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A Proposed Standard of Stability for Passenger Ships.

(Part II : Small Crafts)

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

§ 1. Introduction

Small crafts of less than 5 gross were outside the scope of "Ship Safety Law," but even such crafts intended to carry passengers have become subject to the application of the Law by its Amendment made in July, last year. A standard of stability for these crafts has been prepared accordingly and is now in force in the form of "Small Crafts Safety Ragulations."

This standard was worked out in a similar manner as that for Smooth Water Area*, that is by the Ministry of Transportation with cooperation of Tokyo and Kyushu Universities, and Nippon Kaiji Kyokai (Japan Marine Corporation).

Notations used in this paper are shown in Table 1, unless expressly defined elsewhere.

TABLE 1.

			No. of passengers o	No. of passengers n
Boat's length, in m	L			
Boat's breadth, in m	B			
Boat's depth, in m	D	Draft, above K, in m	d_0	d
Average weight of a person, in ton	w	Freeboard, in m	f_0	f
Number of passengers	n	Displacement, in ton	Δ_0	Δ
Athwartship distance, within which passengers may move, in m	$\bar{B}$	Volume displacement, in m^3	V_0	V
Area of passenger space, in m^2	A_t	Waterplane area, in m^2	A_{w0}	A_w
Total area of passenger spaces, in m^2	A	Moment of inertia of waterplane area, in m^4	I_0	I
Height of top of passenger floor, above K, in m	h_t	Block coefficient	C_{b0}	C_b
Average height of tops of passenger floors above K, in m	h	Waterplane area coefficient	C_{w0}	C_w
Shifting weight, in ton	W	Center of gravity	G_0	G
Distance of movement of shifting weight, in m	b	Center of buoyancy	B_0	B
Length of pendulum, in m	l	Transverse metacenter	M_0	M
Deflection of pendulum, in m	s	Top of keel	K	K
		Specific gravity of water	σ	σ

§ 2. Basic Principles

It was decided to adapt and simplify the standard for vessels in the Smooth Water Area, and thus to follow the same basic principles with the following modifications :—

(1) Stability of a small craft must be determined in terms of L, B, D and d_0 or f_0 as the exact form or displacement of such a craft may not be readily available in most cases. Incidental inac-

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curacy of a certain degree must be tolerated.

(2) $\Delta_0\cdot G_0M_0$ ($\equiv S_0$) will be determined by means of inclining experiment, and thence $\Delta\cdot GM$ estimated from data on existing crafts.

(3) Steady wind of 10 m/sec strength can incline small crafts only as little as about 2 degrees. Therefore, heeling moment due to movement of passengers to be considered.

(4) Maximum permissible inclination, or side immersion, will be limited, with a certain allowance for wind pressure, to 70% of available freeboard.

§ 3. Δ·GM when carrying Passengers

When $\Delta_0\cdot G_0M_0$ is known, $\Delta\cdot GM$ can be estimated by the following formula:

$$GM \doteqdot KB+BM-KG \qquad \text{therefore,} \qquad \Delta\cdot GM=\Delta\cdot KB+\Delta\cdot BM-\Delta\cdot KG$$

where $$KB=d-\frac{1}{3}\left(\frac{1}{2}d+\frac{V}{A_w}\right)=\frac{5}{6}d-\frac{1}{3}\frac{\Delta}{\sigma A_w} \quad \text{and} \quad BM=\frac{I}{V}=\frac{\sigma I}{\Delta}$$

Assuming that the center of gravity of passengers is located 1.00m above the top of floor,

$$KG=\{\Delta_0\cdot KG_0+wn(h+1)\}/\Delta$$

Thence, $$\Delta\cdot GM=\frac{5}{6}\Delta d-\frac{1}{3}\frac{\Delta^2}{\sigma A_w}+\sigma I-\Delta_0 KG_0-wn(h+1)$$

and $$\Delta_0\cdot G_0M_0=\frac{5}{6}\Delta_0 d_0-\frac{1}{3}\frac{\Delta_0^2}{\sigma A_{w0}}+\sigma I_0-\Delta_0\cdot KG_0$$

