PART 2

AN OUTLINE OF CURRENT STUDIES ON THE MANOEUVRABILITY OF SHIPS IN RESTRICTED WATERS IN JAPAN

by S. MOTORA (*Univ. of Tokvo*)

In this report, the reporter summarizes theoretical and experimental studies on the manoeuvrability of ships in restricted waters in Japan, and is much indebted to the paper "Manoeuvrability on Shallow Water" published by Y. Yamanouchi and N. Mori in 1968[1].

2.1. THEORETICAL STUDIES

Assuming that the advance speed of ships is, in general, so small in shallow water that the phenomenon of wave making is negligible with respect to the manoeuvrability of ships, M. Kan and T. Hanaoka approximately calculated the effect of finite water depth on the turning ability of ships[2].

According to this, the effect of shallow water on the hydrodynamic force and moment generated by drifting or turning motions are represented by the coefficient k_F which means the ratio of the hydrodynamic force or moment at a certain water depth, H, to those at infinite water depth.

$$k_F = \frac{4x}{\pi^2}\int_{-1}^{1} \cos h^{-1}\left(\frac{\frac{\pi\eta}{2x}}{\frac{\pi}{2x}}\right) d\eta$$

where X = H/d (water depth/draft of ship).

With respect to the rudder force, a similar coefficient, k_α, is also introduced in the same way as the wall effect of wind tunnel to the lift of wing.

$$k_\alpha = \frac{1 + 2k\frac{1+\tau}{\lambda}}{1 + 2k\frac{1+\tau-\sigma}{\lambda}}$$

where

$$\sigma \fallingdotseq \frac{1}{4}\log\frac{\sin\left(\frac{\pi}{x}\right)}{\frac{\pi}{x}}$$

λ: aspect ratio,

$C_\Delta = 2\pi ki$: lift coefficient,

i: effective attack angle,

τ: dependent of aspect ratio (for instance $\tau \fallingdotseq 0.13$, $k \fallingdotseq 1$ in case of $\lambda = 4$).

The values k_F and k_α are calculated and plotted in Fig. 2.1.

2.2. EXPERIMENTAL STUDIES

2.2.1. *Experiments on Free-Running Models*

Some of the experiments with self-propelled models are introduced in this section.

Figs. 2.2 and 3 show the test results of turning ability conducted at the Ship Research Institute with variation of water depth and rudder area. The prototypes of the models used are a large oil-tanker and a normal cargo-ship. The abscissas of these figures are rudder angle δ' and the ordinates are non-dimensional turning rate r' (= ship's length/steady turning radius)[3].

In Figs. 2.4 and 5, similar test results are shown for a large oil-tanker with single screw and twin screws, which were conducted at the Technical Research and Development Center of Defence Agency[4].

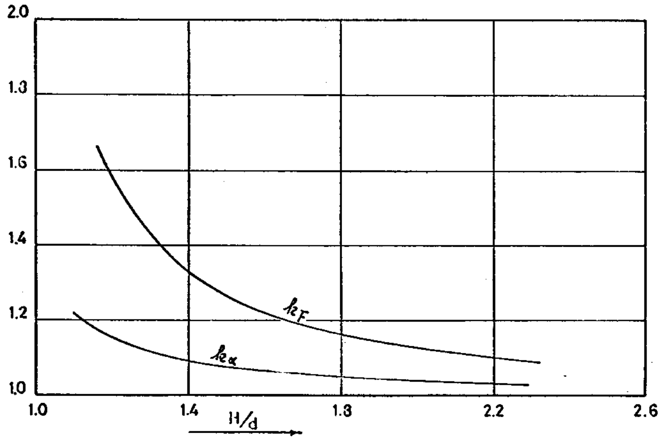

Fig. 2.1. The coefficients k_F and k_α versus the ratio of water depth to ship's draft H/d

Figs. 2.6–8 are similar test results of a large oil-tanker at Kyushu University[4].

In order to distinguish the effect of finite water depth on turning ability, the test results of Figs. 2.2 and 3 are rearranged and shown in Fig. 2.9, where the ratios of turning rate r' at a certain water depth, H, to turning rate, r', at infinite water depth are plotted on the H/d basis. Similary, Figs. 2.4–8 are also rearranged and summarized in Fig. 2.10.

