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A Proposed Standard of Stability for Passenger Ship

(Part I : Smooth Water Area)

By Mitsuo Sato, *Kogakushi, Member.*
Yasubumi Yamanouchi, *Kogakushi, Member.*
Seizo Motora, *Kogakushi, Member.*
Mamoru Uchida, *Kogakushi, Member.*

§ 1. Introduction

Need of a suitable standard of stability for ships has long been recognized, in view of promoting safety of lives and vessels at sea. The problem is, however, rather complex and involves so many difficulties, and it may be said that little development of significance has been made in this field in Japan.

At present, in conjunction with the program to revise various regulations under the new Ships Safety Law, a drafting board has been set up within Ministry of Trasportation, and the work on establishing standards of stability for various types and duties of vessels are now being in steady progress with the cooperation of Tokyo and Kyushu Universities, Nippon Kaiji Kyokai (Japan Maritime Corporation), etc.. As the first step, a standard of stability for ships engaged in Smooth Water Service has been developed, and inspections based on this standard have been in force since the beginning of this year. The authors intend to describe the basic principles and process followed in preparing this standard, and would like to have wider recognition and criticism on our scheme.

The standard cannot be declared, of course, to be a perfect one, containing many an open question in itself, and any unreasonable provisions are subject to amendment in the future. It would be nevertheless of interest to note that a standard has been established, in that it may at least be utilized as a measure to compare stabilities of different vessels. It is strongly hoped that, making this standard as an initiative, an improved criterion for ship's stability may be developed.

§ 2. Basic Principles

As the heeling forces, wind pressure and movement of passengers were considered, and it was aimed to require the ship to have an initial stability which will not allow the ship to heel over and beyond a certain limitation by these heeling moments.

The following basic principles were assumed to proceed with the preparation of this standard :

(1) Use of statical stability for the final criterion.

(2) As the heeling forces, only the wind pressure and the shifting of passengers were considered, and the effects of wave, steering, etc. were excluded from the considerations.

(3) Overloading of passengers in excess of permissible capacity would not be dealt with, as there are other existing regulations prohibiting it.

(4) Passengers of the capacity number were assumed to move within the space allotted for them.

(5) The maximum angle of inclination was limited to 80% of the freeboard, allowing for

other effects such as waves. The freeboard in the calculation was also limited to the depth of side which will submerge at the angle of heel of 20°, thus preventing at the same time the ship from inclining to an excessive angle.

§ 3. Heeling Moment due to Wind Pressure

When considering the heeling moment caused by wind pressure, let us first assume the center of pressure is located at the geometrical center of the projected lateral area of portion of ship above waterline, as shown in Fig. 1. Then the heeling moment due to wind pressure, M_w, in ton-m, may be expressed by the equation :

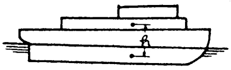


Fig. 1

$$M_w=\frac{1}{2}\rho C_D A v^2 h$$

where, ρ = density of air, in tons sec$^2/m^4$
$=1.25\times10^{-4}$ tons sec$^2/m^4$
C_D = lateral air drag coefficient
A = projected lateral area of portion of vessel above waterline, in m^2
v = wind velocity, in m/sec
h = vertical distance between the center of pressure and the center of lateral resistance of water, which is the geometrical center of projected lateral area of the hull under waterline, in m.

The measured values of C_D have been made available by many observers and some of the results are listed in Table 1.

TABLE 1. Values of C_D

Ship	C_D	Measured by
London Mariner	1.14	G. Hüghes [1]
San Gerardo	1.20	〃
Mauretania	1.23	〃
(Proposed)	1.28	D. W. Taylor [2]
Toya Maru	1.00	H. Araki & T. Hanaoka [3]
Kitami Maru	1.05	〃
Kogane Maru with awnings	1.15	S. Okada [4]
Kogane Maru without awnings	0.95	〃

On the other hand, the actual magnitude of heeling moment due to wind pressure directly measured by Mr. Okada and the results published in the paper [4], reveals that the center of pressure is located considerably above the geometrical center of projected lateral area of portion of ship above waterline. If we now take :

h_0 = vertical distance from the actual center of pressure to the center of lateral resistance
h = vertical distance from the center of area A to the center of lateral resistance,

ratio of h_0 to h has been found to be in the order exemplified in Table 2.

TABLE 2. Ratio of h_0 to h

Ship	C_D	h_0/h	$C_D\cdot h_0/h$
Kogane Maru, with awning	1.15	1.155	1.33
Kogane Maru, without awning	0.95	1.23	1.17

Therefore, h may be used in lieu of h_0 to simplify the calculations, provided that the values of C_D should be increased to incorporate the effect of rise in actual center of pressure. Weighing the averge value of $C_D.h_0/h$ shown in Table 2, and also with reference to papers [1] & [2], the value of 1.25 for C_D was adopted for our purpose. Therefore :

$$M_w = 0.78\times10^{-4}Ahv^2 \qquad (1)$$

In passing, Mr. Kato's paper shows the variation of heeling moment due to wind pressure at different angle of heel. In view of far less magnitude of heeling moment due to wind pressure compared to that due to movement of passengers, with the ships engaged in Smooth Water Service, equation (1) was adopted for simplification.

In the United States, as shown in Appendices II & [6] ; III & [7], the steady wind velocity of 37 miles per hour (or 16.5 m/sec) is adopted for fully protected areas such as rivers, harbors, etc., and the value of 45 miles per hour (or 20.1 m/sec) for partially protected areas such as lakes, bays, sounds, etc., as well as for Great Lakes (summer). It is difficult to determine the clear-cut standard for steady wind velocity for ships engaged in Smooth Water Service, but it seems not too unfit to assume the average wind velocity of about 10.m/sec. In actual cases however, it is essential to take into consideration the sudden gusts of the order of 1.4 times the averge wind velocity, and therefore the standard wind velocity of 15 m/sec was adopted by the board. Substituting this value with v in equation (1), we have :

$$M_w = 0.0176\ Ah \qquad (2)$$

§ 4. Heeling Moment due to Movement of Passengers

In the case of passenger ships for Smooth Water Service, which carry on board a relatively large number of passengers compared to the size of these ships, heeling moment due to movement of passengers is of considerable magnitude, but little useful informations on this subject may be found. Whereupon, authors have decided to determine the heeling moment due to normally incidental movement of passengers by the method described below.

