Selected Papers of The Society of Naval Architects of Korea, Vol. 1, No.1, 1993. pp. 37~44.

Experimental Study on the Deck Wetting of a Container Ship in Irregular Head Waves

Sa Young Hong*, Pan Mook Lee* and Do Sig Gong*

(From T.S.N.A.K., Vol.27, No.2, 1990)

Abstract

Deck wetness phenomenon has long been considered as one of the factors that degrade the performance of a ship in waves. In rough weather, the frequent shipping of water may give rise to the capsizing of the ship. Therefore an appropriate above-water bow-shape design is an important asset to a ship of which successful performance in rough weather is a prerequisite such as a warship.

In this paper an experimental technique for estimation of deck-wetness frequency is presented. The results of the model tests are compared with those of computations using Ochi's formula. Finally the applicability of Ochi's formula is discussed.

1. Introduction

The deck wetness phenomenon which causes damages on equipments, cargos on the deck and crews of a ship degrades her performance in waves. Especially, frequent shipping of water in rough weather may give rise to the capsizing of the ship.

This phenomenon is one of the important factors that determine the performance of the ship in waves especially for the ships such as a container of which cargos are on the deck and a warship of which crew's activity on the deck is important. An accurate quantitative estimation of deck wetness phenomena is therefore necessary for the design of the bow shape which prevents (of minimizes) the shipping of water. Upto now, the estimation of deck wetness is made mostly based on the experimantal method due to its nonlinearity and rarity.

Lloyd[1] has presented a survey on the existing experimental techniques and results on the deck wetness phenomena at 20th ATTC and his own experimantal results at RINA,[2]. His research on the deck wetness showed the lack of consistency between the deck wettings and the relative motions at bow, which is contrary to the existing viewpoint commonly recognized. There have been many other experimental investigations on the relation between the bow shape and the deck wettings, where the results did not show the consistent correlations between them. It implied that most experiments were performed relied mainly on human observation and there was no standard experimental techniques and procedures. Questions also arose if a record len-

* Member, Korea Research Institute of Ships & Ocean Engineering

gth of 30 minutes in full scale is sufficient, which is accepted as a standard record length in seakeeping test.

As mentioned above, in experimental prediction of deck wetness phenomena, the standard method including measuring time and length is not established yet. The modeling of spray phenomena which exist in a real sea environment is not realized either.

As an effort to improve the experimental method on the deck wetness phenomena, ITTC seakeeping committee proposed "the Experimental Study on the Deck Wetness" as a comparative study of the 19th ITTC Seakeeping Committee [3].

This paper proposes the experimental technique on the measurement of deck wetness and discusses the results for the S−175 container ship, the model ship of ITTC seakeeping committee.

ITTC 2−parameter spectrum of significant wave height, 7.88m, and mean zero-upcorssing period, 10.5 sec is adopted to simulate irregular sea condition, and the froude numbers are 0.15 and 0.275 Incident waves, relative waves, vertical motions at stem and deck wetting frequencies are considered and the applicability of Ochi's formula based on the assumption of Rayleigh distribution is discussed.

2. Model Tests

2.1 Ship Model and Test Condition

A 1/43.75 scaled S−175 container ship made of FRP is taken as a model ship and its principal characteristics are shown in Table 1. The ship is in full load condition and the vertical center of gravity an the gyradius of pitch are adjusted in relative error bounds of 0.6% and −0.7% respectively. Ship speed is achieved by self-propulsion and two heaving rods are installed at the centerline at the midship an the stemhead to maintain heading angle as well as to measure verical displacement(have motion).

Table 1 Principal characteristics of S175

Symbol	Items	Ship	Model**
$L_{pp}(M)$	Length	175.0	4.0
$B(M)$	Breadth	25.4	0.5806
$\nabla(M^3)$	Volume	24,119	0.28825
$T(M)$	Draft(trial)	9.5	0.2171
$KG(M)$	Center of gravity	9.52	0.2190
$LCG(M)$*	Longitudinal center of gravity	−2.48	−0.057
$K_y(M)$	Pitch gyradius	42.0	0.96
$GM_T(M)$	Transverse metacentric height	1.0	0.0216

* Defined from midship
(Positive value means forward direction)
** Scale ratio : 43.75

