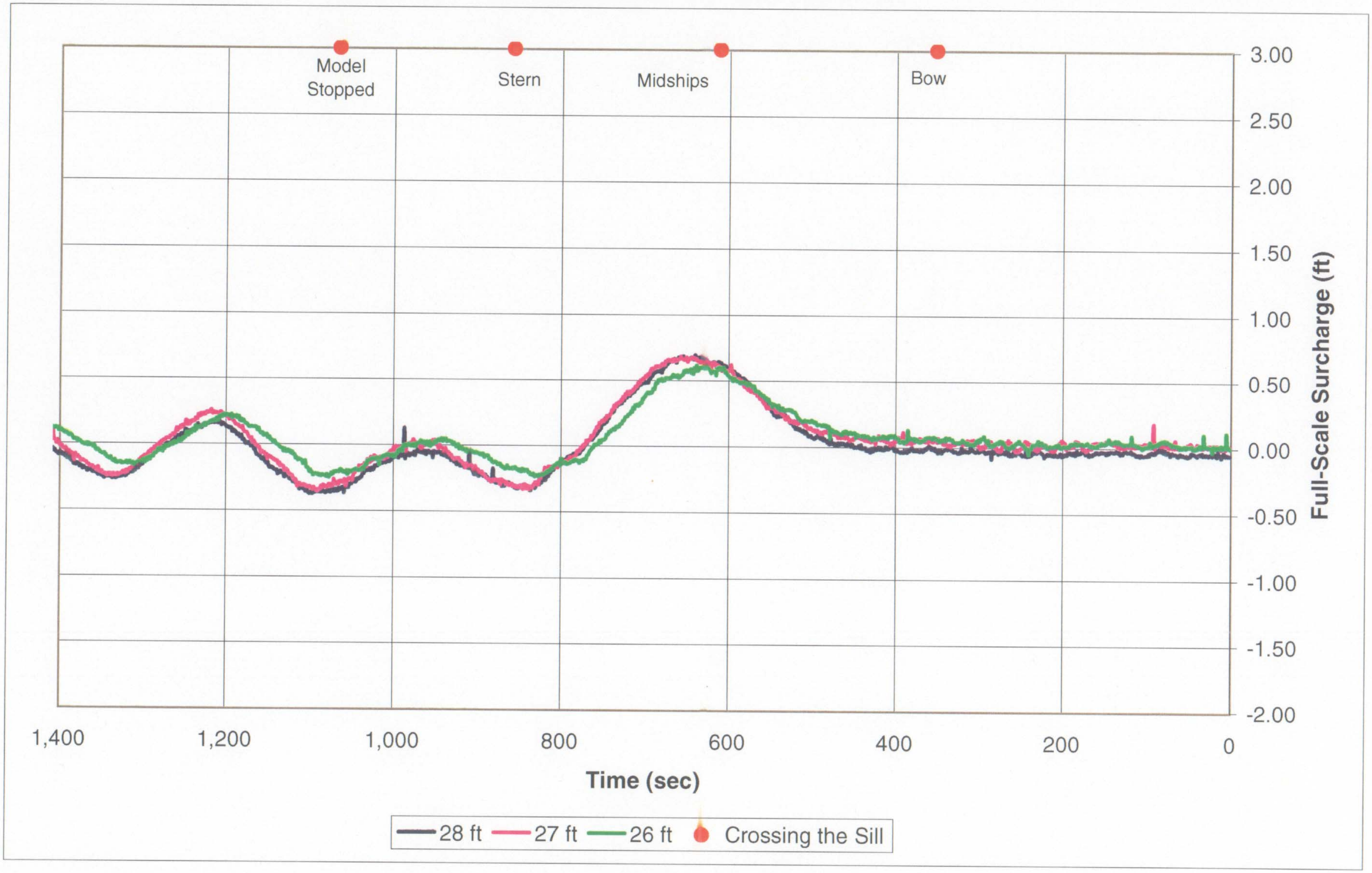


Blockage Ratio vs. Maximum Surcharge
Cases I, II and III
Max. Surcharge (ft)
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
40.0%
50.0%
60.0%
70.0%
80.0%
90.0%
Blockage Ratio
Speeds
0.37 kts
0.57 kts
0.73 kts
1.1 kts
1.47 kts
1.84 kts
2.2 kts

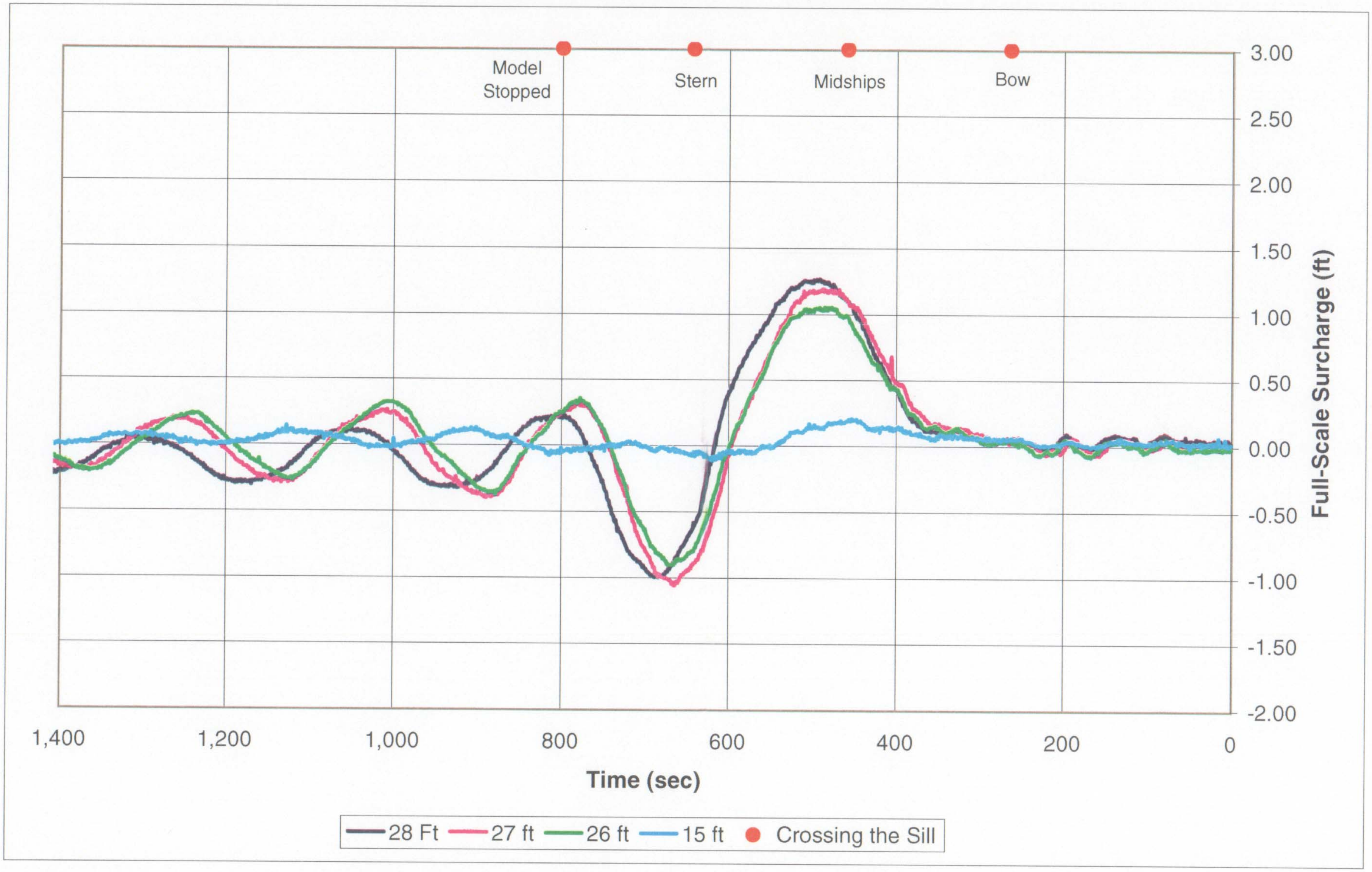


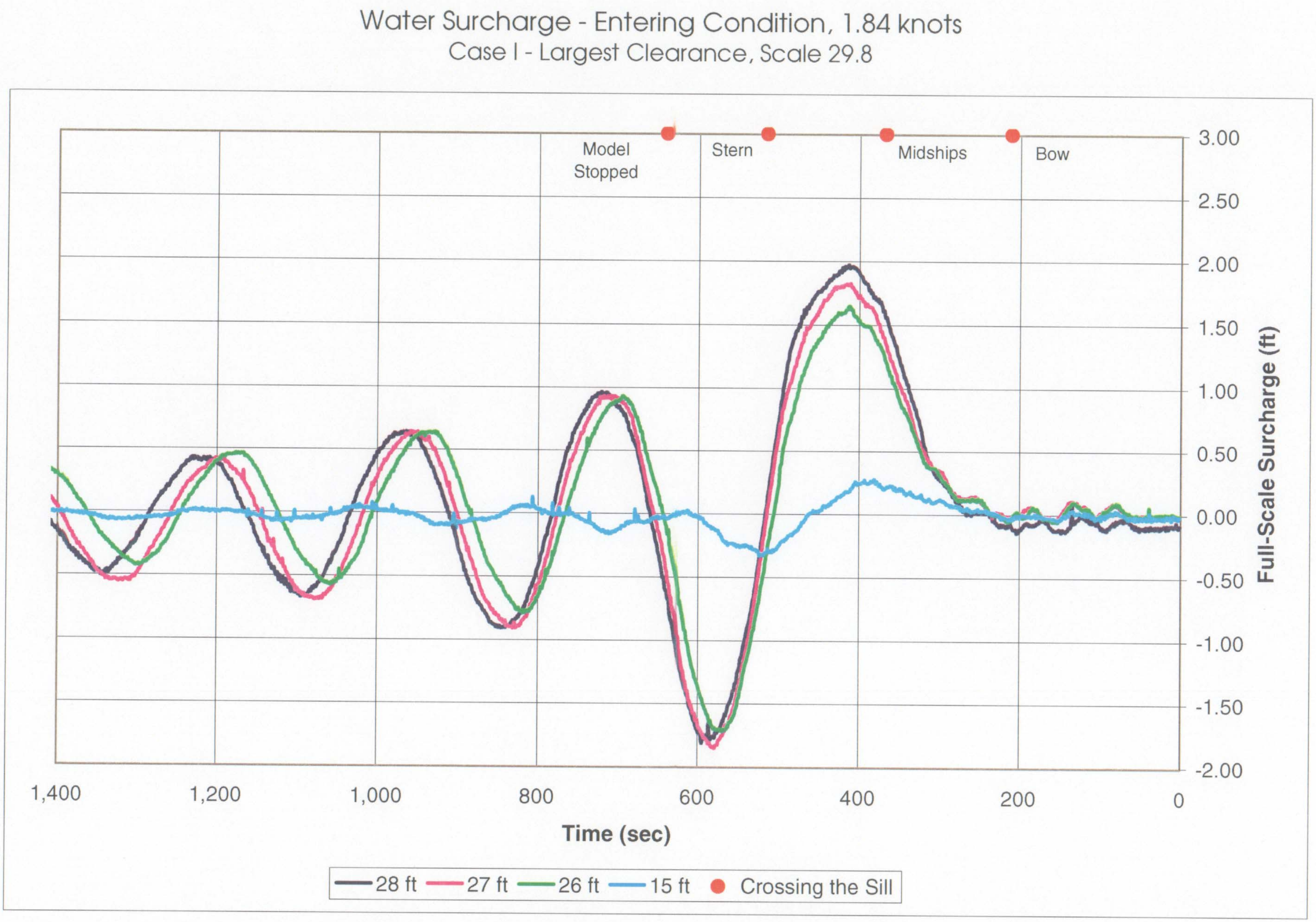
Water Surcharge - Entering Condition, 0.73 knots
Case I - Largest Clearance, Scale 29.8
Model Stopped
Stern
Midships
Bow
3.00
2.50
2.00
1.50
1.00
0.50
0.00
-0.50
-1.00
-1.50
-2.00
Full-Scale Surcharge (ft)
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
Time (sec)
28 ft
27 ft
26 ft
Crossing the Sill

Water Surcharge - Entering Condition, 1.10 knots
Case I - Largest Clearance, Scale 29.8

