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TITLE

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

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KEY WORDS damaged ro-ro ferries, waves, capsize	PAGES iii, 11	FIGS. 12	TABLES 4

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.

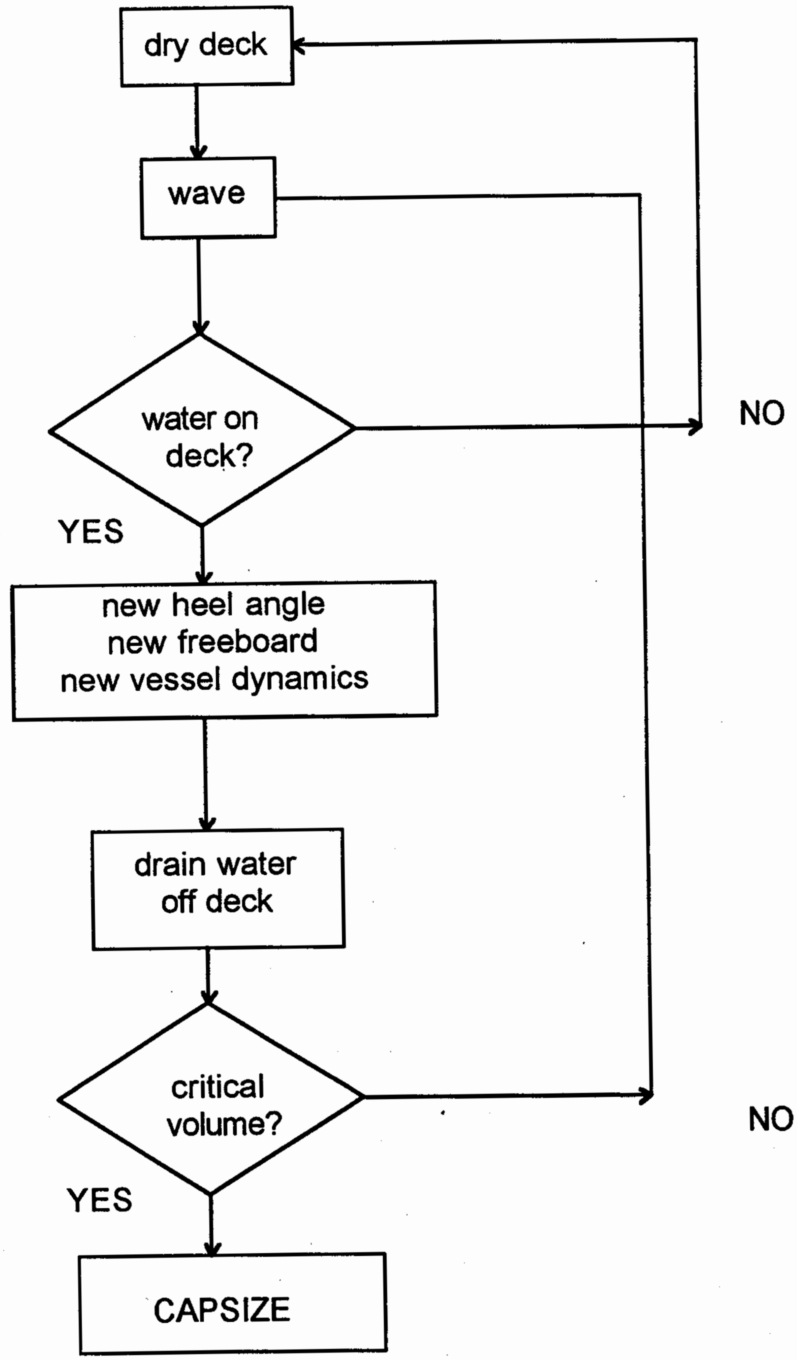

Figure 1: Simplified Representation of Capsize Process