(1) Distance of movement of passengers' load

Let us suppose that a number n of passengers in the passenger spaces are first distributed at the density r per unit floor area (in persons/m^2), and then these passengers have moved and formed the density r_0 (in persons/m^2), and their center of gravity has moved the distance d (in m). When, as shown in Fig. 2, the x-axis is taken along the athwartship direction, and y-axis along the longitudinal direction of the passenger space in the ship, within the small strip area dy, the distributed breadth of passengers is $2x\cdot\frac{r}{r_0}$ after the passengers have moved, and therefore it follows that their center of gravity has moved the distance $x\cdot\left(1-\frac{r}{r_0}\right)$. While the number of passengers in this strip is $r\cdot2x\cdot dy$, it further follows :

$$d=\frac{\int_0^l x\left(1-\frac{r}{r_0}\right)\cdot r\cdot 2x\cdot dy}{n}$$

where $n=r\int_0^l 2x\cdot dy$

therefore $d=2\left(1-\frac{r}{r_0}\right)\dfrac{\frac{1}{2}\int_0^l x^2\cdot dy}{\int_0^l x\cdot dy}$

Where $\frac{1}{2}\int_0^l x^2\cdot dy\Big/\int_0^l x\cdot du$ is not hing but the athwartship distance from the centerline of passenger space to the center -

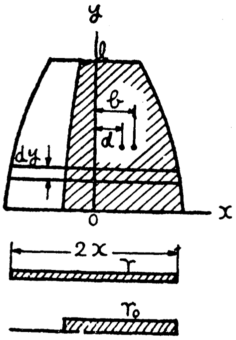


Fig. 2

of passenger space on one side of centerline, namely, b (in m), then :

$$d=2\left(1-\frac{r}{r_0}\right)b$$

When we take $\bar{B}$ (in m) as the average athwartship distance, within which the passengers are free to move, the results of our calculations with the various ships indicate :

$$b \doteqdot \frac{1}{4}\bar{B}$$

Therefore $d=\frac{1}{2}\left(1-\frac{r}{r_0}\right)\bar{B}$ (3)

The actual grouping test of passengers in a limited area demonstrated that the maximum value of 9 persons/m^2 for r_0 may be reached, and the value of 7 persons/m^2 is readily attained under normal conditions. The investigation conducted by the authors (Appendix I) also indicates that all the passengers may easily move from the centerline to either side abreast ($r_0 \doteqdot 2r$). As the r-value of these ships was 3.33 persons/m^2, r_0 comes to 6.66 persons/m^2. Therefore, the r_0-value of 7 persons/m^2 was confirmed here as readily attainable under actual circumstances.

In Fig. 3, where r is the abscissa, $2d/\bar{B}$ the ordinate, equation (3) can be illustrated by line A which corresponds to r_0 of 7 persons/m^2. Line A is correct in theory, while it would be too rigorous to assume that all the passengers move at the same time to a uniform density.

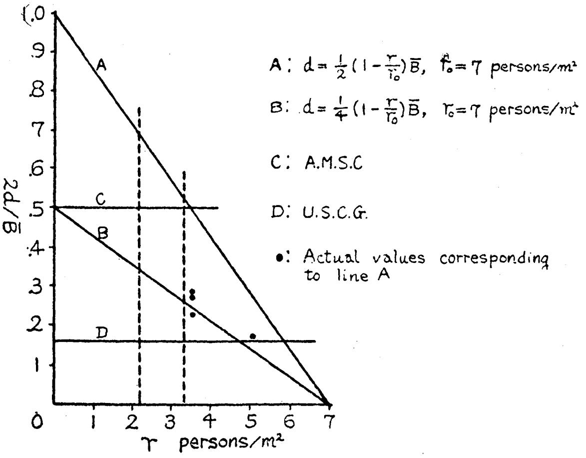


Fig. 3

The authors' field investigations (Appendix I) involved the experiments of moving passengers. When the distance of passengers' CG movement is assessed from the actual angle of heel in these experiments, it comes as plotted in Fig. 3, showing the values about one-half the height of line A. This tendency may be attributed to the fact that each ship was under way and that the movement of passengers could not be accomplished to a uniform density due to various obstructions on board. The authors have, therefore, seen fit to adopt, as the optimum measure, line B of Fig. 3, namely,

$$d=\frac{1}{4}\left(1-\frac{r}{r_0}\right)\bar{B} \text{ and } r_0=7 \text{ persons}/m^2 \qquad (4)$$

Let us now attempt to translate the meaning of equation (4) in other words. Supposing that the passengers move from the density r to r', then :

$$d=\frac{1}{2}\left(1-\frac{r}{r'}\right)\bar{B}$$

By equating this equation to (4), we have :

$$\frac{1}{r'}=\frac{1}{2}\left(\frac{1}{r}+\frac{1}{r_0}\right)$$

That is to say, the passengers condensate to the arithmetical mean value between the original and the possible per capita floor area.

The recommendations by American Marine Standards Committee (See Appendix II and [6]), may be interpreted to have assumed the movement of all the passengers from the centerline to either one side of the centerline ($d=b$), and U.S. Coast Guard Regulations (See Appendix III and [7]) to have reduced it to $d=0.31\,b$, and therefore these requirements may be expressed by lines C and D respectively in Fig. 3. In both cases however, the maximum angle of heel is limited to one-half the freeboard or 7 degrees whichever is less. There are also shown in Fig. 3, r-values of 3.333 persnos/m^2 and 2.222 persons/m^2, that are most frequently found with the passenger ships for Smooth Water Service.

