CHAPTER 7

THE CALCULATION

The question of external forces acting on the ship is closely related to the question of rating stability.

The stability rates imply the requirements for stability which can be made of a given type of ship [71; 72; 75]. These requirements are usually specified in the order for the development of the project of a ship and are closely related to the purpose of the ship, the service conditions and structural features. Thus the question of rating stability does not lie within the theory of the ship but pertains, in the main, to the field of ship design.

Having considered above various kinds of static and dynamic external moments which may act on the ship in actual conditions, one may imagine the situation when the ship is subject simultaneously to all or nearly all the afore-mentioned static or dynamic moments and the ship capsizes under their action. The question then arises as to whether it is reasonable to require of the ship that she shall not capsize under the action of the sum of all the possible moments [60; 68; 73]. It is to be noted that such a requirement would be irrational for the following reasons :

(1) in practice the probability that all the

external moments will act simultaneously, in the same direction and will therefore be added up is very small;

(2) a ship satisfying this requirement would be ideal from the point of view of stability but she would possess a large number of other structural and service disadvantages since the requirements for stability are to some extent in contradiction with the other structural and service requirements [55; 61; 62].

Then, it is not reasonable to require the ship to withstand the effect of the sum of all the possible external heeling moments but it is reasonable to require that she withstand the effect of the sum of two, at most three, of them. It may be stated that the most probable combination is the simultaneous action of waves and wind since in practice the waves are almost invariably accompanied by a wind and the wind happens without waves but on rare occasions [66]. On the other hand, the combined action of wind and waves is the most dangerous. Hence it is natural to require that the ship withstand the action of wind moment when rolling in a seaway.

The current conception of rating stability consist in recognizing the need to make such a requirement for projected ships. Naturally the numerical characteristics of this kind of requirements must depend on the type and

service of the ship [42; 43].

Besides rating external effects,as outlined above, it is possible to rate the characteristics themselves of the stability of a ship. For example,it is possible to specify the lower and upper bounds of the metacentric height. It is possible to specify requirements for the diagram of statical stability by limiting the minimum angles of heel corresponding to its decline and maximum. It is possible to prescribe the minimum permissible value of the maximum ordinate of the diagram of statical stability or to prescribe the minimum permissible value of the ordinate of the diagram of dynamical stability for a given value of the angle of heel. This kind of requirements are made at present for the stability of ships. Certainly the numerical values characterizing these requirements are dependent on the type of ship and the service conditions [24; 26].

The current state of rating stability is such that there are no unified viewpoints concerning this question as yet.

7.1 The vessels

Five sizes of typical Thai fishing vessels have been chosen to study in detail, representing the fleet. They are :-

Name	Length (m)	Breadth (m)	Draught (m)	Depth (m)
Ship-A	18.55	5.50	2.00	2.50
Ship-B	22.52	5.96	1.80	2.60
Ship-C	24.14	5.26	2.10	2.80
Ship-D	36.00	8.60	2.50	4.20
Ship-E	39.80	9.24	3.00	4.50

Their lines plans are presented in Fig. (7.1) through (7.5). Hydrostatic data are calculated according to each line plans and shown in Table (7.1) through (7.5) for ships-A to E.

Since there is no information available on actual KG values of these ships. It was considered to perform experimentation on stability surveys (inclining test) of the above prescribed vessels. Special thanks are due to Daeng Charoen Panich Ltd., the owner, who gave permission of lending some of the fishing vessels in the fleet for the experimental works. Detail of such test is described in Appendix (A) which is considered to be an acceptable standard method to determine the KG values. Location of the tests were taken place at Samutprakarn. The results yield that the values of KG for the vessels at full load

condition are :-

Ship-A : 2.21 m. above base line

Ship-B : 2.32 m. above base line

Ship-C : 2.45 m. above base line

Ship-D : 3.45 m. above base line

Ship-E : 3.65 m. above base line

Hence, statical and dynamical stability particulars for Ship-A to E can be determined using the program in appendix (B). The calculation have been done on 16 Bit PC/AT IBM Compatible microcomputer.

The results of statical stability particulars are shown for the five ships in Table (7.6) to (7.10).

Table (7.11) through (7.15) also show the results of dynamical stability particulars for the prescribed ships.

Note that dynamical stability is characterised by the amount of work done from the righting moment (internal moment) in the process of inclination of vessel.