M. NO	1527
L	4.5000 m
B	0.7021 m
d	0.2695 m
C_b	0.81
Δ	690.1 kg

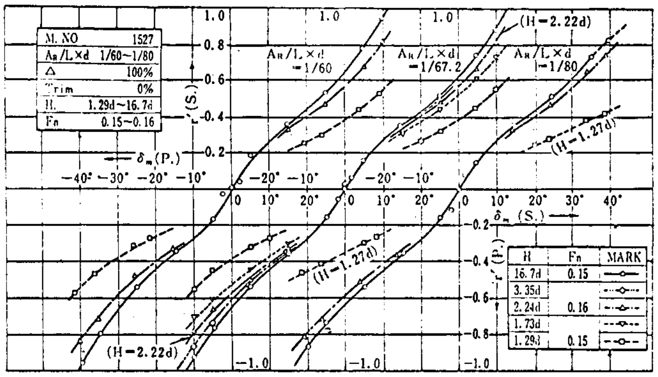

Fig. 2.2. r′ – δ′ curve in shallow water

M. NO	30
L	4.5000 m
B	0.6166 m
d	0.2466 m
C_b	0.70
Δ	479.4 kg

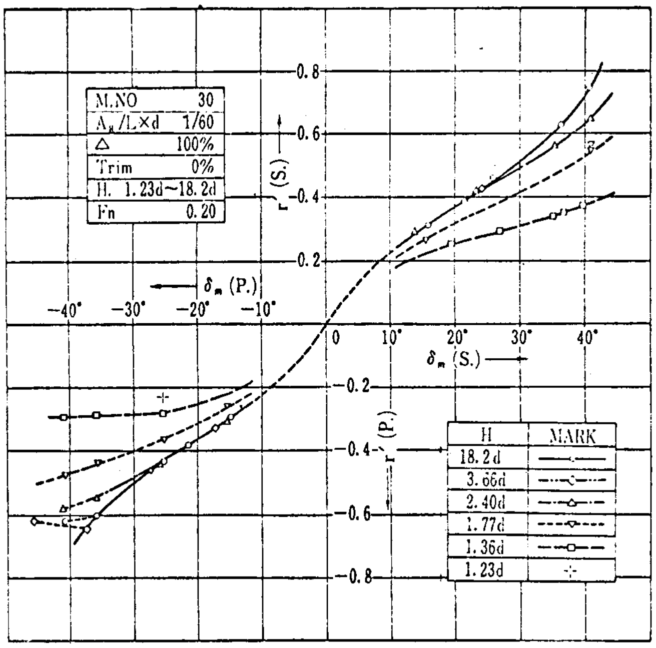

Fig. 2.3. r′ – δ′ curve in shallow water