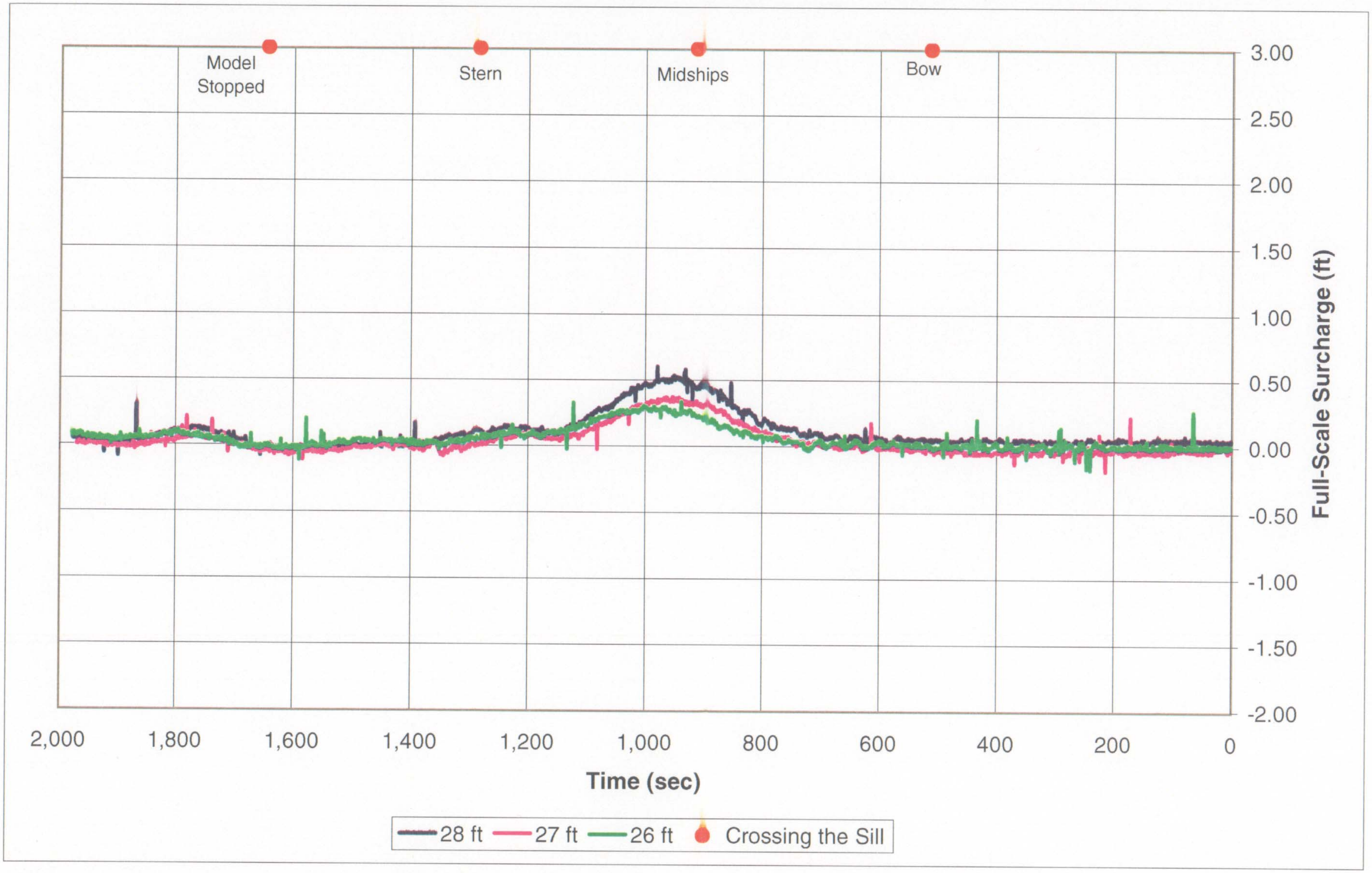


Water Surcharge - Entering Condition, 1.47 knots
Case I - Largest Clearance, Scale 29.8

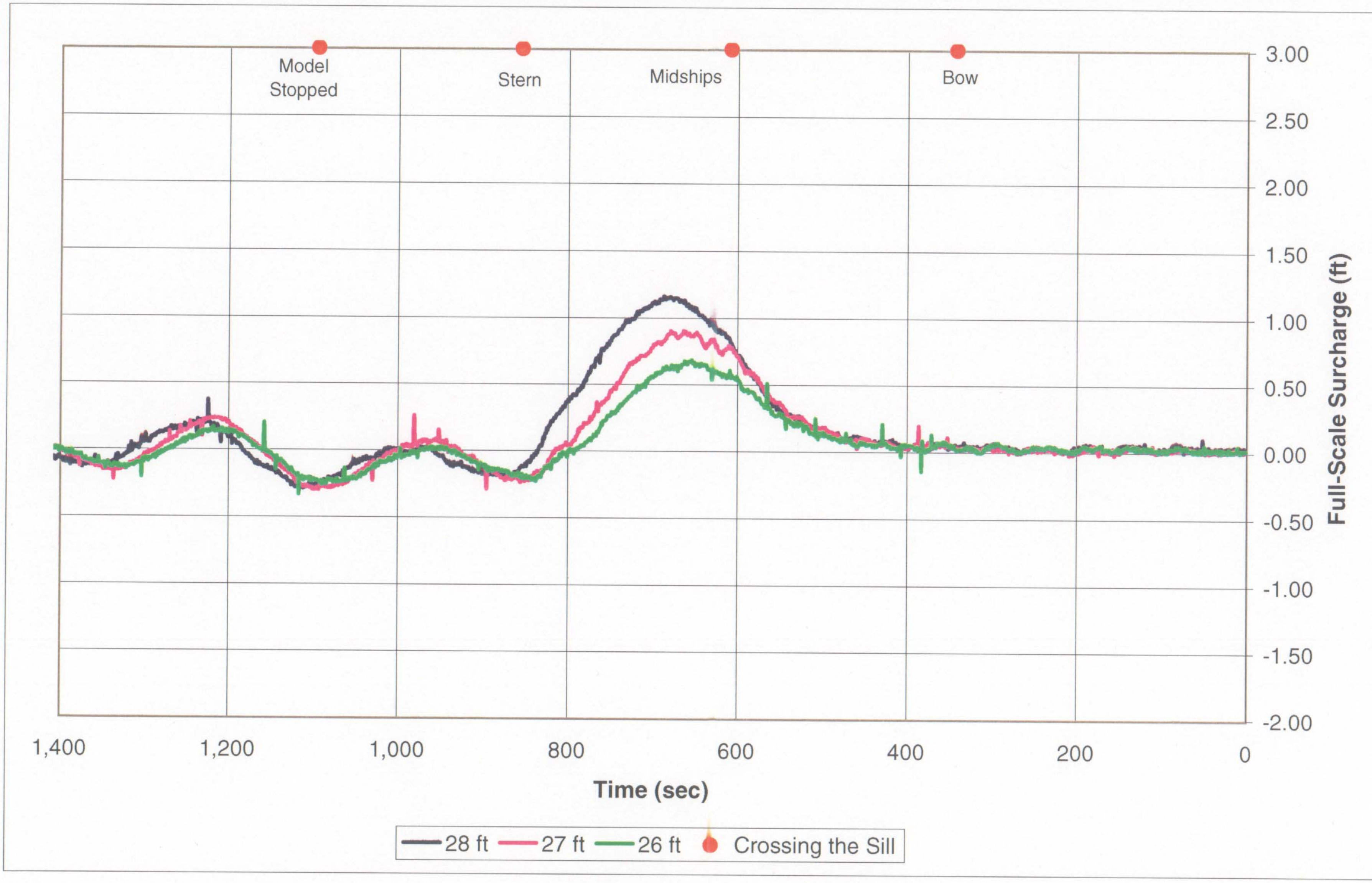


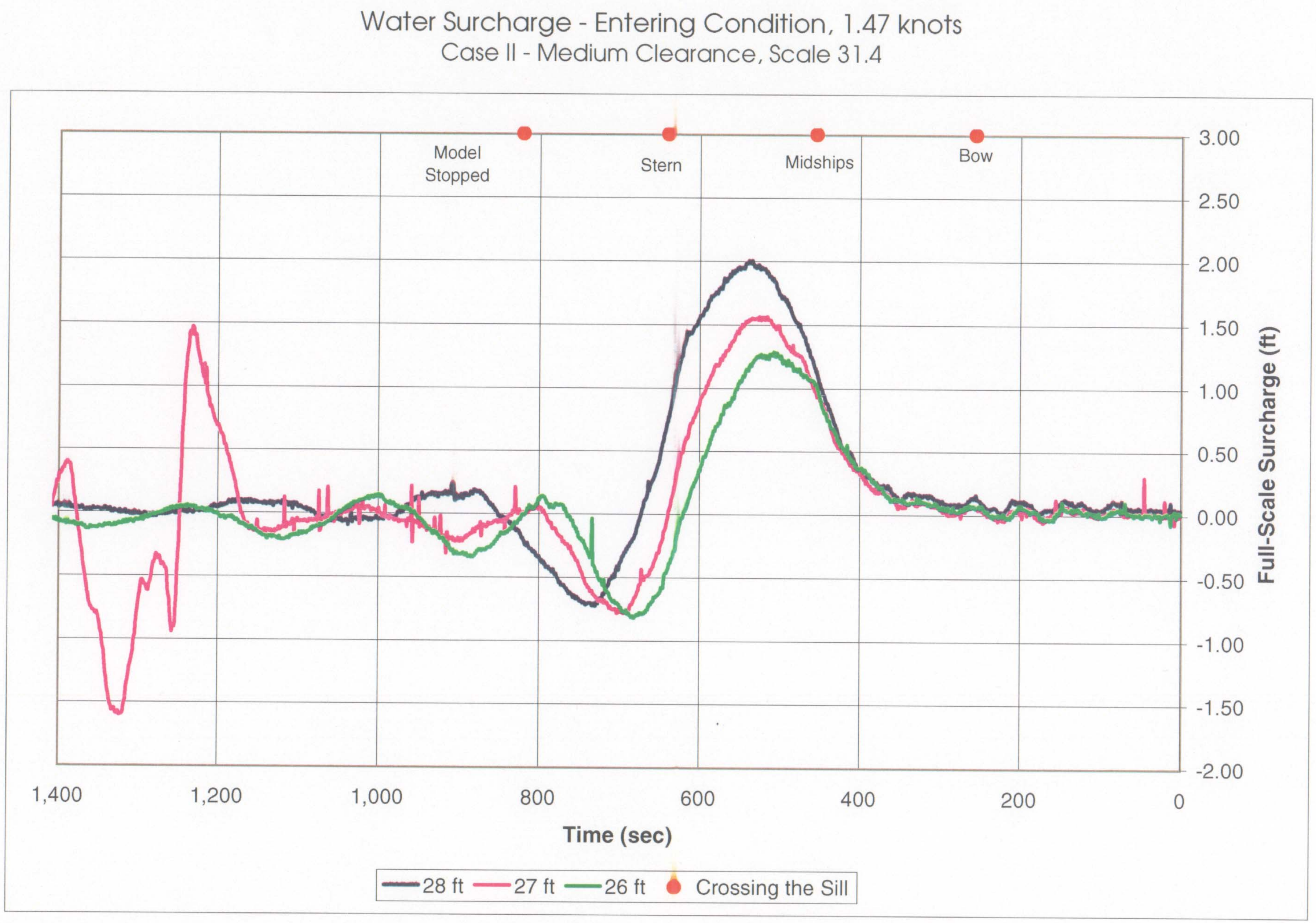

Water Surcharge - Entering Condition, 1.84 knots
Case I - Largest Clearance, Scale 29.8
Model Stopped
Stern
Midships
Bow
3.00
2.50
2.00
1.50
1.00
0.50
0.00
-0.50
-1.00
-1.50
-2.00
Full-Scale Surcharge (ft)
1,400
1,200
1,000
800
600
400
200
0
Time (sec)
28 ft
27 ft
26 ft
15 ft
Crossing the Sill

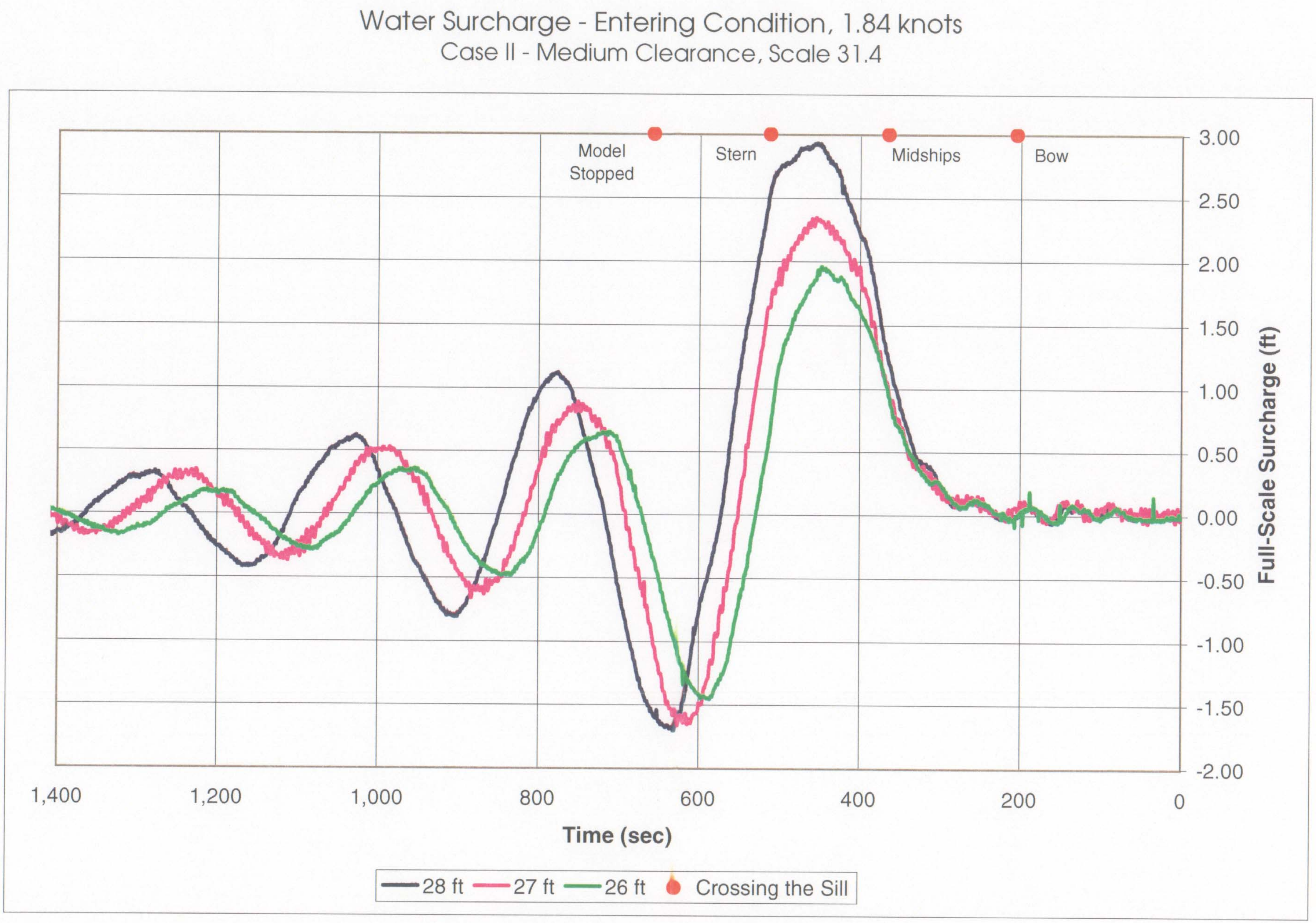
Water Surcharge - Entering Condition, 0.73 knots
Case II - Medium Clearance, Scale 31.4