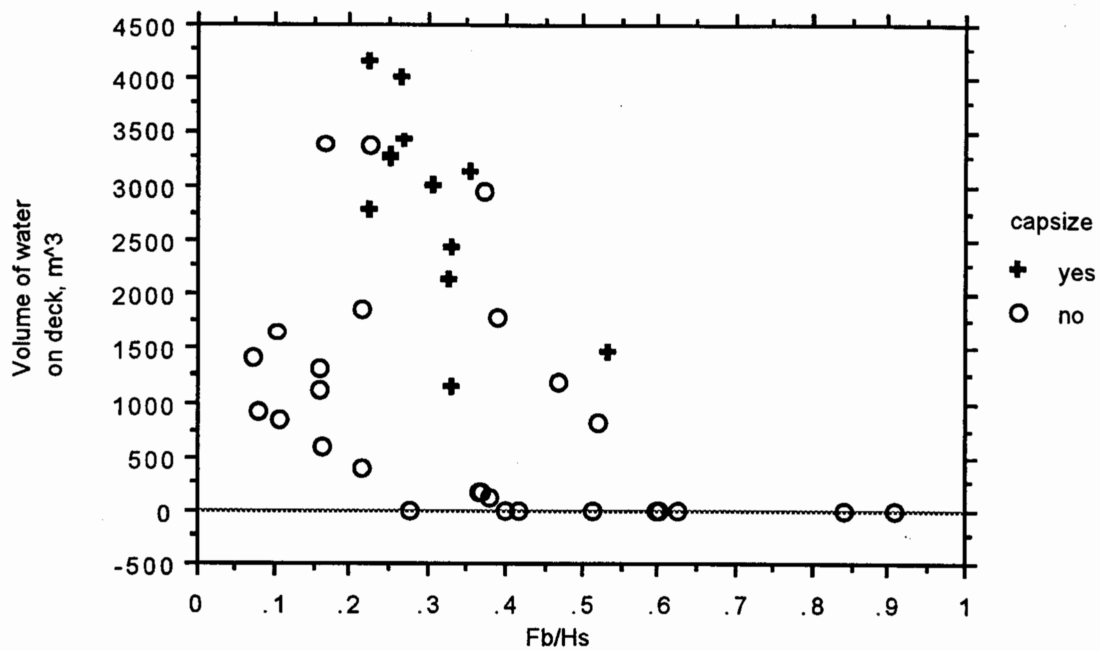

Figure 2, Volume of water on deck against Fb/Hs, freeing ports closed

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.

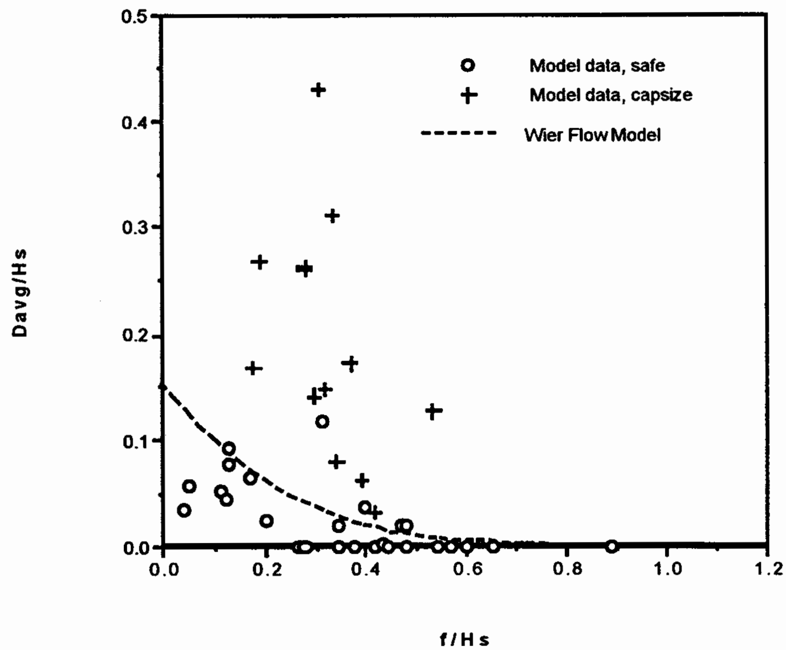

Figure 3, Non-dimensional depth of water on deck against non-dimensional freeboard

Note that Figure 3 shows very little data for Fb/Hs 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.

