DEVELOPMENT OF A PERFORMANCE BASED FISHING VESSEL STABILITY CRITERIA; A METHODOLOGY BASED ON SCALABLE MODEL TESTS

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SUMMARY

An essential step in the development of performance based stability criteria is knowledge of the vessel motions which result from various sea conditions. This has been traditionally done through the use of model tests. More recently, numerical methods have been used to predict ship motions, although characterizations in extreme waves of the type that can cause capsizing are still very difficult. This paper explores a methodology for characterizing vessel responses to wave action up to and including capsizing using a series of fishing vessel model tests performed at SSPA in the 1980s. These tests are well documented and the video tapes are very useful for interpreting the vessel motions.

1. INTRODUCTION

Working Group A of SNAME Ad Hoc Panel #12, Fishing Vessel Operations and Safety, is pursuing the following task as stated in its charter: "Investigate the feasibility of establishing risk-based fishing vessel stability criteria appropriate to the type of vessel and its operating area." The existing IMO stability standard for fishing vessels is a one-size-fits-all pass-fail system, which extrapolates Rahola's original work well beyond what he warns against in his thesis (Francescutto, 2002, Womack, 2002, Bird, 1986, Jens, 1982, Cleary 1982)

A feasible beginning to this long-range task is the development of performance based criteria (Cramer 2002, Francescutto, 2002) based on previous fishing vessel model tests performed by Grochowalski at the SSPA model tank during the 1980s (Grochowalski, 1989). The fishing vessel used for these tests was based on a typical small Canadian, hard-chine stern trawler of 19.8 m length which in a model scale of 1/14 was 1.33 m on the waterline.

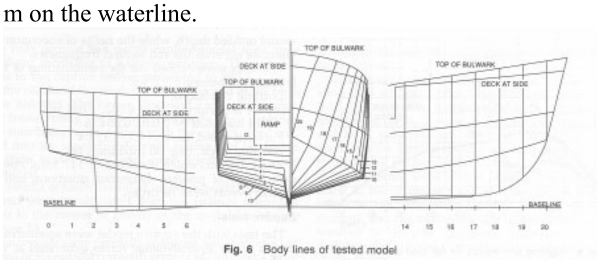

Figure 1 Fig. 6 from Grochowalski, 1989

The model and vessel particulars are as follows:

Table 1	Model	Vessel
LOA, m	1.413	19.8
L, LWL, m	1.328	18.6
B, Beam, m	0.435	6.09
T, FL Draft, m	0.224	3.14
D, Hull Depth, m	0.263	3.68
Bulwark Height, m	0.065	0.91
L/B	3.05	3.05
B/T, Port Departure	2.19	2.19
B/T, Full Load	1.94	1.94

2. METHODOLOGY

In the search for the correlation between the main ship stability characteristics and the elements of ship behaviour in waves, a detailed analysis of the model test results has begun. The objective of the analysis is to identify certain symptoms in ship behaviour which seem to indicate the danger of capsizing, and to find their dependence on ship loading conditions and on wave parameters. This, in turn, should provide the ground for assessment of the risk of capsizing.

Excel spreadsheets which summarize the results of the SSPA tests in the model scale, have been developed. They are summarized in Appendix A, which contains the summary of the model loading conditions, the wave conditions, and the test series summary. Note especially the parameters : Wave Height to Beam, Wave Height to Hull Depth and Nominal Wave Length to Vessel Length for each of the six regular wave conditions and two irregular wave conditions.

Figure 2 shows the righting arm curves for the four conditions compared to the IMO standard, whose strange shape is the result of the inconsistency in the area requirements (Womack 2002).