Therefore $$\Delta_0\cdot G_0M_0-\Delta\cdot GM=\frac{5}{6}(\Delta_0 d_0-\Delta d)-\frac{1}{3\sigma}\left(\frac{\Delta_0^2}{A_{w0}}-\frac{\Delta^2}{A_w}\right)+\sigma(I_0-I)+wn(h+1)$$

By substituting,

$$\Delta=\Delta_0+wn \qquad d\doteqdot d_0+\frac{2wn}{\sigma(A_{w0}+A_w)} \qquad A_{w0}=LBC_{w0} \qquad A_w=LBC_w$$

$$I_0=k_0LB^3 \qquad I=kLB^3 \qquad \Delta_0=\sigma LBd_0C_{b0} \qquad C_w=rC_{w0}$$

The above formula can be written:

$$\Delta_0\cdot G_0M_0-\Delta\cdot GM=-\frac{4r-1}{3r(1+r)\sigma LBC_{w0}}(wn)^2+\left\{(h+1)-\frac{5}{6}d_0-\frac{(3r-2)d_0C_{b0}}{3r(1+r)C_{w0}}\right\}(wn)$$
$$-\frac{(r-1)\sigma LBd_0^2C_{b0}^2}{3rC_{w0}}-\sigma(k-k_0)LB^3$$

By dividing this by LBd_0^2, and writing $\Delta_0\cdot G_0M_0\equiv S_0$ and also assuming $\sigma\doteqdot1$, we have:

$$\frac{S_0-\Delta\cdot GM}{LBd_0^2}=-\frac{4r-1}{3r(1+r)C_{w0}}\left(\frac{wn}{LBd_0}\right)^2+\left\{\frac{h+1}{d_0}-\frac{5}{6}-\frac{(3r-2)C_{b0}}{3r(1+r)C_{w0}}\right\}\frac{wn}{LBd_0}$$
$$-\frac{(r-1)C^2_{b0}}{3rC_{w0}}-(k-k_0)\left(\frac{B}{d_0}\right)^2$$

Hence, $(S_0-\Delta\cdot GM)/LBd_0^2$ appears to be dependent mainly on n/LBd_0 and $(h+1)/d_0$. The change in $\Delta\cdot GM$ due to change in h may be determined, when, for instance, $\Delta\cdot G_1M$ at h_1 is known, by the formubla:

$$\Delta\cdot GM-\Delta\cdot G_1M=-wn\{(h+1)-(h_1+1)\}$$
$$=-wnd_0\left(\frac{h+1}{d_0}-\frac{h_1+1}{d_0}\right) \qquad (1)$$

Thus, assuming a certain value of $(h+1)/d_0[=(h_1+1)/d_0\equiv p]$, and when the actual values of S_0, Δ, G_1M, etc. are determined from available ship data, and curve of $(S_0-\Delta\cdot G_1M)/LBd_0^2$ plotted on the basis of n/LBd_0, then $(S_0-\Delta\times$

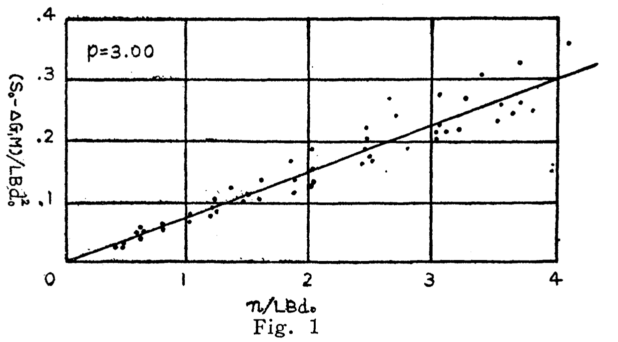

Fig. 1

$GM)/LBd_0^2$ of an, given ship corresponding to an arbitrary value of $(h+1)/d_0$ may be approximately estimated. Fig. 1 illustrates such a curve plotted from actual ship data with $p=3.00$. $(S_0-\Delta\cdot G_1M)/LBd_0^2$ may be regarded to vary linearly with n/LBd_0. When, for instance, writing $(S_0-\Delta\cdot G_1M)/LBd_0^2=awn/LBd_0$ for $(h_1+1)/d_0=p$,

$$S_0-\Delta\cdot G_1M=a\,w\,n\,d_0$$

Introducing into this equation allowance for change in h,

$$S_0-\Delta\cdot GM=a\,w\,n\,d_0+w\,n\,d_0\left(\frac{h+1}{d_0}-p\right)=w\,n\,\{h+1-(p-a)\,d_0\} \tag{2}$$