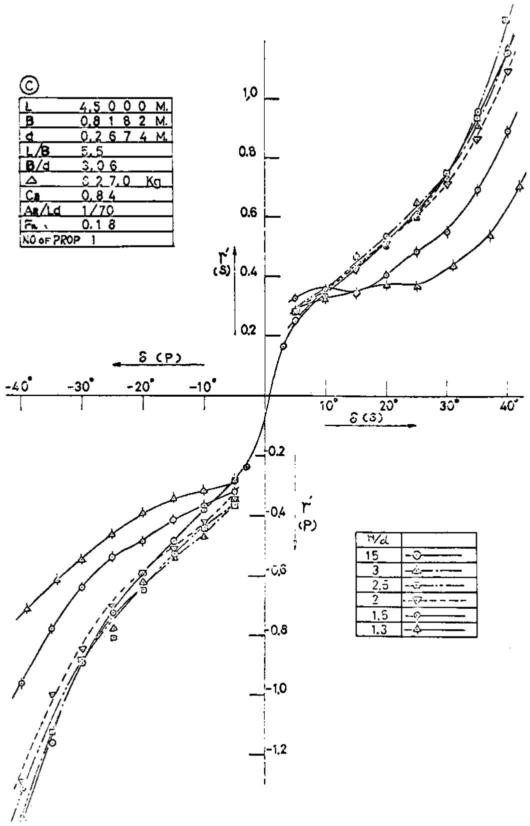

Fig. 2.4. r′ – δ′ curve in shallow water

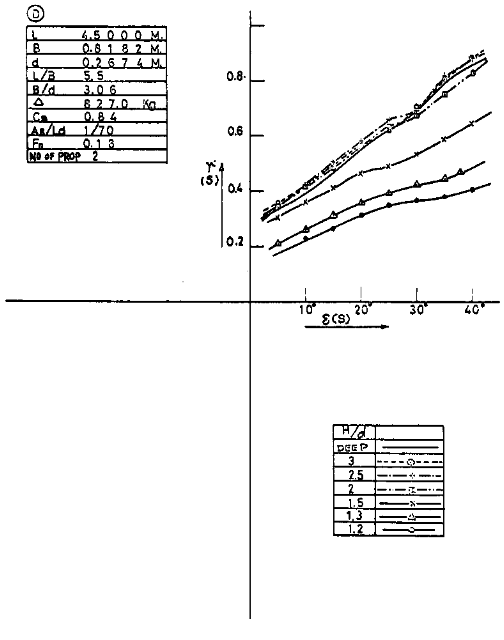

Fig. 2.5. r′ – δ′ curve in shallow water

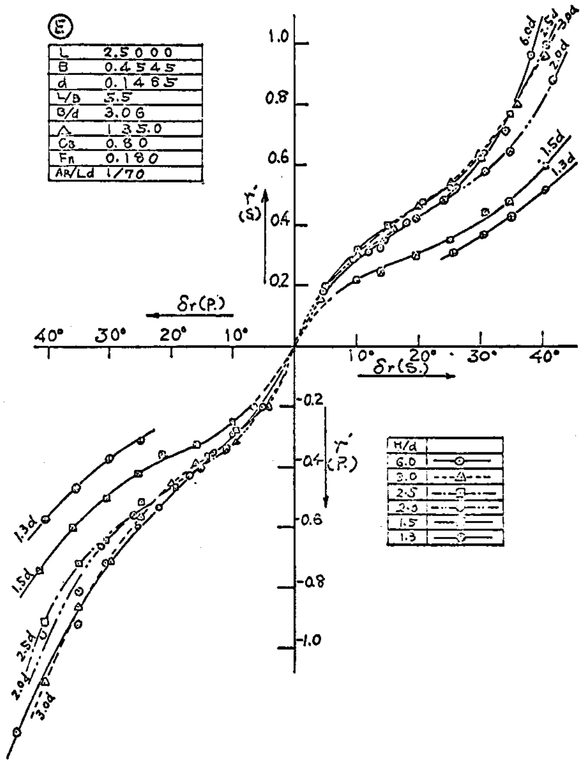

Fig. 2.6. r' – δ' curve in shallow water

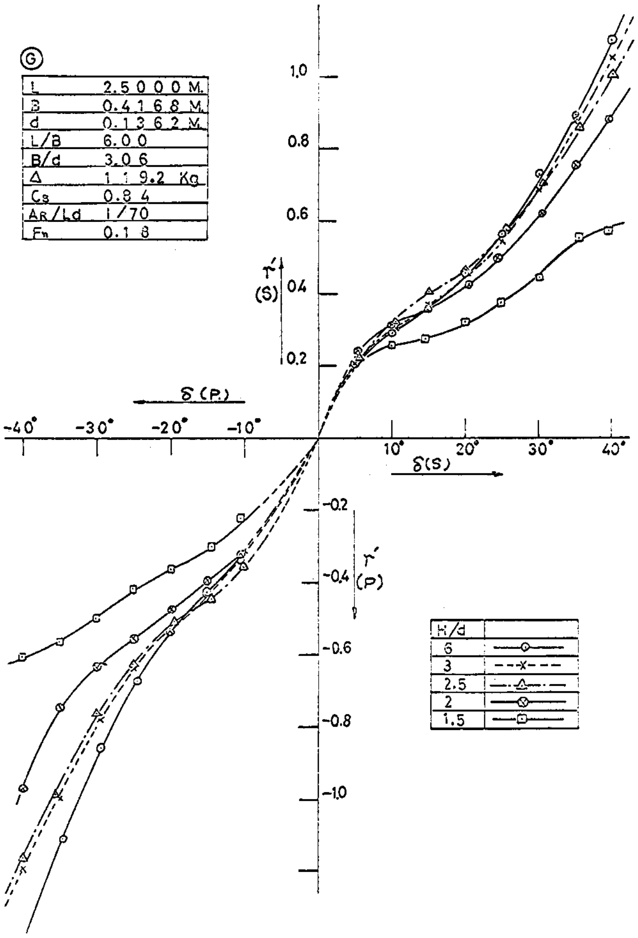