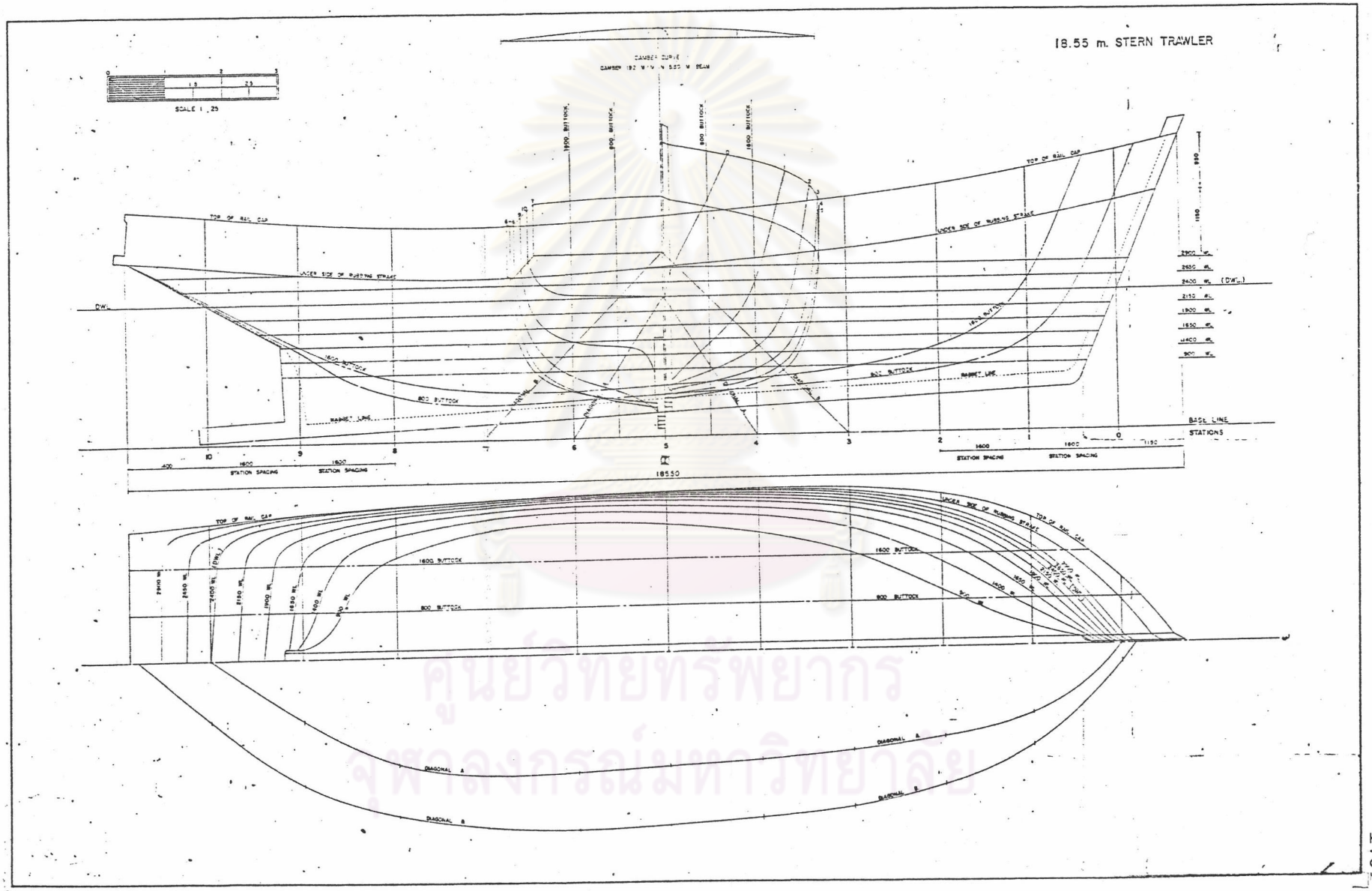

Fig. 7.1 Line plans Ship - A

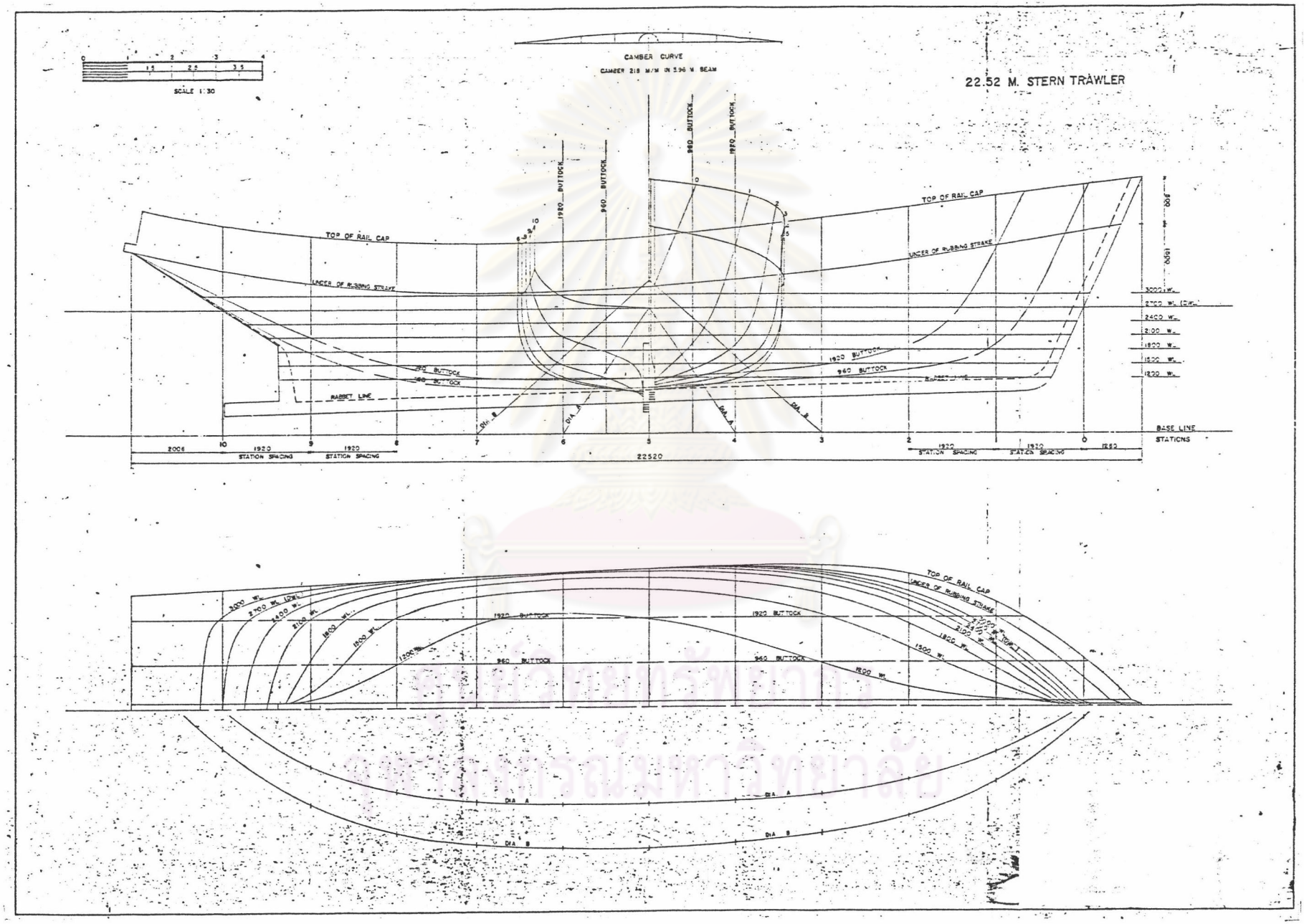

Fig. 7.2 Line plans Ship - B

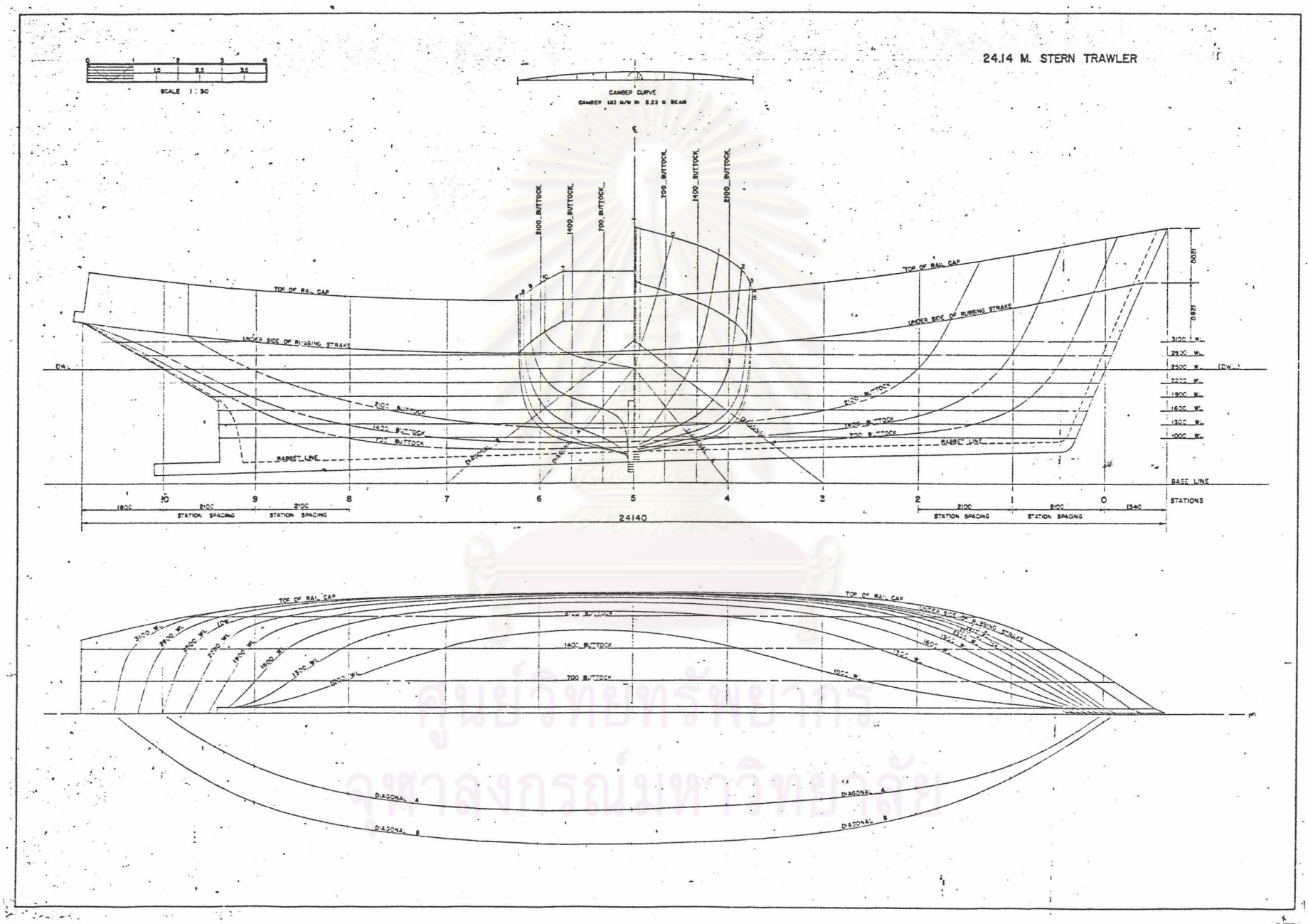

Fig. 7.3 Line plans Ship - C

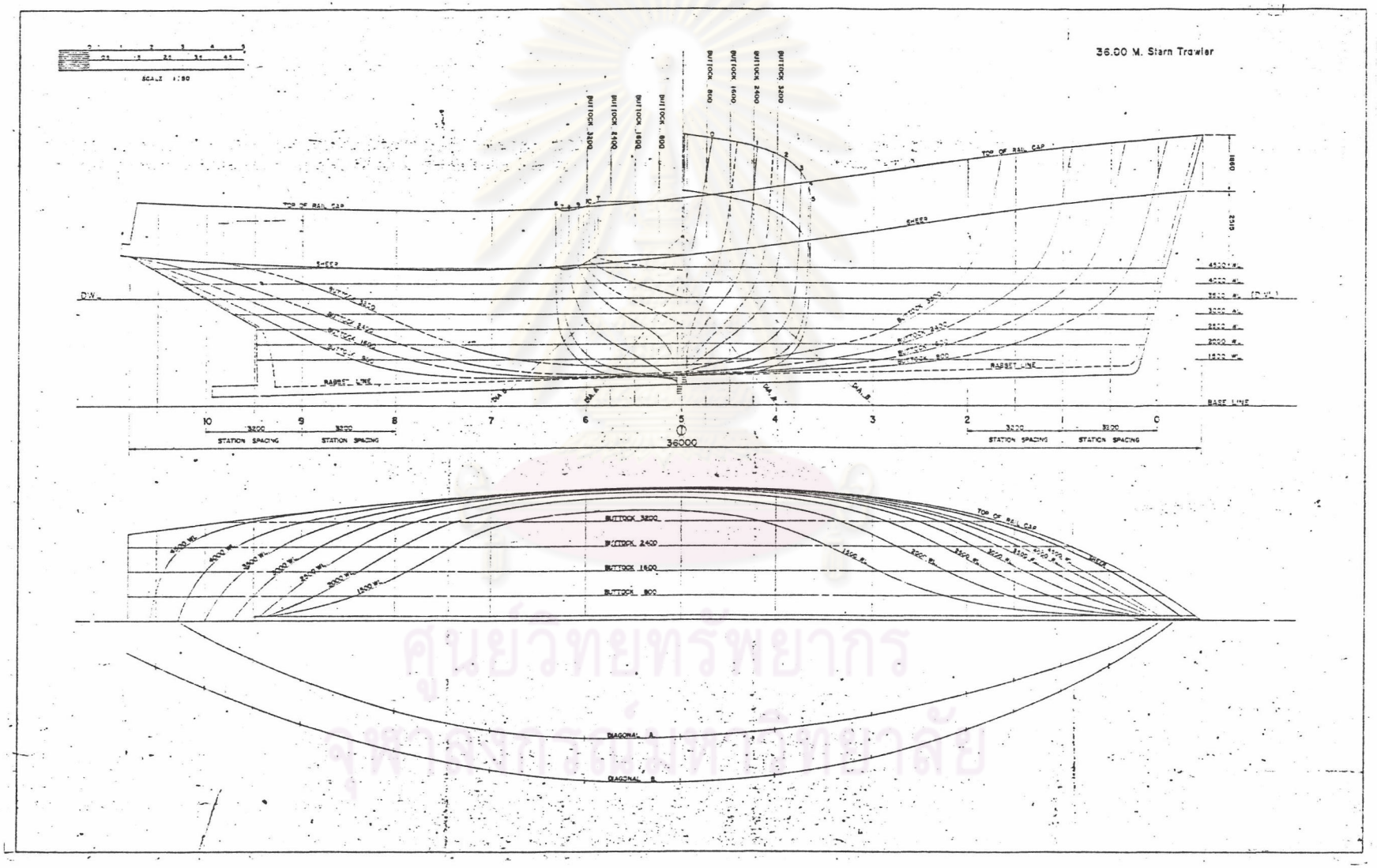

Fig. 7.4 Line plans Ship - D

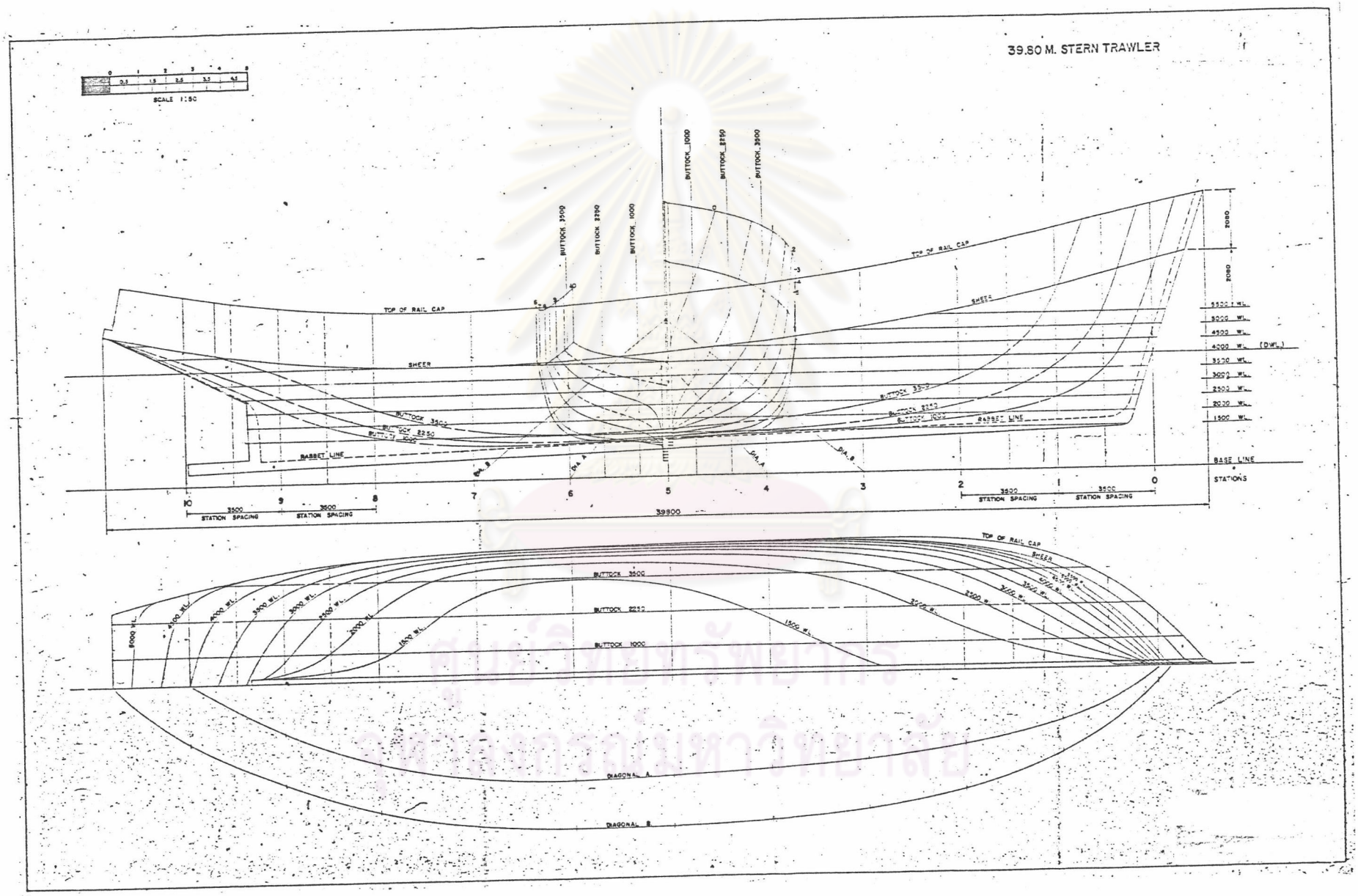

Fig. 7.5 Line plans Ship - E

DRAFT m.	DISPT Tons	KB m.	BMt m.	BMl m.	LCB m.	LCF m.	TPC Ton/cm	MCT 1m Ton.m/m	WParea sqr m
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000	0.00	0.00
0.25	1.06	0.25	2.28	11.09	-3.01	-3.01	0.085	0.73	8.27
0.50	5.36	0.37	4.81	39.71	-2.09	-1.08	0.304	13.29	29.60
0.75	15.02	0.53	3.68	27.83	-1.02	-0.24	0.437	26.12	42.65
1.00	26.80	0.69	3.03	21.27	-0.59	-0.02	0.521	35.63	50.83
1.25	41.22	0.84	2.53	21.21	-0.46	-0.46	0.623	54.64	60.74
1.50	57.59	1.00	2.20	18.04	-0.49	-0.46	0.682	64.92	66.54