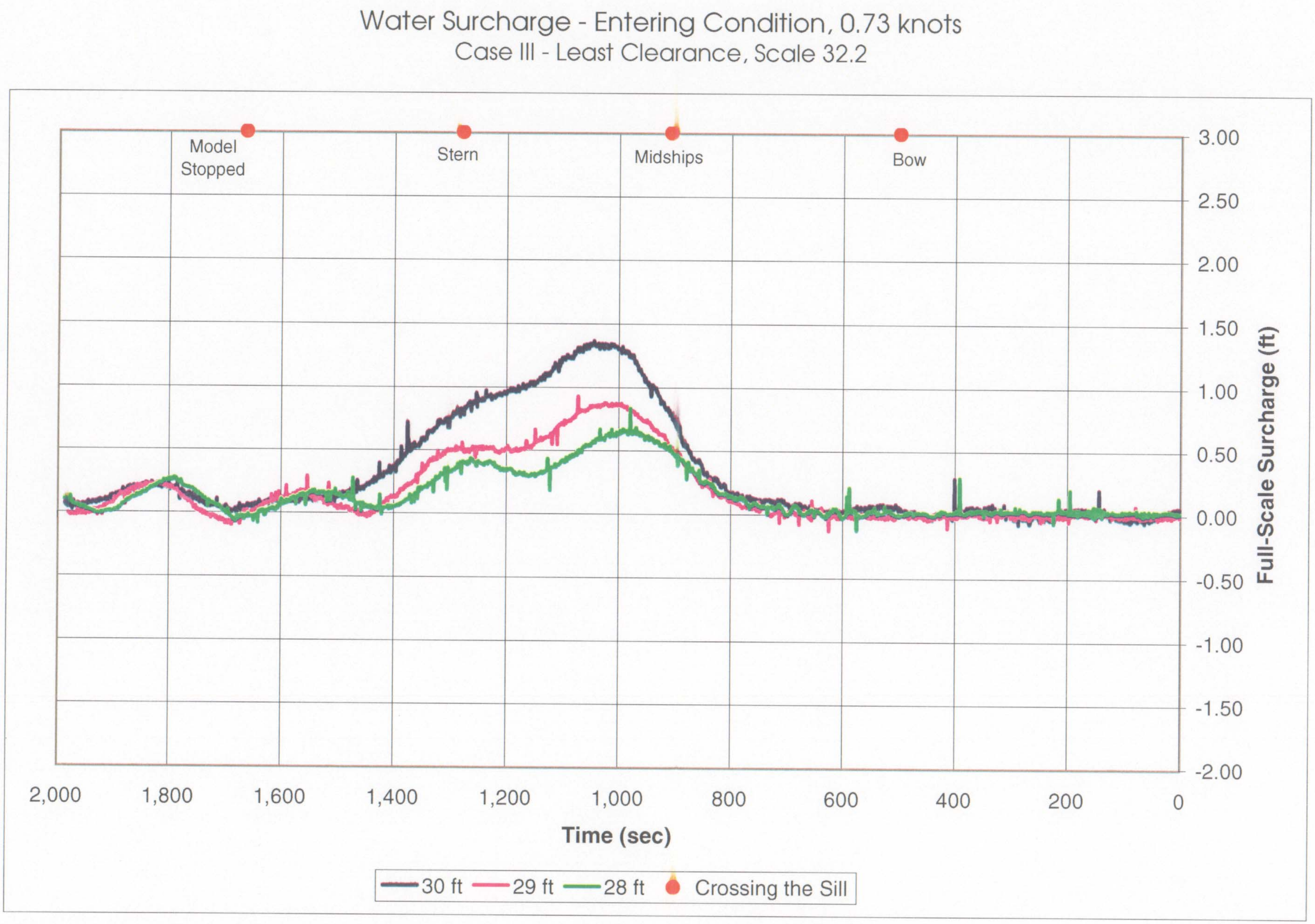
Water Surcharge - Entering Condition, 1.10 knots
Case II - Medium Clearance, Scale 31.4



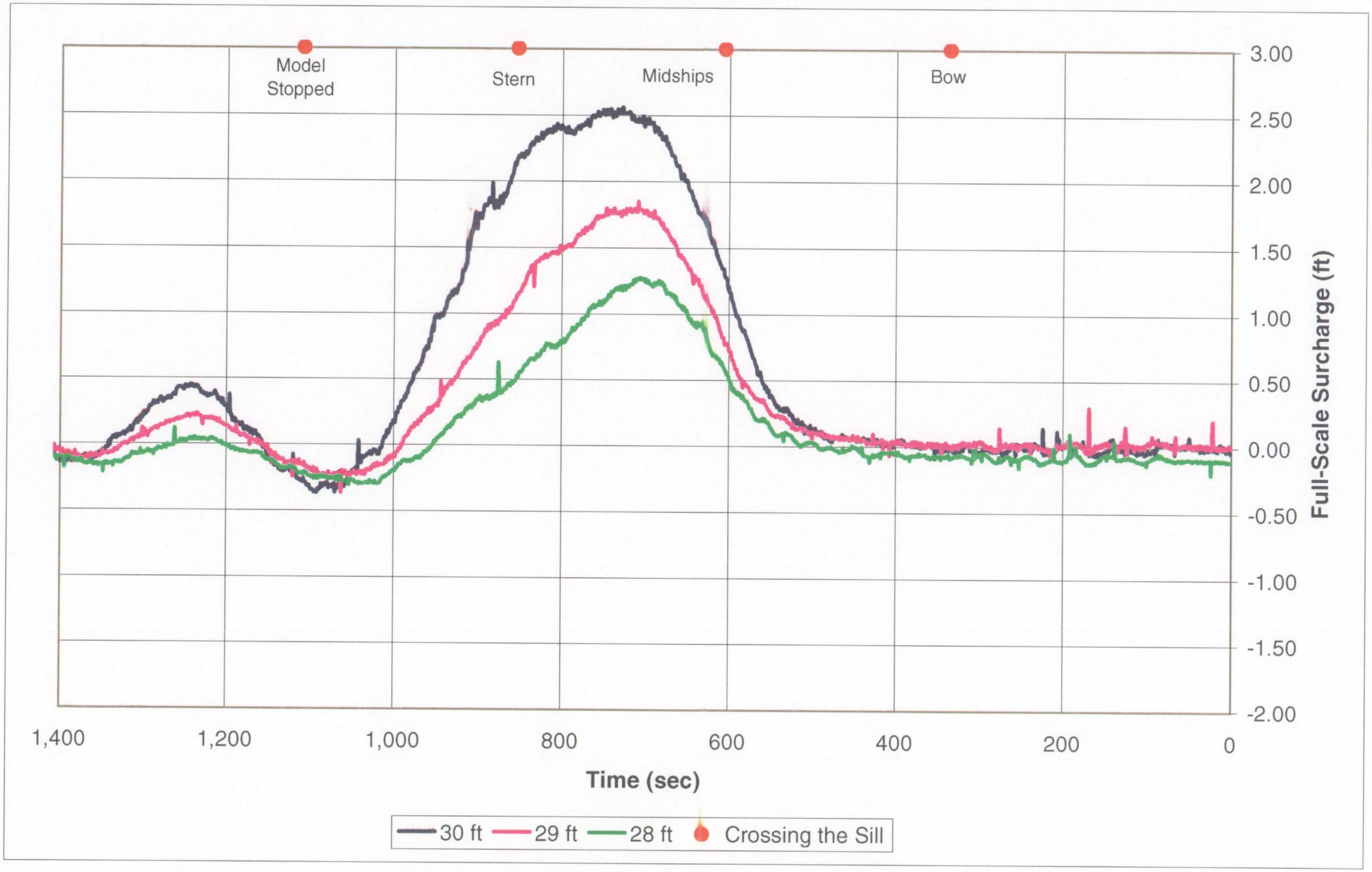

Water Surcharge - Entering Condition, 1.47 knots
Case II - Medium Clearance, Scale 31.4
Model Stopped
Stern
Midships
Bow
3.00
2.50
2.00
1.50
1.00
0.50
0.00
-0.50
-1.00
-1.50
-2.00
Full-Scale Surcharge (ft)
1,400
1,200
1,000
800
600
400
200
0
Time (sec)
28 ft
27 ft
26 ft
Crossing the Sill



Water Surcharge - Entering Condition, 1.84 knots
Case II - Medium Clearance, Scale 31.4
Model Stopped
Stern
Midships
Bow
3.00
2.50
2.00
1.50
1.00
0.50
0.00
-0.50
-1.00
-1.50
-2.00
Full-Scale Surcharge (ft)
1,400
1,200
1,000
800
600
400
200
0
Time (sec)
28 ft
27 ft
26 ft
Crossing the Sill

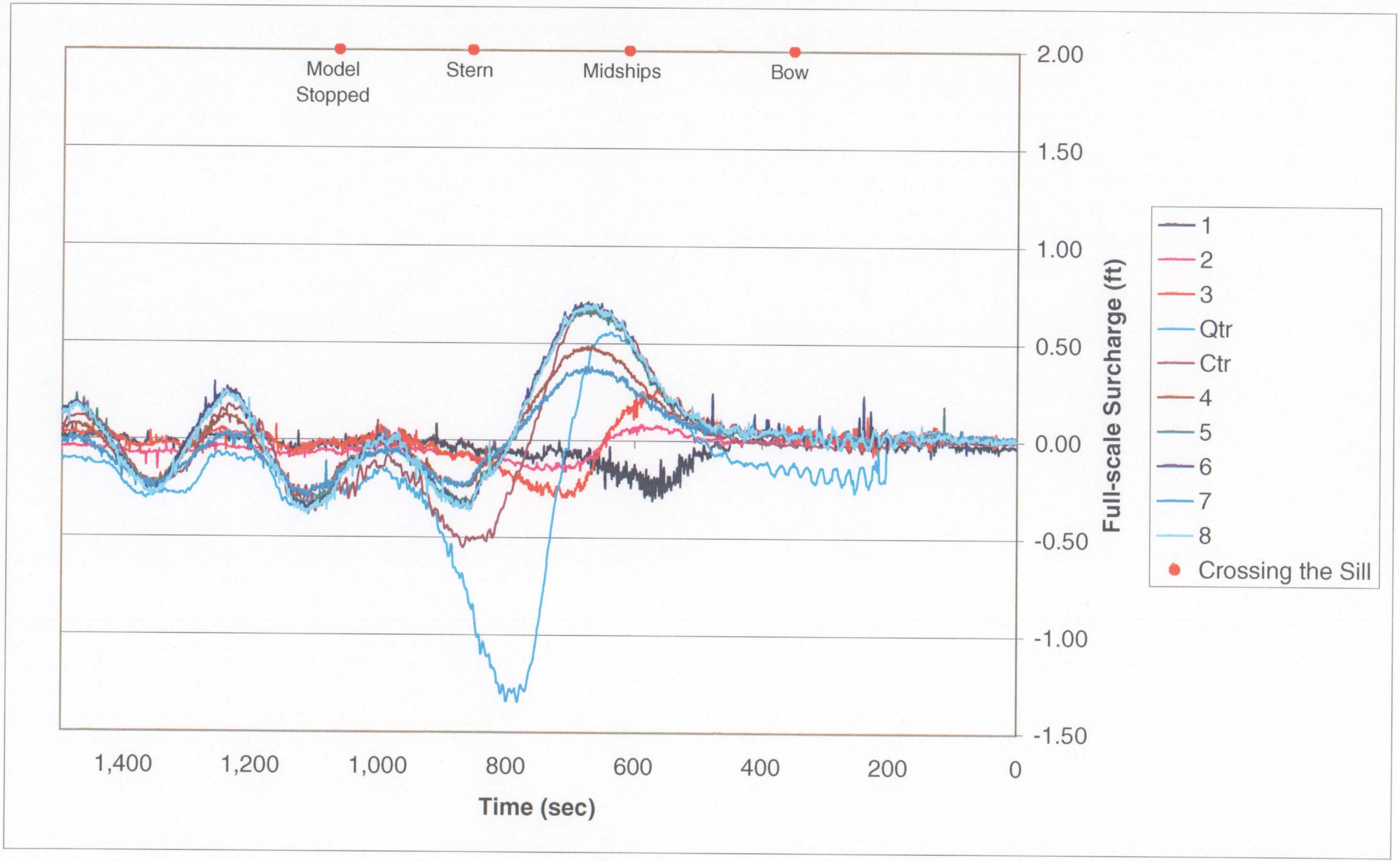

Water Surcharge - Entering Condition, 0.73 knots
Case III - Least Clearance, Scale 32.2
Model
Stopped
Stern
Midships
Bow
3.00
2.50
2.00
1.50
1.00
0.50
0.00
-0.50
-1.00
-1.50
-2.00
Full-Scale Surcharge (ft)
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
Time (sec)
30 ft
29 ft
28 ft
Crossing the Sill