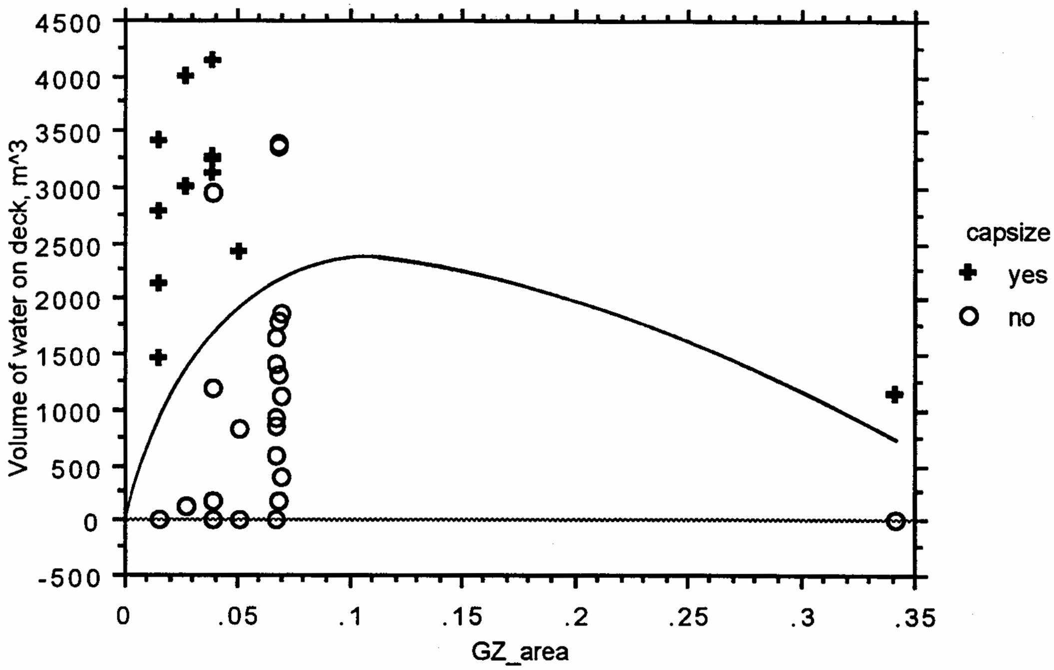

Figure 4, Volume of water on deck against GZ area (m-radians)