Fig. 2.8. r' – δ' curve in shallow water

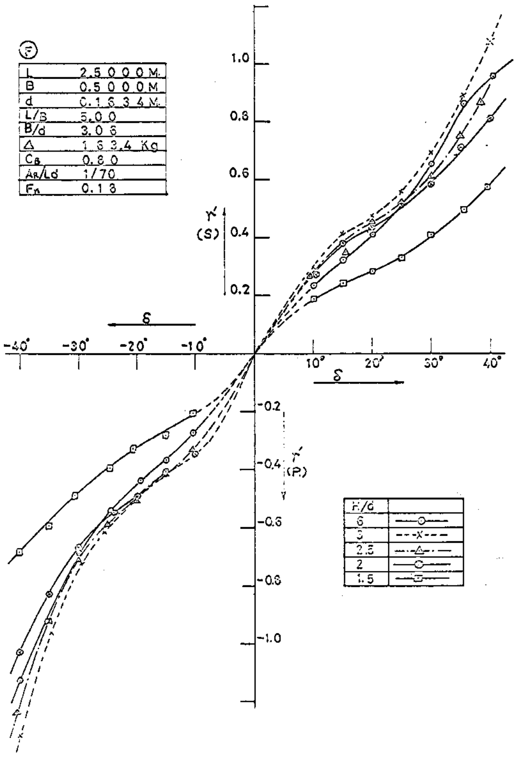

Fig. 2.7. r' – δ' curve in shallow water

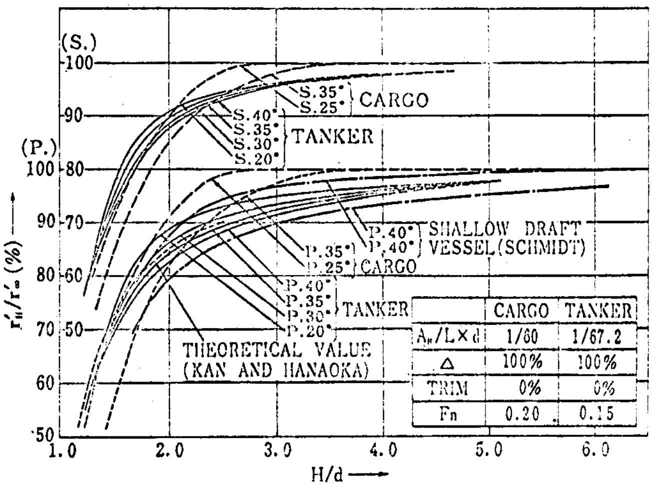

Fig. 2.9. Shallow water effect on turning rate

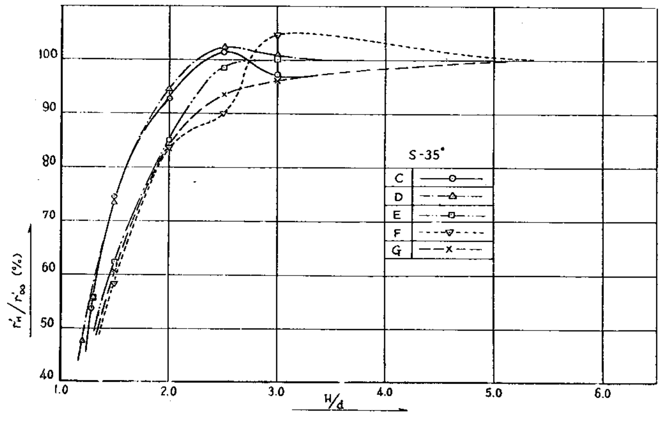