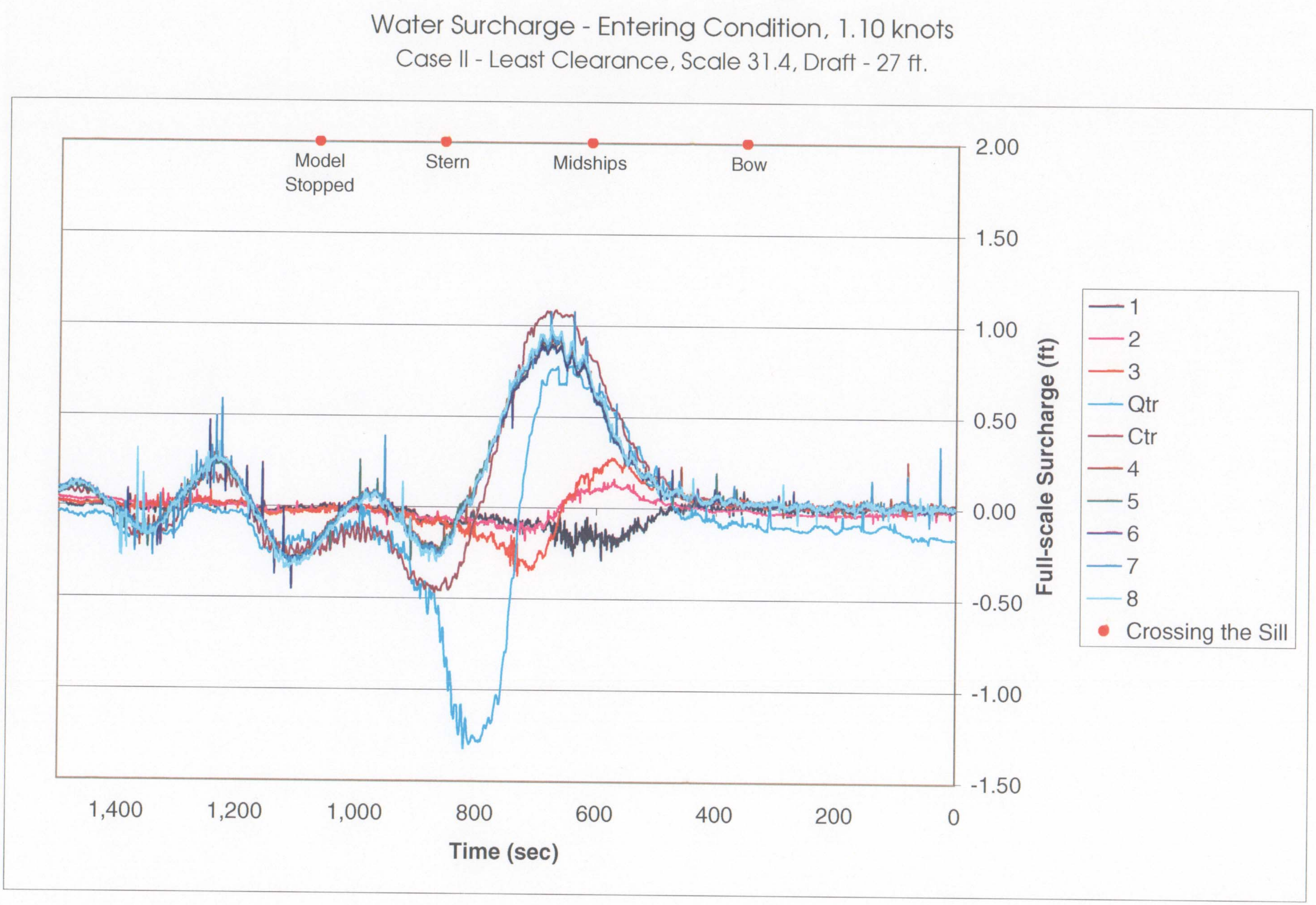
Water Surcharge - Entering Condition, 1.10 knots
Case III - Least Clearance, Scale 32.2



Water Surcharge - Entering Condition, 1.10 knots

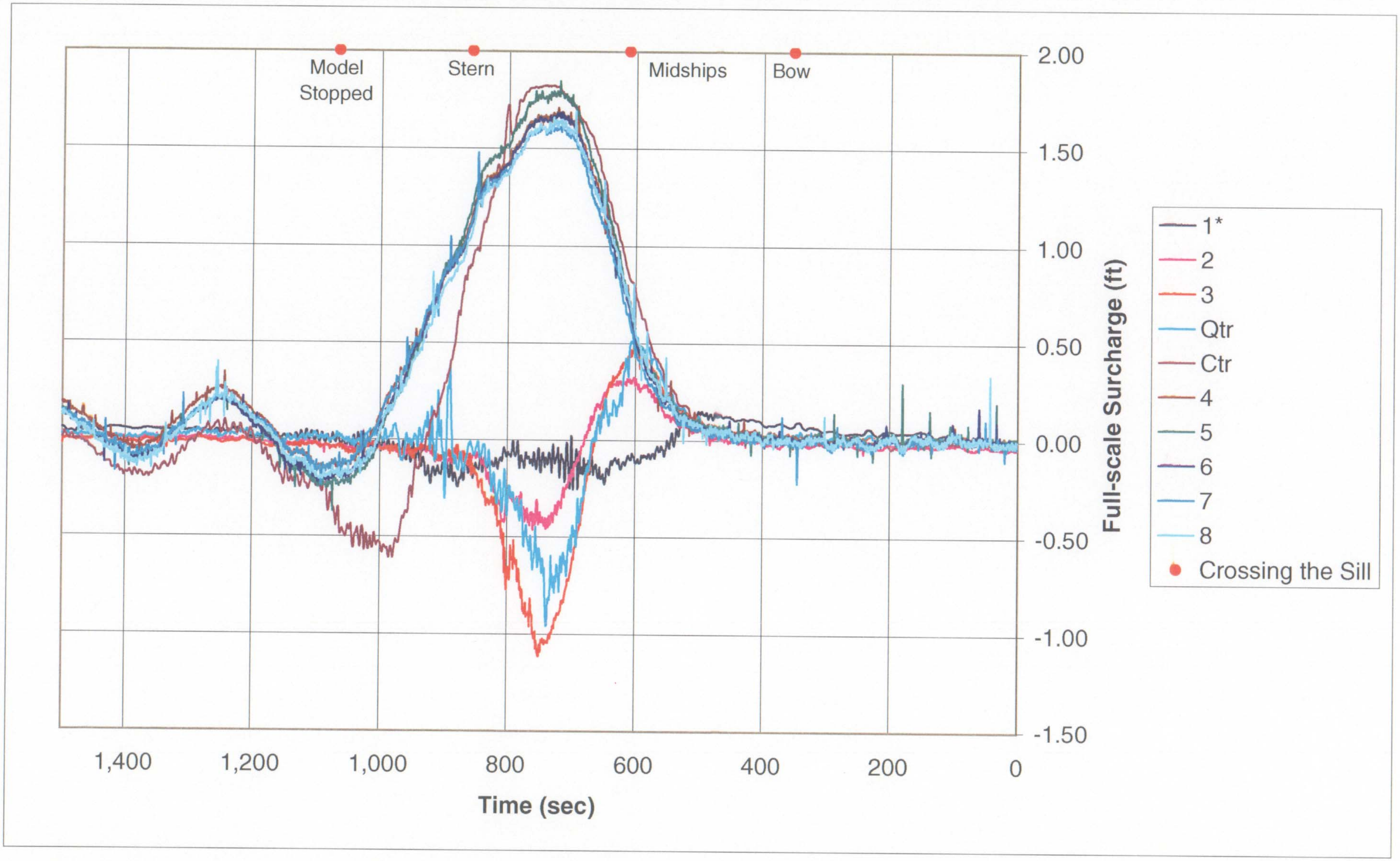
Case I - Largest Clearance, Scale 29.8, Draft - 27 ft.




Water Surcharge - Entering Condition, 1.10 knots
Case II - Least Clearance, Scale 31.4, Draft - 27 ft.
Model Stopped
Stern
Midships
Bow
2.00
1.50
1.00
0.50
0.00
-0.50
-1.00
-1.50
Full-scale Surcharge (ft)
1,400
1,200
1,000
800
600
400
200
0
Time (sec)
1
2
3
Qtr
Ctr
4
5
6
7
8
Crossing the Sill

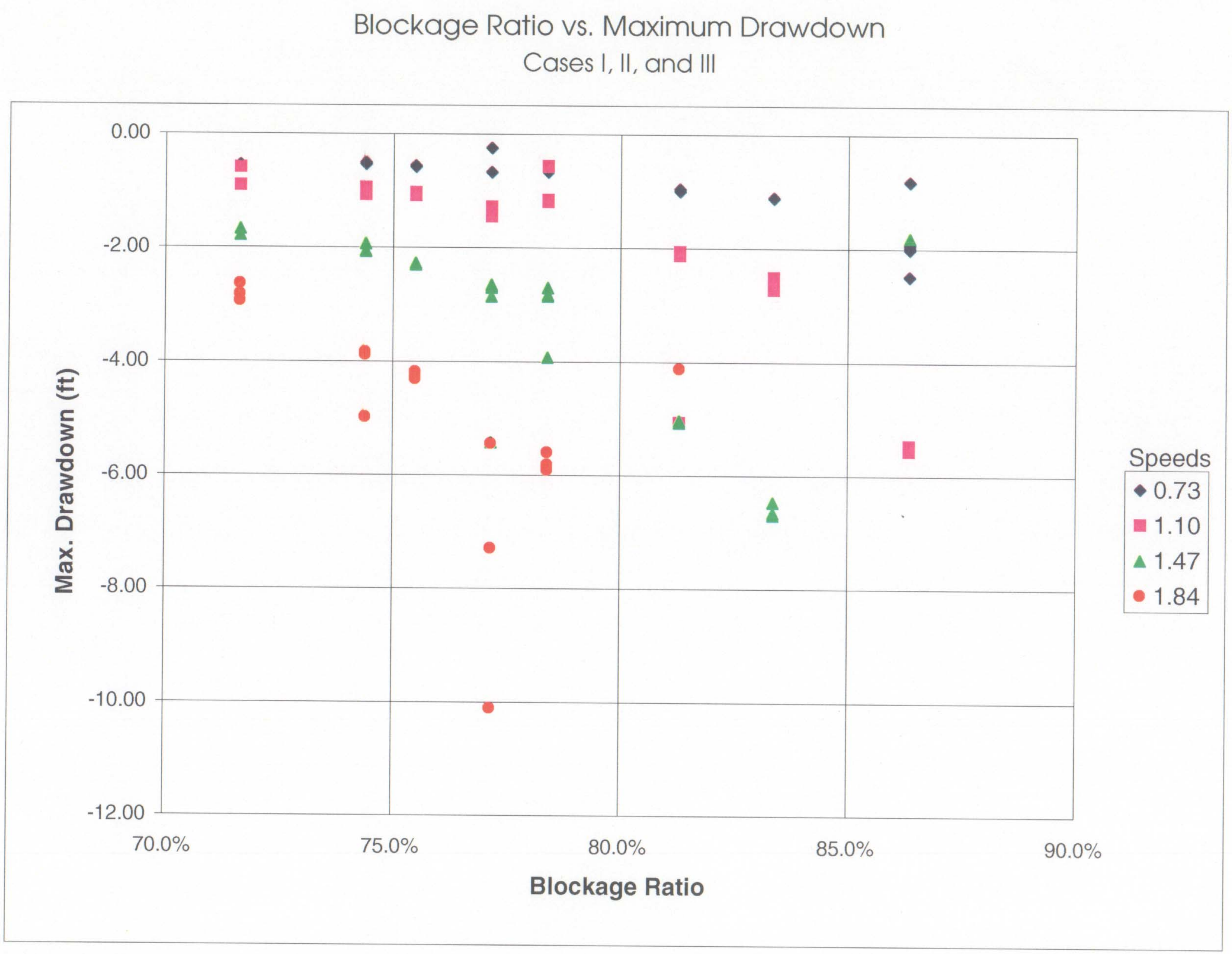
Water Surcharge - Entering Condition, 1.10 knots

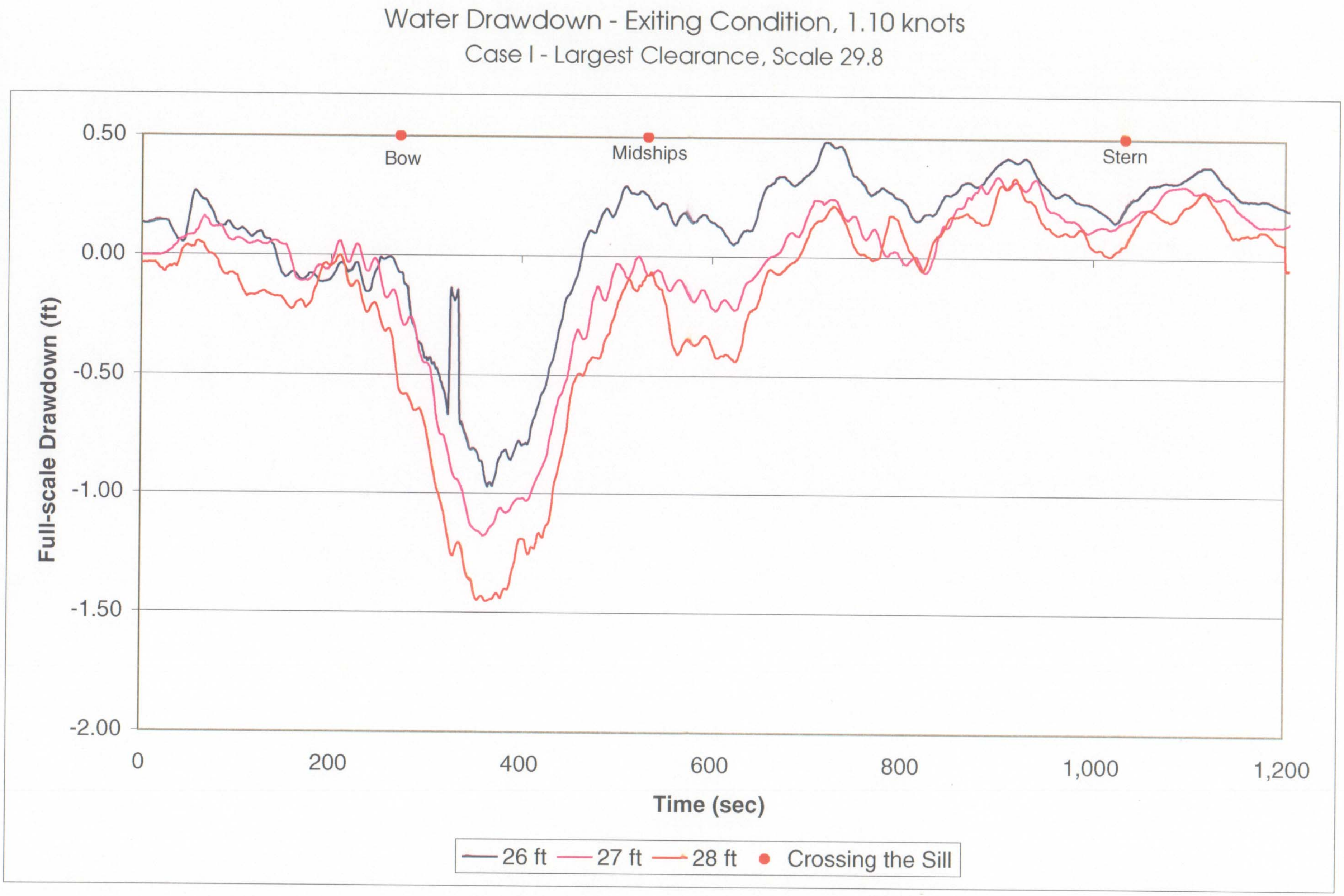
Case III - Least Clearance, Scale 32.2, Draft - 29 ft.