1.75	75.10	1.14	1.88	15.03	-0.46	-0.43	0.714	70.53	69.63
2.00	93.19	1.28	1.62	12.71	-0.47	-0.38	0.735	74.04	71.67
2.25	112.01	1.42	1.47	12.18	-0.45	-0.58	0.776	85.25	75.69
2.50	131.76	1.57	1.30	10.69	-0.49	-0.54	0.790	88.03	77.07

TABLE (7.1) HYDROSTATIC PARTICULARS FOR SHIP - A

DRAFT m.	DISPT Tons	KB m.	BMt m.	BMl m.	LCB m.	LCF m.	TPC Ton/cm	MCT 1m Ton.m/m	WParea sqr m
0.00	0.00	0.00	0.00	0.00	0.00	-4.06	0.056	0.00	5.48
0.30	6.66	0.26	5.13	68.53	-1.17	-0.76	0.388	23.76	37.81
0.60	22.26	0.38	4.49	42.13	-0.69	-0.22	0.619	48.85	60.42
0.90	43.21	0.56	3.47	32.36	-0.45	-0.28	0.763	72.82	74.44
1.20	67.69	0.74	2.85	26.79	-0.44	-0.49	0.870	94.44	84.89
1.50	94.86	0.91	2.29	21.31	-0.46	-0.56	0.921	105.28	89.81
1.80	122.69	1.08	1.88	17.49	-0.47	-0.48	0.947	111.78	92.37
2.10	151.86	1.25	1.60	16.16	-0.48	-0.68	0.991	127.84	96.70