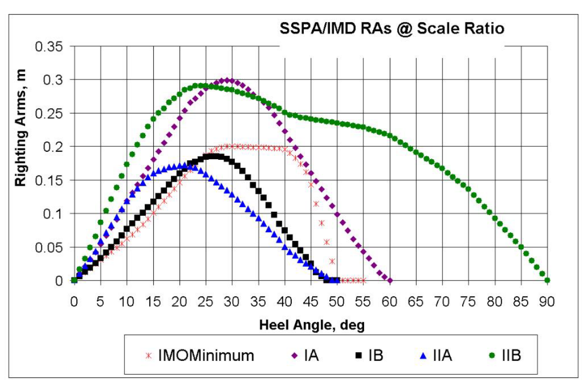

Figure 2: Righting Arm Curves @ SR = 14

Table 2 shows the results of scaling the model results back up to the original scale ratio of 14

Table 2

Scale Ratio	14	Length	61	Beam	19.8
Matches Canadian F/V		Port Departure		Full Load	
Loading Condition		IA	IB	IIA	IIB
Displacement, tons		149	149	185	185
Meets IMO Requirements		yes	no	no	yes+
Survived in Wave Heights to, m		7.0	5.3	2.5	9.1

The results of these model tests have been used in the forensic analysis of sinking of the fishing vessel Arctic Rose. By increasing the scale ratio to 17.3 in Table 3 and Appendix B, it was possible to match the beam and displacement of the Arctic Rose. Then the scaled righting arm curves of the model tests can be compared with those of the Arctic Rose for intact stability. Using this comparison, the Marine Investigation Board concluded it was unlikely that the Arctic Rose capsized and sank in the intact stability condition (Borlase 2002).

Table 3

Scale Ratio	17.3	Length	75	Beam	24.7
Matches Arctic Rose Displ.		Port Departure		Full Load	
Loading Condition		IA	IB	IIA	IIB
Displacement, tons		282	282	349	349
Meets IMO Requirements		yes	no	no	yes+
Survived in Wave Heights to, m		8.7	6.6	3.1	11.2

The Arctic Rose comparison is near the upper bound of scale ratios which give realistic bulwark heights. Something to remember when planning generic model tests for capsizing studies is to use several different adjustable bulwark heights to enable scaling to both larger and smaller scale ratios. For example, changing the scale ratio to 22.5 (a 30 m vessel) brings Condition IB up to the IMO criteria with a survival wave height of 8.6 meters and a bulwark height of 1.46 m, which could trap a lot of water on deck. On the other hand, changing the scale ratio to 11.3 (a 15 m vessel) lets a vessel loaded as condition IA barely meet IMO standards with a survival wave height of 5.7 m and a bulwark height of 0.71 m which wouldn't be high enough for crew safety.

Note also in Appendix B that the area under the righting arm curve all the way to vanishing stability divided by the apparent survivable wave height is nearly a constant number for the two full load conditions. The survivable wave height for full load Condition IIB was 3.7 times the survivable wave height of Condition IIA as was the area under the respective righting arm curves to the point of vanishing stability. Other trends in the data are being explored for insights on possible alarm parameters for the risk assessment analysis which will be needed for operational guidance (Womack, 2002).

3. FUTURE WORK

Appendix C shows the test matrix for condition IA, which satisfies the IMO convention for both model scale and for full scale extrapolations. It is intended to analyze all of the model runs for various measures of vessel performance and capsize risk as a function of the wave heights and wave lengths, forward speeds and course angles recorded in the testing. (See Table 4 for SR = 14) The mean and maximum amplitudes of roll, the relative motion of water on both sides at the midships, the height of water surface above the bulwark, the lasting time when deck edge is in water, and when bulwark top is immersed will be tabulated.

Special attention will be given to specific dangerous phenomena which were identified in the tests and which could be considered as the symptoms of possible disaster, such as:

- Riding on the wave crest
- Broaching to
- Deep immersion of a part of the deck
- Combination of sway and yaw with roll in the cases when bulwark is immersed
- Combination of dangerous phenomena shortly before capsizing.

It will be attempted to establish the relationship of these phenomena with the area under the righting moment curve in capsize- and non-capsize cases. (See also Blume 1993 and 1987, Cramer and Tellkamp 2002)

The analyses of time series plots performed (Grochowalski, 1989), presented in Appendices D and E as the examples, and the video records of all tests provide possibility of such detail analysis, both qualitatively and quantitatively.

Once the critical parameters for safe operation are established from a combination of model test results and numerical methods, then numerical experiments can be used to expand beyond the model test data. It is hoped that the data from the ITTC benchmark testing for Intact Ship Stability (Umeda 2002) can be analyzed and added to the database of the model tests. Other model tests which are adequately documented should also be added to the database. A use of a modern time-domain simulation program could be used in the future to give a more complete range of parameters to consider in this task.