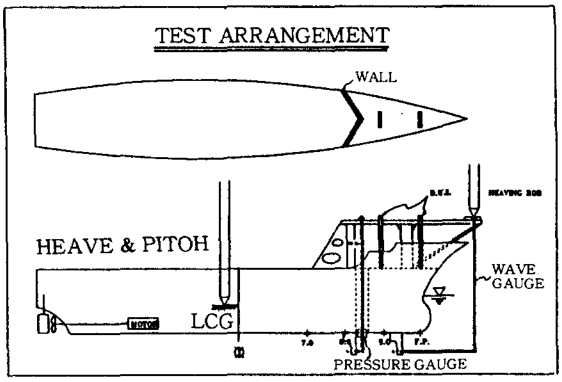

Fig.1 Test arrangement

Relative waves are measured using resistance-type wave probes at the center of stemhead and port-side of 0.15Lpp abaft F.P.. Deck-wetnesses are measured at the center of F.P. and 0.1Lpp abaft F.P. by deck-wetness measuring sensors, the modified wave probes of capacitance type. The specifications of deck-wetting sensor is described in section 2.3. Overall test arrargement is shown in Fig. 1 and the test conditions are summarized as follows.

◎ Ship speed (F_n) : 0.15, 0.275

◎ Incident waves : ITTC 2−parameter spectrum
$H_{1/3}=7.88m$, $T_z=10.53$sec

◎ Measuring items :
Incident waves, Relative waves

($0.15L_{pp}$ abaft F.P., Stemhead)
Deck wetness(F.P., $0.1L_{pp}$ abaft F.P.)
Vertical displacement(F.P.)

◎ Heading : Head Sea

2.2 Irregular Waves

Irregular waves are generated corresponding to ITTC 2-parameter spectrum of $H_{1/3}=7.8m$ and $T_z=10.53$sec in full scale. Six sets of wave signals with same parameters are used to prevent encountering of same waves during the measurements. Generation of different wave signals with same parameters can be achieved by putting random initial phase and unequaling the frequency interval of component wave[10]. Generated wave statistics are shown in Table 2 and an example of wave spectra is illustrated in Fig. 2. The histogram of measured wave heights is compared with Rayleigh distribution curve in Fig.5(a).

2.3 Deck-Wetness Measuring Sensor

Previous experiments on deck wetness have mainly been relying on human observation (including video camera), pressure transducers, catch tank and resistance type wave probes.

Table 2 Measured wave statistics

Wave	SP1	SP2	SP3	SP4	SP5	SP6	Average
rms^*	1.99	2.01	1.88	2.05	2.00	2.01	1.99
$H^*_{1/3}$	7.81	7.57	7.35	7.75	7.67	7.67	7.64
T^*_z	11.52	11.52	11.20	11.56	10.88	11.48	11.36
$H^*_{1/10}$	9.49	9.15	9.13	9.27	9.22	9.12	9.23
H^*_{MAX}	10.60	11.25	11.73	10.66	11.81	10.26	11.05
n^*_z	142	141	147	141	181	169	-
$H^★_{1/3}$	7.94	7.88	7.52	8.04	8.01	7.85	7.87
$T^★_z$	11.20	11.08	10.74	10.81	10.63	10.73	10.87

* : Superscript * means analyzed by 'zero-upcrossing method'.
★ : Superscript ★ means analyzed by 'spectral method'.
rms : Root mean square value
$H_{1/N}$: Wave height, subscript 1/N means average of one-Nth highest values.
T_z : Mean zero-upcrossing period$=2\pi\sqrt{m_0/m_2}$
m_n : n-th moment of wave spetrum
N_z : Measure number of waves

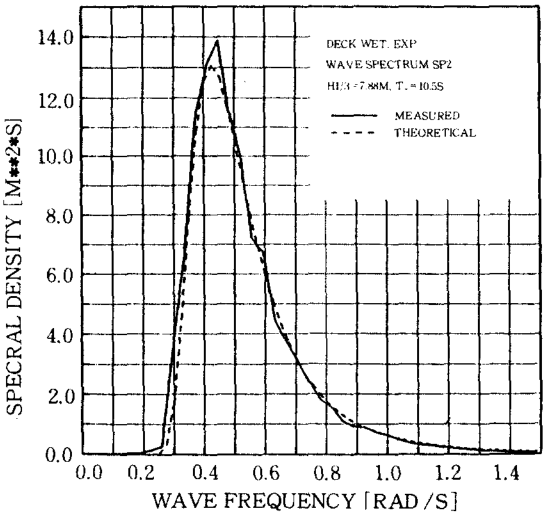

Fig.2 Wave spectrum(SP2)

Here, human observation could cause bias errors of measurements due to personal subject. Measurements using pressure transducers may provide quantitative results if a rather expensive sensors are constructed. The catch-tank can be used if the effects of shipped water on the ship motion is judged to be neglected[1]. The resistance-type wave probes can be used but They do not provide the results with a sufficient accuracy.