(2) Density of passengers before movement

When the passenger capacity of the passenger space is denoted by n persons, and the area of the space by a (in m^2), the average area per passenger is a/n. Article 93 of our Sempaku Setsubi Kitei (Regulations for the Arrangements of Ships) provides the values of a/n as shown in Table 3 for the passenger ships engaged in Smooth Water Service.

TABLE 3. Minimum Area per Passenger

Class of passenger	Space on and above Upper Deck and Space immediately under U.D.		Space under and below 2nd Deck	
	a/n (m^2/person)	n/a (persons/m^2)	a/n (m^2/person)	n/a (persons/m^2)
1 st	0.85	1.176	1.10	0.909
2 nd	0.55	1.818	0.85	1.176
3 rd	0.45	2.222	0.55	1.818
3 rd (For the ships capable of cruising the maximum distance within one hour)	0.30	3.333	0.45	2.222

It appears therefore permissible to take n/a for the values of r. As the investigations by the authors indicate, however, passengers do not occupy the area in between couches, tables, etc. Thus, when the area occupied by these obstructions is denoted by a_1 (in m^2), r then becomes $n/(a-a_1)$. It should be noted again that the area a in these Regulations consists only of the space fitted for the accomodation of passengers, and do not include such spaces as passage-ways, stairways, etc., where the passengers may also freely move about. When the area of these spaces totals a_2, then :

$$r=\frac{n}{a-a_1+a_2}$$

TABLE 4. Values of a, a_1 and a_2

Ship	$a(m^2)$	$a_1(m^2)$	$a_2(m^2)$
L 1	213.30	37.25	74.58
L 2	156.00	44.00	48.61
L 3	39.00	14.64	12.22
L 4	36.00	17.12	12.46

Table 4 lists the values of a, a_1 and a_2 of some ships, and indicates that a_1 is larger than a_2 for the smallest ships, but becomes smaller than a_2 as the size of the ship increases. It follows that it is not necessary to consider couches, tables, etc., except for smallest ships, and it would not constitute too heavy a demand in general even though r were represented by n/a. Eventually, n/a was adopted for the value of r with ordinary ships in question. Incidentally, values of $r(=n/a)$ are mostly either 3.333 or 2.222 persons/m^2.

(3) The maximum athwartship distance of free passenger movement

The average athwartship distance of free passenger movement within the passenger spaces is, in ordinary cases, equal to the average extreme breadth of the passenger spaces, as shown in Fig. 4. When there are such spaces as passage-ways outside the proper passenger-carrying spaces, as shown in Fig. 5, these should be included to assess the mean breadth. When these outside spaces are narrower than 40 cm, as shown in Fig. 6, they are to be excluded in obtaining $\overline{B}$, as being impassable by passengers.

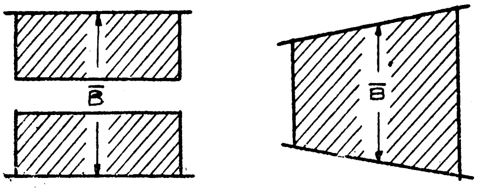


Fig. 4

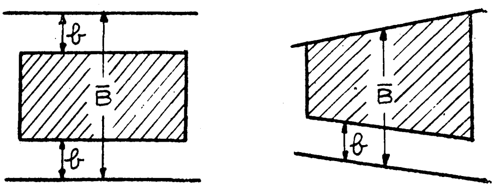


Fig. 5

(4) Heeling moment

When,

M_p = Heeling moment due to movement of passengers, in ton-m

w = Average weight of a passenger, in tons

then, M_p is the sum of heeling moments due to movement of passengers in each passenger-carrying space, that is :

$$M_p=\sum nwd$$

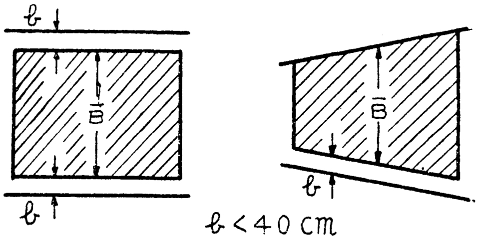


Fig. 6

Therefore, entering $d(4)$ into this equation, we have

$$M_p=\frac{1}{4}w\sum\left(1-\frac{r}{r_0}\right)n\overline{B} \qquad (5)$$

Assuming $w=0.06$ ton, $r_0=7$ persons/m^2, and $r=\frac{n}{a}$:

$$M_p=0.00214\sum\left(7-\frac{n}{a}\right)n\overline{B} \qquad (6)$$

§ 5. Maximum Permissible Angle of Heel

Maximum angle of heel adopted in the United States is limited to one-half the freeboard or 7 degrees, but to either wind pressure or movement of passengers, independent on each other, as quoted in Appendices II & [6] ; III & [7]. In our standard, the heeling moment was assumed as a sum of the moments due to combined wind pressure and movement of passengers, and the maximum angle of heel was limited to 80% of the freeboad, making a certain allowance for waves and other effects. That is,

