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A NOTE FOR PLANNING FURTHER EXPERIMENTS ON FLOODING PROTECTION OF RO-RO FERRIES

LM-1996-06

W.D. Molyneux and C. Smith

July 1996

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SUMMARY This report gives the results of additional analysis of experiments to determine the survival limit of damaged RO-RO ferries in waves. Limiting criteria are presented based on waveheight, residual freeboard and stability parameters for the ship.			
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A NOTE FOR PLANNING FURTHER EXPERIMENTS ON FLOODING PROTECTION OF RO-RO FERRIES

1. INTRODUCTION

Since 1993, Transport Canada have been sponsoring a project with Polar Design Research and the Institute for Marine Dynamics on the Flooding Protection of RO-RO Ferries. The project used a prismatic model to represent a simplified hull form of a large Canadian ferry. This work has been successful in establishing the parameters causing a flooded ferry to capsize, but the prismatic model has been an obvious limitation in the practical application of the results.

The next phase of the project is to progress to a more realistic hull shape, although still simplified. The purpose of this note is to review the results of the previous set of experiments, with the objective of developing a test plan for the second phase of the test program. It will identify trends from the previous set of experiments, and try to ensure that the test program for the next phase covers the required range of parameters to ensure an effective evaluation of the SOLAS 90 regulations.

The description of the model and the detailed results of the previous experiments are given in full in Reference 1.

2. REVIEW OF PREVIOUS DATA SET

A summary of the data from the previous experiments is given in Tables 1 to 4.

In order to understand the problem of ferry capsize after flooding, we should consider the simplified flow chart shown in Figure 1. The two critical points in the flooding and subsequent capsize process are marked with diamonds. The first one is critical because a capsize can be avoided if no water gets onto the car deck. The second point is critical since a capsize will not occur if the hull has sufficient stability to withstand the acquired volume of water on the deck.

This process gives options for presenting the data with the objective of obtaining a limiting parameter to prevent the capsize of the damaged ferry.

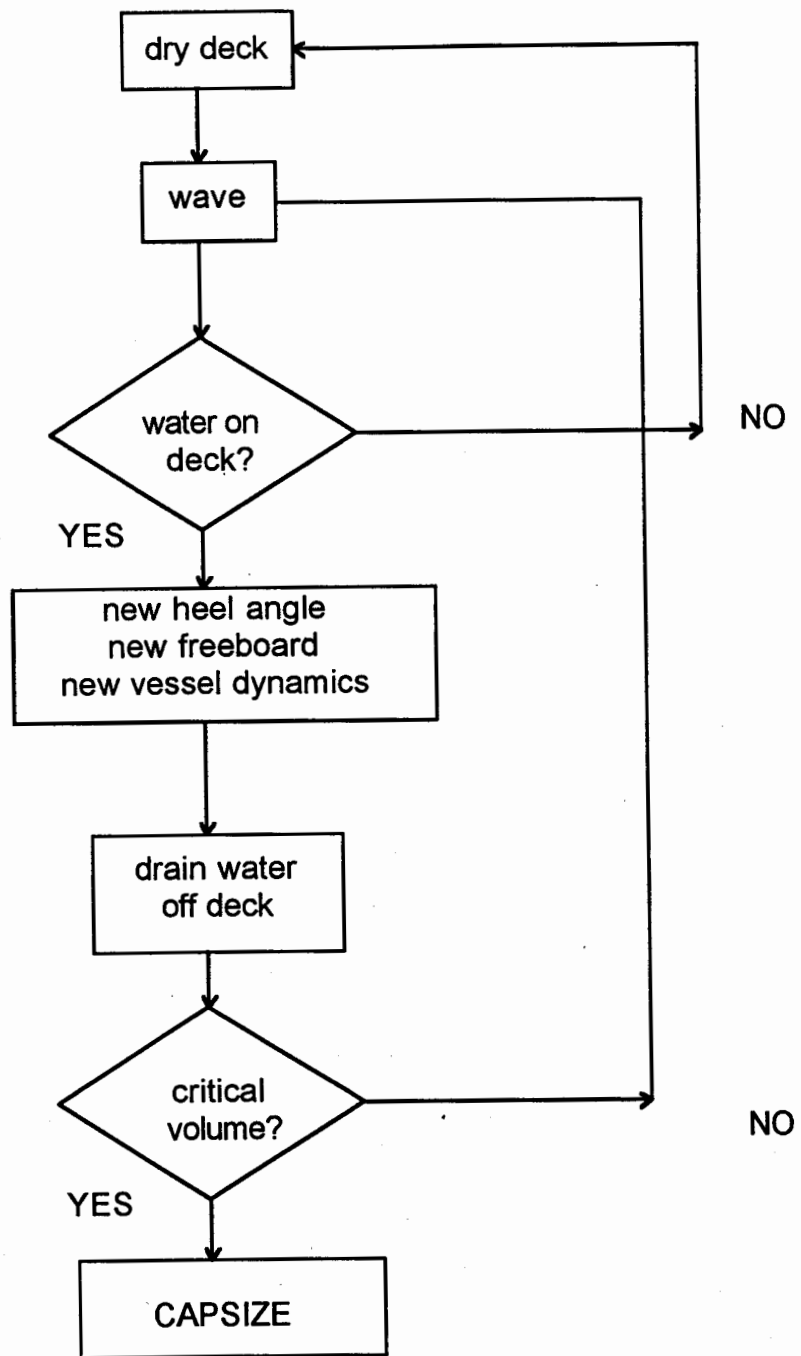


Figure 1: Simplified Representation of Capsize Process

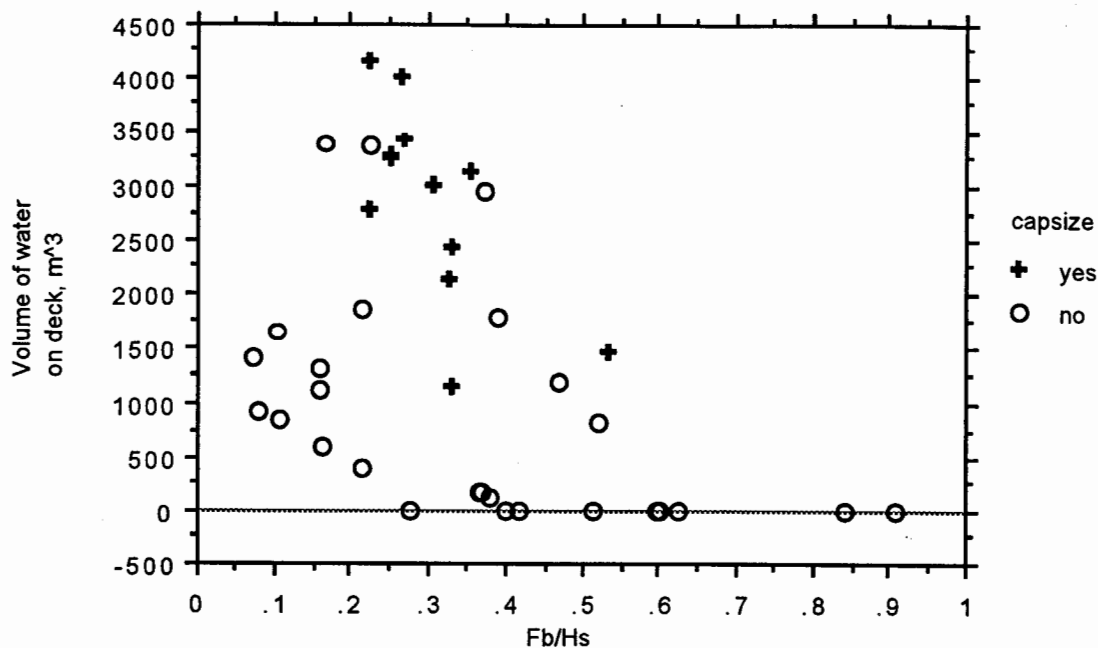


Figure 2, Volume of water on deck against Fb/Hs, freeing ports closed

3. ADDITIONAL ANALYSIS OF EXPERIMENT RESULTS

3.1 Volume of Water on Deck

The most obvious parameter to consider for limiting volume of water on deck is freeboard. Intuitively, a high freeboard in low waves will accumulate less water than a low freeboard in high waves. A non-dimensional parameter that limits the volume of water on the deck is the ratio of freeboard (Fb) to significant waveheight (Hs). Figure 2 shows measured volume of water on deck against freeboard divided by significant waveheight. Although there is a considerable amount of scatter, it is clear that high volumes of water are only observed at low values of freeboard to waveheight ratio. Analytical methods developed by Hutchison et al [2], give a justification to this trend. Figure 3 shows the IMD model data superimposed on the limiting depth of water on the deck taken from [2], and, in general, cases where the observed volume of water on the deck was higher than the limit resulted in a capsize. Water depths observed on the model may be greater than the limit line, since the prediction method made no allowance for the dynamics of the hull.