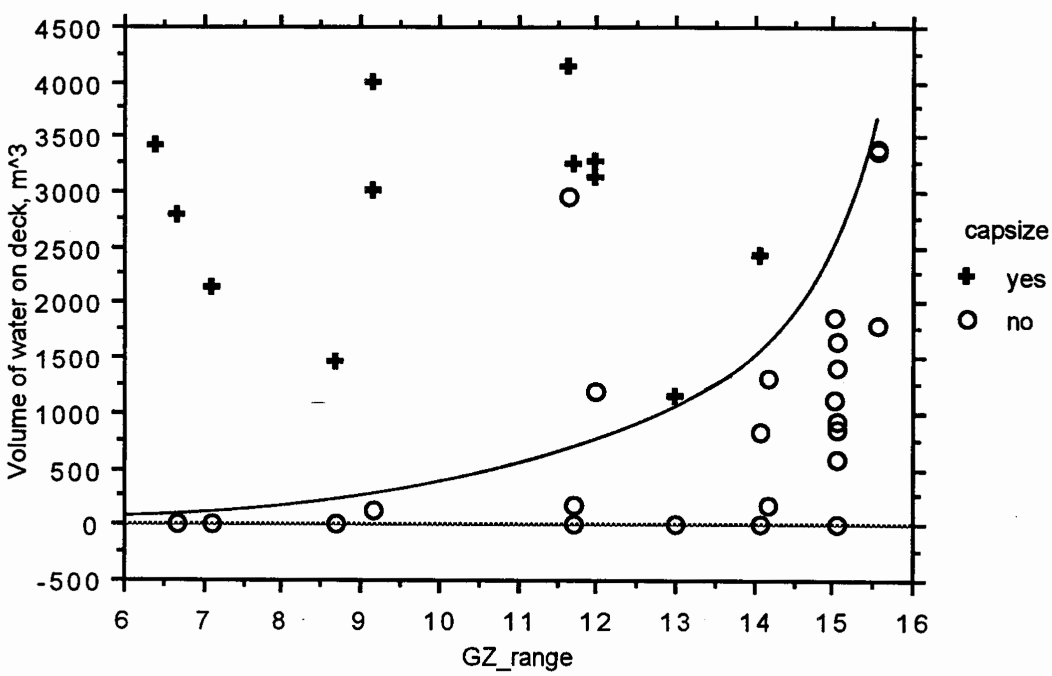

Figure 5, Volume of water on deck against GZ range (degrees)

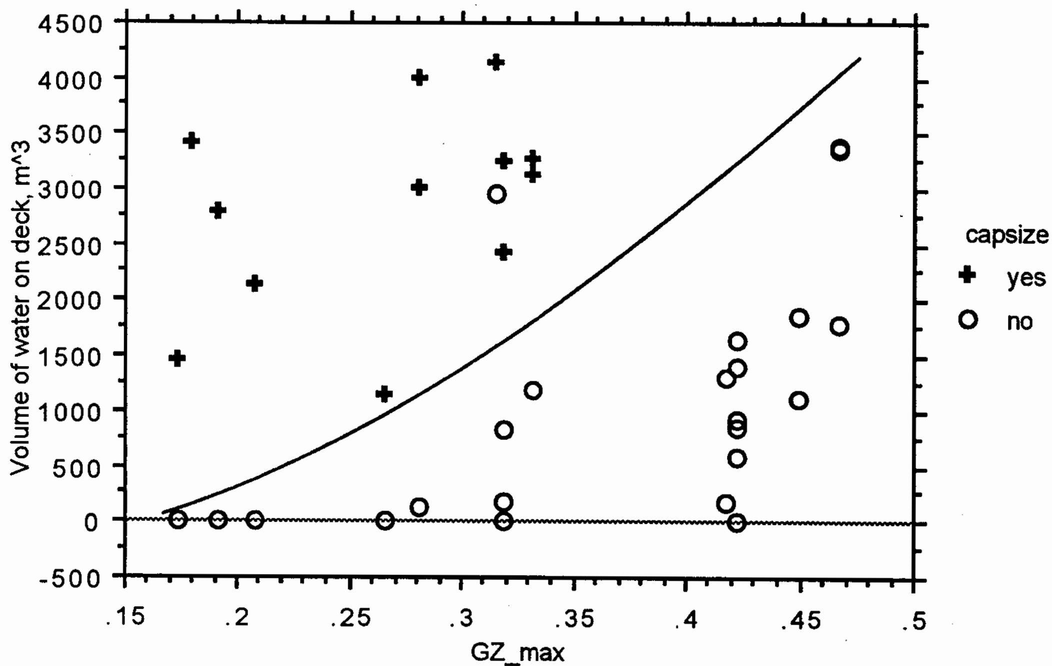

Figure 6, Volume of water on deck against maximum GZ (metres)

