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Overall studies on the IMO manoeuvrability standard and problems arising in application of the criteria of it to various kinds of vessels

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Abstract : *The IMO manoeuvrability standard was established for preventing sea accidents such as collisions and strandings due to the lack of manoeuvrability. The standard of ship manoeuvrability enforced by resolution MSC.137(76) has been applied to vessels of 100m or more in length and all chemical tankers and gas carriers regardless of the length, which were constructed on or after 1 July 1994. The IMO manoeuvrability standard is able to be divided into three kinds as followings; (1) Turning capability standard : Estimated values in design stage are to be certified by turning circle test of the actual vessel. (2) Course keeping quality standard : Estimated values in design stage are to be certified by 10 deg. and 20 deg. zig-zag tests of the actual vessel. (3) Shortest stopping distance standard : Estimated value in design stage is to be certified by the shortest stopping distance tested by the actual vessel. In this paper, the authors verified the criteria of IMO manoeuvrability standard comparing them with the values resulted from sea trial tests of various kinds of actual vessels and examined separately the validity of all criteria of the standard.*

Key words : *IMO manoeuvrability standard, Sea accidents, Sea trial test, Actual vessel.*

1. Introduction

As a result of various investigations that had been carried out for cutting down F.O.(Fuel Oil) consumption of merchant vessels in past 40 years, remarkable results in improving propulsive efficiency and decreasing hull resistance were achieved. The bulbous bow, greater block coefficient, large diameter of ship propeller and stern profile for increasing propulsive efficiency etc. have greatly improved operational profit of merchant vessels, but they also affected bad effects on manoeuvring capabilities of vessels. Since then, many vessels of unfavorable manoeuvrabilities had appeared making ship handling and manoeuvring very difficult in harbor, narrow channel, shallow water and congested water area. About 5 percent of vessels of length over 90m all over the world had come into collision with other objects and 80 percent of the collisions had occurred between vessels according to the statistical data investigated in the year of 1990. The causes of accidents were found in imperfect understanding and appreciation of the manoeuvring characteristics of vessels in conning bridge and incorrect information about traffic situation of congested water areas and also in unfavorable manoeuvring characteristics of large vessels. Sea accidents such as collision or grounding of vessels in harbor or near coastal waters may make loss of human lives and cause great pollutions of sea environment. Therefore, IMO under UN collected data of marine accidents and safety suggestions of membership countries for long time and on these bases, IMO made manoeuvring standard of ship and put it in effect internationally from the 1st of July 1994. All vessels of length of 100m or more and chemical and LNG tankers regardless of length shall satisfy the IMO standard. The purpose of establishing the manoeuvring standard of vessels by IMO is to exclude vessels which might be found to have unfavorable manoeuvring characteristics insufficient to the IMO standard by classification survey in sea trial tests. However the confirmation of manoeuvring standard of a vessel to be satisfactory or not might be able to be checked only in sea trial after completion of the vessel. So, very strict mathematic checkings would have to be done in design stage of a vessel prior to actual building in shipyard. Already, world famous classification societies started to inspect the IMO manoeuvring standard in sea trial of vessels. The purpose of this paper is to make a conning officer in bridge understand the substance of the standard and the degree of manoeuvring capability of his own vessel to use it for safe manoeuvring and to suggest amending some inappropriate criteria of the standard.

2. The IMO manoeuvring standard and examination about it

As mentioned already in chapter 1, the IMO standard was adopted for the purpose to exclude vessels with insufficient