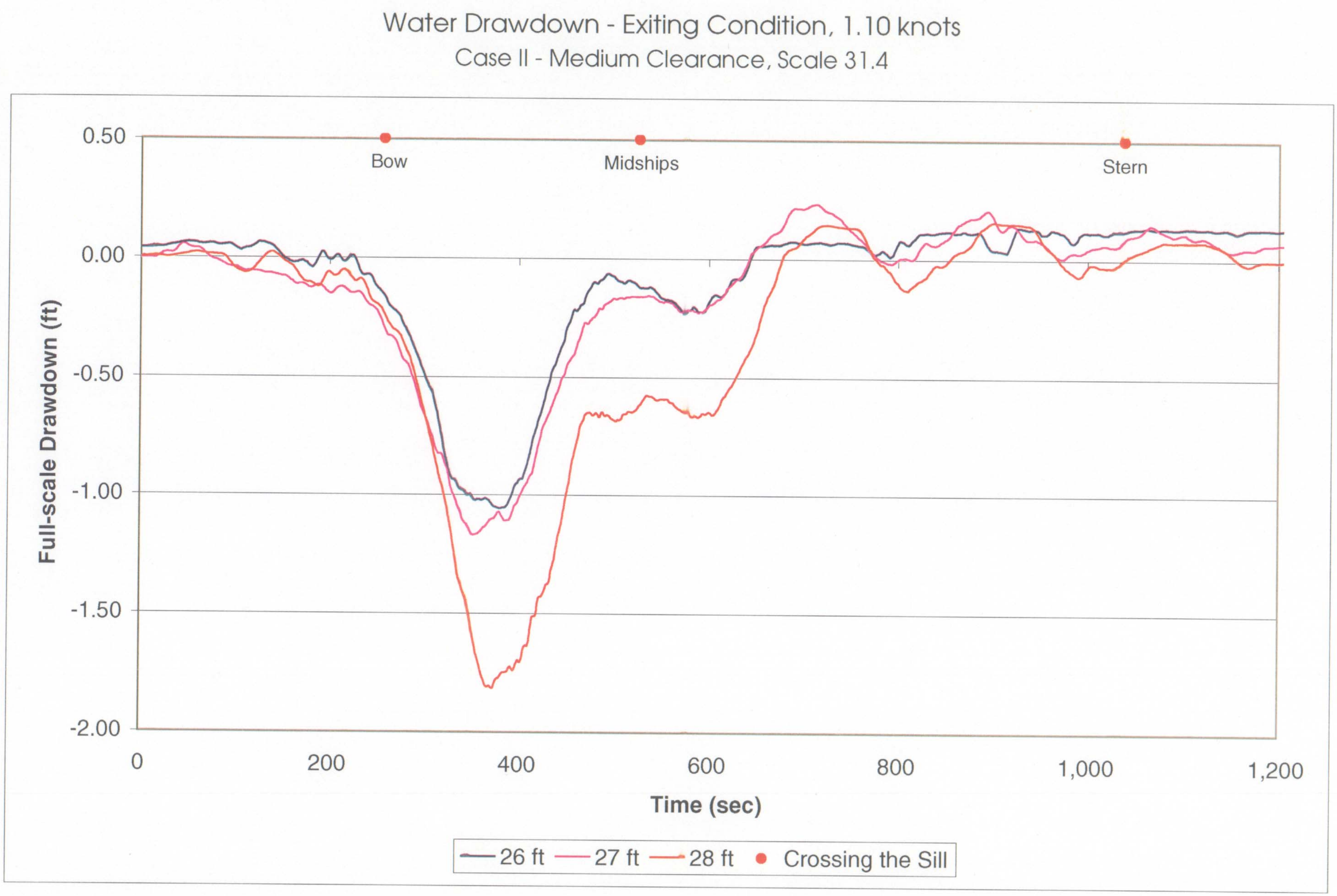
1* - Channel 1a was averaged (10 points) to eliminate channel noise - this run only.

Appendix A – Exiting

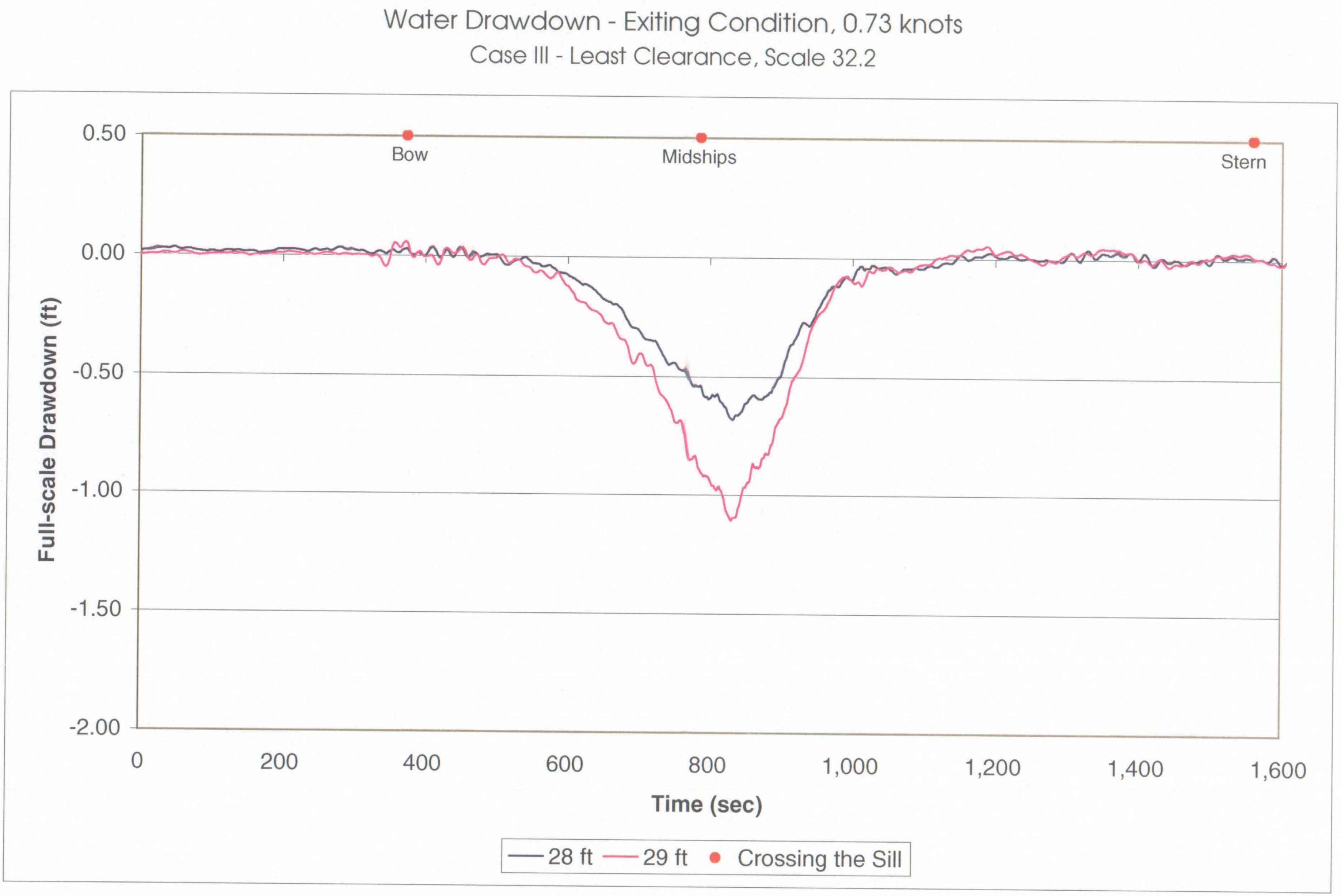

Blockage Ratio vs. Maximum Drawdown
Cases I, II, and III
0.00
-2.00
-4.00
-6.00
-8.00
-10.00
-12.00
Max. Drawdown (ft)
70.0%
75.0%
80.0%
85.0%
90.0%
Blockage Ratio
Speeds
0.73
1.10
1.47
1.84



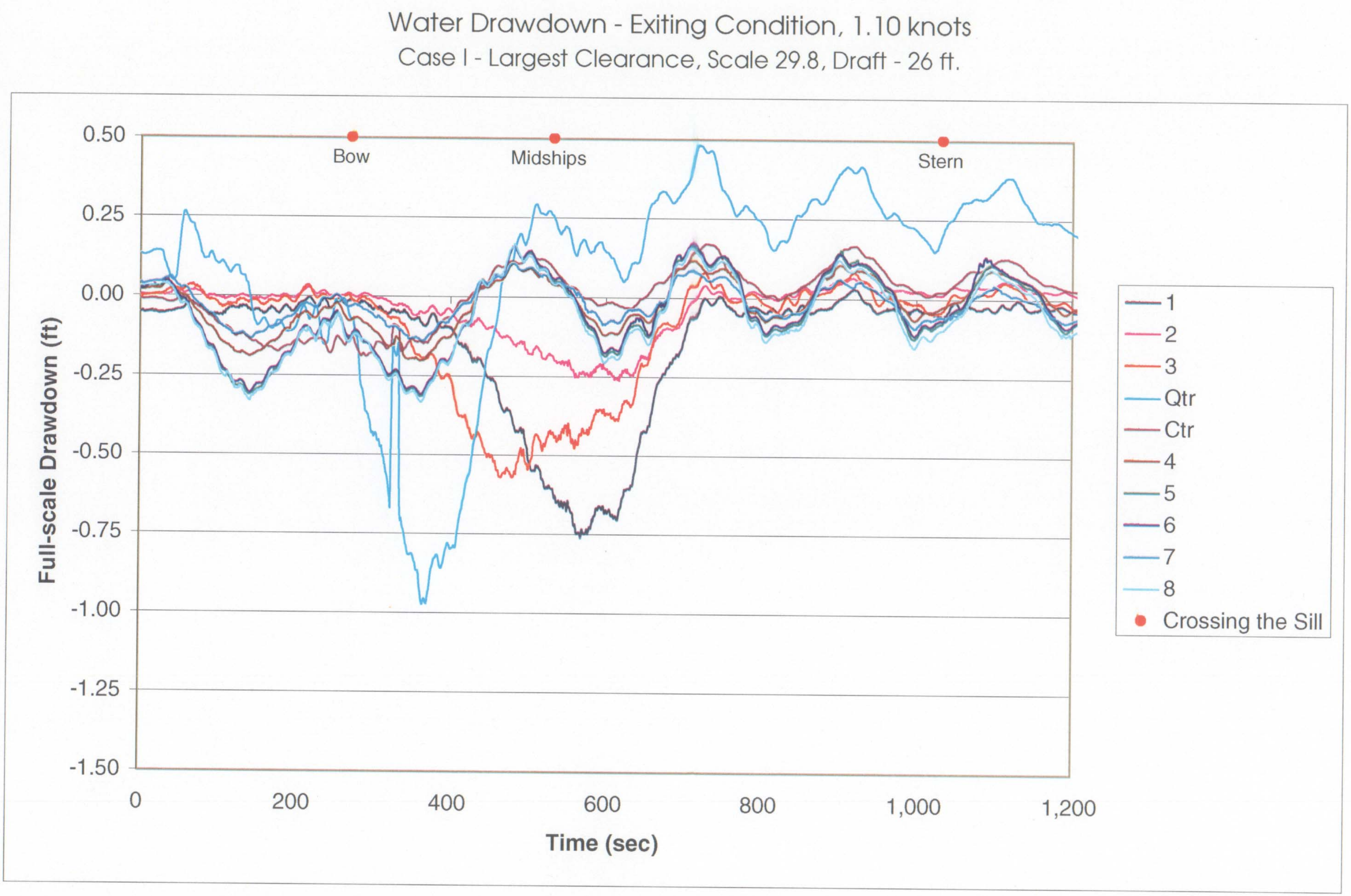
Readings from waveprobe located at 1/4 chamber length.