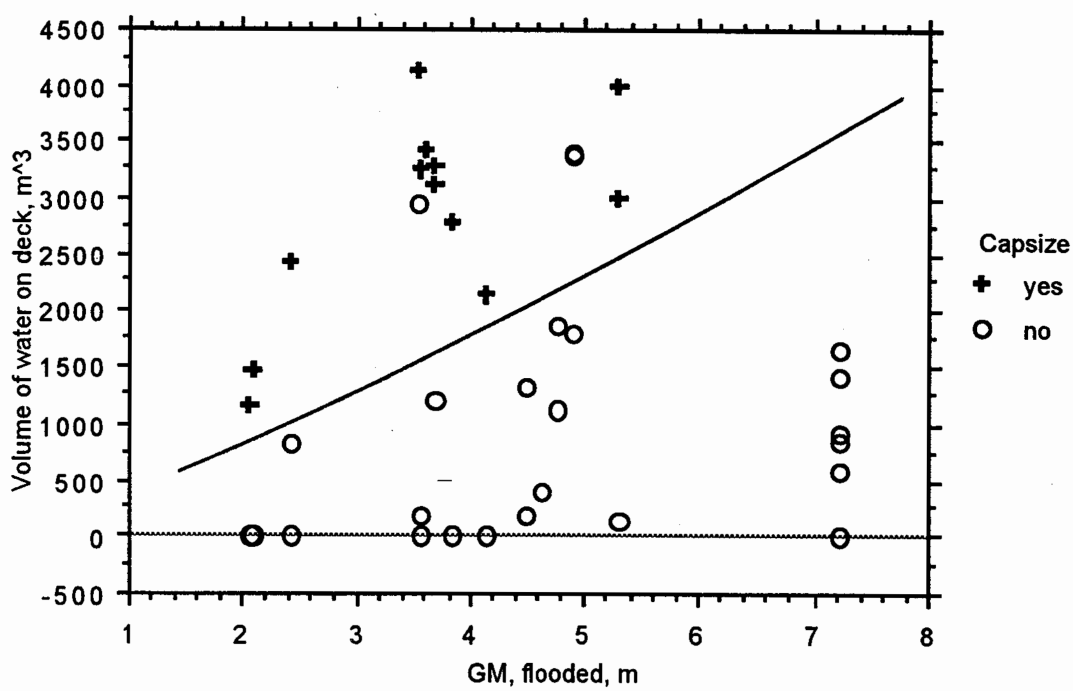

Figure 7, Volume of water on deck against flooded metacentric height (metres)

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.

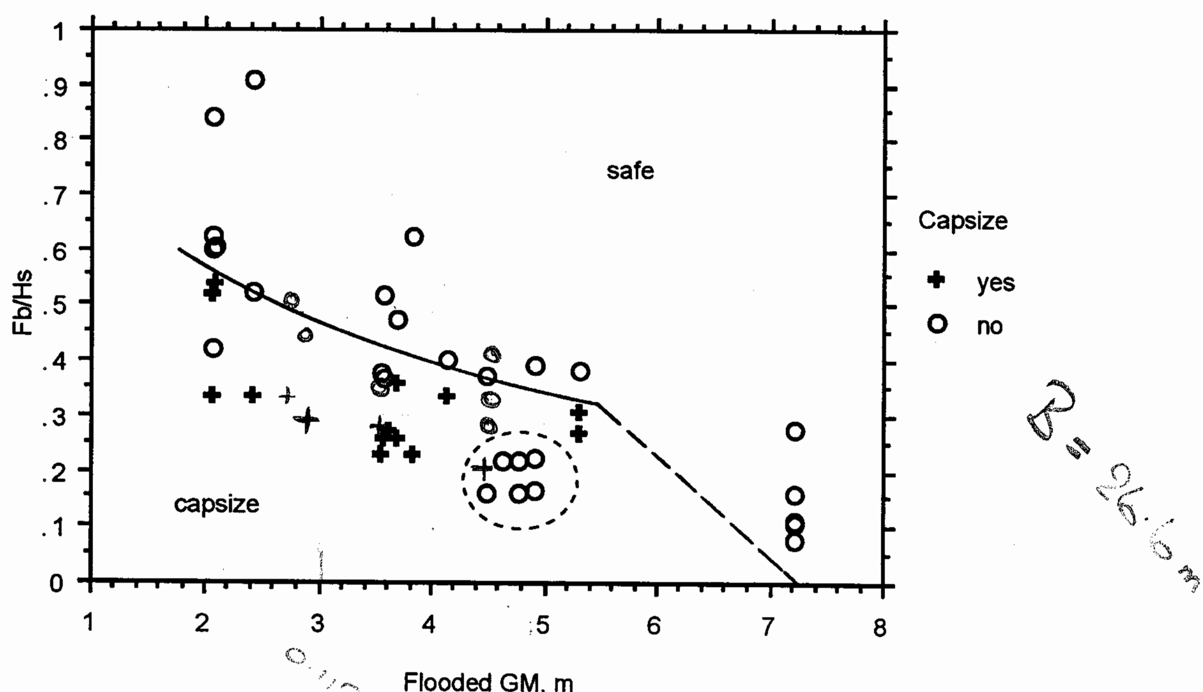

Figure 8, Fb/Hs against flooded GM (metres)