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manoeuvring capability from shipping service. The manoeuvring standard is as manifested in Table 1. Sooner or later the standard would be accommodated into related rules or regulations of membership countries and the classification society nominated to inspect the vessels under construction will have to inspect the manoeuvring standard of her according to the regulations of her flag country regardless with the own rules of classification society. Observing details of the standard in Table 1, we know IMO separated manoeuvring characteristics of a vessel into three kinds of motion behavior. Firstly, the overall turning capability check consisting of advance and tactical diameter by the usual turning circle test. Advance must be less than 4.5L and tactical diameter less than 5.0L. Secondly, course keeping / changing manoeuvrability check consisting of track reach according to heading angle change and yaw checking manoeuvrability consisting of overshoot angle of 10^oZ and 20^oZ test combined with ship's speeds. The former would be demonstrated with the track reach of 10^oZ test that must be less than 2.5L by the time when heading angle change reaches 10^o from initial course and the latter would be demonstrated with various quantity of overshoot angles according to ship speeds. Thirdly, stopping ability check would be demonstrated with shortest stopping distance by sea trial test. Track reach along the trace of shortest stopping distance must be less than 15L in principle. In any case stopping distance should not exceed 20L.

Table 1 IMO manoeuvring standard

Ability	Test	Criteria
Turning ability	Turning Test with Max. rudder angle	Advance p 4.5L , Tactical Diameter p 5.0
Initial Turning Ability	$10^o/10^o$ Zig-zag Manoeuvring Test	Track reach p 2.5L , by the time that 10^o deviation is reached from the original heading in execution of 10^o rudder angle.
Yaw Checking & Course Keeping Ability	$10^o/10^o$ Zig-zag Manoeuvring Test	(1) First overshoot angle -10^o , :if L/V is less than 10 sec. - 20^o, if L/V is 30 sec. or more. - (5+1/2(L/V)) degrees, if L/V is 10 sec. or more but less than 30 sec. (2) Second overshoot angle - 25^o, :if L/V is less than 10 sec. - 40^o, if L/V is 30 sec. or more. - (17.5+0.75(L/V)) degrees, if L/Vis 10 sec. or more but less than 30 sec.
	$20^o/20^o$ Zig-zag Manoeuvring Test	First overshoot angle p 25^o
Stopping Ability	Stopping Test	Track reach p 15L Stopping distance (track reach) should not exceed p 20L

3. Theoretical analysis about each criterion of IMO manoeuvring standard

In this chapter, we intend to examine substantial aspect of each criterion of IMO manoeuvring standard that is pertinent or not through mathematic model and/or actual sea trial tests carried out in open sea.

3.1 Turning ability

Until the middle part of last century shipyard has made only turning circle test for reference of manoeuvring after complete construction of a vessel and gave it to the vessel for reference of her handling and the turning circle test diagrams had been most important papers to the master of the vessel. Even nowadays it is also a very important one but we do not think it as important as before. Even nowadays we feel very familiar with it at a glance. We find in turning circle tests of actual vessels that almost all of the vessels always satisfy this criteria of turning ability. Generally speaking, advance of a vessel is less than 4.5L and tactical diameter less than 5.0L. The criteria seem to be appropriate and reasonable.

3.2 Initial turning ability

Almost all of track reaches of large vessels are less than 2.5L in actual sea trial tests but track reaches of small vessels might become larger than 2.5L (see the sea trial diagram of Hanbada). The criterion "track reach < 2.5L " seems to be inappropriate for small vessels and we do not find any unreasonableness in what it might be longer than 2.5L in 10^oZ test. Initial track reach in 10^oZ test can be calculated with following equation(Yoon, 2002);

$$T_R = [\frac{1}{2}t_1 + T_{10} + \frac{10^o}{\dot{\phi}_{10}}]v \quad \text{p } 2.5L \tag{1}$$

where, T_R : track reach

t_1 : time to take rudder angle

T_{10} : time constant in 10^o rudder angle

$\dot{\phi}_{10}$: angular velocity in 10^o rudder angle

Equation (1) manifest ship length L is very important factor in this criterion. For example, suppose two vessels $L_1 = 300m$ and $L_2 = 30m$. The former T_R 2.5L is 750m on the contrary that of latter is 75m. So, it will be better to amend this criterion: T_R p 2.5L for a vessel of length 100m or more, T_R p 3.0L for a vessel of length less than 100m

3.3 Yaw checking & course keeping ability

Theoretical analysis seems to be necessary in examining these criteria appropriate or not because these criteria are a little bit complicated ones. If a vessel proceeding on straight course receives a kind of disturbing external force, she will deviate from her original course turning with a angular velocity $\dot{\phi}$ and she will resume again straight running on another course with angular velocity of zero if the external force disappears, which demonstrates she is a course stable ship. If a vessel continues turning with control fixed at zero after external force disappeared then she is unstable on her course.