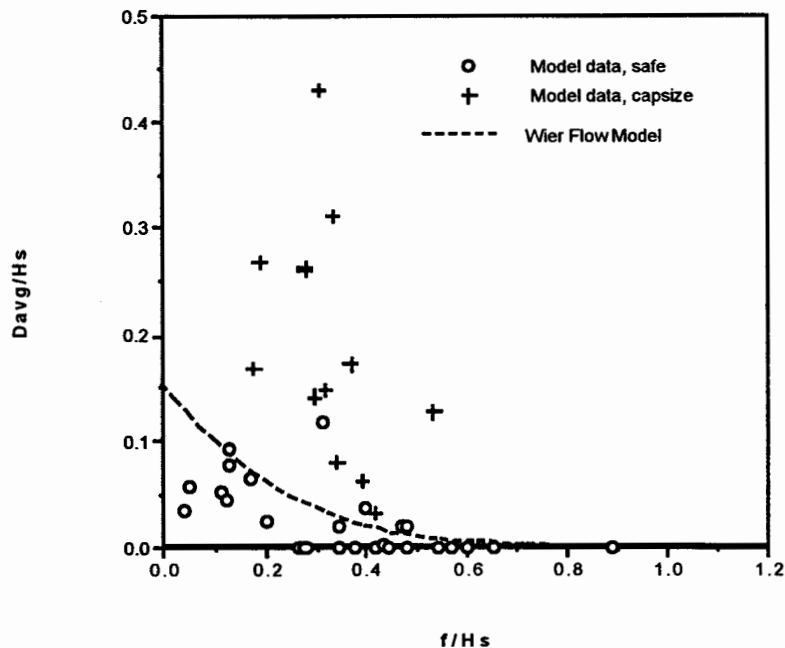


Figure 3, Non-dimensional depth of water on deck against non-dimensional freeboard

Note that Figure 3 shows very little data for Fb/H_s values less than 0.1 and so there is poor information on the limiting level of water on the car deck at low residual freeboards. This is particularly important for most existing ferries, since the freeboards are often much lower than the 0.5 metre minimum value tested at IMD.

3.2 Stability of Damaged Hull

The next critical point in the process is the relationship between volume of water on the deck and the stability of the ship. Figures 4 to 7 show volume of water plotted against stability parameters GZ area, GZ range, maximum GZ and flooded GM. From these figures it can be seen that the clearest limiting stability criteria can be drawn from using maximum GZ or flooded GM as the abscissa.

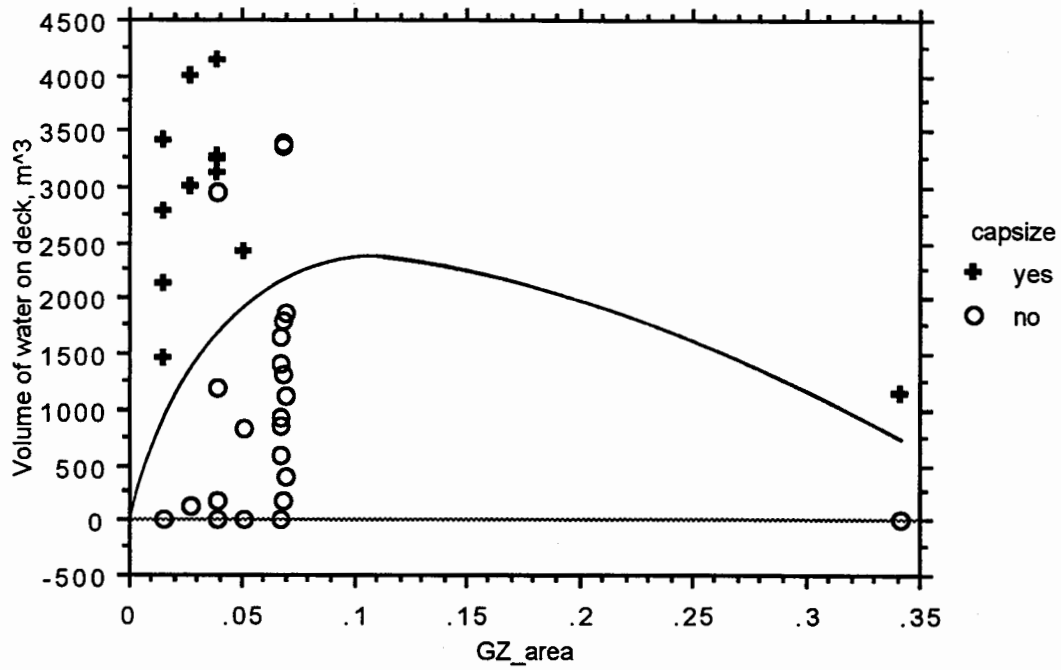


Figure 4, Volume of water on deck against GZ area (m-radians)

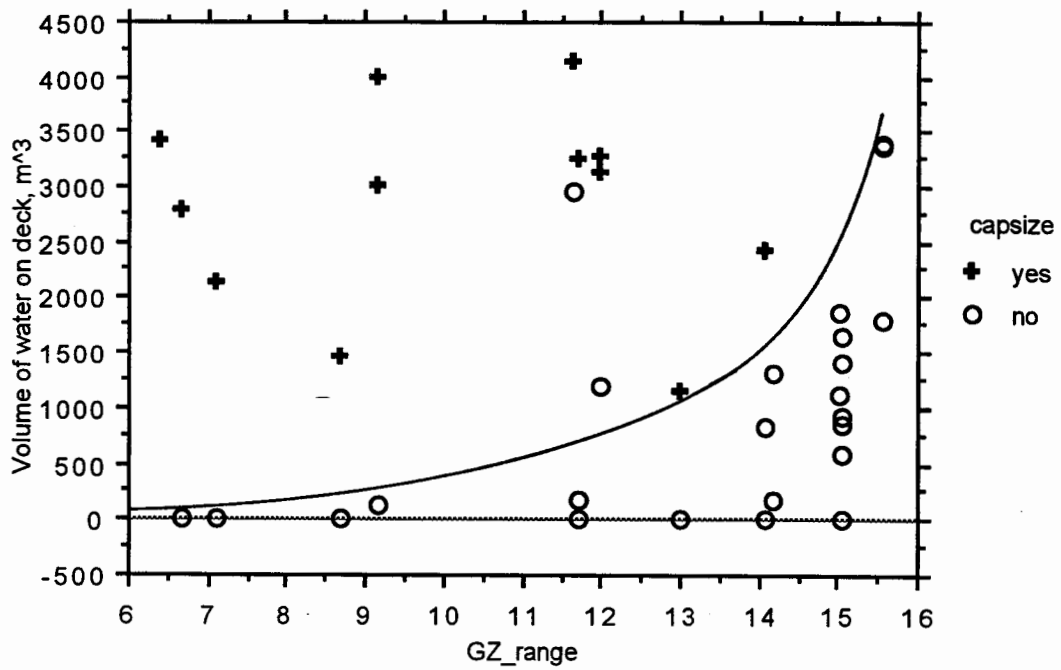


Figure 5, Volume of water on deck against GZ range (degrees)

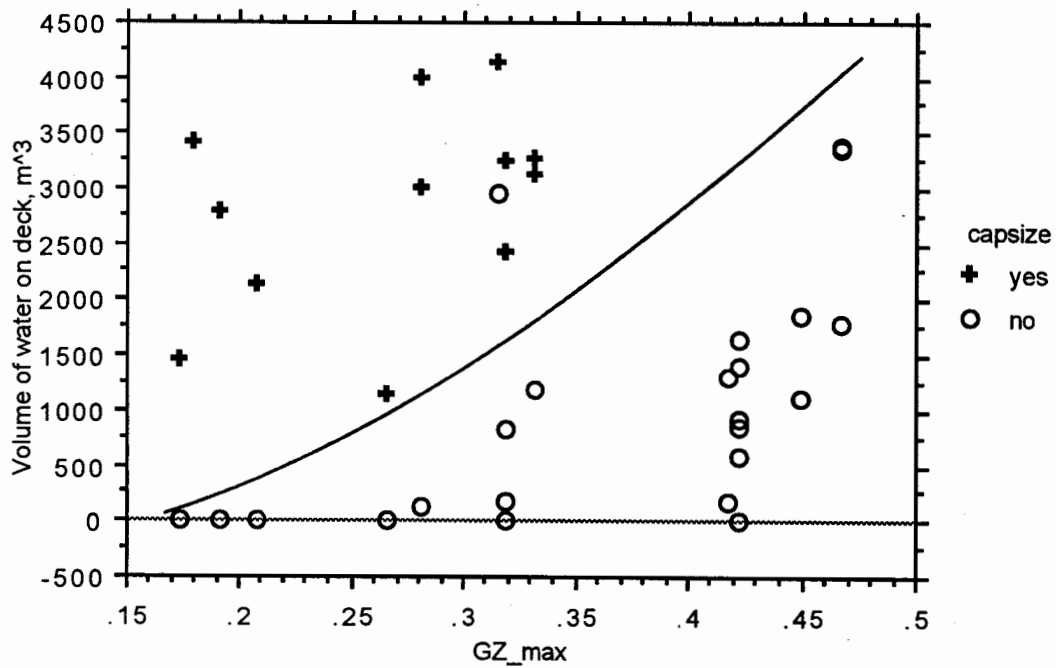


Figure 6, Volume of water on deck against maximum GZ (metres)