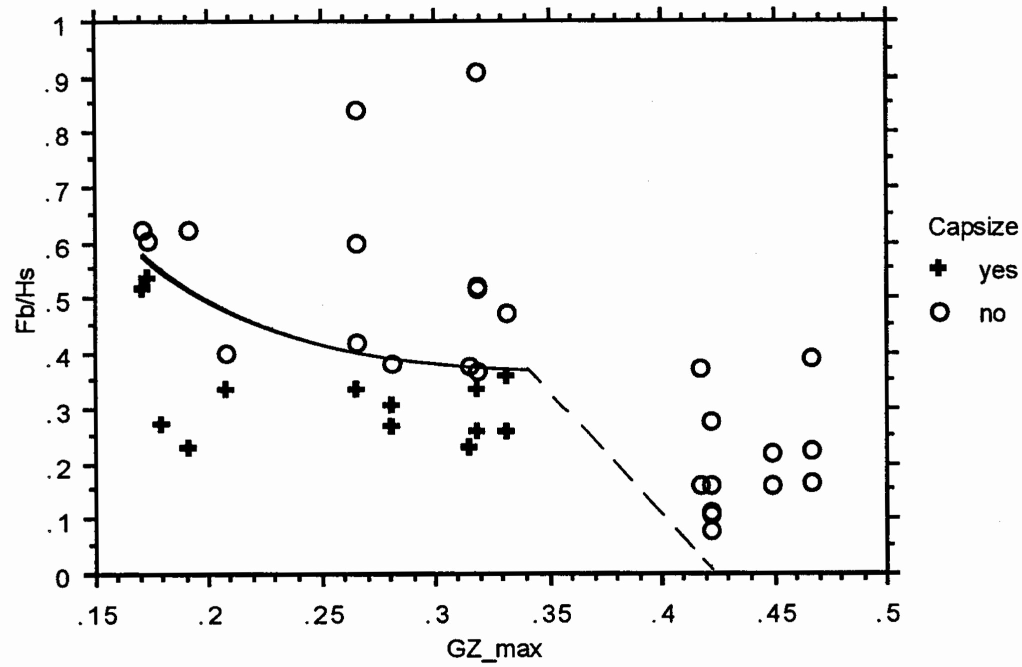

Figure 9, Fb/Hs against Maximum GZ (metres)

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/Hs to survivability at very low values of Fb/Hs.

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/Hs 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/Hs for a given value of GZ increases, meaning that the waveheight that the model will survive is lower.