Fig. 2.10. Shallow water effect on turning rate

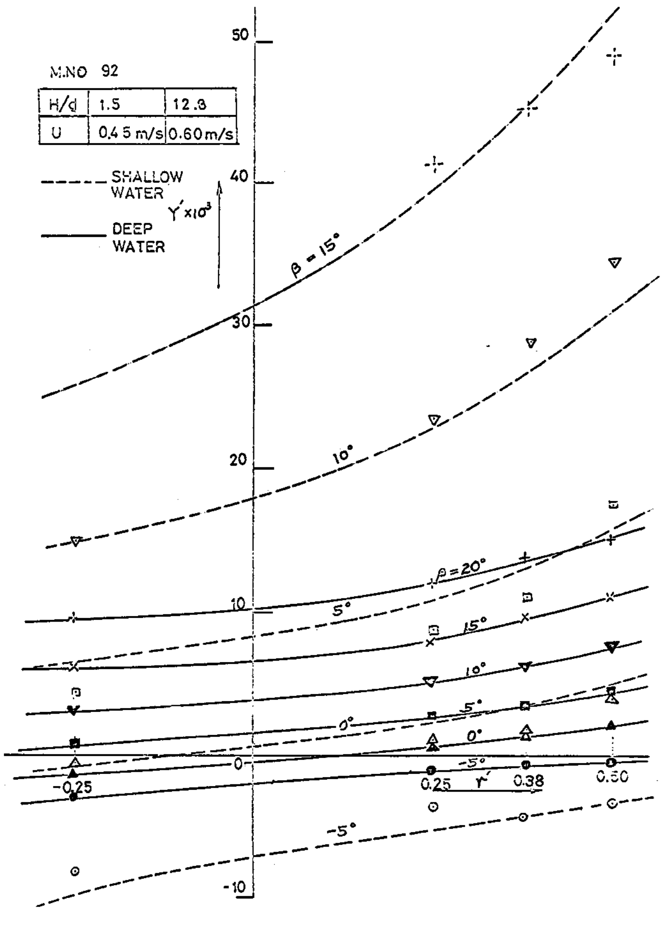

Fig. 2.11. Non-dimensional hydrodynamic force in shallow and deep water

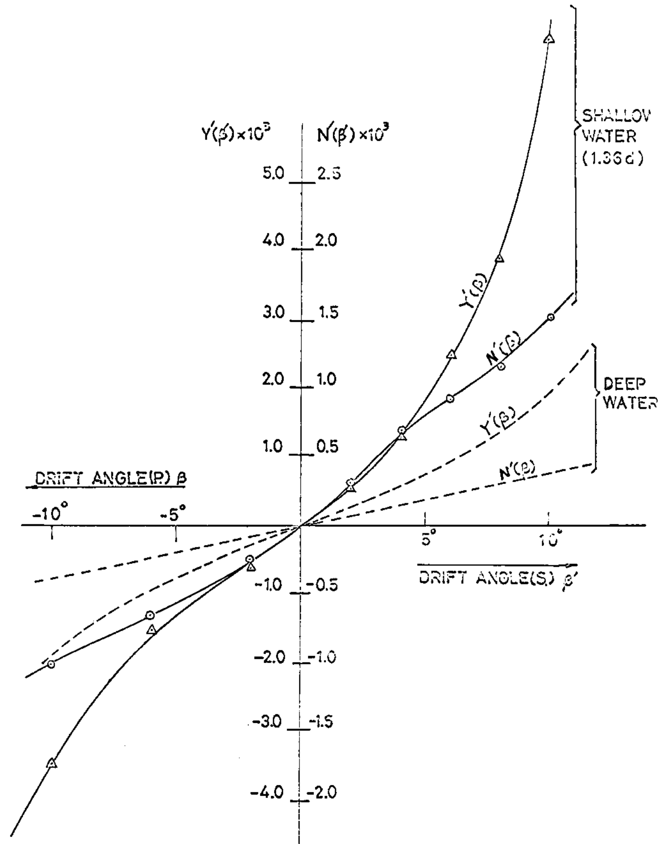

Fig. 2.12. Non-dimensional hydrodynamic force and moment in shallow and deep water (r = 0)