1) The course stability criterion

Using only linear terms, solutions to the sway and yaw equations provide linear transfer functions permitting the review of the course keeping motion (Yoon, 1978 ; Yoon, 1979 ; Yoon, 1984 ; Kijima et al., 1981).

$$\begin{aligned} &(m' - Y'_{\dot{v}})\dot{v}' - Y'_v v' - Y'_{\dot{r}}\dot{r}' - (Y'_r - m')r' = 0 \\ &-N'_{\dot{v}}\dot{v}' - N'_v v' + (I'_z - N'_{\dot{r}})\dot{r}' - N'_r r' = 0 \end{aligned} \tag{2}$$

The solutions for v' and r' correspond to the standard solutions of second-order differential equations which are as follows ;

$$\begin{aligned} v' &= V_1' e^{\sigma_1' t'} + V_2' e^{\sigma_2' t'} \\ r' &= R_1' e^{\sigma_1' t'} + R_2' e^{\sigma_2' t'} \end{aligned} \tag{3}$$

where,

V_1 , V_2 , R_1 *and* R_2 are constants of integration, also σ_1 *and* σ_2 are the stability indexes with dimension of $\frac{1}{t'}$
From equation (3), we get following characteristic equation.

$$A\sigma'^2 + B\sigma' + C = 0 \;\; , \;\; \sigma_1', \sigma_2' = \frac{-B \pm \sqrt{B^2 - 4AC}}{2A} \tag{4}$$

where,

$$\begin{aligned} A &= (m' - Y'_{\dot{v}})(I'_z - N'_{\dot{r}}) \\ B &= (m' - Y'_{\dot{v}})(-N'_r) + (-Y'_v)(I'_z - N'_{\dot{r}}) \\ &= (Y'_\beta)(I'_z - N'_{\dot{r}}) - (m' - Y'_{\dot{v}})(N'_r) \\ C &= (Y'_v)(N'_r) - (N'_v)(Y'_r - m') \\ &= -[(Y'_\beta)(N'_r) + (N'_\beta)(m' - Y'_r)] \end{aligned}$$

It is seen from solution (3) that if both values of σ are negative, v' *and* r' will approach zero with increasing time which means that the path of the ship will eventually resume a new straight-line direction. So now, we can get following discriminant equation certifying σ_1 *and* σ_2 to be negative from equation (4): $C = (Y_v')(N_r') - (N_v')(Y_r' - m')$ f 0, Note : A and B are always positive (Inoue et al, 1981). We can evaluate discriminant value of C as C f 0 in design stage of a vessel and then she will satisfy the yaw checking course ability(limited overshoot angle of 10^o and 20^o Z test)

3.4 Stopping ability

Shortest stopping distance means the length of track reach in which a vessel proceeding at her full ahead speeds reverses her main engine to full astern R.P.M. and then she stops completely at zero speed. Generally, almost all of shortest stopping distances of vessels seem to be shorter than 15L. The criterion "Track reach p 15L" seems to be very appropriate and reasonable

4. Results of 10^o and 20^o Z test of actual vessels

4.1 M.V. Hanbada

(a) Owner : Korea Maritime University Training Vessel
(b) ship's particular

L_{PP}	F.L.D	Disp.(F)	G/T	C_b	Speed	trim
90m	5.1	4,230ton	3,492	0.576	13kt	(+) 2.0m

(c) Date and place of trial : 1976. 1. 21, Southern coastal sea of Korea

C	σ_1	σ_2	Track reach	1st O.S.A (10^o Z)	2nd O.S.A (10^o Z)	1st O.S.A (20^o Z)
(+) 0.00012	(-) 0.0067	(-) 3.2137	2.6L	3^o	5^o	10^o