TABLE (7.2) HYDROSTATIC PARTICULARS FOR SHIP - B

DRAFT m.	DISPT Tons	KB m.	BMt m.	BMl m.	LCB m.	LCF m.	TPC Ton/cm	MCT 1m Ton.m/m	WParea sqr m
0.00	0.00	0.00	0.00	0.00	0.00	-3.83	0.049	0.00	4.82
0.30	6.49	0.27	4.02	85.45	-0.77	-0.41	0.383	26.41	37.39
0.60	21.64	0.37	3.24	46.87	-0.39	-0.06	0.581	48.29	56.66
0.90	41.01	0.56	2.53	35.31	-0.24	-0.15	0.703	68.95	68.54
1.20	63.63	0.73	2.08	30.60	-0.27	-0.47	0.808	92.71	78.79
1.50	89.00	0.91	1.71	25.16	-0.35	-0.55	0.866	106.65	84.47
1.80	115.36	1.08	1.44	20.92	-0.39	-0.55	0.901	114.92	87.87
2.10	143.16	1.25	1.25	19.11	-0.44	-0.74	0.946	130.30	92.26
2.40	171.90	1.42	1.09	16.82	-0.50	-0.77	0.970	137.65	94.61

TABLE (7.3) HYDROSTATIC PARTICULARS FOR SHIP - C

DRAFT m.	DISPT m.	KB m.	BMt m.	BMl m.	LCB m.	LCF m.	TPC Ton/cm	MCT 1m Ton.m/m	WParea sqr m
0.00	0.00	0.00	0.00	0.00	0.00	-3.94	0.433	0.00	42.27
0.50	39.48	0.36	8.39	87.03	-1.82	-0.99	1.146	107.36	111.76
1.00	108.21	0.58	5.10	50.21	-1.13	-0.71	1.476	169.79	143.97
1.50	187.99	0.87	3.89	40.14	-0.95	-0.70	1.727	235.79	168.49
2.00	280.01	1.16	3.05	34.74	-0.88	-0.86	1.922	304.02	187.52
2.50	379.39	1.45	2.51	30.53	-0.90	-0.91	2.067	361.90	201.60
3.00	486.55	1.73	2.14	28.12	-0.91	-1.15	2.203	427.55	214.88
3.50	599.20	2.02	1.90	25.87	-0.99	-1.47	2.310	484.41	225.37

TABLE (7.4) HYDROSTATIC PARTICULARS FOR SHIP - D

DRAFT m.	DISPT m.	KB m.	BMt m.	BMl m.	LCB m.	LCF m.	TPC Ton/cm	MCT 1m Ton.m/m	WParea sqr m
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000	0.00	0.00
0.50	22.44	0.50	10.94	82.23	-2.57	-2.57	0.898	52.72	87.56
1.00	87.33	0.66	7.39	83.50	-1.94	-0.68	1.649	208.34	160.86
1.50	181.08	0.97	5.22	60.28	-1.13	-0.37	2.017	311.89	196.78
2.00	288.23	1.26	4.12	52.58	-0.89	-0.46	2.335	432.96	227.79
2.50	413.12	1.43	3.44	44.29	-0.76	-0.56	2.564	522.72	250.06
3.00	543.04	1.5	2.58	37.31	-0.73	-0.59	2.699	578.89	263.26
3.50	683.47	2.13	2.53	34.62	-0.71	-0.88	2.862	676.04	279.15
4.00	827.29	2.42	2.16	29.75	-0.76	-0.79	2.909	703.22	283.73

TABLE (7.5) HYDROSTATIC PARTICULARS FOR SHIP - E

TABLE (7.6) STATICAL STABILITY PARTICULARS FOR SHIP-A

HEELING ANGLE (DEG.)	RIGHTING - LEVER GZ (m)
0	0.0000
10	0.1246
20	0.2725
30	0.4803
40	0.8103
50	0.9286
60	0.8537
70	0.5500

TABLE (7.7) STATICAL STABILITY PARTICULARS FOR SHIP-B

HEELING ANGLE (DEG.)	RIGHTING - LEVER GZ (m)
0	0.0000
10	0.1166
20	0.2613
30	0.4770
40	0.8370
50	1.0659
60	1.1025
70	0.8537

TABLE (7.8) STATICAL STABILITY PARTICULARS FOR SHIP-C

HEELING ANGLE (DEG.)	RIGHTING - LEVER GZ (m)
0	0.0000
10	0.1079
20	0.2334
30	0.4044
40	0.6687
50	1.1637
60	1.2583
70	1.0672

TABLE (7.9) STATICAL STABILITY PARTICULARS FOR SHIP-D

HEELING ANGLE (DEG.)	RIGHTING - LEVER GZ (m)
0	0.0000
10	0.0960
20	0.2311
30	0.4646
40	0.8960
50	1.2635
60	1.3358
70	1.1295

TABLE (7.10) STATICAL STABILITY PARTICULARS FOR SHIP-E

HEELING ANGLE (DEG.)	RIGHTING - LEVER GZ (m)
0	0.0000
10	0.0820
20	0.2053
30	0.4304
40	0.8604
50	1.3276
60	1.4630
70	1.3421

TABLE (7.11) DYNAMICAL STABILITY PARTICULARS FOR SHIP-A

HEELING ANGLE (DEG.)	DYNAMICAL STABILITY (t - m)
0	0.0000
10	1.0133
20	4.1787
30	10.1939
40	20.4621
50	35.4067
60	49.6160
70	61.02924

TABLE (7.12) DYNAMICAL STABILITY PARTICULARS FOR SHIP-B

HEELING ANGLE (DEG.)	DYNAMICAL STABILITY (t - m)
0	0.0000
10	1.2481
20	5.1931
30	12.9316
40	26.6475
50	46.6000
60	70.9157
70	91.8562

TABLE (7.13) DYNAMICAL STABILITY PARTICULARS FOR SHIP-C

HEELING ANGLE (DEG.)	DYNAMICAL STABILITY (t - m)
0	0.0000
10	1.3475
20	5.5370
30	13.3800
40	26.5184
50	48.7170
60	81.3161
70	110.3632

TABLE (7.14) DYNAMICAL STABILITY PARTICULARS FOR SHIP-D

HEELING ANGLE (DEG.)	DYNAMICAL STABILITY (t - m)
0	0.0000
10	3.1779
20	13.5736
30	35.8944
40	79.4561
50	153.1755
60	240.2388
70	321.8446

TABLE (7.15) DYNAMICAL STABILITY PARTICULARS FOR SHIP-E

HEELING ANGLE (DEG.)	DYNAMICAL STABILITY (t - m)
0	0.0000
10	3.8853
20	16.8455
30	45.9230
40	104.8923
50	210.2544
60	346.0209
70	479.1889

7.2 The wave

As it has been mentioned earlier, an accepted description of the sea state appropriate to various significant wave heights is afforded by the sea state code. (See Chapter 5)

Work done for the precribed ships due to wave may be found by drawing the wave profile at a particular sea state superimpose to cross-section of the vessel from AP to FP at each particular of heeling angle. Hence surface length of wave profile for the vessel at any Sea States may be found. For each equal of station spacing along the vessel's length, integration of wave profile length yields actual surface area or actual waterplane area. The process is rather tedious and time-consuming.

Multiplication of actual waterplane area with kinetic energy per unit area of wave yields work done due to wave for each angle of heeling and sea state. The problem lies in the consideration of wave energy per unit area.

It has been shown in chapter (5) that the tracing radius (r) for a trochoidal wave surface varies with the depth ie;

$$r = r_o \exp(-z/R)$$

and

$$R = \lambda/2\pi$$

also

r_o = $h_w/2$

WHERE

R = Radius of generating circle

r_o = Tracing radius of wave surface

r = Tracing radius of wave at any depth (z)

λ = Wave length

h_w = Wave height

Therefore, for a given sea states the values of r_o and R may be determined as :-

Sea States	r_o (m)	R (m)
0	0.000	0.00
1	0.025	0.33
2	0.125	1.94
3	0.438	3.44
4	0.937	4.37
5	1.622	7.13
6	2.500	8.54
7	3.750	13.83
8	5.750	31.53

Refering to the first of above prescribed equation, the values of tracing radius (r) at any depth can be calculated.

It is considered to use the wave energy from the lowest point of the vessel ie. keel up to the

wave surface, since it is the only portion of the vessel's body that interacts with the wave.