From Fig. 1, $p=3.00$ and $a=1.25$, and also taking $w=0.06$ (ton),

$$S_0-\Delta\cdot GM=0.06\,n\,(h+1-1.75\,d_0) \tag{3}$$

§ 4. $\Delta_0\cdot G_0M_0$ when carrying no Passengers

$\Delta_0\cdot G_0M_0$, or S_0, could be determined by inclining experiment of the craft at standby condition without passengers, and from the formula :

$$S_0=W\cdot b\Big/\frac{s}{l} \tag{4}$$

So thus obtained, however, will not give real S_0 on account of the effects of shifting weights and measurers on board during the experiment. In order to minimize the error, the test must be made without the crew aboard, and also the total weight of shifting weights and measurers should be less than that of (No. of crew+2) men. This is practicable with small crafts, for which shifting weight of 60 kg on each side is sufficient to carry out the experiment.

To obtain the real S_0, complete with crew on board, correction must be made for weight of the order of (No. of crew+2)–No. of crew=2 persons and for its position. But such correction may be omitted and formula (4) used as it is, because it is on the safe side, and also because of small difference between experimental S_0 and real $S_0(\equiv S_0')$, as shown on Table 2.

§ 5. Inclination due to Shift of Passengers and its Limit

If the inclination of a ship due to shift of passengers is limited to an angle θ,

$$\Delta\cdot GM\geq c\cdot w\,n\bar{B}/\tan\theta,\quad \text{or}\quad S_0\geq S_0-\Delta\cdot GM+\frac{c\,w\,n\,\bar{B}}{\tan\theta} \tag{5}$$

The results of calculations with the various ships indicate :

$$\bar{B}\doteqdot 0.9\,B$$

Where, taking the density of passengers before and after the shift, similar to the previous case of Smooth Water Area, as 3.33 and 7.00 persons/m^2 respectively,

$$c=\frac{1}{4}\left(1-\frac{3.33}{7}\right)=0.131$$

If the maximum inclination or side immersion, is limited to that in the case of Smooth Water Area plus a certain allowance for wind pressure, i.e. to 70% of freeboard,

$$\tan\theta=2(0.7f)/B=1.4f/B$$

Also introducing $w=0.06$ (ton) into equation (5)

$$S_0\geqq(S_0-\Delta\cdot GM)+\frac{0.01\,nB^2}{2f} \tag{6}$$

Where, limiting f to the depth of side immersion at 20° angle of heel, similar to the previous case

$$f\leqq\frac{1}{2}B\tan 20^\circ\qquad\text{or}\qquad f\leqq B/5.5 \tag{7}$$

Next, f may be estimated by

$$f\doteqdot f_0-\frac{2\,wn}{\sigma(C_{w0}+C_w)LB}$$

Where, $\frac{1}{2}(C_{w0}+C_w) \doteqdot 0.7$ for ordinary small crafts, and taking $\sigma \doteqdot 1$ and $w=0.06$ (ton),

$$f=f_0-\frac{0.085n}{LB} \qquad (8)$$

On Table 3 are shown f-values of ships, of which data are known, calculated from formula (8) in comparison with $f(\equiv f')$ values obtained from their hydrostatic curves. It may be said that formula (8) is acceptable for practical use.

TABLE 2

Ships	S_0 (ton−m)	S_0' (ton−m)
K 1	1.98	2.03
K 2	2.61	2.67
K 3	2.16	2.19
K 4	6.71	6.78
K 5	5.59	5.66
K 6	4.62	4.70
K 7	5.72	5.73
K 8	8.85	8.88

TABLE 3

Ships	$f(m)$	$f'(m)$
K 1	0.55	0.55
K 2	0.75	0.75
K 3	0.57	0.57
K 4	0.68	0.68
K 5	0.83	0.84
K 6	0.77	0.77
K 7	0.45	0.46
K 8	0.64	0.66