4. VIDEO PROJECT

As part of the forensic analysis of the sinking of the F/V Arctic Rose in April 2001, the video tape of portions of these tests (Table 5) was shown to the Marine Investigation Board for the Arctic Rose. It was a valuable tool in working out the various scenarios of possible motions of the vessel during the sinking. The original capsize tape, however contains no videos of the tests on Loading Condition IIB, which, like the Arctic Rose, had a range of intact stability out to 90 degrees and did not capsize in the generated seas. However, it was possible to use the observed vessel motions in waves to set up time stepping scenarios based on getting lifted up by an oncoming wave crest for 2 seconds, riding the wave crest for 3 seconds and sliding back along the trough for 5 seconds for an average wave period of 10 seconds as an example of one of the many scenarios analyzed.

The objective of the current SNAME T&R project is to better organize the video sequences in terms of the behaviour of each loading condition in the identical seaways. This is essential for establishing a correlation between the shape and areas of the intact righting arm curve and the ship motions in a given seaway. Various correlations between possible stability righting arm curves in flooded conditions and the intact loading conditions IA, IB, IIA and IIB will be attempted to establish the higher risks associated with reduced righting arm curves.

The project will edit large number of hours of tapes down to a subset of the originals, arranged by loading condition, which should fit on a one to one and a half hour DVD and/or a set of CDs. The report will be in a form suitable for release by SNAME as a T&R Report on CDs and DVDs.

5. CONCLUSIONS

By tabulating sufficient model and wave characteristics from model scale tests, one can scale up the resulting ship motions to any scale ratio where the scaled bulwarks are reasonable.

Detailed analysis of the model tests from the viewpoint of various symptoms of dangerous behaviour in waves and combinations of motion parameters, wave heights and righting moment characteristics in capsize- and non-capsize cases should provide the correlation between the ship operational conditions and the risk of capsizing.

It is the authors' belief that once complete, this project will provide the basis for establishment of risk based stability criteria for fishing vessels.

Table 4 Wave Conditions for Scale Ratio of 14 Ratio of Vessel Speed to Wave Celerity

Reg	Wave	Wave	Wave		Wave	Wave	Wave	Vessel	Speed	
Wave	Height	Period	Length	λ/LWL	Steep.	Celerity	Celerity	5.1	8.0	10.2
#	m	Sec	m			m/sec	Knots	Knots	Knots	Knots
#1	2.52	3.37	17.7	.95	0.142	5.26	10.2	0.50	0.78	1.00
#2	3.78	4.12	26.4	1.42	0.143	6.43	12.5	0.41	0.64	0.81
#3	5.32	4.86	36.9	1.99	0.144	7.59	14.8	0.34	0.54	0.69
#4	6.16	5.24	42.8	2.30	0.144	8.16	15.9	0.32	0.50	0.64
#5	7.00	5.61	49.2	2.65	0.142	8.76	17.0	0.30	0.47	0.60
#6	9.10	6.36	63.2	3.40	0.144	9.93	19.3	0.26	0.41	0.53

Table 5 Existing IMD_SSPA Video Summary

Section #	Time	Elapse Time	Subject	Models:Run #
1	5:49	5:49	Introduction	
2	1:07	6:56	Capsize due to Poor Inherent Stability,	IB:4/56, 4/68
3	2:48	9:44	Loss of Stability due to Water on Deck	IIA: 5/99 IB: 4/53
4	3:47	13:31	Stability Reduction on a Wave Crest	IB: 4/73, 4/79
5	2:31	16:02	Water on Deck and Stability Reduction on a Wave Crest	IIA: 5/111
6	5:04	21:06	Riding on a Wave Crest and Broaching Phenomena	1A: 3/11,3/23,3/26/27,3/10 IB, 4/63, 4/78, 4/80 IIA: 5/97
7	14:17	35:23	Influence of Bulwark and Deck Edge Submergence	IA: 3/25, 3/26/27, 3/21
			Explanation of Bulwark Submergence	IA: 3/15, 3/19, 3/25
			Capsize in vessels which meet Stability Standards	IA: 3/27
			Light Load vs. Full Load Conditions	IB: 4/54, 4/58 IIA:?
8	1.12	36:35	Beam Seas	IB:?
9	3:06	39:41	Capsize caused by a Combination of Various Factors	IB: 4/80, 4/78 IIA: 5/117