Therefore, the values of tracing radius (r_T) that carrespond to each vessel's draught (T) are calculated to be :-

Sea States	Ship A	Ship B	Ship C	Ship D	Ship E
0	0.0000	0.0000	0.0000	0.0000	0.0000
1	9.83×10^{-5}	5.31×10^{-5}	3.9×10^{-5}	1.14×10^{-5}	2.4×10^{-6}
2	0.0591	0.0535	0.0508	0.0413	0.0320
3	0.2603	0.2449	0.2379	0.2118	0.1813
4	0.6214	0.5929	0.5795	0.5288	0.4716
5	1.2630	1.2253	1.2082	1.1423	1.0649
6	2.0254	1.9780	1.9550	1.8655	1.7595
7	3.2921	3.2451	3.2217	3.1299	3.0187
8	5.4313	5.3966	5.3795	5.3117	5.2280

Originally,kinetic energy of wave is given by [59] :-

$$KE = -\pi R\rho g \int_{r_o}^{o} r\,(1-r^2/R^2)\,dr$$

For the purpose of calculation, the limit of integration must be changed from zero (0) to the corresponding "r_T" at each draught (T) of each vessel. Hence

$$KE = -\pi R\rho g \int_{r_o}^{r_T} r\,(1-r^2/R^2)\,dr$$

Substituting $h_w = 2r_o$, $\lambda = 2\pi R$ and breadth = b

KE. for breadth "b" $= -\lambda b \rho g \int_{r_o}^{r_T} (r - r^3/R^2)\, dr$

$= -\lambda b \rho g \left| r^2/2 - r^4/4R^2 \right|_{r_o}^{r_T}$

KE. for unit area $= -(\rho g/2) \left| r^2/2 - r^4 R/4R^2 \right|_{r_o}^{r_T}$

The term $(r^4/4R^2)$ is considered to be relatively small and may be rejected.

Hence,

KE. for unit area $= \frac{\rho g h w^2}{16} - \rho g \frac{r_T^2}{4}$

One will see that the first term is actually the overall kinematic evergy of wave and the second term may be regarded as a corrected term.

Multiplication of K.E. per unit area with actual waterplane area yields work done due to wave at each particular heeling angle. The results of calculation are shown for the chosen vessels in Table (7.16) up to (7.20)

HEEL'G ANGLE (DEGREE) / SEA STATES	0	10	20	30	40	50	60	70
0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1	0.0115	0.0119	0.0123	0.0134	0.0149	0.0179	0.0230	0.0336
2	0.3496	0.3549	0.3760	0.4036	0.4569	0.5439	0.6991	1.0221
3	2.2775	2.3126	2.4238	2.6298	2.9730	3.5432	4.5550	6.6590
4	9.0683	9.2081	9.6504	10.4712	11.8375	14.1078	18.1367	26.2922
5	19.3708	19.6696	20.6139	22.3674	25.2873	25.6966	38.7365	56.6363
6	39.7535	40.3664	42.3047	45.9033	48.8944	61.8454	79.5070	116.2315
7	59.3822	60.2982	63.1932	68.5768	77.5179	92.3823	118.7645	173.6222
8	65.8579	66.5175	70.0844	76.0463	85.9711	102.4565	131.7159	192.5560

TABLE (7.16) WORK DONE DUE TO WAVE, AFTER CORRECTION, FOR SHIP - A

HEEL'G ANGLE (DEGREE) / SEA STATES	0	10	20	30	40	50	60	70
0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1	0.0135	0.0137	0.0145	0.0156	0.0177	0.0210	0.0271	0.0396
2	0.4652	0.4723	0.4939	0.5371	0.6072	0.7236	0.9303	1.3599
3	3.1158	3.1636	3.3158	3.5978	4.0673	4.8472	6.2315	9.1097
4	12.4950	12.6866	13.2973	14.4280	16.3109	19.4382	24.9900	36.5325
5	27.0068	27.4201	28.7413	31.1850	35.2546	42.0137	54.0137	78.9615
6	55.4151	56.2621	58.9746	63.9887	72.3386	86.2071	110.8303	162.0201
7	83.7902	85.0649	89.1749	96.7254	109.3786	130.3464	167.5803	244.9795
8	93.6961	95.1415	99.7254	108.1936	122.3076	177.7465	187.3922	273.9337

TABLE (7.17) WORK DONE DUE TO WAVE, AFTER CORRECTION, FOR SHIP - B

HEEL'G ANGLE (DEGREE) / SEA STATES	0	10	20	30	40	50	60	70
0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1	0.0149	0.0150	0.0157	0.0171	0.0193	0.0230	0.0326	0.0432
2	0.4712	0.4785	0.5015	0.5442	0.6152	0.7253	0.9425	1.3778
3	3.1920	3.2414	3.3967	3.6858	4.1669	4.9657	6.3839	13.8284
4	12.8515	13.049	13.6761	14.8397	16.7765	20.0936	25.7030	37.5752
5	27.9584	28.3875	29.7521	32.2839	36.4973	43.4949	55.9169	81.7449
6	57.4878	58.3694	61.1756	66.3816	75.0451	89.4333	114.9755	168.0527
7	87.2680	83.6028	92.2386	100.7696	113.9206	135.7610	174.5359	255.5431
8	97.9410	99.4242	104.2174	113.0952	133.8539	152.3599	195.6819	286.3586

TABLE (7.18) WORK DONE DUE TO WAVE, AFTER CORRECTION, FOR SHIP - C

HEEL'G ANGLE (DEGREE) / SEA STATES	0	10	20	30	40	50	60	70
0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1	0.0317	0.0322	0.0338	0.0366	0.0414	0.0494	0.0645	0.0928
2	1.0749	1.0915	1.1439	1.2413	1.4032	1.6723	2.1499	3.1429
3	7.5812	7.6982	8.0677	8.7540	9.8964	11.7942	15.1623	22.1659
4	31.0554	31.5345	33.0483	35.8597	40.5399	48.3136	62.1107	90.8000
5	69.0949	70.1607	73.5291	79.7842	90.1969	107.4925	138.1897	202.0205
6	143.2825	145.4929	152.4776	165.449	187.0418	222.9080	286.5650	418.9319
7	222.8135	224.2199	234.9839	254.9747	288.2512	343.5247	441.6270	645.6191
8	251.4607	255.3393	267.5963	290.3644	330.2571	391.2025	502.3316	737.2293

TABLE (7.19) WORK DONE DUE TO WAVE, AFTER CORRECTION, FOR SHIP - D

HEEL'G ANGLE (DEGREE) / SEA STATES	0	10	20	30	40	50	60	70
0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1	0.0420	0.0426	0.0447	0.0485	0.0549	0.0653	0.0841	0.1228
2	1.4496	1.4721	1.5427	1.6739	1.8924	2.2550	2.8993	4.2385
3	10.6755	10.8855	11.4084	12.3787	13.9940	16.6774	21.4401	31.3434
4	44.3220	45.0057	47.1665	51.1794	57.8580	68.9528	88.6441	129.5888
5	101.7524	103.3222	108.2824	117.4960	132.8274	158.2988	203.5049	297.5037
6	213.0277	216.3139	226.6986	245.9888	269.6447	331.4125	426.0553	560.8022
7	334.4743	339.6340	355.9385	386.2303	436.6196	520.3501	668.9485	977.9346
8	387.8817	393.8654	412.7715	447.9173	506.3306	603.4380	775.7635	1134.0841

TABLE (7.20) WORK DONE DUE TO WAVE, AFTER CORRECTION, FOR SHIP - E

7.3 The wind moment

At any particular sea state, there will be a correspondence of wind speed and Beaufort Number (see Chapter 5). It is obvious that the vessel will heel in the same manner as analogy to wave.