§6. Standard of Stability

Standard of stability may be written, from equations (2) and (5), as

$$S_0 \geqq wn\left\{1+h-(p-a)d_0+\frac{c\cdot\bar{B}}{\tan\theta}\right\} \qquad (9)$$

To transform this formula into a practical one, substitute equations (3), (6), (7) and (8), and we have

$$S_0 \geqq \frac{n}{100}\left(6+6h-10.5d_0+\frac{B^2}{2f}\right), \quad f=f_0-\frac{0.085n}{LB} \leqq \frac{B}{5.5} \qquad (10)$$

Whereas, Article 16 of Small Crafts Safety Regulations provides that area of passenger space be not less than $0.25\,m^2$ per person, $n(\equiv n_A)$ may be determined from available area for passengers, and substituted into formula (10) to check the stability. In practice, however, it is more convenient to find $n(\equiv n_s)$ from formula (10) at first, then compare it with n_A, and determine the capacity of passengers. For this purpose, the next method is recommended to simplify the calculation, which may be otherwise complicated, as the formula (10) is a quadratic equation of variable n. First, substitute n in equation (8) with $n_A=A/0.25$, and from equation (7), we have

$$f=f_0-\frac{0.34A}{LB} \leqq \frac{B}{5.5}$$

Therefore, the solution is to use this f-value for f in equation (10), determine $n(\equiv n_S)$, and compare the result with n_A. When, however, n_S is found less than n_A, and $f_0-0.34\,A/LB$ also less than $B/5.5$, it will give too rigorous a result, since a freeboard with n_A number of passengers, more than n_S, has been used to obtain n_S. In this case, equation (8) must be used.

To sum up the foregoing discussions, the standard of stability for small crafts and its calculation procedure may be numerated as follows:

(1.) Inclining experiment to be made at the condition without passenger and crew but with fuel, water, equipment and outfit aboard at their normal position. But the total weight of shifting weights and measurers should not exceed 0.06 x (No. of crew+2) tons.

$$S_0=W\cdot b\Big/\frac{s}{l} \qquad (11)$$

TABLE 4

Ships	$L(m) \times B(m) \times d_0(m)$	S_0 (ton-m)	n_A	n_S	n_S'
K 1	7.50 × 2.30 × 0.40	1.98	30	☆20	—
K 2	7.80 × 2.50 × 0.42	2.61	☆21	☆21	—
K 3	8.50 × 2.30 × 0.50	2.16	☆19	23	—
K 4	11.00 × 2.58 × 0.27	6.71	☆37	51	—
K 5	11.00 × 2.64 × 0.56	5.59	52	☆51	—
K 6	11.00 × 2.70 × 0.41	4.62	41	☆37	—
K 7	11.20 × 2.65 × 0.66	5.72	☆37	49	—
K 8	11.38 × 2.97 × 0.73	8.85	☆56	59	—
K 9	7.00 × 2.10 × 0.50	1.30	24	☆11	☆11
K 10	12.38 × 2.83 × 0.40	7.83	☆49	63	—
K 11	7.53 × 1.69 × 0.28	0.94	18	☆10	—
K 12	7.75 × 1.88 × 0.26	1.71	20	☆18	—
K 13	8.55 × 2.10 × 0.26	2.73	27	☆25	—
K 14	8.95 × 2.04 × 0.21	2.09	34	18	☆19
K 15	6.40 × 1.86 × 0.24	2.26	☆14	23	—
K 16	5.58 × 1.75 × 0.33	0.70	11	☆ 8	—
K 17	12.35 × 2.87 × 0.23	7.45	66	☆52	—
K 18	9.70 × 2.04 × 0.20	2.33	40	31	☆32
K 19	12.77 × 2.57 × 0.22	6.38	☆74	83	—
K 20	8.60 × 16.2 × 0.35	1.80	☆15	20	—
K 21	8.85 × 1.98 × 0.22	1.45	35	12	☆13
K 22	7.42 × 2.02 × 0.27	1.60	☆13	16	—
K 23	10.00 × 2.59 × 0.34	4.83	☆29	43	—
K 24	7.90 × 2.47 × 0.51	2.38	27	☆22	—
K 25	10.25 × 2.18 × 0.49	7.88	☆32	88	—
K 26	10.20 × 2.37 × 0.22	3.25	☆15	27	—
K 27	11.50 × 2.68 × 0.21	5.74	53	☆46	—
K 28	8.40 × 2.35 × 0.47	3.21	30	☆27	—
K 29	7.25 × 2.06 × 0.38	1.38	26	☆12	—
K 30	9.30 × 1.95 × 0.29	2.28	25	☆22	—

Note : ☆ shows n to be adopted.