The capacitance-type deck-wetness measuring sensor is devised to measure the deck-wetness quantity as well as its frequency. As shown in Fig.3, the resistance-type wave probe provides the wave elevation by measuring the resistance of the circuit formed by shadow region, where the capacitance type wave probe produces an electric signal proportional to the wetted area of sensing area(shadow region of(b)). By utilizing the advantage of the capacitance type wave probe, the deck wetting quantity as well as deck wetting frequency cna be precisely measured by integrating the deck wetting signals as illustrated intergrating the deck wetting signals as illustrated in Fig. 3(d), The deck-wetness measuring sensor used in the present case is shown in Fig 3(c)

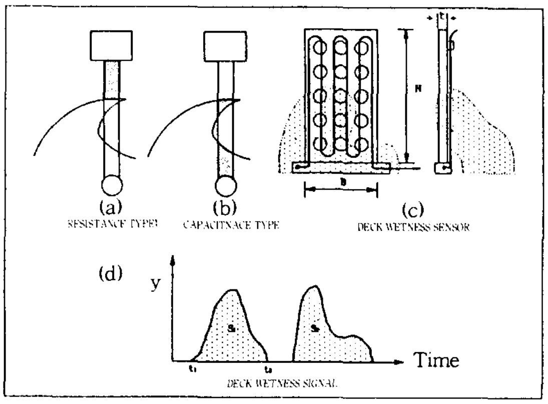

Fig.3 Deck wetness measuring instrument

made of porous aluminum plate of B=5cm, H=15cm, t=0.3cm and enamel coated copper wire.

2.4 Measurements and Analysis of Results

A series of tests was performed at KRISO's towing tank(L×B×D=200×16×7m) for the measurement of the deck wetness of S−175 container model for 2 ship speeds and one irregular wave condition. Sampling time is determined by the ship speed and the length of the towing tank. To avoid the repeated wave signal, the starting time of measurement was shifted by one minute for the same wave signals.

Wave	No. of Runs (No. of waves encountered)	
	Fn=0.275	Fn=0.15
SP1	4(200)	1.5(119)
SP2	5(243)	2(141)
SP3	4(207)	2(150)
SP4	4(191)	2(155)
SP5	4(196)	2(166)
SP6	4(212)	−
Time /Each Run (Ship Scale)	5.64 min.	11.29 min.
Total Run Time	141.1 min.	107.3 min.

Data sampling rate is 20 H_z(0.33 sec in full scale) and the record length for 6 sets of waves are summarized in the table below. Zero-upcrossing method and spectral method using FFT technique are used for the analysis of the measured data. Analysis methods are indicated in the results. Test results are arranged with respect to all 6 wave sets.

2.5 Test Results and Discussion

The measured wave spectrum is compared with the theoretical one in Fig. 2 and the measured wave statistics are presented in Table 2. In Fig. 5(a), the measured wave height histogram is compared with the Rayleigh distribution curve. From these results, it is confirmed that the generated waves in the towing tank follow Rayleigh distribution and the statistial values of each set of waves are within 5% relative error.

The measured relative waves at stemhead(6.88m ahead F.P.) and at port-side of 0.15 L_{pp} abaft F.P., and the absolute vertial motion at F.P. are summarized in Table 3. The negative mean values of vertical motion at F.P. indicate the sinkage of the ship at stem. The positive mean value of relative waves implies the decrease of effective freeboard in waves. These effects are attributed to the sinkage of the ship and the waves generated by the ship motion. Significant values of the relative motions at stemhead are higher than calculated ones while the measured values are lower than the calculated ones at 0.15L_{pp} abaft F.P.. The calculated results are taken form reference[7] which uses strip method without considering the effect of dynamic swell-up. In the case of zero-upcrossing periods of relative motions, the measured value at F.P. shows a good agreement with the calculated one while the measured one at 0.15L_{pp} abaft F.P. shows somewhat shorter value than calculated one. The discrepancies in the comprisons of the measured and computed results are presumably due to the fact that the effect of wave scattering by the body motion is not taked into account in the present computations.