Wind pressure and its centre of action blowing abeam was investigated experimentally using wind tunnel. Normally the relation of wind heeling moment and wind speed is expressed in the form of : -

$$M_w = \frac{1}{2} C_M \rho A l V_w^2$$

where

M_w = Wind heeling moment

C_M = Coefficient of wind heeling moment

ρ = Density of air

V_w = Wind velocity

A = Lateral projected area above waterplane of vessel

l = Moment arm

Since, there has been no wind tunnel in this country, the values of C_M used in the calculation are based on the experimental works of Ref.[68]. Fig.(7.6) shows the values of C_M for fishing vessels are plotted on the base of the heeling angle. The most important thing in the calculation is to get actual value of the moment arm when the ship heels due to wind. Again, Fig. (7.7) shows the values of actual moment arm in term of heel angle,

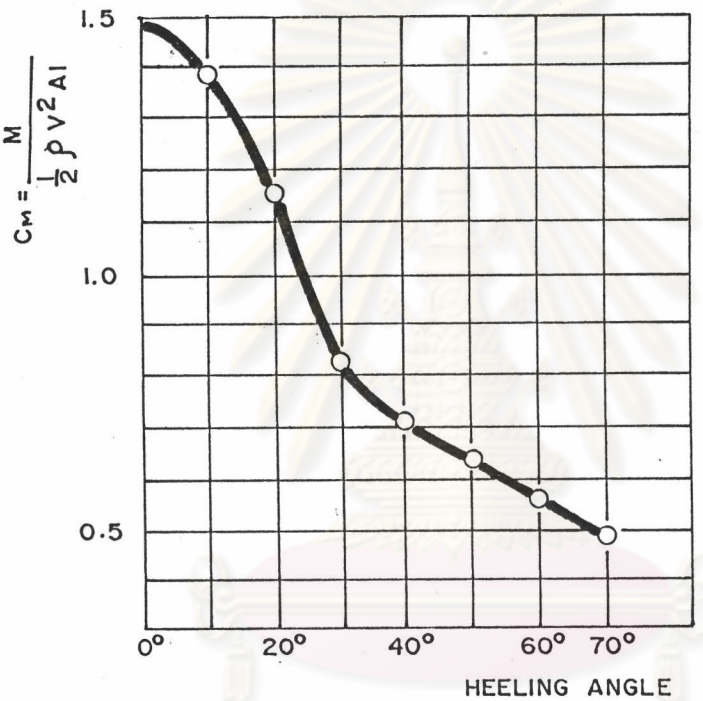

Fig. (7.6) Values of wind moment coefficients (C_M)

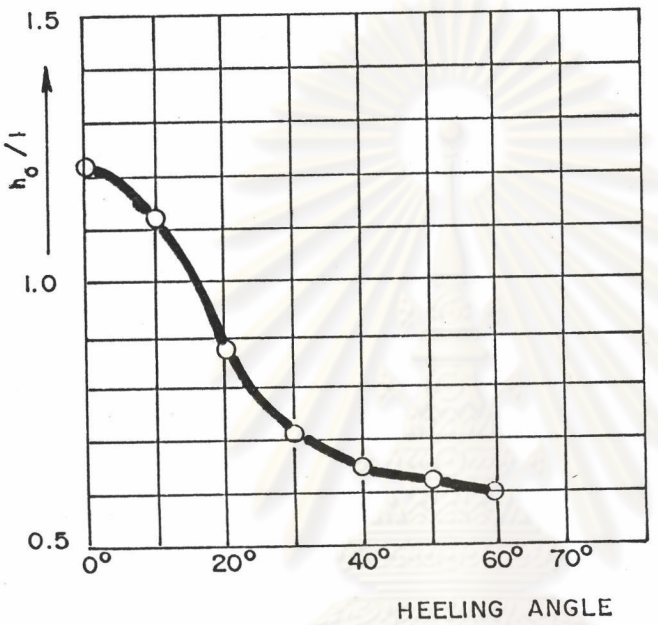

Fig. (7.7) Wind moment arm for heeling

Fig. (7.7) has been taken from Ref.[68] as well.

It can be easily notice that the wind moment decreases rapidly when the heeling angle of a ship increases. The results of the experiment of Ref. (68) indicate that the centre of water pressure rises apparently when the ship heels and becomes even higher than the waterline level when she heels to large angles.

Later on, from the calculation in this chapter, it will be clearly seen through the ship heels as the wind pressure increases, the centre of water pressure rises remarkably when the ship heels beyond certain angle, causing the considerable decrease of the moment, and consequently, she may not be easily capsized by the wind pressure only.

Hence, from Fig. (7.6) and (7.7) in cooperation with the above equation GZ values(heeling arm) for the proposed ships could be calculated for various heeling angle and Sea States.

The results are shown in Table (7.21) through (7.25). Multiplication of displacement of ships will yield heeling moments due to wind as shown in Table (7.26) to (7.30).

Work done due to wind moment at various Sea States may be found by integration the heeling moments along angles of heeling. Tables (7.31 to 7.35)

show the results.

Superposition of work done by wind and wave are show in Table (7.36) to (7.40). It is assume that superposition theory can be held in the case.

HEEL'G ANGLE (DEGREE) / SEA STATES	0	10	20	30	40	50	60	70
0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1	0.0049	0.0036	0.0027	0.0021	0.0018	0.0017	0.0016	0.0015
2	0.0283	0.0208	0.0158	0.0122	0.0102	0.0101	0.0091	0.0088
3	0.0472	0.0348	0.0263	0.0204	0.0170	0.0168	0.0152	0.0147
4	0.0672	0.0495	0.0375	0.0291	0.0243	0.0239	0.0217	0.0209
5	0.0994	0.0732	0.0554	0.0431	0.0359	0.0353	0.0320	0.0310
6	0.1596	0.1175	0.0890	0.0691	0.0576	0.0567	0.0514	0.0497
7	0.2837	0.2089	0.1581	0.1228	0.1023	0.1009	0.0914	0.0884
8	0.4813	0.3544	0.2683	0.2084	0.1736	0.1711	0.1551	0.1499

TABLE (7.21) " GZ " VALUES FOR VARIOUS HEELING ANGLES AND SEA STATES DUE TO WIND (SHIP -A)

HEEL'G ANGLE (DEGREE) / SEA STATES	0	10	20	30	40	50	60	70
0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1	0.0062	0.0045	0.0034	0.0026	0.0022	0.0021	0.0019	0.0019
2	0.0358	0.0250	0.0194	0.0150	0.0130	0.0123	0.01112	0.0108
3	0.0597	0.0433	0.0324	0.0251	0.0208	0.0205	0.0186	0.0180
4	0.0851	0.0617	0.0462	0.0357	0.0296	0.0292	0.0264	0.0256
5	0.1259	0.0913	0.0683	0.0528	0.0438	0.0432	0.0391	0.0379
6	0.2020	0.1465	0.1097	0.0848	0.0703	0.0693	0.0627	0.0608
7	0.3590	0.2604	0.1949	0.1507	0.1250	0.1232	0.1115	0.1080
8	0.6092	0.4418	0.3308	0.2557	0.2121	0.2090	0.1893	0.1833

TABLE (7.22) " GZ " VALUES FOR VARIOUS HEELING ANGLES AND SEA STATES DUE TO WIND (SHIP -B)

HEEL'G ANGLE (DEGREE) / SEA STATES	0	10	20	30	40	50	60	70
0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1	0.0060	0.0044	0.0033	0.0026	0.0022	0.0021	0.0019	0.0019
2	0.0347	0.0255	0.0193	0.0150	0.0125	0.0123	0.0111	0.0108
3	0.0578	0.0425	0.0322	0.0250	0.0208	0.0205	0.0186	0.0180
4	0.0824	0.0606	0.0458	0.0356	0.0296	0.0292	0.0265	0.0256
5	0.1218	0.0896	0.0677	0.0526	0.0438	0.0432	0.0391	0.0378
6	0.1955	0.1438	0.1087	0.0844	0.0703	0.0693	0.0628	0.0607
7	0.3476	0.2556	0.1933	0.1501	0.1250	0.1232	0.1116	0.1080
8	0.5897	0.4389	0.3280	0.2546	0.2106	0.2090	0.1894	0.1831

TABLE (7.23) " GZ " VALUES FOR VARIOUS HEELING ANGLES AND SEA STATES DUE TO WIND (SHIP -C)

HEEL'G ANGLE (DEGREE) / SEA STATES	0	10	20	30	40	50	60	70
0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1	0.0105	0.0075	0.0056	0.0043	0.0036	0.0035	0.0032	0.0031
2	0.0604	0.0434	0.0322	0.0248	0.0205	0.0202	0.0183	0.0177
3	0.1009	0.0724	0.0537	0.0414	0.0342	0.0337	0.0305	0.0296
4	0.1437	0.1031	0.0766	0.0590	0.0487	0.0480	0.0435	0.0422
5	0.2125	0.1525	0.1132	0.0872	0.0721	0.0711	0.0643	0.0624
6	0.3410	0.2450	0.1817	0.1399	0.1157	0.1140	0.1032	0.1001
7	0.6062	0.4349	0.3230	0.2487	0.2057	0.2027	0.1834	0.1779
8	1.0286	0.7380	0.5481	0.4221	0.3490	0.3440	0.3112	0.3018

TABLE (7.24) " GZ " VALUES FOR VARIOUS HEELING ANGLES AND SEA STATES DUE TO WIND (SHIP -D)