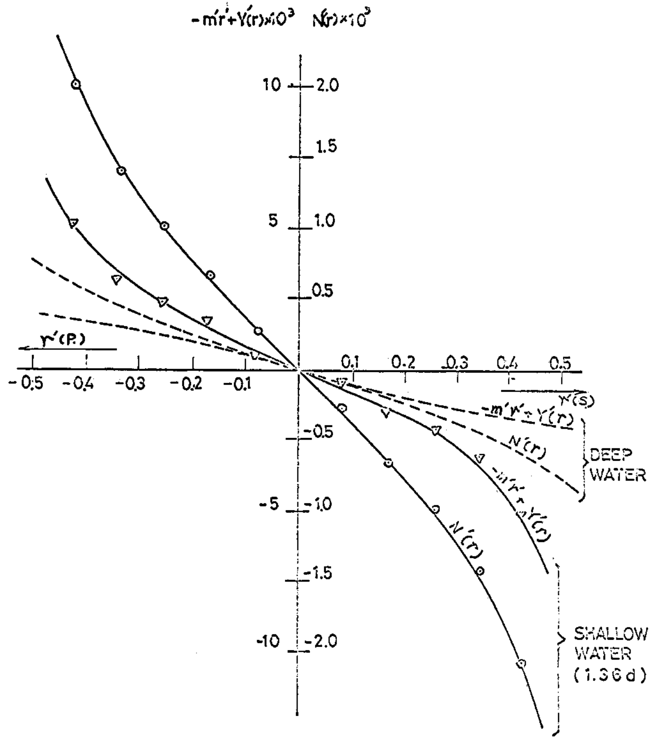

Fig. 2.13. Non-dimensional hydrodynamic force and moment in shallow and deep water ($\beta = 0$)