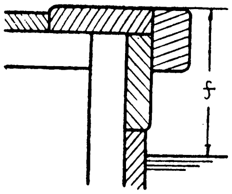


Fig. 7

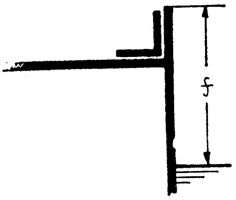


Fig. 8

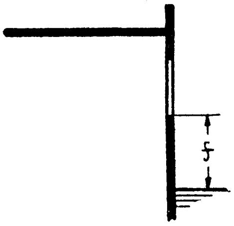


Fig. 9

when,

θ = Maximum angle of heel, in degrees

B = Beam of the ship, in m

f = Freeboard of the ship, in m

We may write,

$$\tan\theta=\frac{2(0.8f)}{B}=\frac{1.6f}{B} \qquad (7)$$

Even though the ship may have sufficient freeboard, excessive angle of heel must be avoided. Therefore, it was decided to limit the value of freeboard, f, in the formula to be not in excess of depth of side submersion at the angle of heel of 20 degrees.

$$f \leqq \frac{1}{2} B \tan 20^\circ$$

$$\text{or} \quad f \leqq B/5.5 \tag{8}$$

The freeboard should be measured in general to the top of the upper deck as shown in Fig. 7, but in such cases as Fig. 8 where the side plating is watertight to a certain level above the upper deck, or where there is an opening below the upper deck, Fig. 9, it should be measured to the lowest edge of non-watertight portion.

§ 6. Standard of Stability

As stated, the ships must have an inital stability which will not allow the ships to heel in excess of the limited angle under wind pressure and movement of passengers. This is expressed by the following equation, where GM is the metacentric height (in m) and $\varDelta$ the displacement (in tons) of the ship :

$$GM \geqq (M_w + M_p)/\varDelta \tan \theta \tag{9}$$

Substittuting equations (1) and (5) into above, it follows :

$$GM \geqq \left\{ 0.78 \times 10^{-4}\, Ahv^2 + \frac{1}{4}\, w \sum \left(1 - \frac{r}{r_0}\right) n\overline{B} \right\} / \varDelta \tan \theta \tag{10}$$

The working formula is obtained by introducing equations (2), (6), (7) and (8) into the above general equation (9) :

$$\left.\begin{aligned} & GM \geqq (1.1\, Ah + \textstyle\sum kn\overline{B}) B/100 f \varDelta \\ & f \leqq B/5.5 \\ & k = 0.134\left(7 - \frac{n}{a}\right) \end{aligned}\right\} \tag{11}$$

TABLE 5. Values of k

a/n(m^2/person)	k
0.30	0.49
0.45	0.64
0.55	0.69
0.85	0.78
1.10	0.82

where values of k may be obtained from Table 5, because n/a may be substituted by n/a from Table 3.

Table 6 illustrates the results derived from the actual ships using the formula (11). The calculated results required by U.S. Coast Guard Regulations are also shown for comparison.

TABLE 6. Calculated Results for Actual Ships

Ships	Hull Material	G.T.	$L(m) \times B(m) \times D(m)$	$d(m)$	Passenger Capacity	$\varDelta$(tons)	Actual $GM(m)$	Required $GM(m)$	GM required by U.S.C.G.(m)
L1	Wooden	150	27.00×6.40×2.40	1.83	705	153.65	0.710	☆1.144	☆1.210
L2	〃	123	24.00×5.80×2.30	1.80	520	127.07	0.410	☆0.870	☆0.945
L3	〃	19	14.90×3.90×1.32	0.87	130	23.69	1.030	0.594	0.753
L4	〃	19	14.25×3.72×1.46	0.90	120	19.21	0.460	☆0.554	☆0.756
L5	〃	19	14.50×3.85×1.25	0.87	160	25.90	1.667	0.674	0.850
L6	Wooden	18	14.50×3.95×1.33	0.86	157	21.84	1.746	0.734	1.009
L7	Steel	600	53.00×8.50×2.20	1.58	957	346.00	2.600	1.789	1.273
L8	Wooden	42	18.29×4.27×1.83	1.26	131	51.77	0.580	0.288	0.366
L9	〃	12	11.28×2.76×1.37	0.89	51	9.15	0.717	0.462	0.576
H1	〃	11	12.42×2.83×1.27	1.08	37	18.39	0.361	0.226	0.171
H2	Wooden	9	11.00×2.70×1.30	0.53	34	6.85	0.470	0.363	0.381
H3	〃	7	11.00×2.58×1.06	0.42	29	6.13	1.161	0.300	0.323
S1	Steel	81	21.34×5.49×2.44	1.90	195	93.88	0.630	0.447	0.420
S2	〃	172	23.00×5.80×2.50	2.07	322	164.03	0.610	☆0.706	☆0.679
S3	Wooden	42	18.13×4.49×1.67	0.96	170	41.04	0.820	0.480	0.634

Note : ☆ shows required GM larger than actual GM.

§ 7. Additional Notes

There are some features to be born in mind when using this standard above outlined. They are:

(1) The standard assumes that the stability curve forms a sine curve, as may be seen from equation (9). This is justified on account of the limitation of the maximum angle to about 16° (which is 80% of the freeboard corresponding to the inclination of 20°), and also because the maximum GZ's of the majority of ships are found between 20 and 25 degrees of heel. The assumption, $GZ=GM\sin\theta$, is therefore always on the safety side for the ordinary ships, and it does not give too different a value from the actual GZ. For the ships with pronounced flare or tumble-home, and those with bulge, etc., it is necessary of course to derive and use the actual GZ.

(2) Passengers were supposed to be of capacity number and to move on athwartship direction on a predetermined level. If the passngers were to move on to higher decks, for example, GM would be reduced, and the ships passable under this requirement might not necessarily remain safe.

(3) The ships were supposed to carry capacity number of passengers. By substituting $n=ra$ into equation (5).

$$M_p=\frac{1}{4}w\sum r\left(1-\frac{r}{r_0}\right)a\overline{B}$$

The heeling moment due to movement of passengers varies along a parabola, as shown in Fig. 10, reaching to a maximum at $r=\frac{r_0}{2}$. The value of r_0 was taken 7 persons/m^2, and as seen from Table 3, r never reaches to $\frac{r_0}{2}$. Therefore, from Fig. 10, M_p becomes the largest when the ship carries passengers to the capacity. On the contrary, M_w is of course greater when carrying less passengers, but is still far smaller than M_p in magnitude. This condition, however, gives greater freeboard, and thence greater angle of heel permissible, and furthermore increased GM in ordinary vessels. For these reasons, the consideration of the only case when carrying a total of capacity passengers is justifiable.