The histograms of relative motions at F.P. for F_n=0.15 and 0.275 are shown in Fig. 5(b) and Fig. 5(c), respectively. In the figures, the rectangular column represents the distribution of measured relative motions and the solid line for Rayleigh distribution obtained from the measured rms value of the relative motions.

From these results, we can assume that the relative motions of the ship model excited by the

Table 3 Statistics of reative motions and vertical motion

F_n	Items	SP1	SP2	SP3	SP4	SP5	SP6	Average
0.275	$\zeta^{*}_{r1_{1/3}}$	24.47	24.19	22.75	23.16	21.75	23.21	23.26 (21.56)†
	T^{*}_{z1}	7.58	7.52	7.41	7.46	7.46	7.46	7.48 (7.50)
	$\bar{\zeta}^{\star}_{r1}$	0.803	0.691	0.783	0.856	0.846	0.795	0.796
	$\zeta^{*}_{r2_{1/3}}$	18.22	17.97	16.89	16.97	15.90	16.90	17.14 (17.78)
	T^{*}_{z2}	6.93	6.89	6.71	6.68	6.58	6.68	6.75 (7.13)
	$\bar{\zeta}^{\star}_{r2}$	0.466	0.126	0.086	0.038	−0.01	−0.046	0.11
	$\bar{Z}^{\star}_{1}$	−0.386	−0.476	−0.444	−0.450	−0.548	−0.528	−0.472
	$\bar{Z}^{\star}_{1rms}$	4.53	4.52	4.17	4.28	4.11	4.24	4.32
0.150	$\zeta^{*}_{r1_{1/3}}$	20.66	20.73	20.41	20.71	20.19	-	20.54 (19.43)
	T^{*}_{z1}	8.66	8.54	8.38	8.28	8.36	-	8.44 (8.44)
	$\zeta^{*}_{r2_{1/3}}$	12.83	13.09	13.27	14.23	13.34	-	13.35 (15.41)
	T^{*}_{z2}	7.31	7.23	7.16	7.05	7.07	-	7.16 (7.95)
	$Z_1^{\star}$	−0.199	−0.168	−0.159	−0.114	−0.164	-	−0.161
	$Z_{1rms}^{\star}$	4.01	4.01	3.90	4.02	3.91	-	3.96

* : Superscript * means analyzed by 'zero-upcrossing method'.

★ : Superscript ★ means analyzed by 'spectral method'.

† : A letter in the paranthesis means calculated value by strip theory without considering the dynamic swell-up.

ζ_{r1} : Relative wave at stemhead

ζ_{r2} : Relative wave at $0.15L_{pp}$ abft F.P.

Z_1 : Vertical motion at F.P

Upper bar '−' denotes temporal mean value

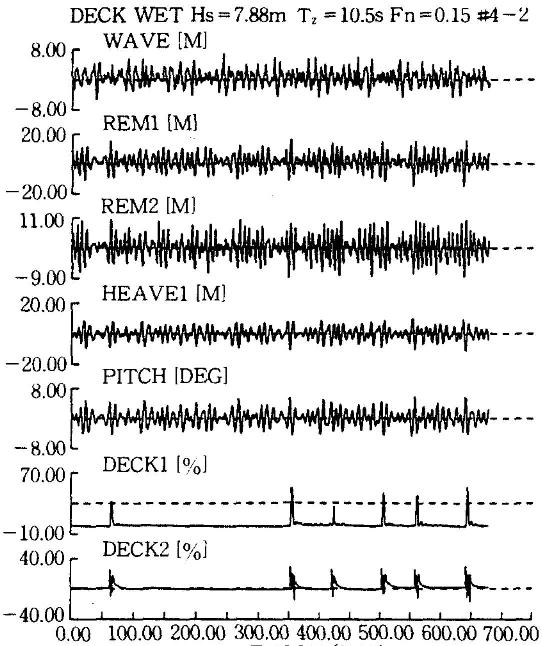

Fig.4a Time history of measured data (F_n=0.15, SP4−2)