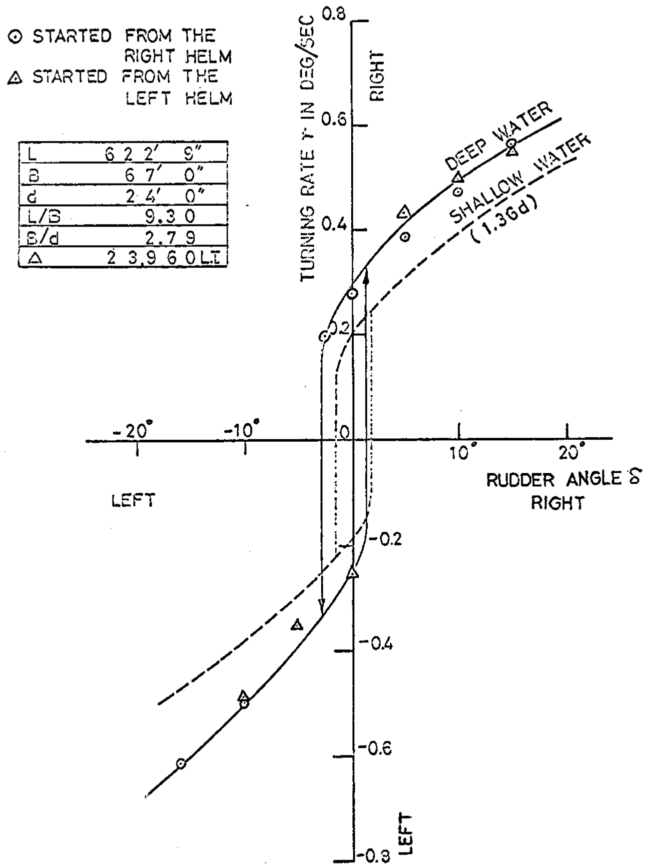

Fig. 2.14. Results of spiral test in deep and shallow water

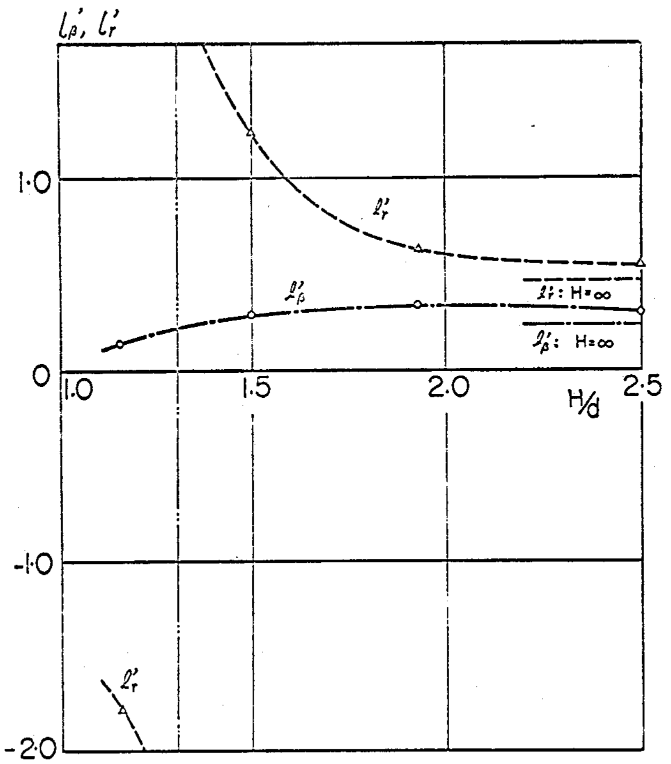

Fig. 2.15. Shallow water effect on ℓ'_r, ℓ'_β Mariner type ship (F_n = 0.0905)

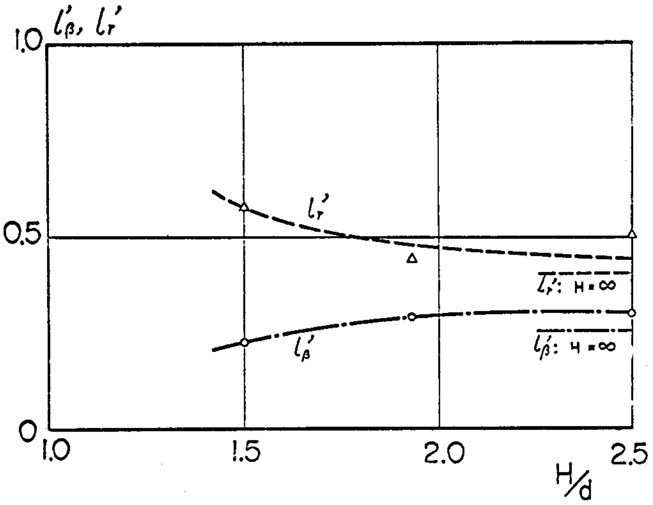

Fig. 2.16. Shallow water effect on ℓ'_r, ℓ'_β Mariner type ship (F_n = 0.155)

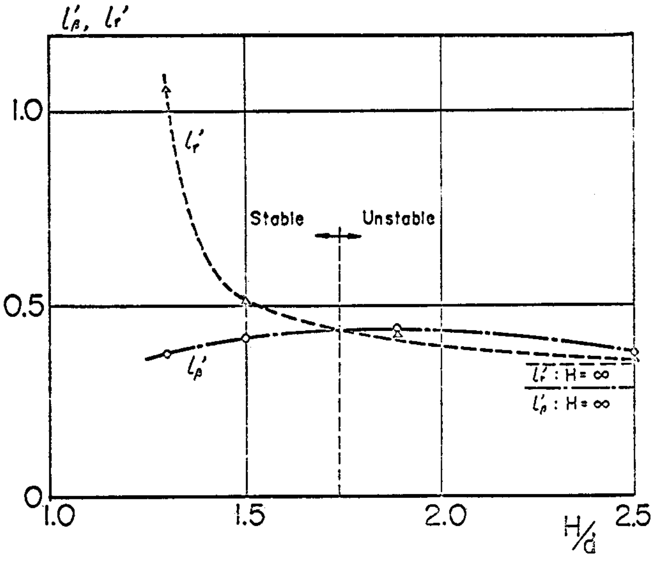

Fig. 2.17. Shallow water effect on ℓ'_r, ℓ'_β "Tokyo maru" (F_n = 0.0675)