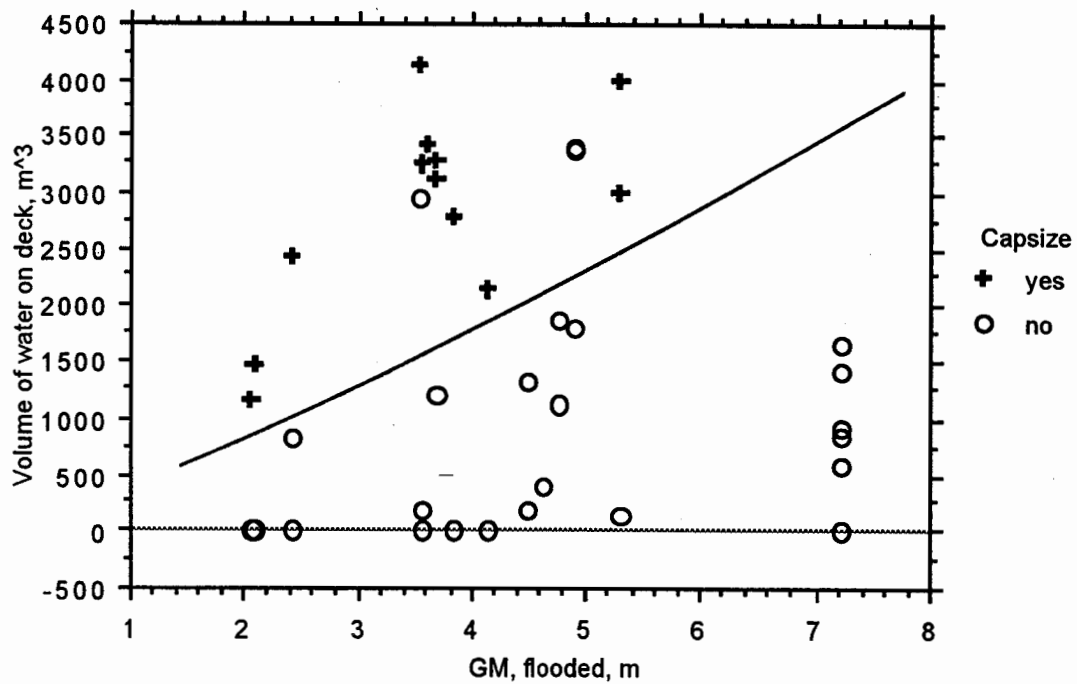


Figure 7, Volume of water on deck against flooded metacentric height (metres)

3.3 Limiting Criteria for Capsize Safety

The next step is to combine Fb/Hs with stability criteria and see if sensible limiting criteria can be used. Figure 8 shows Fb/Hs against flooded GM and Figure 9 shows Fb/Hs against Maximum GZ.

The work of Spouge [3], uses a limiting criteria are based flooded GM, freeboard, significant waveheight and model displacement. Figure 8 does not show a complete transition boundary for the IMD data, but clearly these parameters form a good basis for a simple limiting condition. Figure 8 shows some data with moderate values of flooded GM and a high degree of survivability (marked with an ellipse). Based on GM values alone, it was not expected that these conditions would have survived.

However, when we compare Figure 8 with Figure 9, we can see that these points actually have relatively high values of maximum GZ. These high values are derived from the combination of vertical centre of gravity position and freeboard. The large value of maximum GZ appears to account for the high degree of survivability. Maximum GZ provides a good basis for the stability parameter of the damaged ship.

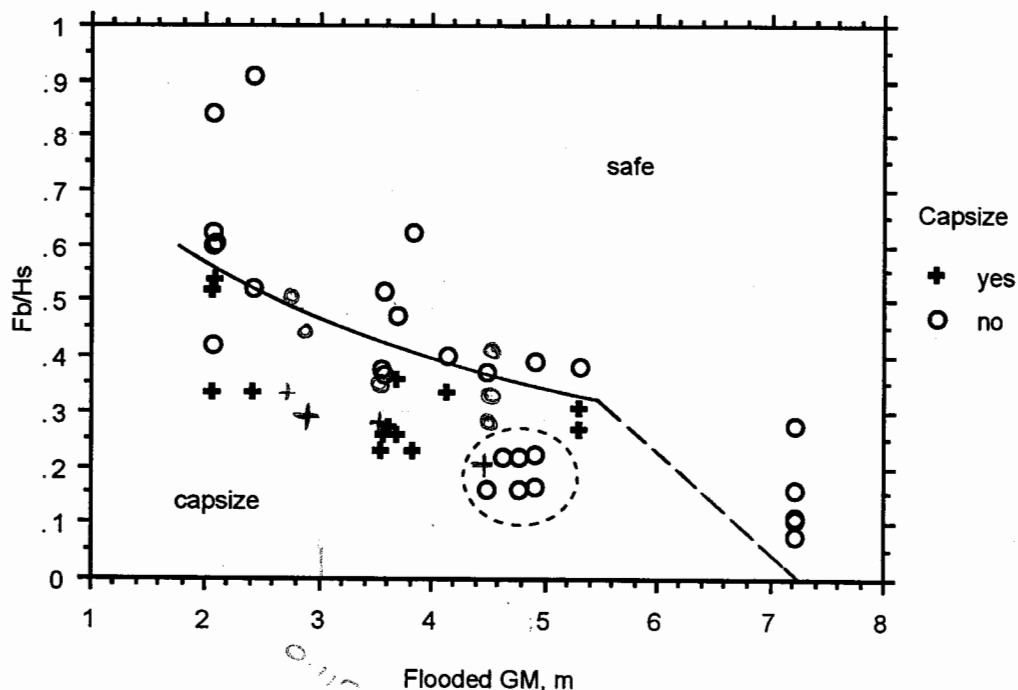


Figure 8, Fb/Hs against flooded GM (metres)

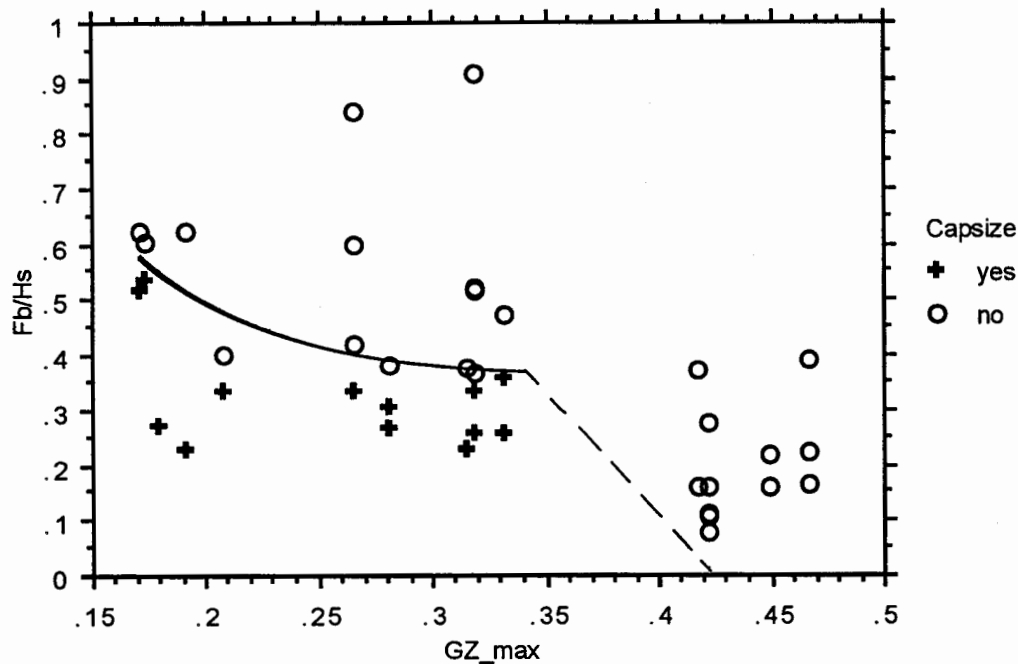


Figure 9, Fb/H_s against Maximum GZ (metres)

Figure 9 also highlights another gap in the previous data set for maximum GZ values between 0.35 and 0.4. This area is particularly interesting, since it represents a transition between survivability at moderate values of Fb/H_s to survivability at very low values of Fb/H_s .