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Appendix A

IMD/SSPA FV Model Tests	Port Departure		Full Load	
Loading Condition	**IA**	**IB**	**IIA**	**IIB**
Model Scale				
Displacement m^3	0.0531	0.0531	0.0657	0.0657
Draft AP, m	0.185	0.185	0.239	0.239
Draft FP, m	0.213	0.213	0.209	0.209
LCG fwd L/2, m	-0.009	-0.009	-0.058	-0.058
KG above BL, m	0.216	0.23	0.208	0.19
GM, m	0.035	0.021	0.036	0.054
kxx, m	0.141	0.141	0.146	0.151
kyy, m	0.31	0.312	0.31	0.313
kzz, m	0.315	0.315	0.322	0.322
Roll period, sec	1.74	2.15	1.71	1.45
Heave period, sec	0.94	0.87	1.08	1.32
Pitch period, sec	0.97	0.99	1.05	1.02
Derived				
Mean Draft, m	0.199	0.199	0.224	0.224
Mean Draft, ft	0.65	0.65	0.73	0.73
Mean Freeboard, m	0.064	0.064	0.039	0.039
Mean Freeboard, ft	0.21	0.21	0.13	0.13
Mean Freeboard/Beam	0.147	0.147	0.090	0.090
Angle of Deckedge Sub.	16.4	16.4	10.2	10.2
Angle of Bullwark Sub.	30.67	30.67	25.56	25.56
KG/T	1.09	1.16	0.93	0.85
KG/D	0.82	0.87	0.79	0.72
KG/Disp^1/3	0.57	0.61	0.52	0.47
Block Coefficient, CB	0.46	0.46	0.51	0.51
Capsized	H/D> #5	H/D>#3	H/D>#1	No Capsize

IMO/Torrelomolinos	m-rad	m-deg	ft-deg	Ft-rad
RA Area 0-30	0.055	3.1515	10.3	0.1804
RA Area 30-40	0.03	1.719	5.6	0.0984
RA Area 0-40	0.09	5.157	16.9	0.2952

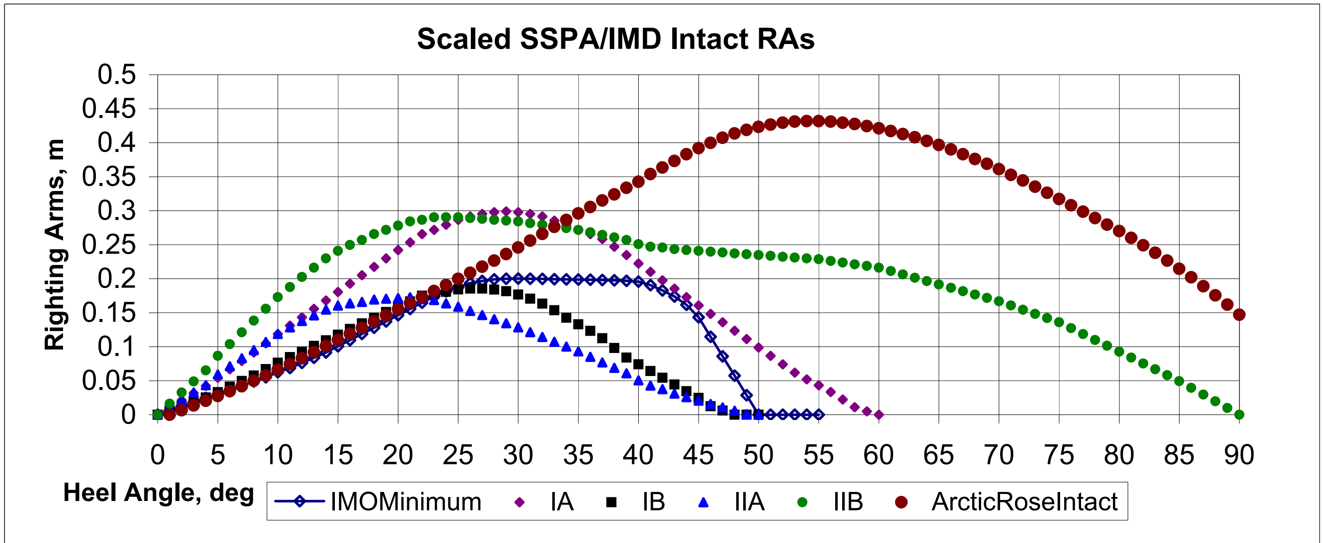
Model Particulars	
LOA, m	1.413
L, LWL, m	1.328
B, Beam, m	0.435
T, FL Draft, m	0.224
D, Depth, m	0.263
Bulwark height, m	0.065
L/B	3.05
B/T Port Departure	2.19
B/T Full Load	1.94