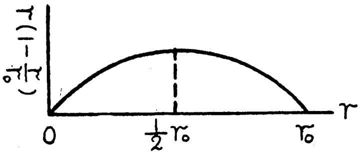


Fig. 10

§ 8. Conclusions

In the foregoing, authors have attempted to describe the principles and procedures in preparing the standard, which may be summarized as follows :

(1) The standard of stability was selected so that a safe initial stability would be maintained against the average wind velocity of about 10 m/sec (steady wind velocity of 15 m/sec) abeam the ship, and under the movement of passengers normally incidental.

(2) Heeling moment due to movement of passengers is far greater than that due to wind pressure.

(3) The athwartship movement of CG of passengers was determined according to the original density of passengers, a departure from the conventional uniform practice.

As admitted in the introduction of this paper, this standard may hardly be asserted as perfect, and contains many problems yet to be solved. For instance, there are some places in the scope of Smooth Water Area, where the effect of waves cannot be neglected. But the patterns of waves are so various and complex at the different places in the same Smooth Water Area, that even the attempt to determine standard wave profile presents a very difficult problem. Including a solution of this important problem, it is strongly hoped that a more reasonable standard of stability will be developed in the future.

APPENDIX II *REPORT OF INVESTIGATIONS ON STABILITY OF SHIPS ON "ASHI-NO-KO" AND "BIWA-KO" LAKES*

The authors have conducted investigations on stability of cruising vessels on "Ashi-no-Ko" and "Biwa-Ko" lakes. There were not many tourists, and therefore few full-load conditions available at the time of these investigations. Besides, passengers did not come out to weather decks due to the unfavourable weather. With these disadvantages, the objects, as previously expected, were not fully attained. Many groups of higher-and middle-school students on excursion were available, on the other hand, and they were willing to cooperate with our experiments on the movement of passengers.

The tests conducted were of the nature listed in Table 7.

TABLE 7. Vessels tested and types of test

Place	Ship	No. of passengers	Date	Type of test
"Ashi-no-Ko"	L2	335 higher-school students	4 June 53	Continuous recording of angle of heel (1 st)
		—	5 June 53	Inclining experiment
		—	〃	Rolling experiment
		320 middle-school students	〃	Continuous recording of angle of heel (2 nd) During this recording, Rolling experiment, Passenger movement test, and turning test were also made.
	L3	—	4 June 53	Inclining experiment
		—	〃	Rolling experiment
		143 higher-school students (girls)	〃	Continuous recording of angle of heel During this recording, Passenger movement test, and turning test were also made.
	L5	—	〃	Inclining experiment
		—	〃	Rolling experiment
		100 middle-school students	5 June 53	Continuous recording of angle of heel During this recording, Turning test was also made.
"Biwa-Ko"	L7	—	3 Nov. 53	Rolling experiment
		589 general passengers	〃	Continuous recording of angle of heel During this recording, Turning test was also made.

For the continuous recording of angle of heel, rolling recorder of U-tube type was used on "Ashi-no-Ko" and that of pendulum type on "Biwa-Ko."

Ship L 2

From the results of inclining experiment, displacement, *GM*, etc. under each condition were calculated and are shown in Table 8.

(1) Normal angle of heel and normal movement of passengers

As indicated by the continuous record of angle of heel, Fig. 11, the ship heels to port and starboard following the guide's explanations, and also when a pleasure boat comes close and attracts passengers on one side. A maximum angle of 5° was registered when the pleasure boat appeared on the starboard side. Heeling moment of 5.73 *t-m* is required to heel the ship to this angle, and this moment would have caused the ship under full load condition ($\varDelta=127.07\,t$) to heel, when $GM=0.410\,m$, i.e., passengers at proper position, to $\theta=7°$, and when $GM=0.297\,m$, i.e., all passengers on promenade deck, to $\theta=9.8°$.

TABLE 8. *GM* under each condition

Passenger	Experiment	$\varDelta(t)$	$GM(m)$	$KG(m)$
—	Inclining	98.77	1.069	2.200
	Rolling			
355 higher-school sutdents (55Kg/head) Distributed: 200 on promenade deck 155 on upper deck	Continuous recording of angle of hell (1st)	115.77	0.570	2.560
320 middle-school students (50Kg/head) Distributed: 95 on promenade deck 225 on upper deck	Continuous recording of angle of heel (2nd)	114.83	0.740	2.410
	Rolling			
	Passenger movement			
	Turning			

Assuming that this moment was caused by the movement of all the passengers on each deck, the change in the density is derived from :

$$355\times0.055\times\frac{\overline{B}}{2}\times\left(1-\frac{r}{r_0}\right)=5.73$$

Therefore, $\frac{r}{r_0}=0.893$, or $r_0=1.12\,r$. Further, athwartship movement of *CG* of passengers $=0.30m \doteqdot \frac{B}{20}$. Assuming that only the passenger, who spotted the pleasure boat, moved, and that they were 200 persons in number, $r_0=1.23\,r$.

(2) Passenger movemont experiment

The results of this experiment is shown in Fig. 12.