Readings from waveprobe located at 1/4 chamber length.



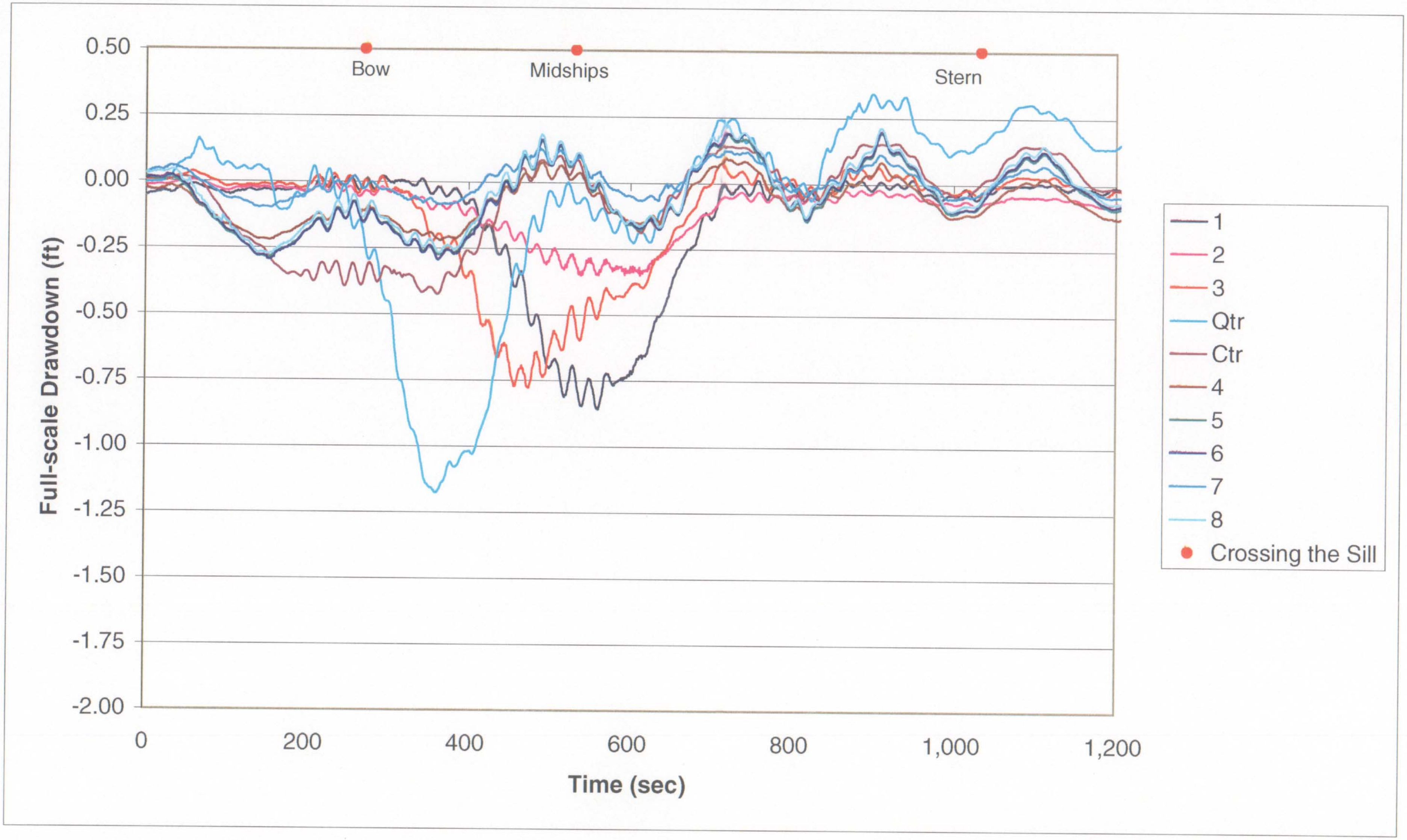
Readings from waveprobe located at 1/4 chamber length.

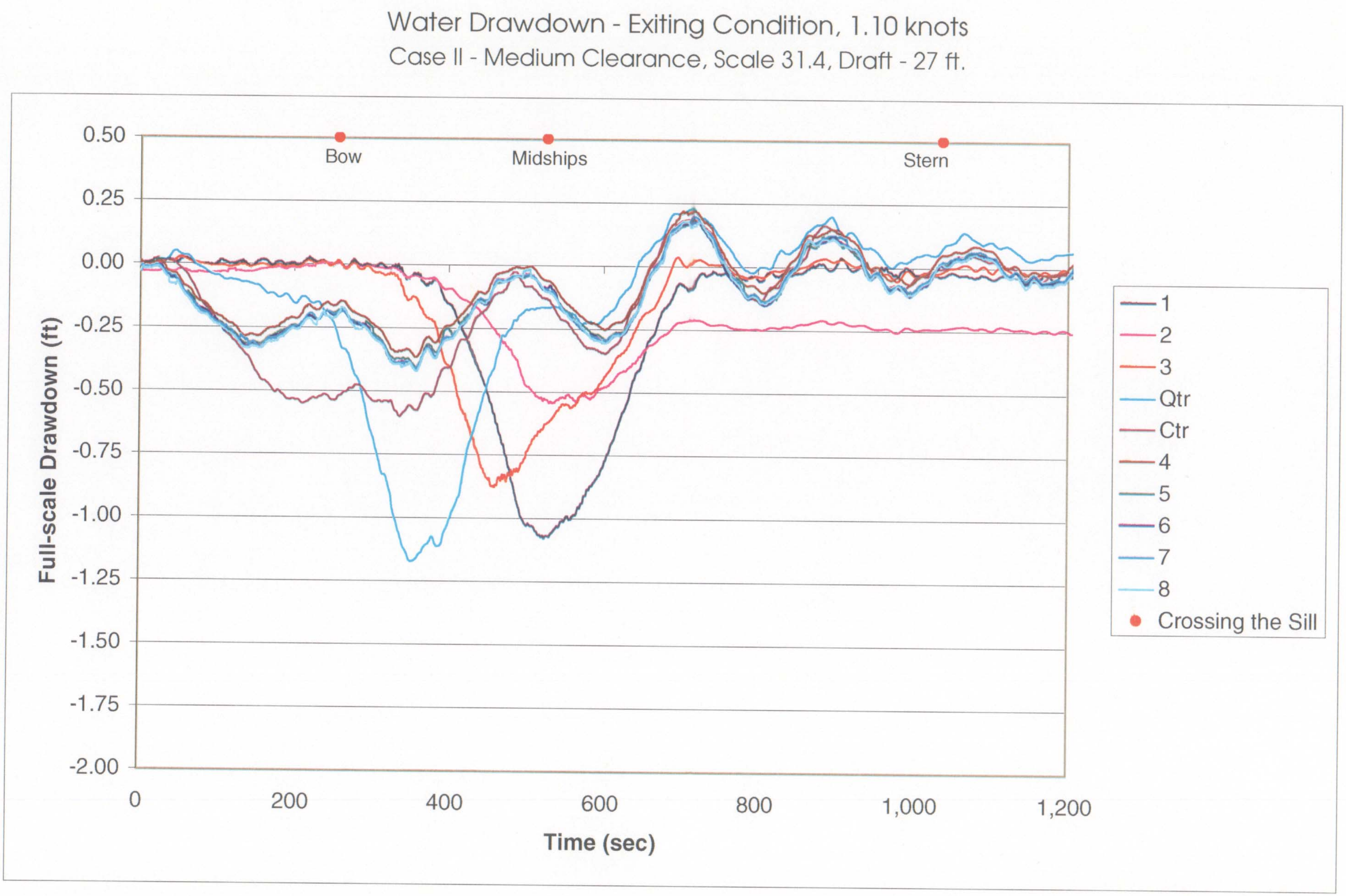


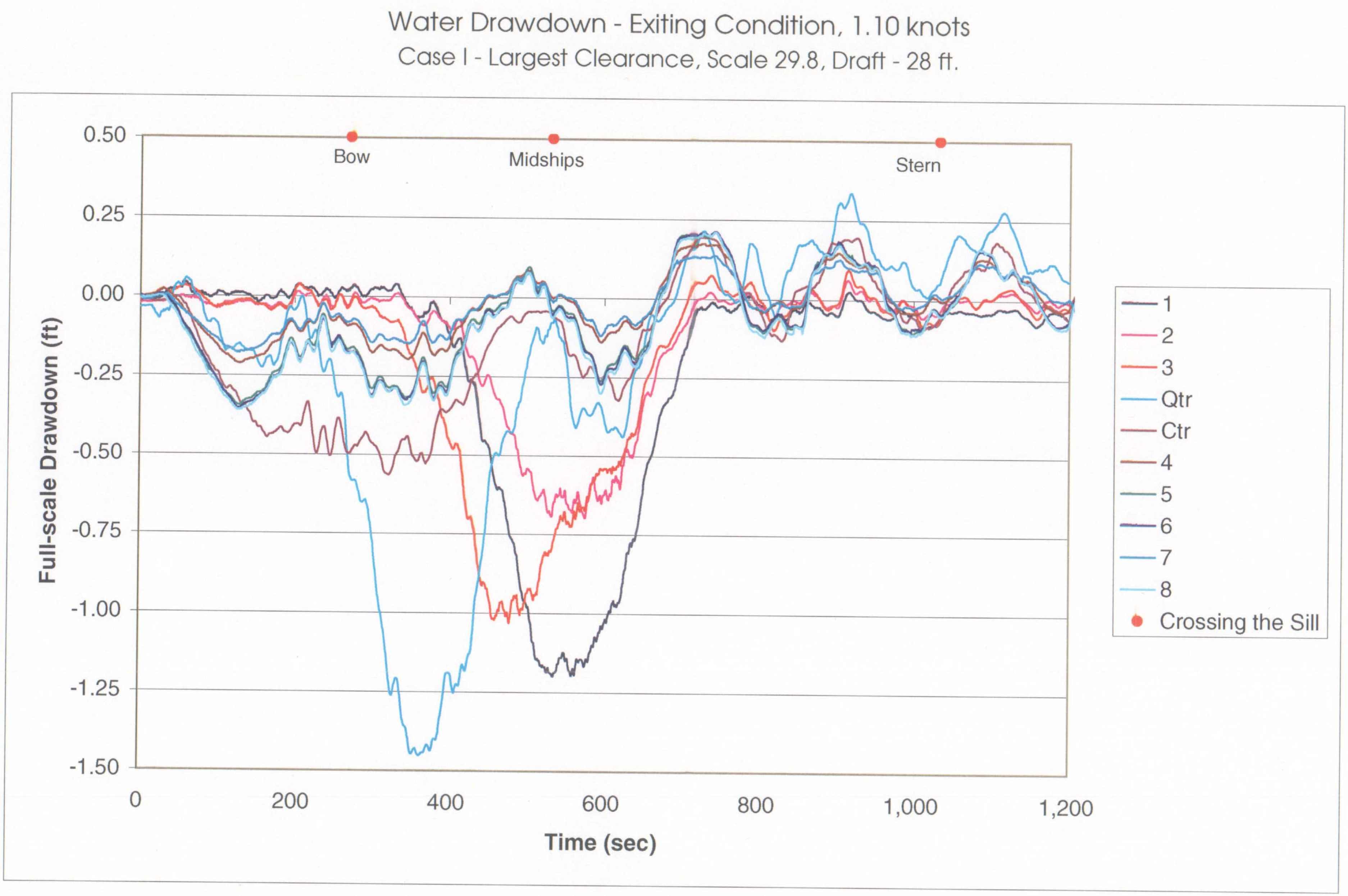
Water Drawdown - Exiting Condition, 1.10 knots
Case I - Largest Clearance, Scale 29.8, Draft - 26 ft.
0.50
0.25
0.00
-0.25
-0.50
-0.75
-1.00
-1.25
-1.50
Full-scale Drawdown (ft)
Bow
Midships
Stern
0
200
400
600
800
1,000
1,200
Time (sec)
1
2
3
Qtr
Ctr
4
5
6
7
8
Crossing the Sill