(1) 10^o Z test
(a) Important time point

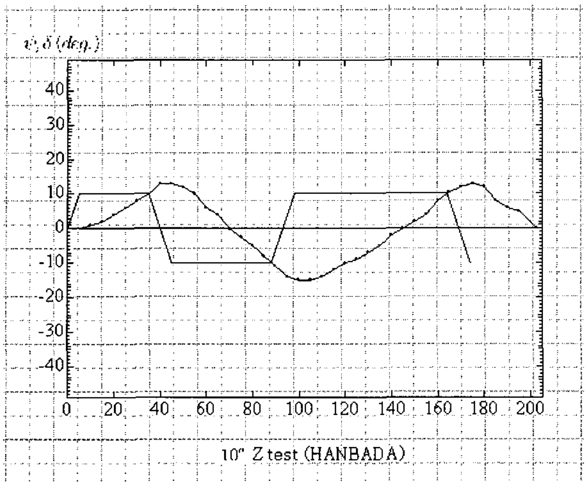
Important time point	t_1	t_2	t_3	t_4	t_5	t_6	t_7	t_8	t_9	t_{10}	t_{11}
t	5	35	42.5	45	70	88	98	102.5	145	164	174

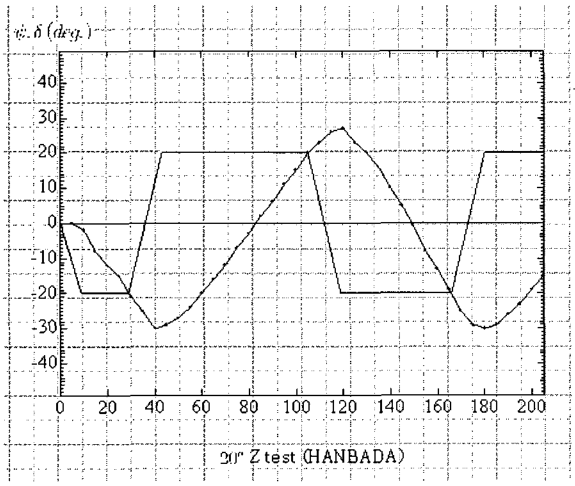
(2) 20^o Z test
(a) Important time point

Important time point	t_1	t_2	t_3	t_4	t_5	t_6	t_7	t_8	t_9	t_{10}	t_{11}
t	9	29	36	40	43	82.5	105	112	119	120	149.5

where, t : time, t_1 , t_2 , ...t_{11} : Rudder executing time

(3) 10^o and 20^o Z test of Hanbada





(4) C and σ values, Track reach and overshoot angle(O.S.A.)

4.2. M.V. Koan Ack San

(a) Owner : Busan National Fisheries University Training Vessel

(b) ship's particular

L_{PP}	F.L.D	Disp.(F)	G/T	C_b	Speed	trim
38m	2.75	480ton	244	0.477	11.8kt	(+) 0.2m

(c) Date and place of trial : 1978. 8. 3, Sooyeong bay Busan, Korea

(1) 10^o Z test

(a) Important time point

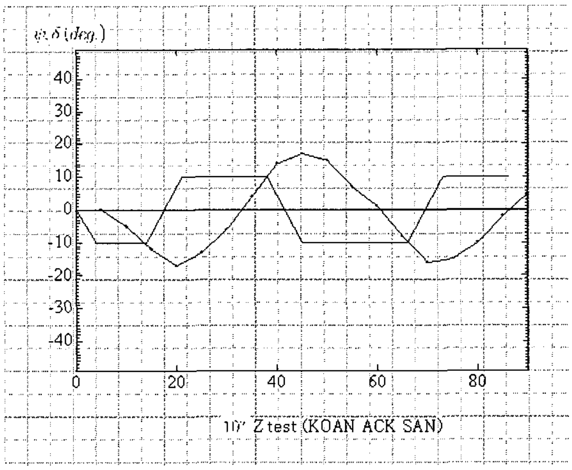
Important time point	t_1	t_2	t_3	t_4	t_5	t_6	t_7	t_8	t_9	t_{10}	t_{11}
t	4	14	17.5	20	21	32.5	38	45	45	59	66