HEEL'G ANGLE (DEGREE) / SEA STATES	0	10	20	30	40	50	60	70
0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1	0.0079	0.0057	0.0043	0.0033	0.0027	0.0027	0.0024	0.0023
2	0.0454	0.0327	0.0247	0.0188	0.0155	0.0153	0.0139	0.0134
3	0.0758	0.0546	0.0416	0.0313	0.0259	0.0255	0.0231	0.0224
4	0.1080	0.0777	0.0586	0.0446	0.0369	0.0364	0.0329	0.0319
5	0.1598	0.1150	0.0867	0.0660	0.0546	0.0538	0.0487	0.0472
6	0.2564	0.1845	0.1392	0.1059	0.0876	0.0864	0.0782	0.0758
7	0.4558	0.3280	0.2474	0.1882	0.1557	0.1535	0.1389	0.1347
8	0.7734	0.5565	0.4198	0.3193	0.2643	0.2605	0.2357	0.2285

TABLE (7.25) " GZ " VALUES FOR VARIOUS HEELING ANGLES AND SEA STATES DUE TO WIND (SHIP -E)

HEEL'G ANGLE (DEGREE) / SEA STATES	0	10	20	30	40	50	60	70
0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1	0.4576	0.3372	0.2551	0.1981	0.16505	0.1627	0.1474	0.1425
2	2.6358	1.9409	1.4694	1.1411	0.9508	0.9372	0.8493	0.8210
3	4.3982	3.2386	2.4518	1.9041	1.5865	1.5638	1.4172	1.3699
4	6.265	4.6132	3.4925	2.7122	2.2599	2.2276	2.0187	1.9514
5	9.2675	6.8242	5.1663	4.0121	3.3429	3.2917	2.9863	2.8867
6	14.8699	10.9495	8.2894	6.4374	5.3638	5.2871	4.7915	4.6317
7	26.434	19.4651	14.7362	11.4440	9.5352	9.3990	8.5179	8.2339
8	44.855	33.0289	25.005	19.4185	16.1797	15.9486	14.4534	13.9715

TABLE (7.26) HEELING MOMENTS FOR VARIOUS HEELING ANGLES AND SEA STATES DUE TO WIND (SHIP_ A)

HEEL'G ANGLE (DEGREE) / SEA STATES	0	10	20	30	40	50	60	70
0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1	0.7624	0.5530	0.4140	0.3200	0.2654	0.2616	0.2369	0.2294
2	4.3921	3.1854	2.3848	1.8433	1.5289	1.5071	1.3645	1.3214
3	7.3288	5.3152	3.9794	3.0757	2.5512	2.5147	2.2769	2.2050
4	10.4394	7.5712	5.6684	4.3812	3.6340	3.5821	3.2433	3.1409
5	15.4427	11.1998	8.3851	6.4809	5.3756	5.2988	4.7976	4.6461
6	24.7779	17.9701	13.4540	10.3987	8.6252	8.5020	7.6978	7.4548
7	44.048	31.9458	23.9174	18.4859	15.3332	I5.1141	13.6846	13.2525
8	74.7422	54.2067	40.5838	31.3674	26.0178	25.6461	23.2204	22.4873

TABLE (7.27) HEELING MOMENTS FOR VARIOUS HEELING ANGLES AND SEA STATES DUE TO WIND (SHIP_ B)

HEEL'G ANGLE (DEGREE) / SEA STATES	0	10	20	30	40	50	60	70
0	0.00000	0.0000	0.0000	0.0000	0.0000	0.00000	0.0000	0.0000
1	0.8612	0.66333	0.4790	0.3718	0.3097	0.3053	0.2766	0.2675
2	4.9612	3.6482	2.7593	2.1419	1.7840	1.7585	1.5936	1.5406
3	8.2784	6.0876	4.6043	3.5741	2.9768	2.9343	2.6591	2.5708
4	11.7922	8.6714	6.5585	5.0911	4.2403	4.1797	3.7877	3.6619
5	17.4437	12.8272	9.7017	7.5310	6.2725	6.1829	5.6031	5.4169
6	27.9885	20.5814	15.5665	12.0837	10.0643	9.9205	8.9902	8.6915
7	49.7557	36.5879	27.6728	21.4814	17.8915	17.6359	15.9820	15.4511
8	84.427	62.8346	46.9561	36.4503	30.3588	29.9251	27.1187	26.2179

TABLE (7.28) HEELING MOMENTS FOR VARIOUS HEELING ANGLES AND SEA STATES DUE TO WIND (SHIP - C)

HEEL'G ANGLE (DEGREE) / SEA STATES	0	10	20	30	40	50	60	70
0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1	3.9495	2.8336	2.1045	1.6205	1.3399	1.3208	1.1950	1.1589
2	22.7511	16.3233	12.1228	9.3352	7.7188	7.6085	6.8841	6.6759
3	37.9632	27.2376	20.2286	15.5771	12.8798	12.6958	11.4871	11.1396
4	54.0763	38.7984	28.8144	22.1886	18.3465	18.0544	16.3626	15.8676
5	79.9929	57.3929	42.6240	32.8228	27.1392	26.7515	24.2046	23.4724
6	128.3495	92.0875	68.3906	52.6645	43.5451	42.9231	38.8365	37.6617
7	228.1691	163.7055	121.5792	93.6226	77.4109	76.3051	69.0403	66.9510
8	387.1644	277.7806	206.2993	158.8617	131.3533	129.4768	117.1497	113.6059

TABLE (7.29) HEELING MOMENTS FOR VARIOUS HEELING ANGLES AND SEA STATES DUE TO WIND (SHIP -D)

HEEL'G ANGLE (DEGREE) / SEA STATES	0	10	20	30	40	50	60	70
0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1	4.2843	3.0830	2.3253	1.7689	1.4639	1.4430	1.3059	1.2659
2	24.6798	17.7599	13.3950	10.1899	8.4331	8.3126	7.5227	7.2923
3	41.1815	29.6348	22.3513	17.0032	14.0718	13.8708	12.5526	12.1682
4	58.66	42.2130	31.8381	24.220	20.0444	19.7581	17.8804	17.3329
5	86.7741	62.444	47.0968	35.8276	29.6509	29.2273	26.4498	25.6398
6	139.23	100.1921	75.5673	57.4858	47.5752	46.8955	42.4389	41.1394
7	247.51	178.1132	134.3374	102.1935	84.5752	83.3670	75.444	73.1342
8	419.986	302.2228	227.948	173.405	143.5098	141.4597	128.0165	124.096

TABLE (7.30) HEELING MOMENTS FOR VARIOUS HEELING ANGLES AND SEA STATES DUE TO WIND (SHIP -E)

HEEL'G ANGLE (DEGREE) / SEA STATES	0	10	20	30	40	50	60	70
0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1	0.0000	0.0774	0.1199	0.1592	0.1904	0.2192	0.2465	0.2713
2	0.0000	0.3993	0.6904	0.9205	1.0966	1.2626	1.4194	1.5624
3	0.0000	0.6663	1.1520	1.5359	1.8299	2.1067	2.3684	2.6071
4	0.0000	0.9491	1.6409	2.1787	2.6065	3.0009	3.3737	3.7137
5	0.0000	1.4040	2.4273	3.2229	3.8558	4.4390	4.9898	5.4931
6	0.0000	2.2527	3.8947	5.1711	6.1866	7.1227	8.0074	8.8144
7	0.0000	4.0047	6.9236	9.1928	10.9980	12.6574	14.2350	15.6650
8	0.0000	6.7954	11.7482	15.5987	18.6619	21.4856	24.1544	26.5888

TABLE (7.31) DYNAMICAL STABILITY FOR VARIOUS SEA STATES AND HEELING ANGLES DUE TO WIND (SHIP - A)

HEEL'G ANGLE (DEGREE) / SEA STATES	0	10	20	30	40	50	60	70
0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1	0.0000	0.1148	0.1971	0.2602	0.3111	0.3575	0.4011	0.4400
2	0.0000	0.6611	1.1353	1.5015	1.7918	2.0591	2.3108	2.5411
3	0.0000	1.1032	1.8944	2.5055	2.9899	3.4359	3.8558	4.2518
4	0.0000	1.5714	2.7159	3.5689	4.2589	4.8942	5.4924	6.0399
5	0.0000	2.3246	3.9918	5.2794	6.3001	7.2399	8.1247	8.9345
6	0.0000	3.7298	6.4050	8.4708	10.2831	11.1048	13.0363	14.3584
7	0.0000	6.6305	11.3860	15.0587	17.9702	20.6507	23.1746	25.5249
8	0.0000	11.2508	19.3202	25.5521	30.4924	35.0464	39.3234	43.3114

TABLE (7.32) DYNAMICAL STABILITY FOR VARIOUS SEA STATES AND HEELING ANGLES DUE TO WIND (SHIP - B)