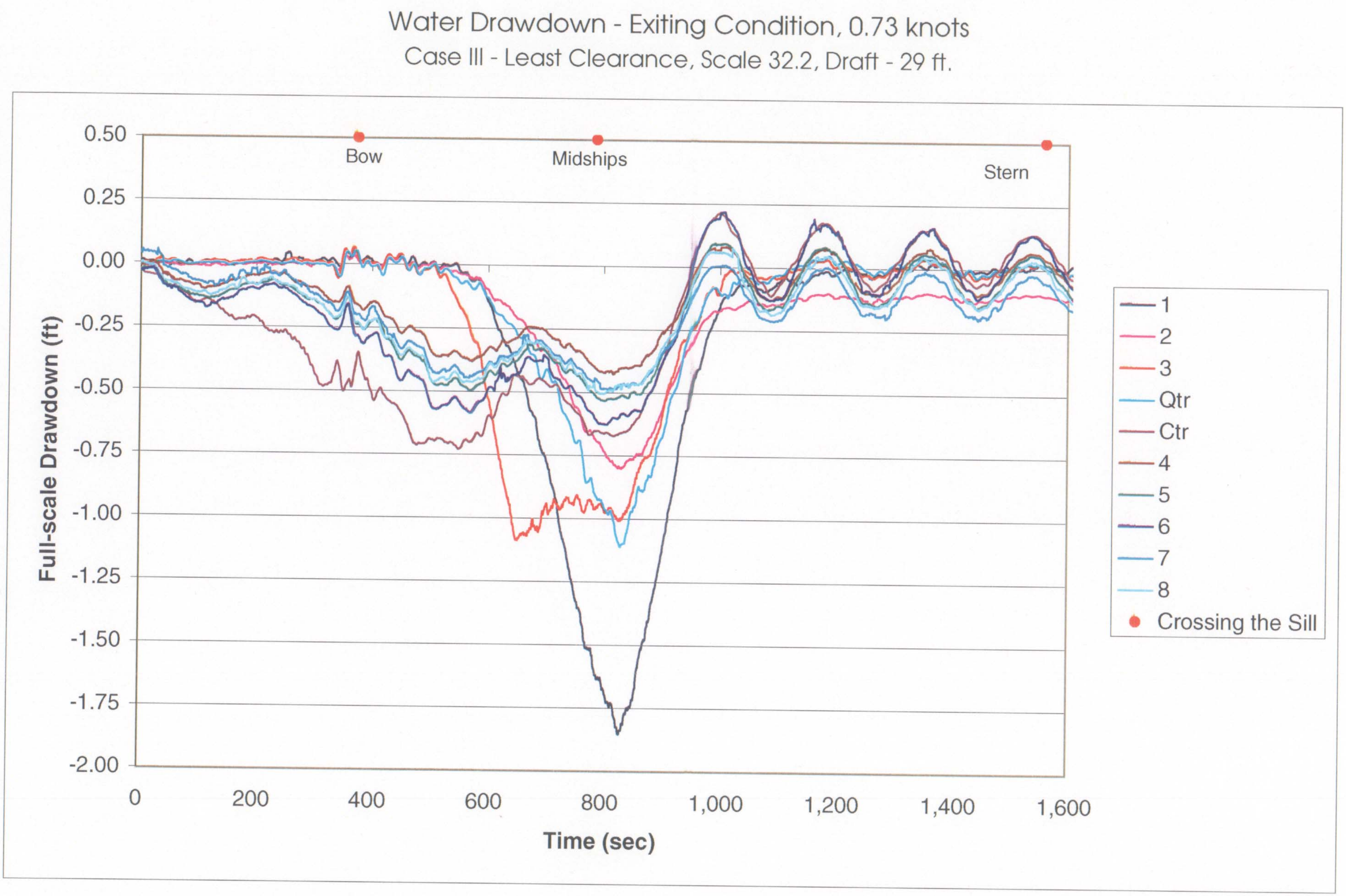
Water Drawdown - Exiting Condition, 1.10 knots

Case I - Largest Clearance, Scale 29.8, Draft - 27 ft.

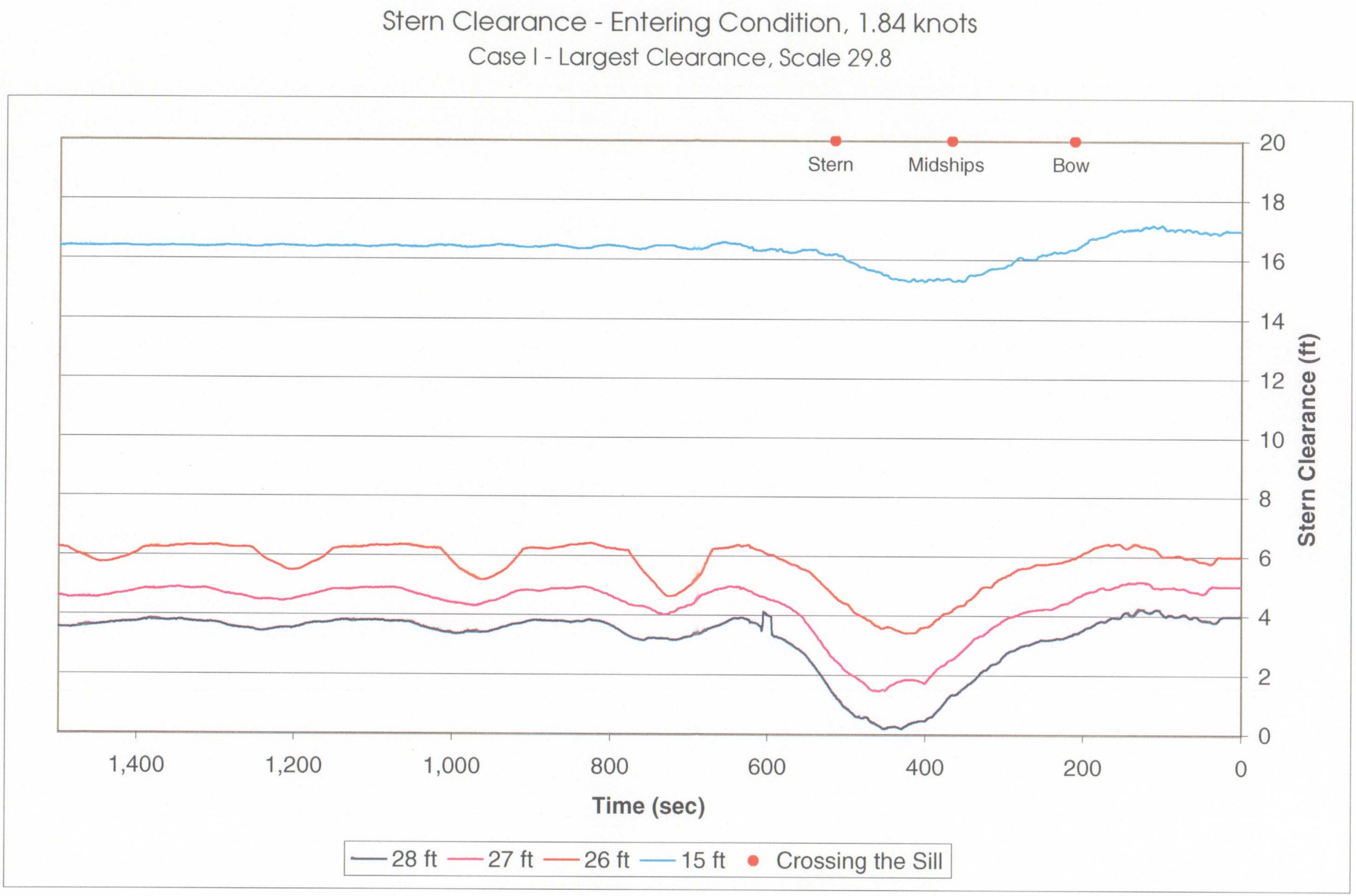



Water Drawdown - Exiting Condition, 1.10 knots
Case II - Medium Clearance, Scale 31.4, Draft - 27 ft.
Bow
Midships
Stern
0.50
0.25
0.00
-0.25
-0.50
-0.75
-1.00
-1.25
-1.50
-1.75
-2.00
Full-scale Drawdown (ft)
0
200
400
600
800
1,000
1,200
Time (sec)
1
2
3
Qtr
Ctr
4
5
6
7
8
Crossing the Sill


Water Drawdown - Exiting Condition, 1.10 knots
Case I - Largest Clearance, Scale 29.8, Draft - 28 ft.
0.50
0.25
0.00
-0.25
-0.50
-0.75
-1.00
-1.25
-1.50
Full-scale Drawdown (ft)
Bow
Midships
Stern
0
200
400
600
800
1,000
1,200
Time (sec)
1
2
3
Qtr
Ctr
4
5
6
7
8
Crossing the Sill

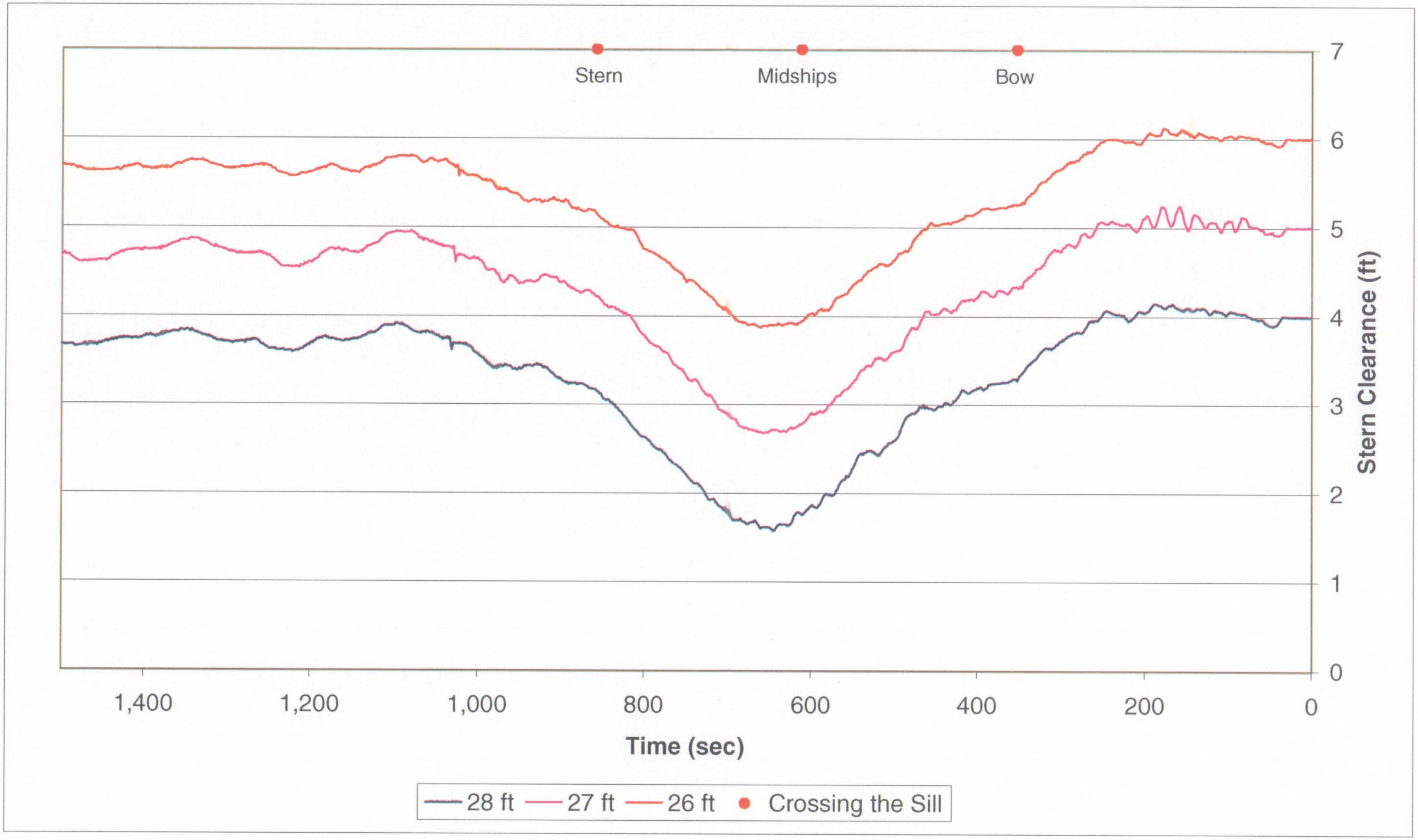

Water Drawdown - Exiting Condition, 0.73 knots
Case III - Least Clearance, Scale 32.2, Draft - 29 ft.
Bow
Midships
Stern
0.50
0.25
0.00
-0.25
-0.50
-0.75
-1.00
-1.25
-1.50
-1.75
-2.00
Full-scale Drawdown (ft)
0
200
400
600
800
1,000
1,200
1,400
1,600
Time (sec)
1
2
3
Qtr
Ctr
4
5
6
7
8
Crossing the Sill

Appendix A –
Stern Clearance

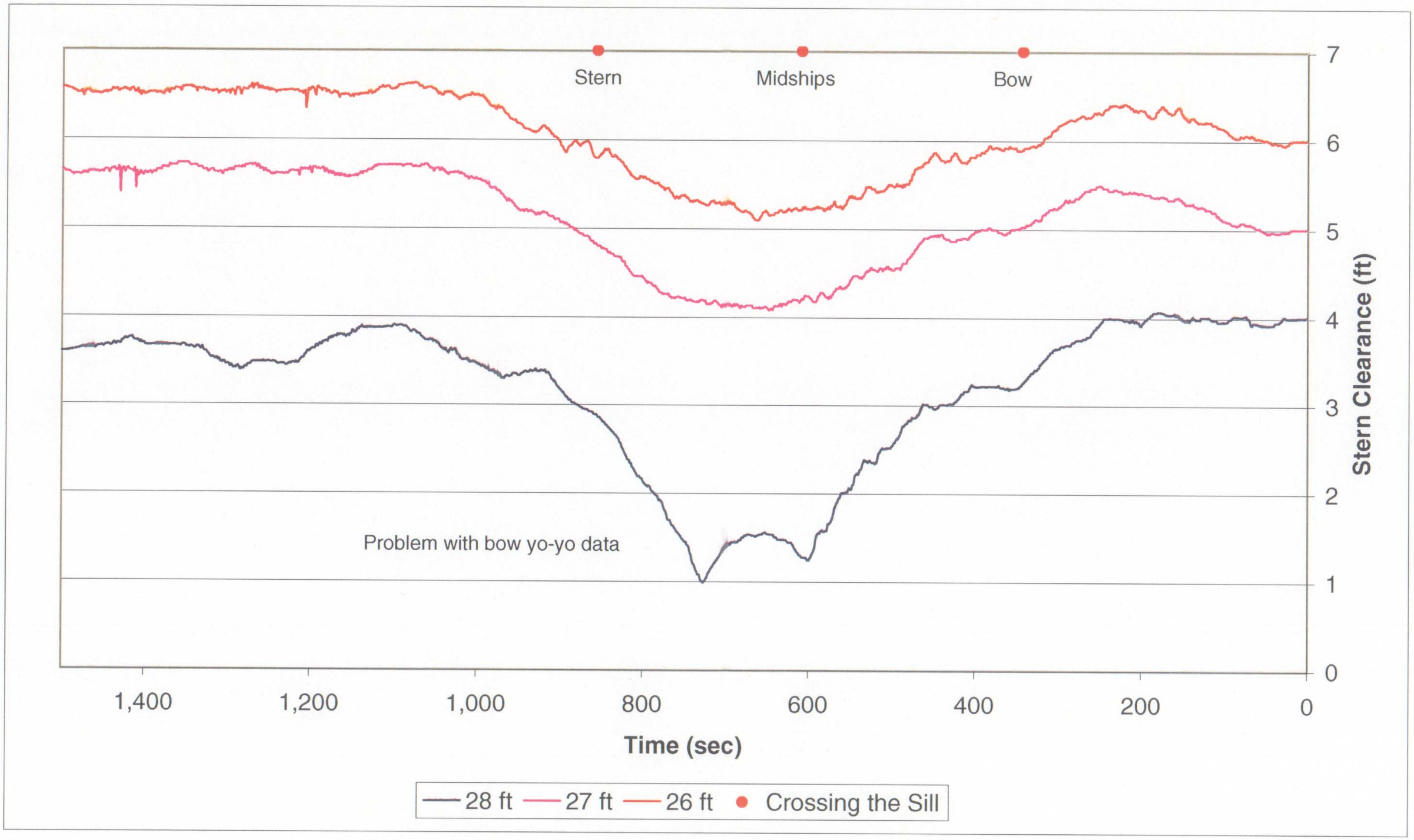

Stern Clearance - Entering Condition, 1.84 knots
Case I - Largest Clearance, Scale 29.8
Stern
Midships
Bow
20
18
16
14
12
10
8
6
4
2
0
Stern Clearance (ft)
1,400
1,200
1,000
800
600
400
200
0
Time (sec)
28 ft
27 ft
26 ft
15 ft
Crossing the Sill