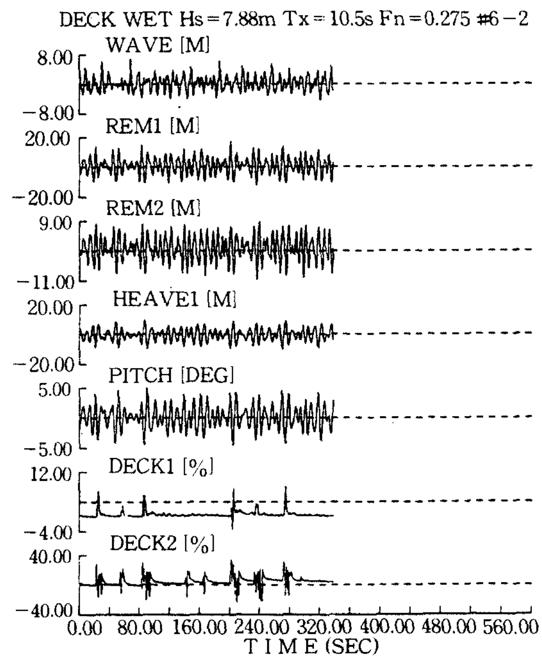

Fig.4b Time history of measured data (F_n=0/ 275, SP6−2)

waves of Rayleigh distribution also have the same characteristics of the waves(Rayleigh distribution). The deck-wetting frequencies at F.P. and $0.1L_{pp}$ abaft F.P. are presented in Table 4. The typical deck-wetting signals are shown in Fig. 4. DECK1 and DECK2 correspond to deck wettings at F.P. and $0.1L_{pp}$ abaft F.P., respectively, in the figure. One can see that the deck wetting at $0.1L_{pp}$ abaft F.P. depends on that of F. P., This fact implies that the estimation of deck-wetting frequency with the freeboard and relative motions at some location(which is not F. P.) using Ochi's formula can mislead the results.

The deck-wetting frequencies in Table 4 are defined as follows.

$\overline{N}_{w1}$: Number of deck wetness measured at F.P.

N_{w1} : Number of deck wetness measured at F.P.

$N_{w1}(c)$: Calculated number of deck wetness per hour at F.P. using Ochi's formula with the relative motion obtained from strip method calculation and the freeboard at calm water

$N_{w1}(o)$: Calculated number of deck wetness per hour at F.P. using Ochi's formula with the measured relative motion at stemhead and the free board at calm water.

$N_{w1}(s)$: Same as the case of $N_{w1}(o)$, considering the sinkage of stem.

$N_{w1}(r)$: Same as the case of $N_{w1}(o)$, considering the mean value of the relative wave.

The ubscript w2 denotes those of $0.1L_{pp}$ abaft F.P.

Ochi's formula is as follows[4].

$$N_w = \frac{3600}{T_z} \exp(-\frac{F^2}{2m_{ro}})$$

F and m_{ro} represent the freeboard and the area of the energy spectrum of the relative motion, respectively.

The measured number of deck wetness per hour at F.P. for F_n =0.275 shows maximum relative error of 30% and about 13% relative error in standard deviation. This is somewhat scattered

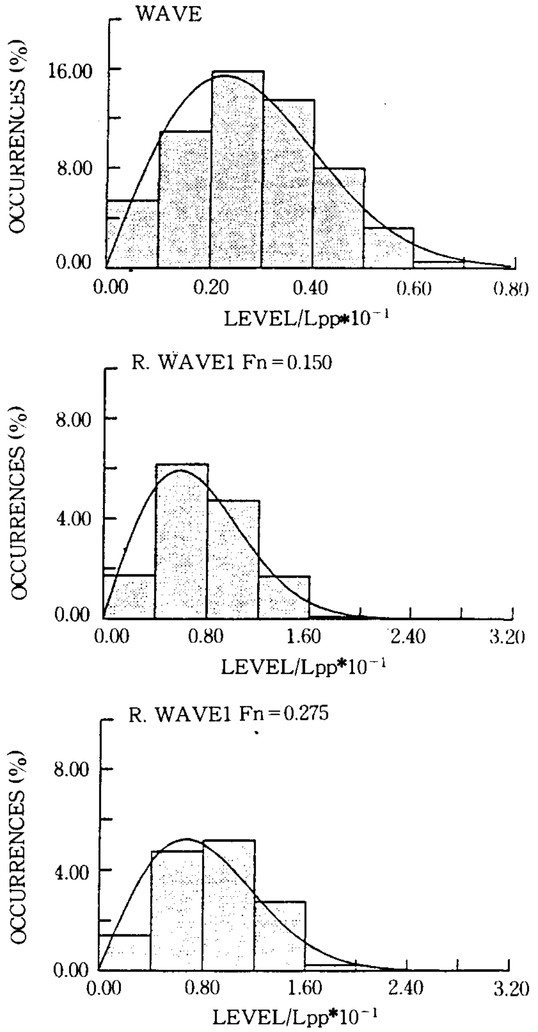

Fig.5 Histogram of wave and relative waves at stemhead

result comparing to the small(5%) deviation of incident waves, but the deck-wetting frequency and the relative motion measured at F.P. show good correlation between them.