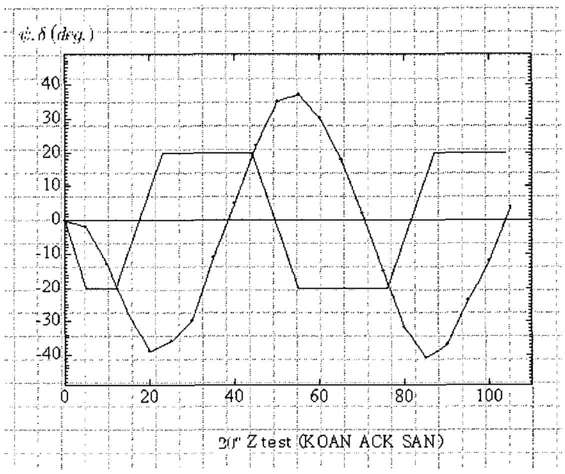
(2) 20^o Z test

(a) Important time point

Important time point	t_1	t_2	t_3	t_4	t_5	t_6	t_7	t_8	t_9	t_{10}	t_{11}
t	5	12	17.5	21	23	39	44	50	55	55	71

(3) 10^o and 20^o Z test of Koan ack san





(4) C and σ values, Track reach and overshoot angle(O.S.A.)

C	σ_1	σ_2	Track reach	1st O.S.A (10^o **Z**)	2nd O.S.A (10^o Z)	1st O.S.A (20^o **Z**)
(+) 0.0027	(-) 0.1186	(-) 4.1011	2.24L	7^o	7^o	19^o

4.3 T.V. Golden Clover

(a) Owner : Eastern Shipping Co., Ltd.

(b) ship's particular

L_{PP}	F.L.D	Disp.(F)	G/T	C_b	Speed	trim
285m	17.43	193,551	101,235	0.802	14kt	(+) 0.4m

(c) Date and place of trial : 1976. 12. 6, South-west coast of Africa (Lat. $4^o-34'S$, Long. $5^o-46'W$)

(1) 10^o Ztest

(a) Important time point

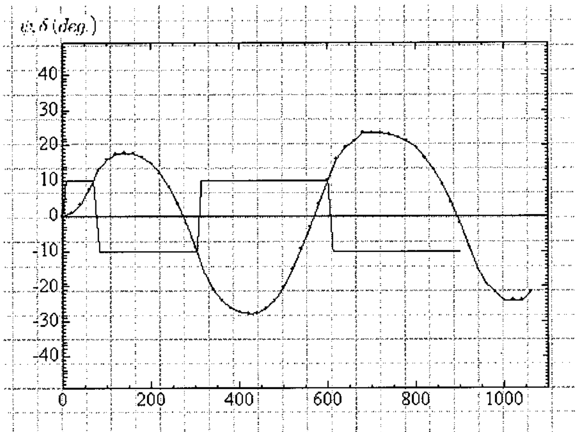
Important time point	t_1	t_2	t_3	t_4	t_5	t_6	t_7	t_8	t_9	t_{10}	t_{11}
t	7	69	83	127	272	304	314	416	570	600	612