Stern Clearance - Entering Condition, 1.10 knots

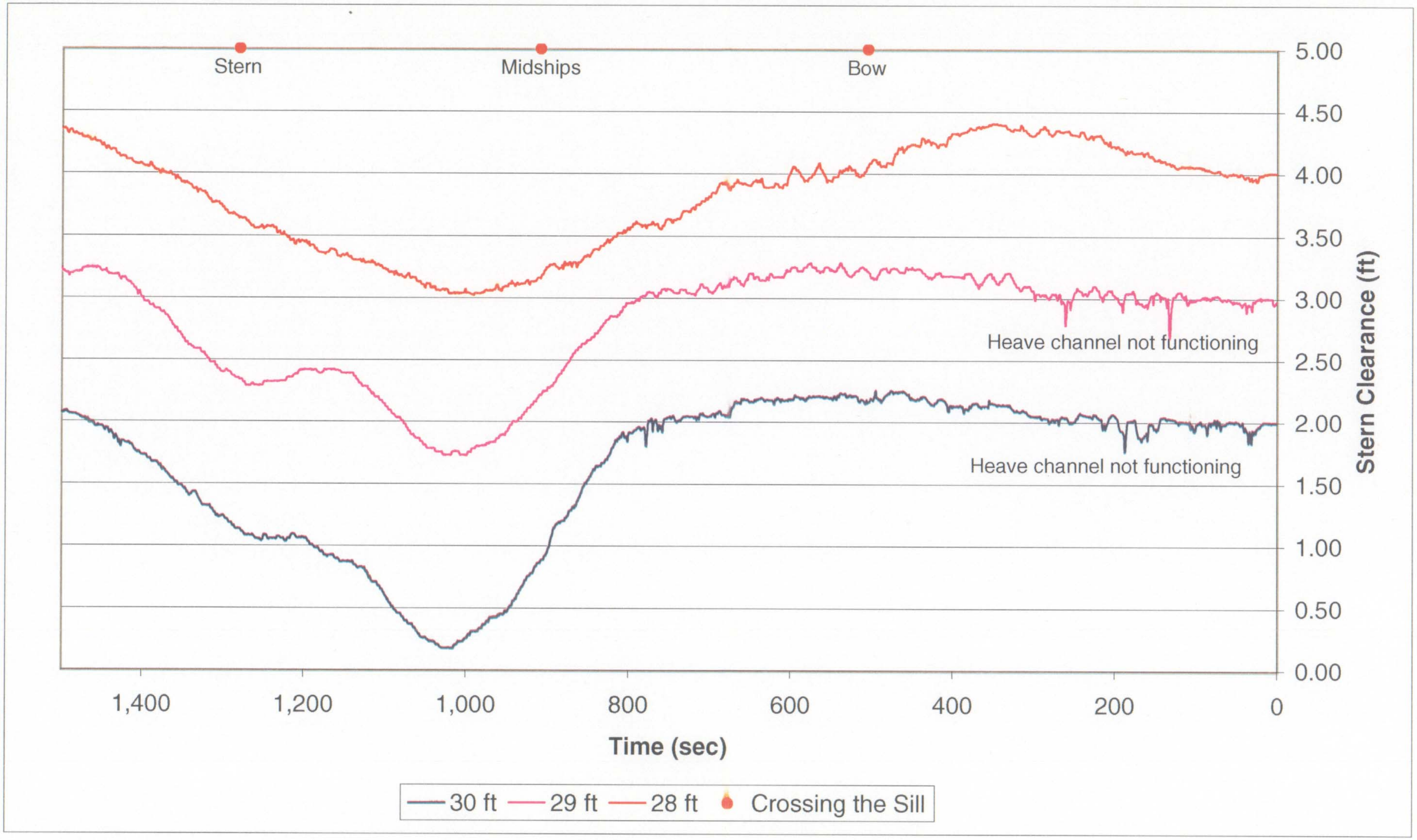
Case I - Largest Clearance, Scale 29.8



Stern Clearance - Entering Condition, 1.1 knots
Case II - Medium Clearance, Scale 31.4

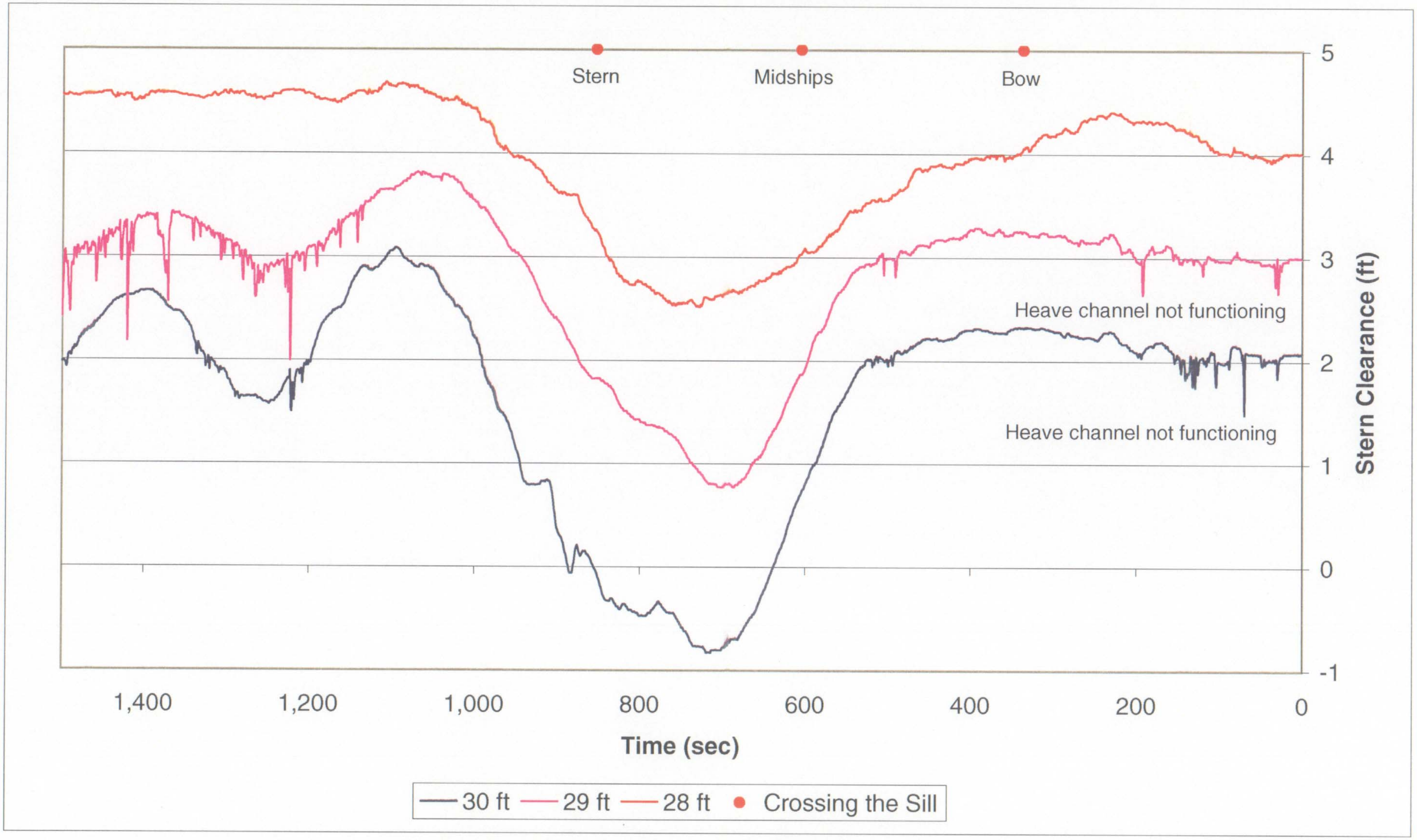


Stern Clearance - Entering Condition, 0.73 knots
Case III - Least Clearance, Scale 32.2



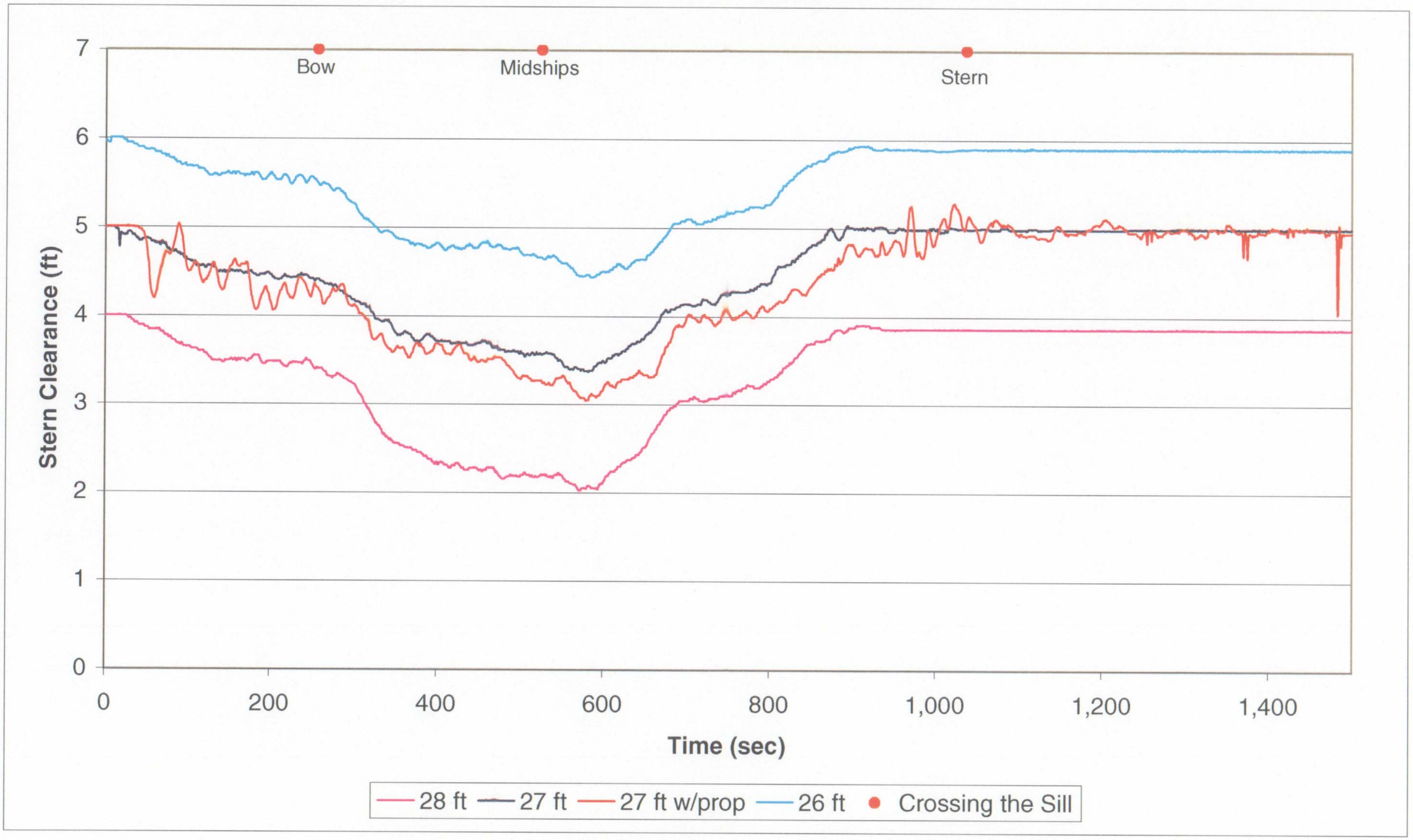
Stern Clearance - Entering Condition, 1.10 knots

Case III - Least Clearance, Scale 32.2



Stern Clearance - Exiting Condition, 1.10 knots
Case I - Largest Clearance, Scale 29.8
Bow
Midships
Stern
7
6
5
4
3
2
1
0
Stern Clearance (ft)
0
200
400
600
800
1,000
1,200
Time (sec)
28 ft
27 ft
27 ft w/prop
26 ft
Crossing the Sill

Stern Clearance - Exiting Condition, 1.10 knots
Case II - Medium Clearance, Scale 31.4



Stern Clearance - Exiting Condition, 1.10 knots

Case III - Least Clearance, Scale 32.2