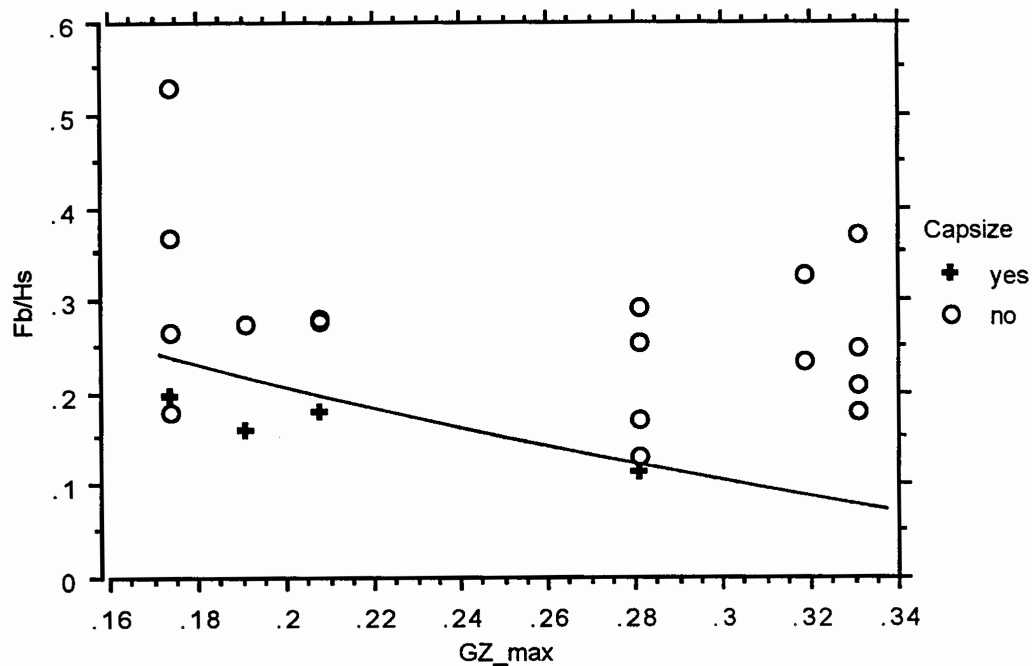

Figure 10, Fb/Hs against Maximum GZ (metres) (100% freeing ports)

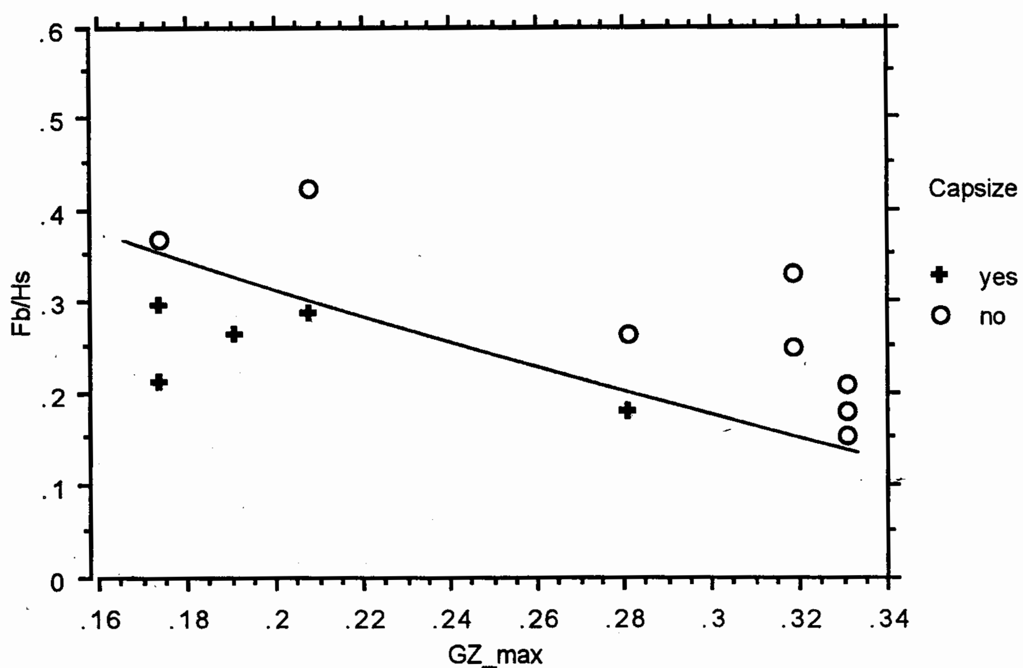

Figure 11, Fb/Hs against Maximum GZ (metres) (50% freeing ports)