Regular Wave Tests	Nom H, m	Nom H/B	Nom H/D	Nominal Wave Period sec.	Nominal Wave Length m	Nominal Wave Len over LWL λ/LWL
#1	0.18	0.41	0.68	0.9	1.26	0.95
#2	0.27	0.62	1.03	1.1	1.89	1.42
#3	0.38	0.87	1.44	1.3	2.64	1.99
#4	0.44	1.01	1.67	1.4	3.06	2.30
#5	0.5	1.15	1.90	1.5	3.51	2.65
#6	0.65	1.49	2.47	1.7	4.51	3.40
Irregular Wave Tests	**Hsig, m**	**Hsig/B**				
#1	0.30	0.69	1.14	1.5	3.51	2.65
#2	0.36	0.83	1.37	1.7	4.51	3.40
Irregular Wave Tests	**H1/10, m**	**H1/10/B**				
#1	0.38	0.88	1.45	1.5	3.51	2.65
#2	0.46	1.05	1.74	1.7	4.51	3.40

Summary of Model Tests	Series	Regular Wave #s	No. Runs	Irregular Waves	No. Runs
Condition IA	3 (30 deg)	1,2,3,4,5,6	18	1,2	7
Condition IB	4 (30 deg)	1,2,3,4,5	15	1,2	13
Condition IIA	5 (30 deg)	1,2,3,4,5	17	1,2	12
Condition IIA	6 (Beam)	4	1		6
Condition IIB	7 (Beam)	4	1	1	3
Condition IIB	8 (30 deg)	1,2,3,4,5,6	17	1,2	6
		Totals	69	116	47

Appendix B

Full Scale Comparison with Arctic Rose



Scale Ratio	17.3	Arctic
Vessel Particulars	SSPA	Rose
Displacement, tons	349	350
LOA, m	24.44	31.10
L, LWL, m	22.97	28.96
B, Beam, m	7.53	7.47
T, FL Draft, m	3.88	3.13
D, Depth, m	4.55	3.59
Bulwark height, m	1.12	0.91
L/B	3.05	3.88
B/T Port Departure	2.19	2.39
B/T Full Load	1.94	2.42

Scale Ratio	17.3	Length, m	23.0	Beam, m	7.5	Depth, m	4.5	Bulwark height, m	1.12

	Port Departure		Full Load	
Loading Condition	IA	IB	IIA	IIB
Displacement, tons	282	282	349	349
GM, m	0.61	0.36	0.62	0.93
KG, m	3.7	4.0	3.6	3.3
KG/T	1.09	1.16	0.93	0.85
KG/D	0.82	0.87	0.79	0.72
Mean Draft, m	3.4	3.4	3.9	3.9
Mean Freeboard, m	1.1	1.1	0.7	0.7
Mean Freeboard/Beam	0.147	0.147	0.090	0.090
Survives in H/B	1.1	0.9	0.4	1.5
Survives in Wave Height, m	**8.7**	**6.6**	**3.1**	**11.2**
Righting Energy/ Wave Height	323	210	540	533
Righting Area/Wave Height	1.15	0.75	1.55	1.53
(FB/B)*RA/HW	0.17	0.11	0.14	0.14