3.4 Effect of Freeing Ports

Figure 10 shows non-dimensional freeboard against maximum GZ, for the model with all the freeing ports active. The effect of the freeing ports is to lower the ratio of Fb/H_s at which the limit of survivability occurs. This trend is progressive, as can be seen from figures 11 and 12, in that as the area of freeing ports is reduced, then the ratio of Fb/H_s for a given value of GZ increases, meaning that the waveheight that the model will survive is lower.

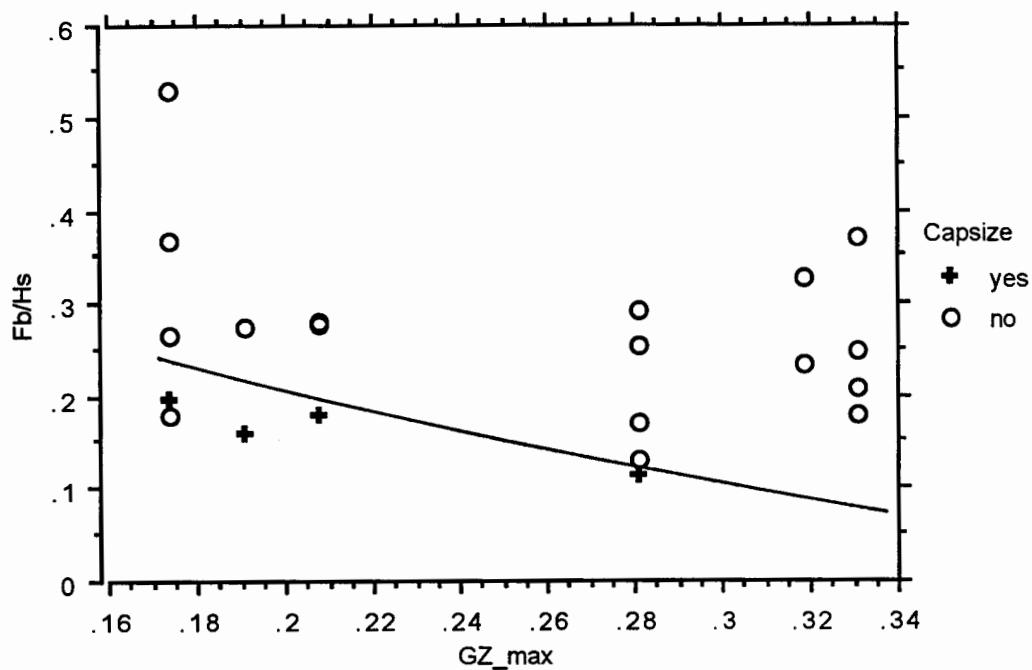


Figure 10, Fb/Hs against Maximum GZ (metres) (100% freeing ports)

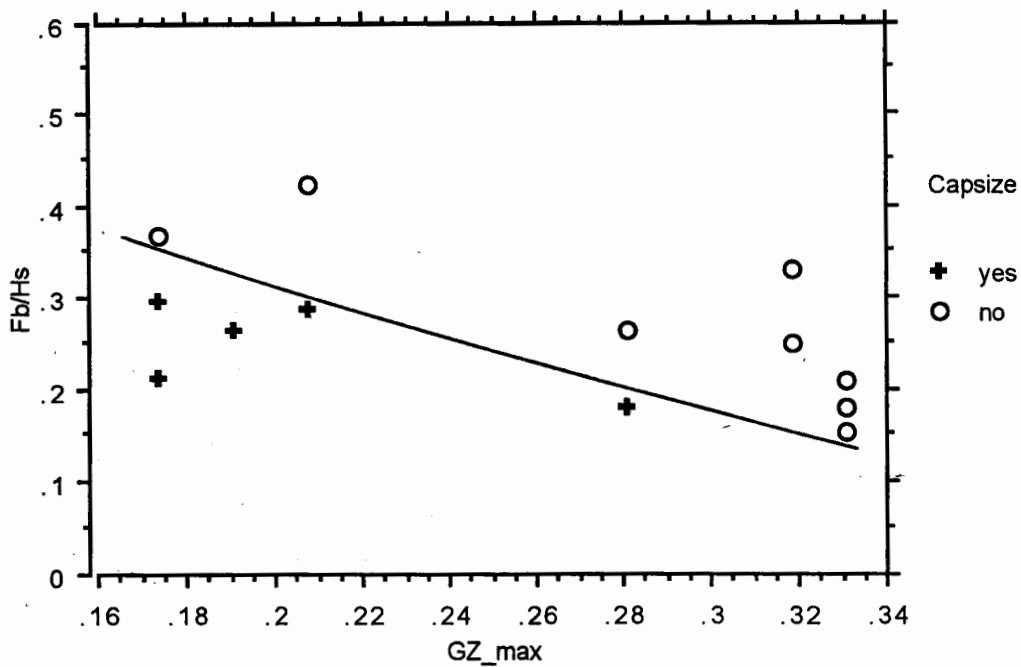


Figure 11, Fb/Hs against Maximum GZ (metres) (50% freeing ports)

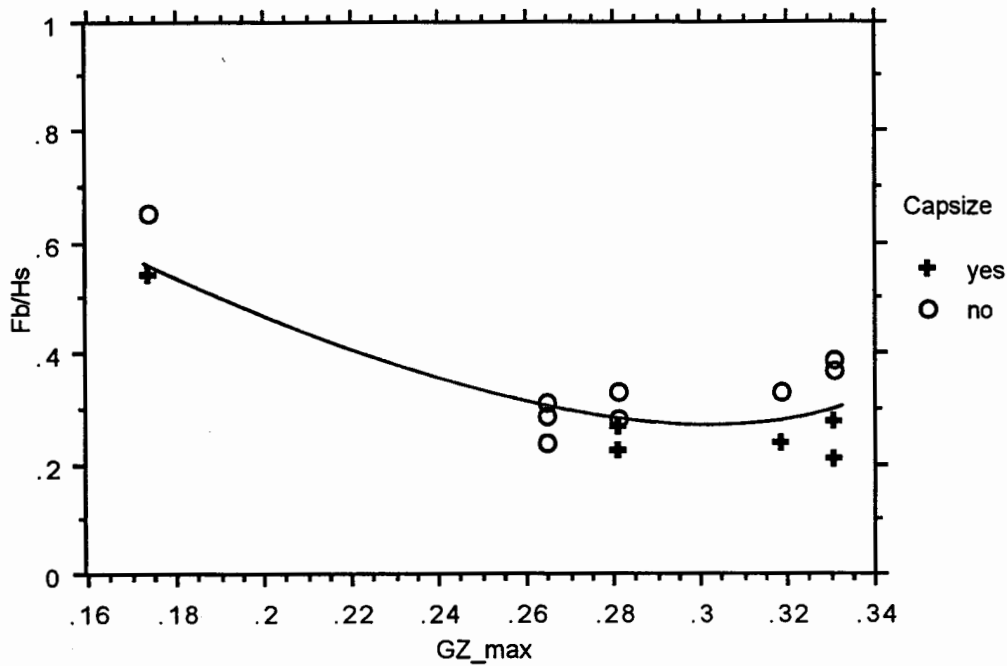


Figure 12, Fb/Hs against Maximum GZ (metres) (Load line freeing ports)

4. PARAMETERS FOR FURTHER STUDY

SOLAS 90 calls for the following limits on stability parameters;

- GZ (maximum) > 0.1m
- GZ range > 15 degrees
- GZ area > 0.015 m-radians

The nature of the hull shape for the previous model was such that strict SOLAS 90 compliance could only be obtained at the 15 degree limit, which meant that the other parameters greatly exceeded their minimum requirement. This is particularly true for maximum GZ value. The minimum value of GZ (maximum) actually tested was 0.17m, which is 70% more than the minimum required. This is a particular concern, when it appears that the maximum value of GZ is a key parameter in determining the vessel's ability to survive a capsize.