(a) Movement only within promenade deck house

No. of passengers moved : 95. Moved to starboard side on centerline. Registered $\theta=1.4°$

Estimated heeling moment $=95\times0.050\times\frac{\overline{B}}{4}$

When $\overline{B}$ = Breadth of the deck house, or $4\,m$, $\theta=3°$

When $\overline{B}=3\,m$, i.e., bench spaces do not admit passengers, $\theta=2.25°$

(b) Movement only within upper deck house

No. of passengers moved : 225. Moved to starboard side on centerline. Registered $\theta=6°$

Estimated heeling moment $=225\times0.050\times\frac{\overline{B}}{4}$

When $\overline{B}=3\,m$, $\theta=6°$.

(3) Turing experiment

The results are shown in Fig. 12.

At $\frac{1}{2}$ ahead and 10° helm, registered $\theta=2.3°$

The equivalent heeling moment would have heeled the ship under load condition ($\varDelta=127.07\,t$) as much as:

When $GM=0.410\,m$, or passengers at proper position, $\theta=3.7°$

When $GM=0.297\,m$, or all passengers on promenade deck, $\theta=5.1°$

Next, at $\frac{1}{2}$ ahead and 20° helm, registered $\theta=3.5°$

The equivalent moment would have caused the ship under load condition ($\Delta=127.07\,t$) and with:

$GM=0.410\,m$, to heel $\theta=5.7$ or $GM=0.297\,m$, to heel $\theta=8°$

(4) Rolling experiment

(a) During inclining experiment,

$$GM=1.069\,\mathrm{m},\ T=4.9\ \mathrm{sec},\ K=2.53\,m=\frac{B}{2.37}$$

(b) During the first trip (Fig. 11)

T was not measured, but from Fig. 11,

$$GM=0.570\,m,\ T=7.4\ \mathrm{sec},\ K=2.78\,m=\frac{B}{2.60}$$

(c) During the 2nd trip (Fig. 12)

$$GM=0.740\,m,\ T=6.0\ \mathrm{sec},\ K=2.53\,m=\frac{B}{2.37}$$

Ship L 3

From the results of inclining experiment, displacement, *GM* etc. under each condition were calculated and given in Table 9.

TABLE 9. *GM* under each condition

Passenger	Experiment	$\Delta(t)$	$GM(m)$	$KG(m)$
—	Inclining	16.15	2.210	1.610
	Rolling			
143 higher-school girl-students (48 Kg/head) Distributed : 101 on promenade deck 42 on upper deck	Continuous recording of angle of heel	23.014	1.114	1.846
	Passenger movement			
	Turning			

Continuous record of angle of heel is shown by Fig. 13.

(1) Normal angle of heel

Normal angle of heel is very small. This can apparently be accredited to the ship's characteristics giving a good command of view from the promenade deck and also having a relatively high *GM*.

(2) Passenger movent experiment (only on promenade deck)

(a) When the passengers on one side of centerline moved to centerline passage-way, registered $\theta=3°$

Since $r=4.12$ persons/m^2, and $r_0=5.75$ persons/$m^2=1.39\,r$

$\overline{B}=3.00\,m$ gives $\theta=4.5°$

which is in excess of the observed value. This is accredited to the fact that the density was not uniform, but was higher adjacent to the centerline.

(b) When the passengers moved from the centerline to starboard side of centerline, registered $\theta=5°$

Since $r=4.12$ persons/m^2, and $r_0=8.24$ persons/$m^2=2.0\,r$

$\overline{B}=3.00\,m$ gives $\theta=8°$

To give actual $\theta=5°$, $\overline{B}$ must be $\overline{B}=(3.00\text{–}1.1)\,m$

(3) Turning experiment

At full ahead and 30° helm, registered $\theta=7.9°$

(4) Rolling experiment

$$GM=2.210\,m,\quad T=2.5\ \text{sec},\quad K=1.85\,m=\frac{B}{2.22}$$

Ship L 5

The results of inclining experiment give the following values of displacement, *GM* etc. for each condition.

TABLE 10. *GM* under each condition

Passenger	Experiment	$\Delta(t)$	$GM(m)$	$KG(m)$
—	Inclining	19.30	2.500	1.190
	Rolling			
100 middle-school students (50 Kg/person) All in passengers' lounge	Continuous recording of angle of heel	24.30	1.871	1.269
	Turning			

Continuous record of angle of heel was obtained, but the angles were very small, as the rain and fog confined the passengers within the lounge.

(1) Turning experiment

At full ahead and 35° helm, registered $\theta=4^\circ$

(2) Rolling experiment

$$GM=2.500\,m,\quad T=2.6\ \text{sec},\quad K=2.05\,m=\frac{B}{1.90}$$

Ship L 7

The values of displacement, *GM* etc. under each condition were calculated as shown in Table 11.

TABLE 11. *GM* under each condition

Passenger	Experiment	$\Delta(t)$	$GM(m)$	$KG(m)$
—	Rolling	315.00	2.630	3.310
589 general passengers (52.6 Kg/person)	Continuous recording of angle of heel	346.00	2.600	3.360
	Turning			

(1) Continuous recording of angle of heel and turning experiment

This ship had a very large *GM* and sufficient stability.

(2) Rolling experiment

$$GM=2.630\,m,\quad T=5.2\ \text{sec},\quad K=4.20\,m=\frac{B}{2.02}$$

Conclusions

The investigations revealed many features, unrecognized in the past, and some of which are listed below :

(1) Angle of heel due to movement of passengers is greater when a novel thing appears on a side of ship than while passengers coming on or off board. When coming on board, even with a rush, passengers usually run to the other side and when leaving, passengers on promenade deck converge to foreward and after stair-ways and only those on upper deck shift to one side. Thus, the angle of heel is not so large in both cases.