(2) 20^o Z test

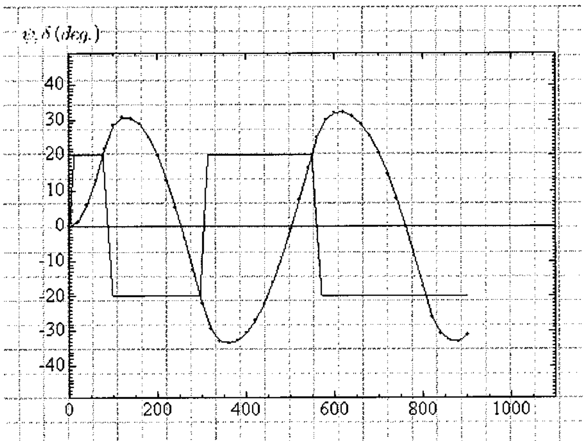
(a) Important time point

Important time point	t_1	t_2	t_3	t_4	t_5	t_6	t_7	t_8	t_9	t_{10}	t_{11}
t	11	76	98	127	252	295	313	357	503	548	570

(3) 10^o and 20^o Z test of Golden Clover



10° Z test (GOLDEN CLOVER)



20° Z test (GOLDEN CLOVER)

(4) C and σ values, Track reach and overshoot angle(O.S.A.)

C	σ_1	σ_2	Track reach	1st O.S.A (10^o Z)	2nd O.S.A (10^o Z)	1st O.S.A (20^o Z)
(+) 0.0023	(-) 0.081	(-) 3.998	1.74L	7.8^o	17.7^o	10.7^o

4.4. M.V. Korea Star

(a) Owner : Hyundai Shipping Co., Ltd.

(b) ship's particular

L_{PP}	F.L.D	Disp.(F)	G/T	C_b	Speed	trim
329m	20.767	292,179	138,764	0.804	15kt	(+) 0.5m

(c) Date and place of trial : 1977. 3. 20, Lat.$13^o-30'N$, Long.113^o-45E

(1) 10^o Z test

(a) Important time point

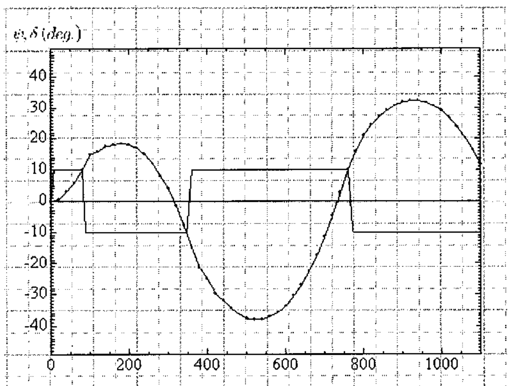
Important time point	t_1	t_2	t_3	t_4	t_5	t_6	t_7	t_8	t_9	t_{10}	t_{11}
t	7	80	88	186	315	347	360	538	732	760	772

(2) 20^o Z test

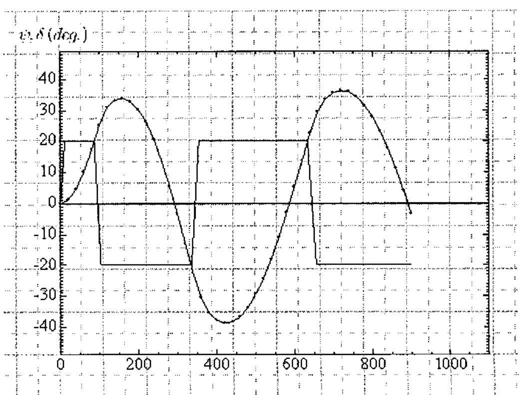
(a) Important time point

Important time point	t_1	t_2	t_3	t_4	t_5	t_6	t_7	t_8	t_9	t_{10}	t_{11}
t	11	87	104	164	292	336	355	427	587	634	656

(3) 10^o and 20^o Z test of Korea Star



10° Z test (KOREA STAR)



20° Z test (KOREA STAR)

(4) C and σ values, Track reach and overshoot angle(O.S.A.)