HEEL'G ANGLE (DEGREE) / SEA STATES	0	10	20	30	40	50	60	70
0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1	0.0000	0.1304	0.2253	0.2990	0.3144	0.4118	0.4628	0.5103
2	0.0000	0.7512	1.2979	1.7227	2.0605	2.3719	2.6661	2.9396
3	0.0000	1.2534	2.1657	2.8746	3.4383	3.9578	4.4488	4.9051
4	0.0000	1.7854	3.0849	4.0946	4.8976	5.6377	6.3370	6.9870
5	0.0000	2.6411	4.5635	6.0569	7.2448	8.3396	9.0252	9.9867
6	0.0000	4.2377	7.3221	9.7185	11.6244	13.3811	15.0409	16.5836
7	0.0000	7.5335	13.0165	17.2768	20.6649	23.7878	26.7385	29.4810
8	0.0000	12.8486	22.2616	29.4632	35.2396	40.4731	45.5454	50.1990

TABLE (7.33) DYNAMICAL STABILITY FOR VARIOUS SEA STATES AND HEELING ANGLES DUE TO WIND (SHIP - C)

HEEL'G ANGLE (DEGREE) / SEA STATES	0	10	20	30	40	50	60	70
0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1	0.0000	0.5918	1.0114	1.3339	1.5889	1.8234	2.1994	2.4048
2	0.0000	3.4092	5.8264	7.6840	9.1524	10.5037	11.7721	12.9552
3	0.0000	5.6888	9.7221	12.8218	15.2722	17.5269	19.6434	21.6176
4	0.0000	8.1033	13.8485	18.2638	21.7543	24.9660	27.9809	30.7930
5	0.0000	11.9869	20.4856	21.4385	32.1803	36.9313	41.3910	45.5508
6	0.0000	19.2331	32.8694	43.3490	51.6336	59.2566	66.4122	73.0867
7	0.0000	34.1911	58.4325	77.0622	91.7900	105.3415	118.0622	129.9275
8	0.0000	58.0165	99.1501	116.2325	155.7520	178.7467	200.3316	220.4650

TABLE (7.34) DYNAMICAL STABILITY FOR VARIOUS SEA STATES AND HEELING ANGLES DUE TO WIND (SHIP - D)

HEEL'G ANGLE (DEGREE) / SEA STATES	0	10	20	30	40	50	60	70
0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1	0.0000	0.6428	1.1017	1.4578	1.7337	1.9935	2.2306	2.4550
2	0.0000	3.7029	6.3468	8.3979	9.9873	11.4835	12.8500	14.1426
3	0.0000	6.1787	10.5905	14.0130	16.6652	19.1618	21.4411	23.5980
4	0.0000	8.8012	15.0855	19.9606	23.7385	27.2948	30.5416	33.6139
5	0.0000	10.4018	22.3155	29.5270	35.1155	41.9896	45.1789	49.7237
6	0.0000	20.8896	35.8054	47.3764	56.3432	64.7839	72.4901	79.7823
7	0.0000	37.1356	63.6518	84.2217	100.1622	115.1672	128.8667	141.8301
8	0.0000	63.0127	108.0053	142.9092	169.9574	195.4189	218.6641	240.6610

TABLE (7.35) DYNAMICAL STABILITY FOR VARIOUS SEA STATES AND HEELING ANGLES DUE TO WIND (SHIP - E)

HEEL'G ANGLE (DEGREE) / SEA STATES	0	10	20	30	40	50	60	70
0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1	0.0115	0.0893	0.1322	0.1726	0.2053	0.2371	0.2695	0.3049
2	0.4135	0.8191	1.1344	1.3979	1.6369	1.9059	2.2463	2.77129
3	3.5190	4.2396	4.8970	5.5993	6.4236	7.5813	9.4064	12.8960
4	16.1508	17.349	18.8283	20.8281	23.6899	28.1271	35.6754	50.7137
5	48.5278	50.6804	54.0694	59.2579	67.2049	75.4958	102.0453	147.3788
6	114.8512	118.8753	126.1167	137.7898	153.1141	185.7994	237.7098	344.6168
7	258.4133	266.4044	281.9213	307.5909	348.3325	414.6771	531.0617	771.2152
8	607.5609	623.3729	658.3009	717.1497	811.7760	966.6824	1239.2763	1802.9784

TABLE (7.36) WORK DONE FOR VARIOUS ANGLES AND SEA STATES DUE TO WAVE AND WIND (SHIP -A)

HEEL'G ANGLE (DEGREE) / SEA STATES	0	10	20	30	40	50	60	70
0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1	0.0197	0.1348	0.2180	0.2829	0.5368	0.3881	0.4404	0.4975
2	0.7078	1.3798	1.8885	2.3188	2.7158	3.1602	3.7264	4.6106
3	6.0241	7.2203	8.3051	9.4615	10.8538	12.8077	15.904	21.865
4	27.6482	30.3994	32.1385	35.4942	40.3509	47.9072	60.7888	86.8778
5	83.0734	86.6797	92.3968	101.2041	114.7444	136.6342	174.2715	251.8249
6	196.6107	203.3741	215.6338	235.497	266.9395	316.9772	406.2578	589.2098
7	442.3711	455.8270	482.1476	525.8641	595.4431	708.8588	907.9167	1318.9315
8	1040.0680	1067.3658	1026.1373	1226.5171	1388.2008	1653.3101	2119.4588	3084.2661

TABLE (7.37) WORK DONE FOR VARIOUS ANGLES AND SEA STATES DUE TO WAVE AND WIND (SHIP -B)

HEEL'G ANGLE (DEGREE) / SEA STATES	0	10	20	30	40	50	60	70
0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1	0.0148	0.1454	0.2410	0.3161	0.3337	0.4348	0.4954	0.5535
2	0.5322	1.2916	1.8640	2.3373	2.7553	3.1921	3.7306	4.4958
3	4.5300	5.8534	6.9863	8.1054	9.3518	11.0051	13.5087	22.6456
4	20.7908	22.8962	25.2098	28.1018	32.0381	38.0827	47.9186	67.7752
5	62.4692	66.0718	71.0412	78.1904	88.7927	105.5238	133.9637	192.6344
6	147.8467	154.3599	164.6556	180.4376	204.6247	243.3897	310.7342	448.858
7	332.6527	345.3065	366.3880	401.3922	454.9125	541.2996	692.0438	1002.4810
8	782.1065	806.9927	854.5527	932.5647	1062.2081	1257.2056	1609.7583	2336.9237

TABLE (7.38) WORK DONE FOR VARIOUS ANGLES AND SEA STATES DUE TO WAVE AND WIND (SHIP -C)

HEEL'G ANGLE (DEGREE) / SEA STATES	0	10	20	30	40	50	60	70
0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1	0.0323	0.6246	1.0458	1.3712	1.6311	1.8737	2.2640	2.4993
2	1.1630	4.5902	7.0641	9.0270	10.6706	12.3131	14.0982	16.3557
3	9.8986	15.7401	20.2559	24.2517	28.1938	32.9263	39.4405	50.5591
4	45.4306	54.2347	62.1946	70.7226	81.0597	95.6434	118.8420	163.6233
5	136.5034	150.596	174.7493	179.0593	210.3727	249.2928	314.3977	444.6606
6	323.064	347.2809	376.6665	416.3918	473.3635	561.8549	712.5402	1017.6645
7	728.8890	772.2935	831.9707	916.4026	1040.6758	1236.1799	1571.8402	2255.2124
8	1709.0040	1793.3841	1417.8316	2089.6229	2386.6967	2837.4840	3618.3386	5219.2658

TABLE (7.39) WORK DONE FOR VARIOUS ANGLES AND SEA STATES DUE TO WAVE AND WIND (SHIP -D)

HEEL'G ANGLE (DEGREE) / SEA STATES	0	10	20	30	40	50	60	70
0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1	0.0422	0.6856	1.1466	1.5065	1.7888	2.0591	2.31150	2.5783
2	1.5187	5.2451	7.9630	10.1516	11.9699	13.8463	15.8875	18.5831
3	12.9261	19.3042	24.3465	28.9390	33.5389	39.2712	47.2932	61.3913
4	59.3256	69.0420	78.2184	88.4647	101.1823	119.5891	149.1929	207.0703
5	178.2533	191.4050	212.0085	235.3586	267.8077	319.3027	401.6856	570.9011
6	421.8742	449.2718	484.7538	534.5204	607.0583	721.1039	916.2384	1313.2586
7	949.2103	1000.9889	1073.7787	1180.2880	1339.2627	1591.8767	2027.2872	2917.1325
8	2231.7076	2329.1480	2482.9353	2719.8932	3083.2320	3667.3409	4682.0794	6765.7314

TABLE (7.40) WORK DONE FOR VARIOUS ANGLES AND SEA STATES DUE TO WAVE AND WIND (SHIP -E)