In the case of F_n=0.15, the measured deck wetness per hour at F.P. shows the maximum relative error of 60% and that at $0.1L_{pp}$ abaft F.P. shows 11.4% relative error in the standard deviation. In the case of F_n=0.15, the deviations of the deck wetness for the six wave sets are of the

Table 4 Deck-wetting frequencies

F_n	Items	SP1	SP2	SP3	SP4	SP5	SP6	Average
0.275	$\overline{N}_{w1}$	42	52	31	37	30	34	37.7
	N_{w1}	111.6	110.6	82.4	98.3	79.7	90.4	95.5
	$N_{w1}(o)$	88.9	86.2	69.9	74.3	57.8	74.9	75.3
	$N_{w1}(s)$	99.6	99.4	81.3	88.8	70.8	88.9	88.1
	$N_{w1}(r)$	112.0	105.8	90.8	97.8	78.7	96.7	97.0
	$N_{w1}(c)$	-	-	-	-	-	-	55.5
	$\overline{N}_{w2}$	36	44	28	32	26	31	
	N_{w2}	95.7	93.5	74.4	85.0	69.1	82.4	83.4
	$N_{w2}(o)$	73.8	70.5	55.3	56.8	42.2	55.7	59.1
	$N_{w2}(r)$	89.8	74.6	57.8	57.9	41.9	54.5	42.3
	$N_{w2}(c)$	-	-	-	-	-	-	64.9
0.15	$\overline{N}_{w1}$	9	12	13	10	15	-	11.8
	N_{w1}	29.2	31.9	34.5	26.6	39.9	-	32.4
	$N_{w1}(o)$	39.6	40.8	38.6	41.9	36.7	-	39.5
	$N_{w1}(s)$	43.0	43.7	41.3	43.9	39.4	-	42.3
	$N_{w1}(c)$	-	-	-	-	-	-	29.9
	$\overline{N}_{w2}$	7	9	11	10	12	-	9.8
	N_{w2}	23.9	23.9	29.2	26.6	31.9	-	27.1
	$N_{w2}(c)$	-	-	-	-	-	-	29.6

where,

N_{w1} : Measured no. of deckwettings per hour at F.P.

N_{w2} : Measured no. of deckwettings per hour at $0.1L_{pp}$ abft F.P.

. : Upper bar '−' denotes measured no. of deckwettings.

. : Subscript '(o) denotes calculated no. of deckwettings per hour with measured relative wave.

. : Subscript '(s)' denotes calculated no. of deckwettings per hour with measured relative wave with considering sinkageof ship.

. : Subscript '(r)' denotes calculated no. of deckwettings per hour with measured relative wave with considering the sinkage of the ship and dynamic swell-up.

. : Subscript '(c)' denotes calculated no. of deckwettings per hour using strip theory.

same order in the case of F_n=0.275 the correlation between the deck wetness and the magnitude of the relative motion being relatively poor comparing to those for F_n=0.275 Same trends are also found in Table 4 where the measured deck wetness and the calculated one using the measured relative motion are compared.

Fig.6 shows the deck wetnesses at F.P. for

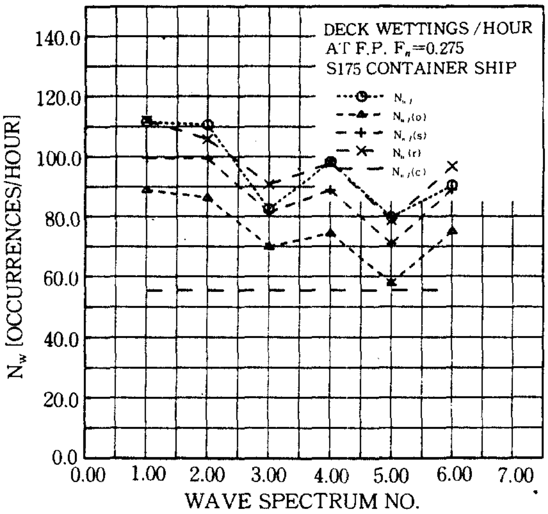

Fig.6 Deck-wetnesses per hour at F.P.