(2) Angle of heel while turning is sometimes too important to be neglected. Even though

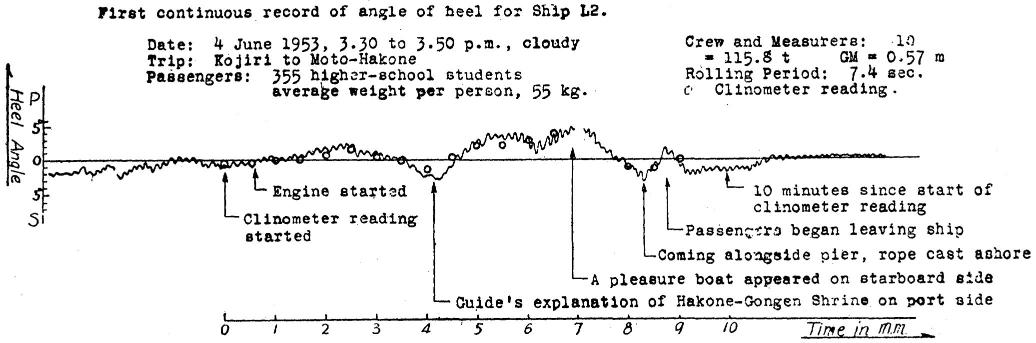
turning while under way full ahead is not imaginable, except when encountering the other ship in a dense fog, and turning alone should not cause excessive heel, turning at a slow speed when nearing to pier may sometimes register an appreciable heel. This is to say, when arriving at pier, combined concentration of passengers to one side and turning may give rise to large angle of heel.

(3) When passengers move, it is safe to assume that they do not come into the area where couches and sofas are placed. Therefore, the effect of couches must be taken into account. This point has been re-examined in § 4 of this paper.

(4) The ratio of densities before and after the passenger movement was, under normal conditions, in the order of : $r_0=1.12r$ for ship L 2. Under intentional conditions, $r_0=2r$, or the movement from centerline to one side of centerline, is fully possible.

(5) When passengers move to one side under nomal conditions, the existence of deck house does not necessarily separate the movement in and out of the house.

Fig. 11.

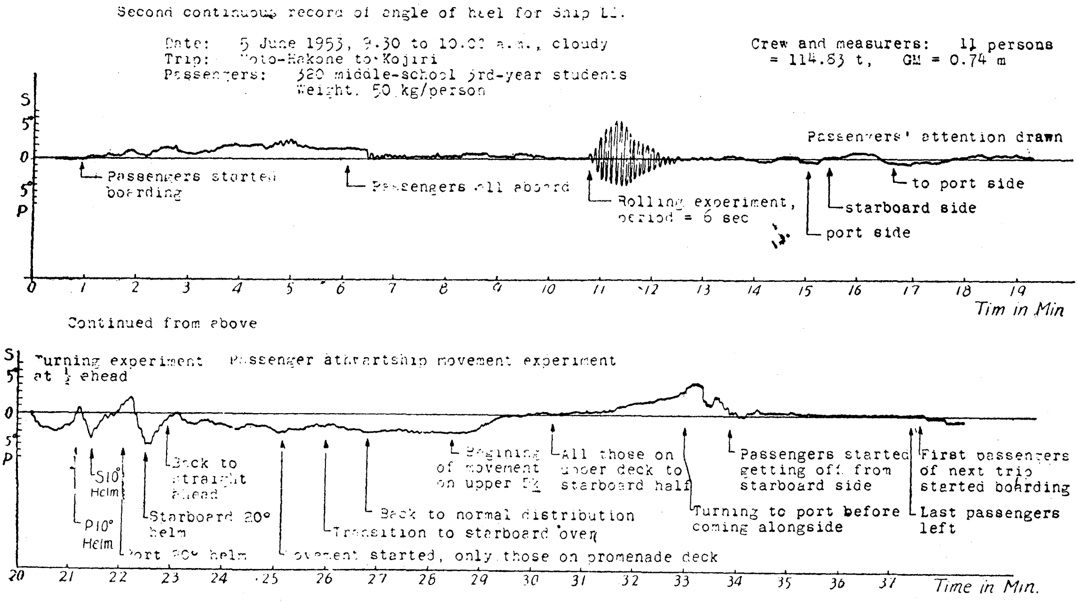


First continuous record of angle of heel for Ship L2.

Date: 4 June 1953, 3.30 to 3.50 p.m., cloudy
Trip: Kojiri to Moto-Hakone
Passengers: 355 higher-school students
average weight per person, 55 kg.

Crew and Measurers: 10
= 115.8 t GM = 0.57 m
Rolling Period: 7.4 sec.
○ Clinometer reading.

Fig 12



Second continuous record of angle of heel for Ship L2.

Date: 5 June 1953, 9.30 to 10.00 a.m., cloudy
Trip: Moto-Hakone to Kojiri
Passengers: 320 middle-school 3rd-year students
Weight. 50 kg/person

Crew and measurers: 11 persons
= 114.83 t, GM = 0.74 m

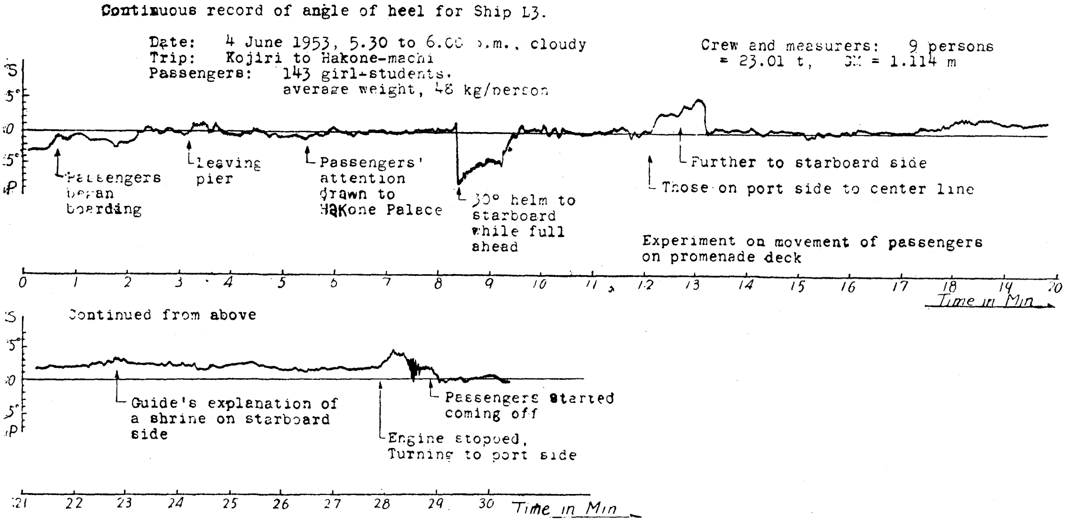
Continued from above

(6) Heeling moment due to movement of passengers may be considered statical, expcet in extraordinary cases.