It appears that the three parameters in the SOLAS 90 regulations only become coincident at high values of KG and high freeboards after damage. For the IMD model tested in [1] the 15 degree range was the limiting factor for compliance with SOLAS 90. This is also true for the modified Camille Marcoux hull form proposed for the next phase of model tests.

The other area of concern is the minimum freeboard to be considered. The IMD data was obtained for a minimum freeboard of 0.5 metres. At this level of freeboard, the minimum significant waveheight to capsize the ship was about 1.25 metres. There is some concern that this freeboard is much higher than the values used in current practice (but it should be noted that these existing ships do not meet SOLAS 90 regulations). Freeboards to meet SOLAS 90 regulations are much higher than those used in previous practice. Another factor to consider with the low freeboard is the limiting volume of water that builds up on the car deck. There is no data for waveheight to freeboard ratios of less than 0.1. It is desirable for any new experiments to validate Hutchison et al's model for limiting water depth on the car deck at low values of freeboard to waveheight ratio.

In conclusion, the areas to be investigated in a new program of experiments, with a hull form closer to a ship shape are;

- Maximum GZ values closer to SOLAS 90 minimum requirement
- Lower freeboards than 0.5 metres to determine limiting water levels for actual ships.

5. REFERENCES

1. Molyneux, D. et al, 'RO-RO Ferry Passenger Vessel Capsize Safety Investigation: Physical Model Experiments, Phase 1', NRC/IMD TR-1994-04, January 1994.
2. B. L., Hutchison, D. Molyneux and P. Little, 'Time Domain Simulation and Probability Domain Integrals for Water on Deck Accumulation', Cybernautics 95, SNAME California Joint Sections Meeting, Long Beach, CA, April 1995.
3. J. Spouge, 'A Technique to Predict the Capsize of a Damaged RO-RO Ferry', Trans. RINA, 1995.

Tables

TABLE 1
Results of Experiments to Determine
Capsize Limits of RO-RO Ferry

run #	KG_nom	KG_act	r_f	GM_fl_nom	GM_fl_act	GZ_area	GZ_range	GZ_max	heel@GZmax	T_roll	casing	freeports
9	10.97	11.189	0.5	4.058	3.839	0.015	6.69	0.191	3.27	7.68	1	0
14	10.97	11.189	0.5	4.058	3.839	0.015	6.69	0.191	3.27	7.68	1	4
15	10.97	11.189	0.5	4.058	3.839	0.015	6.69	0.191	3.27	7.68	1	3
16	10.97	11.189	0.5	4.058	3.839	0.015	6.69	0.191	3.27	7.68	1	4
17	10.97	11.189	0.5	4.058	3.839	0.015	6.69	0.191	3.27	7.68	1	0
18	10.97	11.409	0.5	4.058	3.619	0.015	6.41	0.179	3.21	7.91	0	0
21	10.97	11.409	0.5	4.058	3.619	0.015	6.41	0.179	3.21	7.91	0	4
22	10.97	11.409	0.5	4.058	3.619	0.015	6.41	0.179	3.21	7.91	0	4
24	7.82	7.809	0.5	7.209	7.22	0.0675	15.06	0.422	5	6.47	1	0
25	7.82	7.809	0.5	7.209	7.22	0.0675	15.06	0.422	5	6.47	1	0
26	7.82	7.809	0.5	7.209	7.22	0.0675	15.06	0.422	5	6.47	1	0
27	7.82	7.809	0.5	7.209	7.22	0.0675	15.06	0.422	5	6.47	1	0
28	7.82	7.809	0.5	7.209	7.22	0.0675	15.06	0.422	5	6.47	0	0
29	7.82	7.809	0.5	7.209	7.22	0.0675	15.06	0.422	5	6.47	0	0
32	11.3	11.621	1.5	2.742	2.421	0.051	14.07	0.319	8.11	13.07	1	0
33	11.3	11.621	1.5	2.742	2.421	0.051	14.07	0.319	8.11	13.07	1	0
34	11.3	11.621	1.5	2.742	2.421	0.051	14.07	0.319	8.11	13.07	1	0
35	11.3	11.621	1.5	2.742	2.421	0.051	14.07	0.319	8.11	13.07	1	4
36	11.3	11.621	1.5	2.742	2.421	0.051	14.07	0.319	8.11	13.07	1	4
37	11.3	11.621	1.5	2.742	2.421	0.051	14.07	0.319	8.11	13.07	1	3
39	11.3	11.621	1.5	2.742	2.421	0.051	14.07	0.319	8.11	13.07	1	3
40	11.3	11.621	1.5	2.742	2.421	0.051	14.07	0.319	8.11	13.07	1	2
41	11.3	11.621	1.5	2.742	2.421	0.051	14.07	0.319	8.11	13.07	1	2
42	11.3	11.621	1.5	2.742	2.421	0.051	14.07	0.319	8.11	13.07	1	1
47	9.765	9.602	1	4.759	4.922	0.068	15.55	0.467	6.74	10.66	1	0
48	9.765	9.602	1	4.759	4.922	0.068	15.55	0.467	6.74	10.66	1	0
49	9.765	9.602	1	4.759	4.922	0.068	15.55	0.467	6.74	10.66	1	0
53	9.765	10.031	1	4.759	4.493	0.068	14.17	0.418	6.46	10.66	0	0
54	9.765	10.031	1	4.759	4.493	0.068	14.17	0.418	6.46	10.66	0	0

TABLE 1 (cont)
Results of Experiments to Determine
Capsize Limits of RO-RO Ferry

run #	Hs_nom	T_wave	Hs_act	V_wod	capsize	roll	rms roll	mean_rm	rms_rm	wht/gz_area	fb/hs_act
9	1.5	6	2.21	2775	yes	-8.8491	1.666	5.369	0.780	147.379	0.226
14	1.5	6	1.82	150	no	-2.2542	1.755	3.400	0.704	121.301	0.275
15	1.5	6	1.9	2827	yes	-8.7448	1.834	5.222	0.939	126.813	0.263
16	3	7	3.16	3213	yes	-8.7032	3.577	5.471	1.491	210.403	0.158
17	0.5	5	0.8	0	no	-0.702	0.253	3.173	0.259	53.517	0.625
18	1.5	6	1.85	3401	yes	-16.032	2.142	5.588	0.878	123.475	0.270
21	1.5	6	1.91	3452	yes	-13.83	1.954	5.575	0.713	127.640	0.262
22	1	5.5	1.47	57.73	no	-6.4884	0.991	4.145	0.555	97.917	0.340
24	1.5	6	1.81	0	no	-3.3839	2.260	2.744	1.123	26.816	0.276
25	3	7	3.1	583	no	-5.2271	4.561	3.434	1.113	45.855	0.161
26	5	8	4.58	853	no	-3.8827	5.649	3.301	1.508	67.826	0.109
27	7	9	6.31	914	no	-3.5691	6.020	4.221	1.191	93.409	0.079
28	5	8	4.79	1646	no	-2.3243	5.633	3.149	1.182	71.007	0.104
29	7	9	6.67	1397	no	-1.5795	6.140	3.645	1.194	98.751	0.075
32	1.5	6	1.65	0	no	-4.5849	0.742	1.878	0.593	32.438	0.909
33	3	7	2.87	839.5	no	-7.9681	11.763	2.402	2.987	56.345	0.523
34	5	8	4.5	2415	yes	-16.002	2.149	5.494	1.297	88.282	0.333
35	5	8	4.58	209	no	-4.5997	3.484	3.240	1.598	89.827	0.328
36	7	9	6.35	335	no	-2.7323	5.625	3.010	2.055	124.504	0.236
37	5	8	4.55	189	no	-3.4225	3.736	3.055	1.658	89.310	0.330
39	7	9	6.05	419	no	1.3575	5.497	2.440	2.031	118.638	0.248
40	5	8	4.59	401	no	-0.2247	3.805	2.678	1.636	90.027	0.327
41	7	9	6.37	2338	yes	-10.37	5.567	5.326	1.519	124.887	0.235
42	5	8	4.43	2726	yes	-15.445	4.303	7.572	0.961	86.900	0.339
47	3	7	2.57	1784	no	-2.7984	3.842	3.499	1.200	37.779	0.389
48	5	8	4.46	3361	no	-6.9556	6.082	5.880	1.725	65.552	0.224
49	7	9	6.01	3389	no	-4.7718	6.870	6.057	1.762	88.338	0.166
53	3	7	2.69	184	no	-1.6965	1.173	1.778	0.874	39.578	0.372
54	7	9	6.32	1316	no	2.8366	7.564	2.418	1.814	92.911	0.158