F_n=0.275. The strip method underestimates the deck wetness while the estimation with the measured relative motion shows an excellent agreements with the measured deck wetness in 5% relative error. The excess of the freeboard can be considered as the deck wetness in the case of F_n=0.275, This that Ochi's formula is applicable provided that the effects of the sinkage of the ship and the scattered waves by the ship are properly taken into account.

On the contrary, the measured deck wetnesses at F.P. for F_n=0.15 are divergent while the measured relative motions are convergent in Table 4. The calculated deck wetness overestimates the results by about 30%. This implies that the excess of the freeboard does not always give rise to the deck wetness for F_n=0.15, which should be explained by the effect of the bow shap e of the ship.

From these experimental results, we can deduce the threshold velocity, at which the bow shape does not affect on the deck wetness, for a given bow shape and sea condition. For the same reason, we can deduce the threshold sea state for a given bow shape and ship speed.

The above experimental and theoretical results for the deck wetness of a ship do not account for the spray phenomena which appears frequently in real sea environment. A further research for the effect of the spray on the deck wetness in model experiments and theoretical modelling seems to be necessary to improve the prediction on the deck wetness phenomena.

3. Conclusion

The conclusions made through the present experimental study are as fllows:

1. The deck-wetness measuring sensor(a capacitance type wave probe) is developed and its usefulness is confirmed through the model test for the S-175 container model in irregular head waves.
2. The irregular waves generated in the towing tank and the ship motions in the waves can be assumed to be the Rayleigh distribution.
3. From the model test for the S-175 container model in irregular head waves where the significant wave geight is 7.88m and the mean zero-upcrossing period is 10.5sec, the correlation between the measured deck wetness at F.P. and the estimation using Ochi's formula with the measured relative motion is found to be excellent for $F_n=0.275$, while it is poor for $F_n=0.15$. It seems that the effect of the bow shape is different with respect to the speed of the ship even in the same wave condition and that the effect of the bow shape decreases as the ship speed increases.
4. If the deck wetness is estimated using Ochi's formula, the effect of the sinkage and wave scattering should be Considered, and the reference freeboard should be the one at stemhead. The estimation of the deck wetness by the proposed method gives accurate results when the effect of the bow shape can be neglected. It may give conservative results when the effect of the bow shape can not be neglected.

4. Acknoledgement

This work was fully supported by Korean Ministry of Science and Technology(MOST).

References

[1] Lloyd, A.R.J.M., "Deck Wetness Experiment", *20th ATTC*, 1983.

[2] Lloyd, A.R.J.M. et al., "The Effect of Bow Shape on Deck Wetness in Head Seas", *Transaction of RINA*, VOL. 128, 1986.

[3] *19th ITTC Seakeeping Committee-Minutes of the First Meeting*, ESPOO, Finland, 1988.

[4] Ochi, M.K. and Mottor, L.E., "Prediction of Extreme Ship Response in Rough Seas on the North Atlantic", *Symposium on the Dynamics of Marine Vehicles and Structures in Waves*, London, April, 1972.

[5] "Report of Seakeeping Committe", *Proceedings of 16th ITTC*", Vol.2, 1981.

[6] Hong, S.Y. et al., "Experimental Analysis on the Motion Response of a Container Ship in Irregular Head Waves", *Journal of the Society of Naval Architects of Korea* Vol. 24, No. 2, June 1987.(Korean)

[7] Yang, S.I. et al., "Devlopment of A Computer Program for the Analysis of Ship Motion", KRIS Report No. UCE 37−55.79, 1979.(Korean)

[8] Battacharyya, Rameswar, "Dynamics of Marine Vehicles", *John Wiley & Sons*, 1978.

[9] "Report of Seakeeping Committee", *Proceedings of 18th ITTC*", Vol.1, 1987.

[10] Hong, D.C., Lee, S.M. and Hong, S.Y., "Development of Seakeeping Test Procedure in Irregular Waves", KIMM Report No. UCE280−887.D. 1986.(Korean)