C	σ_1	σ_2	Track reach	1st O.S.A (10°Z)	2nd O.S.A (10°Z)	1st O.S.A (20°Z)
(-) 0.0044	(+) 0.113	(-) 2.552	1.87L	8.5°	28°	13.9°

4.5 M.V. Acclivity Prince

(a) Owner :

(b) ship's particular

L_{PP}	F.L.D	Disp.(F)	G/T	C_b	Speed	trim
245m	15.981	130,990	67,330	0.8211	14.7kt	(+) 0.5m

(c) Date and place of trial : 1978. 2. 9, South China Sea

(1) 10° Z test

(a) Important time point

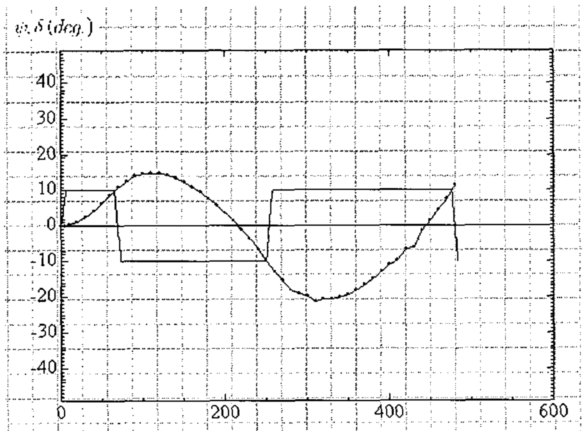
Important time point	t_1	t_2	t_3	t_4	t_5	t_6	t_7	t_8	t_9	t_{10}	t_{11}
t	6	65	69	74	112	215	250	253	257.3	325	445

(2) 20° Z test

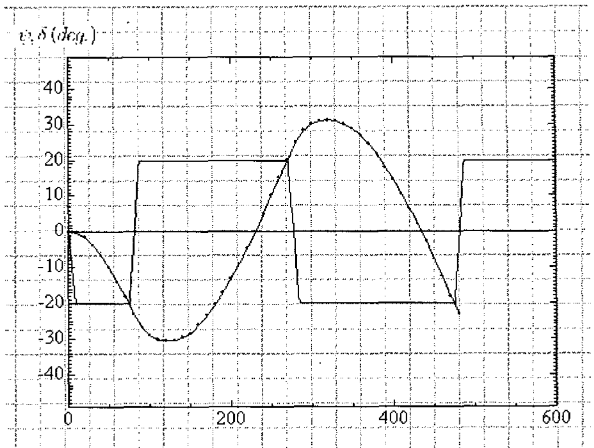
(a) Important time point

Important time point	t_1	t_2	t_3	t_4	t_5	t_6	t_7	t_8	t_9	t_{10}	t_{11}
t	8.6	75	81	87	122	230	270	277	284	320	434

(3) 10° and 20° Z test of Acclivity Prince



10° Z test (ACCLIVITY PRINCE)



20° Z test (ACCLIVITY PRINCE)

(4) C and σ values, Track reach and overshoot angle(O.S.A.)

C	σ_1	σ_2	Track reach	1st O.S.A (10°Z)	2nd O.S.A (10°Z)	1st O.S.A (20°Z)
(+) 0.003	(-) 0.082	(-) 2.232	2.0L	4.8°	10.6°	10.5°

5. Conclusions

In this study, we checked the criteria of IMO manoeuvrability standard comparing them with the values resulted from sea trial tests of various kinds of actual vessels. From the inspection of this investigation, it indicates the following result.

(1) About " Turning Ability"

The criterion " advance p 4.5L and tactical diameter p 5.0L" seems to be appropriate and reasonable.

(2) About "Initial Turning Ability (10°Z test)"

The criterion "track reach p 2.5L" seems to be at limit line of the criterion for small vessels and it is better to be readjusted to 3.0L for a vessel of length less than 100m and less than 2.5L for a vessel of length of 100m or more.

(3) About " Yaw Checking and Course Keeping Ability"

The criterion of the yaw checking & course keeping ability seems to be too loose, compared to the cases of values resulted from sea trial tests of various kinds of actual vessels.

(4) About " Stopping Ability"

The criterion "Track reach p 15L" seems to be appropriate and reasonable, but "stopping distance(track reach) should not exceed p 20L" had better be amended as "stopping distance of a vessel constructed for special service might be extended to 20L"

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