(7) Rolling experiment can be accomplished more effectively by bringing the ship alongside a pier and giving a seesaw by the rail, than the ordinary method of moving weights on board.

(8) This sort of experiments and recordings of angle of heel when underway should be conducted several more times, preferably under full load conditions, to obtain data under more severe circumstances.

Fig. 13



APPENDIX II. *STABILITY AND LOADING OF SHIPS (FINAL REPORT OF THE AMERICAN MARINE STANDARDS COMMITTEE)*

The American Marine Standards Committee recommended the following standard of stability:

(1) Groups of vessels

Group I.—Ocean and coastwise. Group II.—Partially protected waters. Group III.—Smooth and protected waters.

(2) Minimum initial stability

The minimum initial stability when operating is given by three formulas.

Formula 1—In all groups the heel is limited to that which will immerse not more than one-half of the freeboard and a maximum of 7° when the vessel is subjected to a steady beam wind of about 55 miles per hour for Group I, 45 miles per hour for Group II, and 37 miles per hour for Group III.

Formula 2—In all groups the heel is limited to that which will immerse not more than one-half of the freeboard and a maximum of 7° when passengers crowd to one side.

Formula 3—In all groups the heel is limited to that which will immerse not more than one-half the freedboard with limit of 7° when any two adjacent compartments on one side of the vessel are assumed flooded due to damage.

(3) Required minimum *GM*

The minimum initial stability when operating shall be the maximum *GM* as given by the following formulas :

(a) $GM=CAhB/4f \cdots\cdots f$ must not be greater than either $0.246\,B$ or $4\,(f_w-1)$

(b) $GM=0.005MB/\varDelta f \cdots\cdots f$ must not be greater than either $0.123\,B$, $2\ (f_w-1)$, or $2(f_c-1)$.

(c) $GM=(Bwd+fi)/f(u\varDelta+w) \cdots\cdots f$ must not be greater than either $0.123\ B$ or $2\ (f_w-1)$.

In the foregoing formulas the symbols have the following significance :

GM= Metacentric height in feet.

B= Molded beam in feet.

f_o= Shell-opening freeboard in feet.

A= Exposed longitudinal area in square feet above waterline on which the wind may act in the upright position.

M= Sum of the moments about the centerline of the vessel, in feet^3, of the total net passenger-deck areas on one side of the vessel.

d= Distance in feet from the vessel's centerline to the center of gravity of the compartments.

$\varDelta$= Displacement in long tons.

f_w= Weather-deck freeboard in feet.

$$c=\begin{cases} 0.0050+\dfrac{L^2}{200,000,000} & \text{for Group I.} \\ 0.0033+\dfrac{L^2}{200,000,000} & \text{for Group II.} \\ 0.0025+\dfrac{L^2}{200,000,000} & \text{for Group III.} \end{cases}$$

h= Vertical distance in feet from center of A to one-half the draft.

w= Capacity in cubic feet to waterline of at least two adjacent compartments.

u= 35 for salt water, 35.9 for fresh water.

L= Length in feet on waterline.

i= Transeverse moment of inertia of the compartments, in feet^4, at the level of waterline about an axis passing through the center of gravity of the free surface and parallel to the vessel's centerline.

APPENDIX III. *RULES AND REGULATIONS FOR PASSENGER VESSELS (UNITED STATES COAST GUARD)*

The U.S.C.G. Regulations appears to be the modification of the Final Report of the American Marine Standards Committee, and they give the minimum *GM* by the following formulae.

(1) Weather criteria

The required minimum metacentric height (*GM*) in feet at any particular draft is obtained from the following formula :

$$GM=PAh/\varDelta\tan\theta$$

where : L = Length between perpendiculars in feet.

A = Projected lateral area in square feet of portion of vessel above waterline.

h = Vertical distance in feet from center of A to center of underwater lateral area or approximately one-half draft point.

$\varDelta$ = Displacement in long tons.

$P=0.0050+\left(\dfrac{L}{14,200}\right)^2$ tons/ft^2 for ocean and coastwise service.

$=0.0033+\left(\dfrac{L}{14,200}\right)^2$ tons/ft^2 for partially protected waters such as lakes, bays, and sounds, and Great Lakes (summerservice).

$=0.0025+\left(\dfrac{L}{14,200}\right)^2$ tons/ft^2 for protected waters such as rivers, harbors, etc.

θ = Angle of heel to one-half the freeboard to the deck edge or 14 degrees whichever is less. (For vessels having a discontinuous weather deck or abnormal sheer, the angle to one-half the freeboard may be suitably modified.)

(2) Passenger criteria

The required minimum metacentric height (GM) in feet is obtained from the following formula :

$$GM = N \times b/24\Delta \tan\theta$$

where :

N = Number of passengers.

Δ = Displacement in long tons.

θ = Angle of heel to deck edge or 14 degrees, whichever is less.

b = Distance in feet from the vessel's centerline to the geometrical center of the passenger deck area on one side of centerline.

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(Translated by Kazuyo Nakayama, Member.)