(2) Determine maximum No. of passengers allowable by area of passenger space.

$$n_A = A/0.25 = \sum A_i/0.25 \qquad (12)$$

(3) Find maximum No. of passengers allowable by stability point of view.

(Predetermine h from $h=\sum A_i h_i/\sum A_i$)

$$n_S \leqq \frac{100S_0}{6+6h-10.5d_0+\dfrac{B^2}{2f}}, \quad f=f_0-\frac{0.34\,A}{LB} \leqq \frac{B}{5.5} \qquad (13)$$

n_S or n_A, whichever the less, is adopted as the maximum n allowable, except in the next case (4).

(4) When n_S is less than n_A, and $f_0-0.34\,A/LB$ also less than $B/5.5$, the next n_S' gives the n to be assigned.

$$n_S' \leqq \frac{100S_0}{6+6h-10.5d_0+\dfrac{B^2}{2f}}, \quad f=f_0-\frac{0.085n_S'}{LB} \leqq \frac{B}{5.5} \qquad (14)$$

on Table 4 are shown some of the results of calculation on actual ships.

§ 7. Review

(1) For small crafts, their stability must be determined with limited informations available, and consequently inaccuracy of a certain degree cannot be avoided. There are involved (a) adoption of mean line in Fig. 1, (b) neglect of effects of shifting weights as inclining experiment, and (c) uniform assumption of 0.7 for any $\frac{1}{2}(C_w+C_{w0})$. Combined errors of these simplifying measures are shown in Table 5, where F is 70% of the freeboard with n passengers (calculated by the proposed method) or 70% of $\frac{1}{2}B\tan 20°$, whichever the less, and F' is the depth of side immersion when inclined by a heeling moment of $cwn.\bar{B}$. These values were obtained from detailed calculations on ships for which complete data were available. In effect, our method shows the ship to incline as much as F, while the ship actually inclines as much as F'.

TABLE 5

Ships	$F(m)$	$F'(m)$
K 1	0.29	0.27
K 2	0.32	0.30
K 3	0.29	0.29
K 4	0.32	0.22
K 5	0.34	0.38
K 6	0.34	0.20
K 7	0.32	0.30
K 8	0.38	0.34

TABLE 6

Ships	$F(m)$	$F''(m)$
K 11	0.22	0.21
K 16	0.23	0.28
K 21	0.25	0.31
K 22	0.26	0.28

(2) In order to assure the practicability of this standard, the authors conducted passenger-shifting experiments on actual ships at Tokyo Port and Kawaguchi and Yamanaka Lakes, and their results are shown on Table 6. where, F is 70% of the freeboard with n_S passengers aboard, or 70% of $\frac{1}{2}B\tan 20°$, whichever the less, and F'' is the loss of freeboard due to inclination effected by shift of n_S passengers. Both values were obtained from direct measurement. The table shows in effect that the ship should incline as much as F according to our method, but it did incline as much as F'' in fact.

(3) As demonstrated above. the proposed standard may be deemed efficiently practicable at present, but when more informations are gathered to construct Fig. I for each type of ship, and more realistic values of $\frac{1}{2}(C_w+C_{w0})$ determined, higher accuracy maybe obtained in the future.

§ 8. Conclusions

The authors have attempted to describe the principles and procedures in preparing the proposed standard and are pleased to note in conclusion :

(1) that the standard of stability has been selected as such that will give sufficient initial stability to the ship against normally feasible shift of passengers, and

(2) that the method of determining ship's stability only by its length, breadth, stability without passengers, draft and such has been developed. Finally, it is the authors' sincerest wish that many a weak points in this standard will be remedied and more reasonable standard developed in the future.

(Translated by Kazuyo Nakayama, Member)