TABLE 2
Results of Experiments to Determine
Capsize Limits of RO-RO Ferry

	KG_nom	KG_act	r_f	GM_fl_nom	GM_fl_act	GZ_area	GZ_range	GZ_max	heel@GZmax	T_roll	casing	freeports
50	10.9	10.98	1	3.624	3.544	0.039	11.64	0.315	6	14.69	1	0
51	10.9	10.98	1	3.624	3.544	0.039	11.64	0.315	6	14.69	1	0
52	10.9	10.98	1	3.624	3.544	0.039	11.64	0.315	6	14.69	1	1
7	10.97	10.89	0.5	4.058	4.138	0.015	7.12	0.208	3.36	8.03	1	0
8	10.97	10.89	0.5	4.058	4.138	0.015	7.12	0.208	3.36	8.03	1	0
9	10.97	10.89	0.5	4.058	4.138	0.015	7.12	0.208	3.36	8.03	1	4
10	10.97	10.89	0.5	4.058	4.138	0.015	7.12	0.208	3.36	8.03	1	4
11	10.97	10.89	0.5	4.058	4.138	0.015	7.12	0.208	3.36	8.03	1	3
12	10.97	10.89	0.5	4.058	4.138	0.015	7.12	0.208	3.36	8.03	1	3
13	10.97	10.89	0.5	4.058	4.138	0.015	7.12	0.208	3.36	8.03	1	4
25	9.765	9.72	0.5	5.267	5.312	0.027	9.17	0.281	3.78	7.51	1	0
26	9.765	9.72	0.5	5.267	5.312	0.027	9.17	0.281	3.78	7.51	1	0
27	9.765	9.72	0.5	5.267	5.312	0.027	9.17	0.281	3.78	7.51	1	0
28	9.765	9.72	0.5	5.267	5.312	0.027	9.17	0.281	3.78	7.51	1	4
29	9.765	9.72	0.5	5.267	5.312	0.027	9.17	0.281	3.78	7.51	1	4
30	9.765	9.72	0.5	5.267	5.312	0.027	9.17	0.281	3.78	7.51	1	4
31	9.765	9.72	0.5	5.267	5.312	0.027	9.17	0.281	3.78	7.51	1	4
34	9.765	9.72	0.5	5.267	5.312	0.027	9.17	0.281	3.78	7.51	1	3
35	9.765	9.72	0.5	5.267	5.312	0.027	9.17	0.281	3.78	7.51	1	3
36	9.765	9.72	0.5	5.267	5.312	0.027	9.17	0.281	3.78	7.51	1	2
37	9.765	9.72	0.5	5.267	5.312	0.027	9.17	0.281	3.78	7.51	1	2
39	9.765	9.72	0.5	5.267	5.312	0.027	9.17	0.281	3.78	7.51	1	2
40	9.765	9.72	0.5	5.267	5.312	0.027	9.17	0.281	3.78	7.51	1	2
43	9.765	9.72	0.5	5.267	5.312	0.027	9.17	0.281	3.78	7.51	1	4
48	10.9	10.832	1	3.624	3.692	0.039	12	0.331	6	11.45	1	0
49	10.9	10.832	1	3.624	3.692	0.039	12	0.331	6	11.45	1	0
50	10.9	10.832	1	3.624	3.692	0.039	12	0.331	6	11.45	1	0
51	10.9	10.832	1	3.624	3.692	0.039	12	0.331	6	11.45	1	4
52	10.9	10.832	1	3.624	3.692	0.039	12	0.331	6	11.45	1	4
53	10.9	10.832	1	3.624	3.692	0.039	12	0.331	6	11.45	1	4
54	10.9	10.832	1	3.624	3.692	0.039	12	0.331	6	11.45	1	4

TABLE 1 (cont)
Results of Experiments to Determine
Capsize Limits of RO-RO Ferry

run #	Hs_nom	T_wave	Hs_act	V_wod	capsize	roll	rms roll	mean_rm	rms_rm	wht/gz_area	fb/hs_act
9	1.5	6	2.21	2775	yes	-8.8491	1.666	5.369	0.780	147.379	0.226
14	1.5	6	1.82	150	no	-2.2542	1.755	3.400	0.704	121.301	0.275
15	1.5	6	1.9	2827	yes	-8.7448	1.834	5.222	0.939	126.813	0.263
16	3	7	3.16	3213	yes	-8.7032	3.577	5.471	1.491	210.403	0.158
17	0.5	5	0.8	0	no	-0.702	0.253	3.173	0.259	53.517	0.625
18	1.5	6	1.85	3401	yes	-16.032	2.142	5.588	0.878	123.475	0.270
21	1.5	6	1.91	3452	yes	-13.83	1.954	5.575	0.713	127.640	0.262
22	1	5.5	1.47	57.73	no	-6.4884	0.991	4.145	0.555	97.917	0.340
24	1.5	6	1.81	0	no	-3.3839	2.260	2.744	1.123	26.816	0.276
25	3	7	3.1	583	no	-5.2271	4.561	3.434	1.113	45.855	0.161
26	5	8	4.58	853	no	-3.8827	5.649	3.301	1.508	67.826	0.109
27	7	9	6.31	914	no	-3.5691	6.020	4.221	1.191	93.409	0.079
28	5	8	4.79	1646	no	-2.3243	5.633	3.149	1.182	71.007	0.104
29	7	9	6.67	1397	no	-1.5795	6.140	3.645	1.194	98.751	0.075
32	1.5	6	1.65	0	no	-4.5849	0.742	1.878	0.593	32.438	0.909
33	3	7	2.87	839.5	no	-7.9681	11.763	2.402	2.987	56.345	0.523
34	5	8	4.5	2415	yes	-16.002	2.149	5.494	1.297	88.282	0.333
35	5	8	4.58	209	no	-4.5997	3.484	3.240	1.598	89.827	0.328
36	7	9	6.35	335	no	-2.7323	5.625	3.010	2.055	124.504	0.236
37	5	8	4.55	189	no	-3.4225	3.736	3.055	1.658	89.310	0.330
39	7	9	6.05	419	no	1.3575	5.497	2.440	2.031	118.638	0.248
40	5	8	4.59	401	no	-0.2247	3.805	2.678	1.636	90.027	0.327
41	7	9	6.37	2338	yes	-10.37	5.567	5.326	1.519	124.887	0.235
42	5	8	4.43	2726	yes	-15.445	4.303	7.572	0.961	86.900	0.339
47	3	7	2.57	1784	no	-2.7984	3.842	3.499	1.200	37.779	0.389
48	5	8	4.46	3361	no	-6.9556	6.082	5.880	1.725	65.552	0.224
49	7	9	6.01	3389	no	-4.7718	6.870	6.057	1.762	88.338	0.166
53	3	7	2.69	184	no	-1.6965	1.173	1.778	0.874	39.578	0.372
54	7	9	6.32	1316	no	2.8366	7.564	2.418	1.814	92.911	0.158