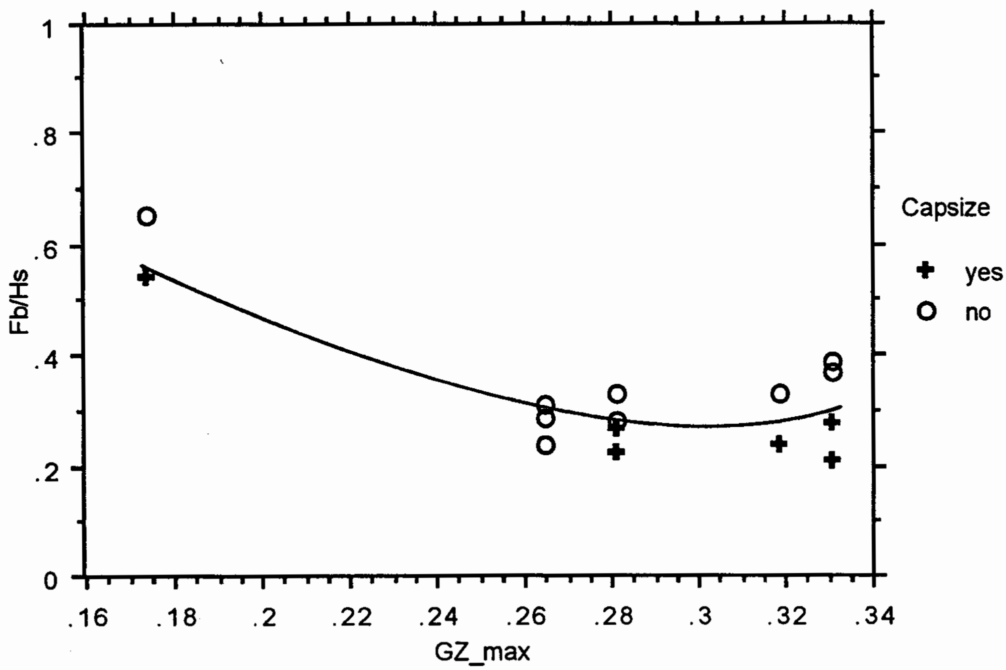

Figure 12, Fb/Hs against Maximum GZ (metres) (Load line freeing ports)

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 Camile 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

run #	Hs_nom	T
108	4	
113	2	
114	3	
115	4	
116	4	
117	5	
118	6	
119	7	
120	4	
121	5	
122	6	
123	7	
131	5	
132	5	
133	7	
146	2	
147	3	
149	5	
150	4	
152	5	
153	6	
154	7	
161	3	

TABLE 3 (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
55	5	8	4.78	584	no	-1.6796	6.180	22.835	4.431	122.663	0.209
56	6	8.5	5.59	541	no	-1.2859	6.716	8.169	2.077	143.356	0.179
57	7	9	6.46	650	no	-1.424	7.672	7.985	2.106	165.582	0.155
58	5	8	4.87	3220	yes	-7.5358	7.628	42.459	7.630	124.956	0.205
59	4	7.5	3.65	3301	yes	-13.267	3.772	24.141	19.005	93.565	0.274
60	3	6.5	2.6	•	no	•	•	•	•	66.714	0.385
61	3	6.5	2.72	290	no	-4.1009	3.166	6.983	1.224	69.653	0.368
80	1.5	6	1.66	0	no	-0.5177	0.677	7.489	0.564	110.448	0.602
81	2	6.5	1.87	1459	yes	-8.9346	1.796	9.726	1.078	124.741	0.535
82	2	6.5	1.89	2	no	-2.0564	0.785	8.225	0.632	125.691	0.529
83	3	7	2.72	132	no	-2.2309	1.229	8.494	0.836	181.099	0.368
84	4	7.5	3.77	156	no	-2.6129	2.060	7.953	1.224	251.323	0.265
85	5	8	5.1	1389	yes	-4.432	6.092	9.324	2.651	340.117	0.196
86	6	8.5	5.59	302	no	-2.0107	3.195	16.750	2.102	372.725	0.179
88	5	8	4.73	2251	yes	-12.379	3.175	15.233	3.358	315.035	0.211
89	4	7.5	3.38	1942	yes	-11.133	1.626	-11.133	1.626	225.467	0.296
90	3	7	2.71	85	no	-3.3023	1.208	7.186	0.056	180.891	0.369
91	2	6.5	1.84	998	yes	-7.9312	1.268	9.033	0.988	122.704	0.543
92	1.5	6	1.53	0	no	0.5422	0.499	6.580	0.535	101.824	0.654
96	1.5	6	1.6		no	•	•	•	•	106.651	0.625
97	2	6.5	1.94		yes	•	•	•	•	129.573	0.515
98	5	8	4.61		no	•	•	•	•	307.611	0.217
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

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