Unit Righting Energy, m-deg						Arctic
In m-deg	IA	IB	IIA	IIB	IMO	Rose
RA Area 0-30	5.18	3.32	3.68	6.07	3.15	3.66
RA Area 30-40	2.69	1.31	0.92	2.70	1.72	3.08
RA Area 0-40	7.86	4.62	4.60	8.78	5.16	6.71
RA Area 0-VS	9.91	4.90	4.82	17.18	6.37	24.09
Stability Range	60	48	50	90	NA	99
GM, m	0.61	0.36	0.62	0.93	0.35	0.40
Righting Energy, in meter tons	2,793	1,381	1,680	5,992	2,222	8,384

Test Program, Free Running Model in Waves.

Series 3

Loading contition IA

Heading, degrees 30

Data Tape File Numbe	Run. Number	Speed m/s	Regular Waves H m	Regular Waves T sec	Irregular Waves H m	Irregular Waves T sec
1	4	0.7	0.18	0.9		
2	5	1.1	0.18	0.9		
3	6	1.4	0.18	0.9		
4	7	0.7	0.27	1.1		
5	8	1.1	0.27	1.1		
6	11	1.4	0.27	1.1	Capsize Video	
7	12	0.7	0.38	1.3		
8	13	1.1	0.38	1.3		
9	15	1.4	0.38	1.3	Capsize Video	
10	16	0.7	0.44	1.4		
11	17	1.1	0.44	1.4		
12	19	1.4	0.44	1.4	Capsize Video	
13	20	0.7	0.5	1.5		
14	21	1.1	0.5	1.5	Capsize Video	
15	23	1.4	0.5	1.5		
19	28	1.4	0.5	1.5		
16	24	0.7	0.65	1.7		
17	25	1.1	0.65	1.7	Capsize Video	
	26	1.4	0.65	1.7	Capsize Video	
18	27	1.4	0.65	1.7	Capsize Video	
20	30	0.7			0.25	1.5
21	32	1.1			0.25	1.5
22	33	1.4			0.25	1.5
23	34	0.7			0.32	1.7
24	35	0.7			0.32	1.7
25	36	1.1			0.32	1.7
26	37	1.4			0.32	1.7