TABLE 2
Results of Experiments to Determine
Capsize Limits of RO-RO Ferry

	KG_nom	KG_act	r_f	GM_fl_nom	GM_fl_act	GZ_area	GZ_range	GZ_max	heel@GZmax	T_roll	casing	freeports
50	10.9	10.98	1	3.624	3.544	0.039	11.64	0.315	6	14.69	1	0
51	10.9	10.98	1	3.624	3.544	0.039	11.64	0.315	6	14.69	1	0
52	10.9	10.98	1	3.624	3.544	0.039	11.64	0.315	6	14.69	1	1
7	10.97	10.89	0.5	4.058	4.138	0.015	7.12	0.208	3.36	8.03	1	0
8	10.97	10.89	0.5	4.058	4.138	0.015	7.12	0.208	3.36	8.03	1	0
9	10.97	10.89	0.5	4.058	4.138	0.015	7.12	0.208	3.36	8.03	1	4
10	10.97	10.89	0.5	4.058	4.138	0.015	7.12	0.208	3.36	8.03	1	4
11	10.97	10.89	0.5	4.058	4.138	0.015	7.12	0.208	3.36	8.03	1	3
12	10.97	10.89	0.5	4.058	4.138	0.015	7.12	0.208	3.36	8.03	1	3
13	10.97	10.89	0.5	4.058	4.138	0.015	7.12	0.208	3.36	8.03	1	4
25	9.765	9.72	0.5	5.267	5.312	0.027	9.17	0.281	3.78	7.51	1	0
26	9.765	9.72	0.5	5.267	5.312	0.027	9.17	0.281	3.78	7.51	1	0
27	9.765	9.72	0.5	5.267	5.312	0.027	9.17	0.281	3.78	7.51	1	0
28	9.765	9.72	0.5	5.267	5.312	0.027	9.17	0.281	3.78	7.51	1	4
29	9.765	9.72	0.5	5.267	5.312	0.027	9.17	0.281	3.78	7.51	1	4
30	9.765	9.72	0.5	5.267	5.312	0.027	9.17	0.281	3.78	7.51	1	4
31	9.765	9.72	0.5	5.267	5.312	0.027	9.17	0.281	3.78	7.51	1	4
34	9.765	9.72	0.5	5.267	5.312	0.027	9.17	0.281	3.78	7.51	1	3
35	9.765	9.72	0.5	5.267	5.312	0.027	9.17	0.281	3.78	7.51	1	3
36	9.765	9.72	0.5	5.267	5.312	0.027	9.17	0.281	3.78	7.51	1	2
37	9.765	9.72	0.5	5.267	5.312	0.027	9.17	0.281	3.78	7.51	1	2
39	9.765	9.72	0.5	5.267	5.312	0.027	9.17	0.281	3.78	7.51	1	2
40	9.765	9.72	0.5	5.267	5.312	0.027	9.17	0.281	3.78	7.51	1	2
43	9.765	9.72	0.5	5.267	5.312	0.027	9.17	0.281	3.78	7.51	1	4
48	10.9	10.832	1	3.624	3.692	0.039	12	0.331	6	11.45	1	0
49	10.9	10.832	1	3.624	3.692	0.039	12	0.331	6	11.45	1	0
50	10.9	10.832	1	3.624	3.692	0.039	12	0.331	6	11.45	1	0
51	10.9	10.832	1	3.624	3.692	0.039	12	0.331	6	11.45	1	4
52	10.9	10.832	1	3.624	3.692	0.039	12	0.331	6	11.45	1	4
53	10.9	10.832	1	3.624	3.692	0.039	12	0.331	6	11.45	1	4
54	10.9	10.832	1	3.624	3.692	0.039	12	0.331	6	11.45	1	4

TABLE 2 (cont)
Results of Experiments to Determine
Capsize Limits of RO-RO Ferry

run #	Hs_nom	T_wave	Hs_act	V_wod	capsize	roll	rms roll	mean_rm	rms_rm	wht/gz_area	fb/hs_act
50	5	8	4.44	4131	yes	-11.291	3.184	7.562	0.874	113.936	0.225
51	3	7	2.67	2955	no	-7.3797	3.113	5.647	1.276	68.359	0.375
52	5	8	4.39	4615	yes	-12.005	3.680	7.890	1.130	112.443	0.228
7	1	5.5	1.25	0	no	-0.1407	0.698	7.768	0.524	83.259	0.400
8	1.5	6	1.51	2142	yes	-6.4151	1.694	9.701	1.008	100.571	0.331
9	1.5	6	1.79	124	no	-2.3105	1.363	8.227	0.822	119.659	0.279
10	3	7	2.77	2664	yes	-7.4591	3.454	9.996	1.949	184.896	0.181
11	1	5.5	1.18	0	no	-1.066	0.676	7.960	0.483	78.741	0.424
12	1.5	6	1.75	2318	yes	-7.7028	1.540	9.760	0.881	116.960	0.286
13	2	6.5	1.77	164	no	-1.9486	2.291	8.372	0.929	117.808	0.282
25	2	6.5	1.88	3987	yes	-10.156	2.409	10.942	1.084	69.650	0.266
26	1.5	6	1.64	2991	yes	-8.1787	1.107	9.994	0.635	60.753	0.305
27	1	5.5	1.31	125	no	-1.749	0.987	8.496	0.632	48.593	0.382
28	1.5	6	1.71	127	no	-1.4855	1.732	8.038	0.797	63.487	0.292
29	2	6.5	1.97	216	no	-1.4003	2.777	8.086	0.999	73.022	0.254
30	3	7	2.91	450	no	-1.2513	4.379	8.460	1.467	107.920	0.172
31	4	7.5	3.84	656	no	-1.1582	5.995	8.296	1.715	142.071	0.130
34	3	7	2.78	4113	yes	-10.353	2.856	11.063	1.466	102.824	0.180
35	2	6.5	1.89	2175	no	-4.7439	1.893	9.119	0.960	70.024	0.265
36	2	6.5	2.23	4174	yes	-11.27	2.559	11.400	1.406	82.708	0.224
37	1.5	6	1.77	1711	no	-4.0872	1.433	8.842	0.816	65.662	0.282
39	1.5	6	1.52	1251	no	-3.3945	1.463	8.467	0.750	56.258	0.329
40	2	6.5	1.89	3359	yes	-8.9303	2.145	10.419	0.924	70.107	0.265
43	5	8	4.41	4032	yes	-7.9319	5.477	9.306	0.131	163.239	0.113
48	4	7.5	3.94	3280	yes	-13.26	2.861	11.621	1.994	100.907	0.254
49	3	7	2.8	3132	yes	-14.493	1.036	11.264	0.939	71.871	0.357
50	2	6.5	2.12	1180	no	-6.6736	1.434	9.032	0.959	54.314	0.472
51	3	7	2.69	48	no	-1.7318	2.769	8.202	1.180	69.036	0.372
52	4	7.5	4.01	206	no	-1.0245	4.969	8.176	1.749	102.814	0.249
53	5	7.5	4.8	376	no	-0.8751	6.290	8.144	1.998	123.089	0.208
54	6	8.5	5.53	404	no	-0.9814	6.904	24.453	4.658	141.731	0.181

TABLE 3
Results of Experiments to Determine
Capsize Limits of RO-RO Ferry

run #	KG_nom	KG_act	r_f	GM_fl_nom	GM_fl_act	GZ_area	GZ_range	GZ_max	heel@GZmax	T_roll	casing	freeports
55	10.9	10.832	1	3.624	3.692	0.039	12	0.331	6	11.45	1	3
56	10.9	10.832	1	3.624	3.692	0.039	12	0.331	6	11.45	1	3
57	10.9	10.832	1	3.624	3.692	0.039	12	0.331	6	11.45	1	3
58	10.9	10.832	1	3.624	3.692	0.039	12	0.331	6	11.45	1	2
59	10.9	10.832	1	3.624	3.692	0.039	12	0.331	6	11.45	1	2
60	10.9	10.832	1	3.624	3.692	0.039	12	0.331	6	11.45	1	2
61	10.9	10.832	1	3.624	3.692	0.039	12	0.331	6	11.45	1	2
80	12.42	12.431	1	2.104	2.093	0.015	8.7	0.174	5.3	22.98	1	0
81	12.42	12.431	1	2.104	2.093	0.015	8.7	0.174	5.3	22.98	1	0
82	12.42	12.431	1	2.104	2.093	0.015	8.7	0.174	5.3	22.98	1	4
83	12.42	12.431	1	2.104	2.093	0.015	8.7	0.174	5.3	22.98	1	4
84	12.42	12.431	1	2.104	2.093	0.015	8.7	0.174	5.3	22.98	1	4
85	12.42	12.431	1	2.104	2.093	0.015	8.7	0.174	5.3	22.98	1	4
86	12.42	12.431	1	2.104	2.093	0.015	8.7	0.174	5.3	22.98	1	4
88	12.42	12.431	1	2.104	2.093	0.015	8.7	0.174	5.3	22.98	1	3
89	12.42	12.431	1	2.104	2.093	0.015	8.7	0.174	5.3	22.98	1	3
90	12.42	12.431	1	2.104	2.093	0.015	8.7	0.174	5.3	22.98	1	3
91	12.42	12.431	1	2.104	2.093	0.015	8.7	0.174	5.3	22.98	1	2
92	12.42	12.431	1	2.104	2.093	0.015	8.7	0.174	5.3	22.98	1	2
96	12.42	12.463	1	2.104	2.061	0.015	8.64	0.171	5.28	23.34	0	0
97	12.42	12.463	1	2.104	2.061	0.015	8.64	0.171	5.28	23.34	0	0
98	12.42	12.463	1	2.104	2.061	0.015	8.64	0.171	5.28	23.34	0	4
99	12.42	12.463	1	2.104	2.061	0.015	8.64	0.171	5.28	23.34	0	4
100	12.42	12.463	1	2.104	2.061	0.015	8.64	0.171	5.28	23.34	0	3
101	12.42	12.463	1	2.104	2.061	0.015	8.64	0.171	5.28	23.34	0	3
102	12.42	12.463	1	2.104	2.061	0.015	8.64	0.171	5.28	23.34	0	3
103	12.42	12.463	1	2.104	2.061	0.015	8.64	0.171	5.28	23.34	0	3
104	12.42	12.463	1	2.104	2.061	0.015	8.64	0.171	5.28	23.34	0	2
105	12.42	12.463	1	2.104	2.061	0.015	8.64	0.171	5.28	23.34	0	2
106	12.42	12.463	1	2.104	2.061	0.015	8.64	0.171	5.28	23.34	0	2
107	12.42	12.463	1	2.104	2.061	0.015	8.64	0.171	5.28	23.34	0	2