Appendix C

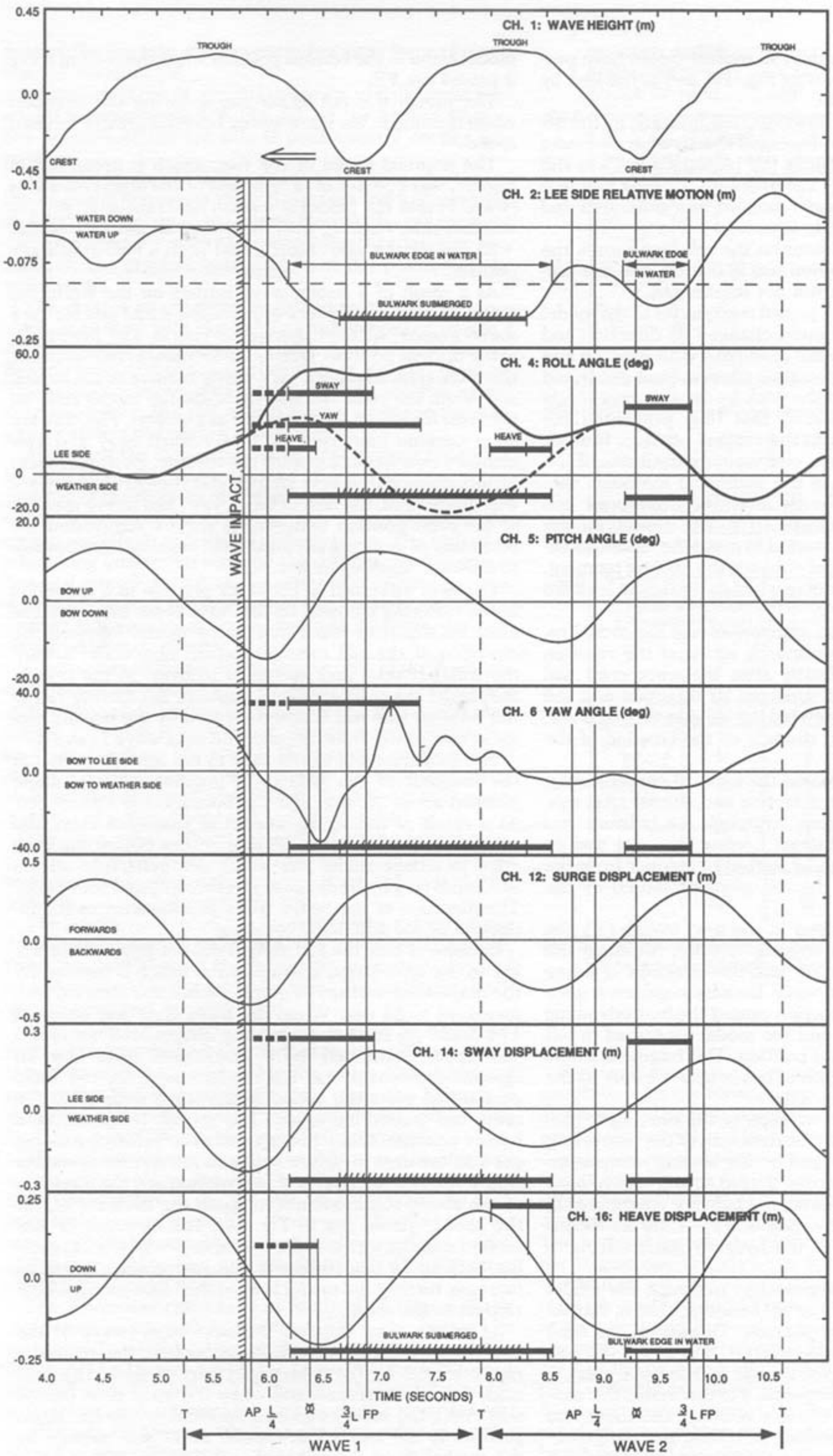
Series 3 Test Program, Free Running Model in Wave

Loading contition IA **Scale Ratio** **14.0**

Heading, degrees 30 Regular W 0 Irregular Waves

Data Tape File Numbe	Run. Number	Speed Knots	Regular Waves H m	Regular Waves T sec	Irregular Waves H m	Irregular Waves T sec
1	4	5.1	2.52	3.37		
2	5	8.0	2.52	3.37		
3	6	10.2	2.52	3.37		
4	7	5.1	3.78	4.12		
5	8	8.0	3.78	4.12		
6	11	10.2	3.78	4.12	Capsize Video	
7	12	5.1	5.32	4.86		
8	13	8.0	5.32	4.86		
9	15	10.2	5.32	4.86	Capsize Video	
10	16	5.1	6.16	5.24		
11	17	8.0	6.16	5.24		
12	19	10.2	6.16	5.24	Capsize Video	
13	20	5.1	7.00	5.61		
14	21	8.0	7.00	5.61	Capsize Video	
15	23	10.2	7.00	5.61		
19	28	10.2	7.00	5.61		
16	24	5.1	9.10	6.36		
17	25	8.0	9.10	6.36	Capsize Video	
	26	10.2	9.10	6.36	Capsize Video	
18	27	10.2	9.10	6.36	Capsize Video	
20	30	5.1			3.50	5.61
21	32	8.0			3.50	5.61
22	33	10.2			3.50	5.61
23	34	5.1			4.48	6.36
24	35	5.1			4.48	6.36
25	36	8.0			4.48	6.36
26	37	10.2			4.48	6.36

Appendix D



Full Scale:
20m vessel
9 m waves
WL/SL 3.2
8 Kt Speed
No Capsize

Fig. 26 Influence of hydrodynamic phenomenon created by bulwark submergence on roll motion—fragment of time record of a free model's run in breaking quartering waves; free running test No. 25; load condition I / A; nominal forward speed $v = 1.1$ m/s; heading angle $\mu = 30$ deg; nominal parameters of periodic waves: $H = 0.65$ m, $T = 1.7$ sec

Appendix E

Full Scale:
20m vessel
9 m waves
WL/SL 3.2
10.2 Kt Speed
Capsize

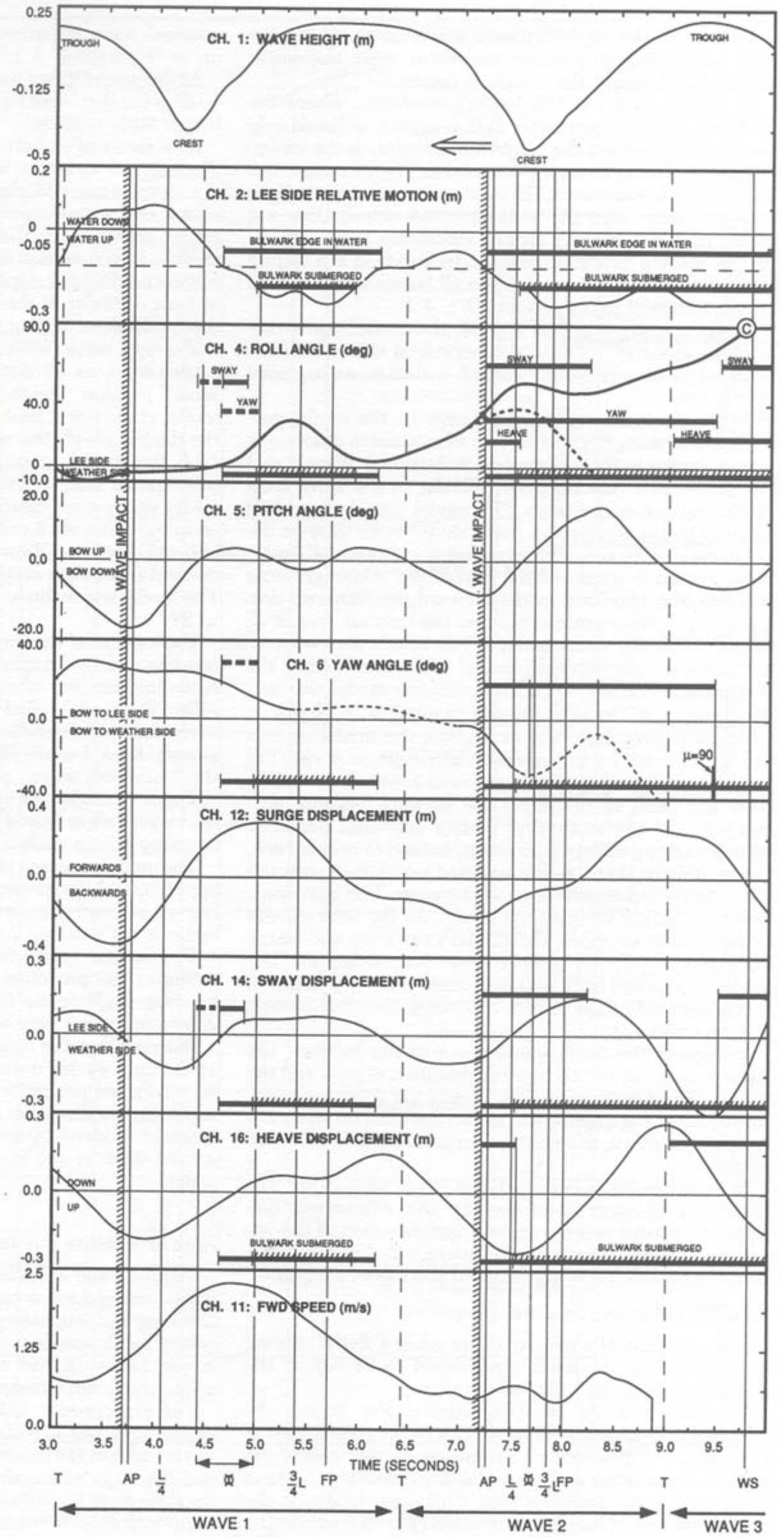


Fig. 27 Time history of model capsize in breaking quartering waves; free running test No. 27; load condition I/A; nominal model speed v = 1.4 m/s; course angle μ = 30 deg; Periodic waves with nominal parameters: H = 0.65 m, T = 1.7 sec