TABLE 3 (cont)
Results of Experiments to Determine
Capsize Limits of RO-RO Ferry

run #	Hs_nom	T	run #	Hs_nom	T_wave	Hs_act	V_wod	capsize	roll	rms roll	mean_rm	rms_rm	wht/gz_area	fb/h_s_act
108	4		55	5	8	4.78	584	no	-1.6796	6.180	22.835	4.431	122.663	0.209
113	2		56	6	8.5	5.59	541	no	-1.2859	6.716	8.169	2.077	143.356	0.179
114	3		57	7	9	6.46	650	no	-1.424	7.672	7.985	2.106	165.582	0.155
115	4		58	5	8	4.87	3220	yes	-7.5358	7.628	42.459	7.630	124.956	0.205
116	4		59	4	7.5	3.65	3301	yes	-13.267	3.772	24.141	19.005	93.565	0.274
117	5		60	3	6.5	2.6	.	no	.	.	.	.	66.714	0.385
118	6		61	3	6.5	2.72	290	no	-4.1009	3.166	6.983	1.224	69.653	0.368
119	7		80	1.5	6	1.66	0	no	-0.5177	0.677	7.489	0.564	110.448	0.602
120	4		81	2	6.5	1.87	1459	yes	-8.9346	1.796	9.726	1.078	124.741	0.535
121	5		82	2	6.5	1.89	2	no	-2.0564	0.785	8.225	0.632	125.691	0.529
122	6		83	3	7	2.72	132	no	-2.2309	1.229	8.494	0.836	181.099	0.368
123	7		84	4	7.5	3.77	156	no	-2.6129	2.060	7.953	1.224	251.323	0.265
131	5		85	5	8	5.1	1389	yes	-4.432	6.092	9.324	2.651	340.117	0.196
132	5		86	6	8.5	5.59	302	no	-2.0107	3.195	16.750	2.102	372.725	0.179
133	7		88	5	8	4.73	2251	yes	-12.379	3.175	15.233	3.358	315.035	0.211
146	2		89	4	7.5	3.38	1942	yes	-11.133	1.626	-11.133	1.626	225.467	0.296
147	3		90	3	7	2.71	85	no	-3.3023	1.208	7.186	0.056	180.891	0.369
149	5		91	2	6.5	1.84	998	yes	-7.9312	1.268	9.033	0.988	122.704	0.543
150	4		92	1.5	6	1.53	0	no	0.5422	0.499	6.580	0.535	101.824	0.654
152	5		96	1.5	6	1.6		no	.	.	.	.	106.651	0.625
153	6		97	2	6.5	1.94		yes	.	.	.	.	129.573	0.515
154	7		98	5	8	4.61		no	.	.	.	.	307.611	0.217
161	3		99	6	8.5	5.33		no	.	.	.	.	355.376	0.188
			100	3	7	2.78		no	.	.	.	.	185.376	0.360
			101	4	7.5	3.84		no	.	.	.	.	255.957	0.260
			102	5	8	4.75		no	.	.	.	.	316.901	0.211
			103	6	8.5	5.4		no	.	.	.	.	359.856	0.185
			104	1.5	6	1.85		no	.	.	.	.	123.477	0.541
			105	2	6.5	1.99		no	.	.	.	.	132.624	0.503
			106	3	7	2.66		no	.	.	.	.	177.616	0.376
			107	5	7.5	4.77		yes	.	.	.	.	317.920	0.210

ports

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 100 101 102 103 104 105 106 107 108 109 110 111 112 113 114 115 116 117 118 119 120 121 122 123 124 125 126 127 128 129 130 131 132 133 134 135 136 137 138 139 140 141 142 143 144 145 146 147 148 149 150 151 152 153 154 155 156 157 158 159 160 161 162 163 164 165 166 167 168 169 170 171 172 173 174 175 176 177 178 179 180 181 182 183 184 185 186 187 188 189 190 191 192 193 194 195 196 197 198 199 200 201 202 203 204 205 206 207 208 209 210 211 212 213 214 215 216 217 218 219 220 221 222 223 224 225 226 227 228 229 230 231 232 233 234 235 236 237 238 239 240 241 242 243 244 245 246 247 248 249 250 251 252 253 254 255 256 257 258 259 260 261 262 263 264 265 266 267 268 269 270 271 272 273 274 275 276 277 278 279 280 281 282 283 284 285 286 287 288 289 290 291 292 293 294 295 296 297 298 299 300 301 302 303 304 305 306 307 308 309 310 311 312 313 314 315 316 317 318 319 320 321 322 323 324 325 326 327 328 329 330 331 332 333 334 335 336 337 338 339 340 341 342 343 344 345 346 347 348 349 350 351 352 353 354 355 356 357 358 359 360 361 362 363 364 365 366 367 368 369 370 371 372 373 374 375 376 377 378 379 380 381 382 383 384 385 386 387 388 389 390 391 392 393 394 395 396 397 398 399 400 401 402 403 404 405 406 407 408 409 410 411 412 413 414 415 416 417 418 419 420 421 422 423 424 425 426 427 428 429 430 431 432 433 434 435 436 437 438 439 440 441 442 443 444 445 446 447 448 449 450 451 452 453 454 455 456 457 458 459 460 461 462 463 464 465 466 467 468 469 470 471 472 473 474 475 476 477 478 479 480 481 482 483 484 485 486 487 488 489 490 491 492 493 494 495 496 497 498 499 500 501 502 503 504 505 506 507 508 509 510 511 512 513 514 515 516 517 518 519 520 521 522 523 524 525 526 527 528 529 530 531 532 533 534 535 536 537 538 539 540 541 542 543 544 545 546 547 548 549 550 551 552 553 554 555 556 557 558 559 560 561 562 563 564 565 566 567 568 569 570 571 572 573 574 575 576 577 578 579 580 581 582 583 584 585 586 587 588 589 590 591 592 593 594 595 596 597 598 599 600 601 602 603 604 605 606 607 608 609 610 611 612 613 614 615 616 617 618 619 620 621 622 623 624 625 626 627 628 629 630 631 632 633 634 635 636 637 638 639 640 641 642 643 644 645 646 647 648 649 650 651 652 653 654 655 656 657 658 659 660 661 662 663 664 665 666 667 668 669 670 671 672 673 674 675 676 677 678 679 680 681 682 683 684 685 686 687 688 689 690 691 692 693 694 695 696 697 698 699 700 701 702 703 704 705 706 707 708 709 710 711 712 713 714 715 716 717 718 719 720 721 722 723 724 725 726 727 728 729 730 731 732 733 734 735 736 737 738 739 740 741 742 743 744 745 746 747 748 749 750 751 752 753 754 755 756 757 758 759 760 761 762 763 764 765 766 767 768 769 770 771 772 773 774 775 776 777 778 779 780 781 782 783 784 785 786 787 788 789 790 791 792 793 794 795 796 797 798 799 800 801 802 803 804 805 806 807 808 809 810 811 812 813 814 815 816 817 818 819 820 821 822 823 824 825 826 827 828 829 830 831 832 833 834 835 836 837 838 839 840 841 842 843 844 845 846 847 848 849 850 851 852 853 854 855 856 857 858 859 860 861 862 863 864 865 866 867 868 869 870 871 872 873 874 875 876 877 878 879 880 881 882 883 884 885 886 887 888 889 890 891 892 893 894 895 896 897 898 899 900 901 902 903 904 905 906 907 908 909 910 911 912 913 914 915 916 917 918 919 920 921 922 923 924 925 926 927 928 929 930 931 932 933 934 935 936 937 938 939 940 941 942 943 944 945 946 947 948 949 950 951 952 953 954 955 956 957 958 959 960 961 962 963 964 965 966 967 968 969 970 971 972 973 974 975 976 977 978 979 980 981 982 983 984 985 986 987 988 989 990 991 992 993 994 995 996 997 998 999 1000 1001 1002 1003 1004 1005 1006 1007 1008 1009 1010 1011 1012 1013 1014 1015 1016 1017 1018 1019 1020 1021 1022 1023 1024 1025 1026 1027 1028 1029 1030 1031 1032 1033 1034 1035 1036 1037 1038 1039 104