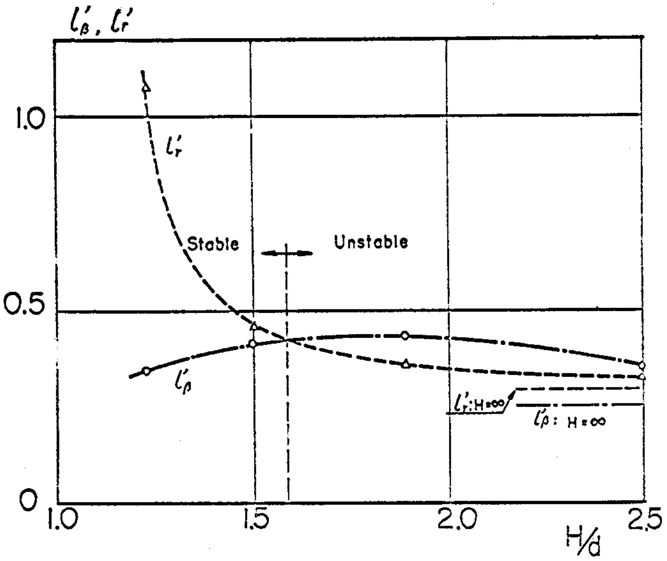

Fig. 2.18. Shallow water effect on ℓ'_r, ℓ'_β "Tokyo maru" (F_n = 0.103)

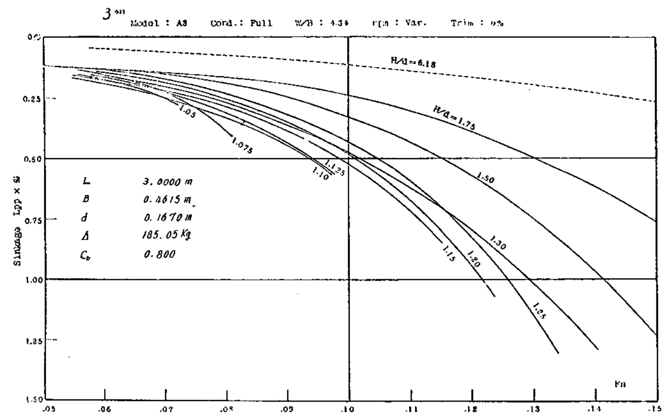

Fig. 2.19. Fore body sinkage

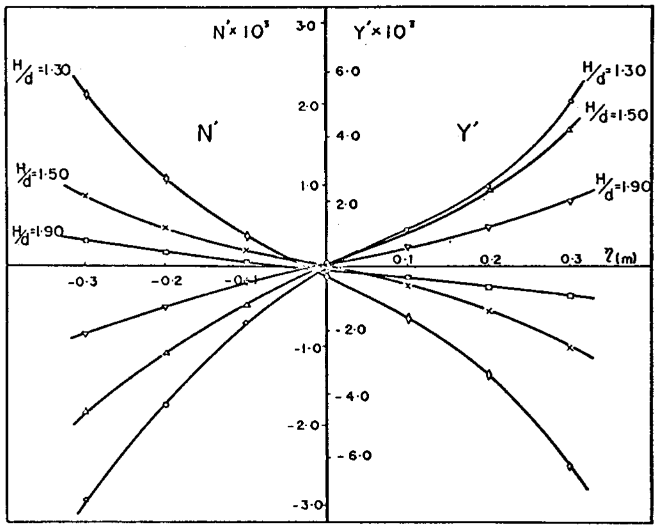

Fig. 2.20. Mariner type ship: Asymmetric hydrodynamic force and moment.
Channel width 1.0 m, $F_n = 0.0905$

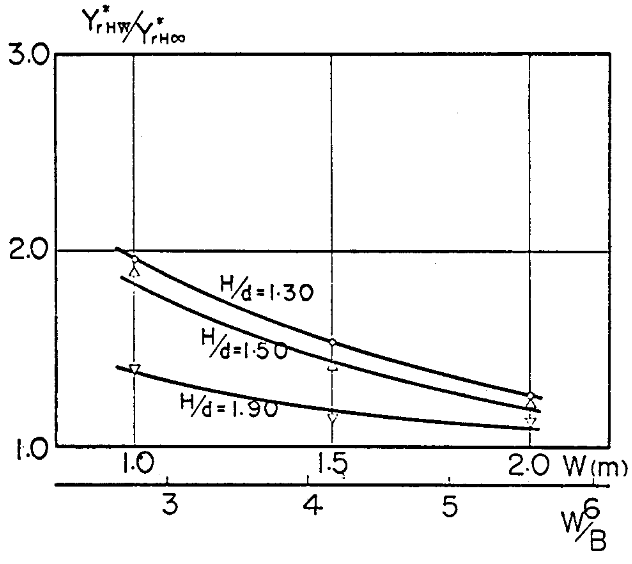

Fig. 2.21. Mariner type ship: Finite width effect on rotary derivative Y^*_r

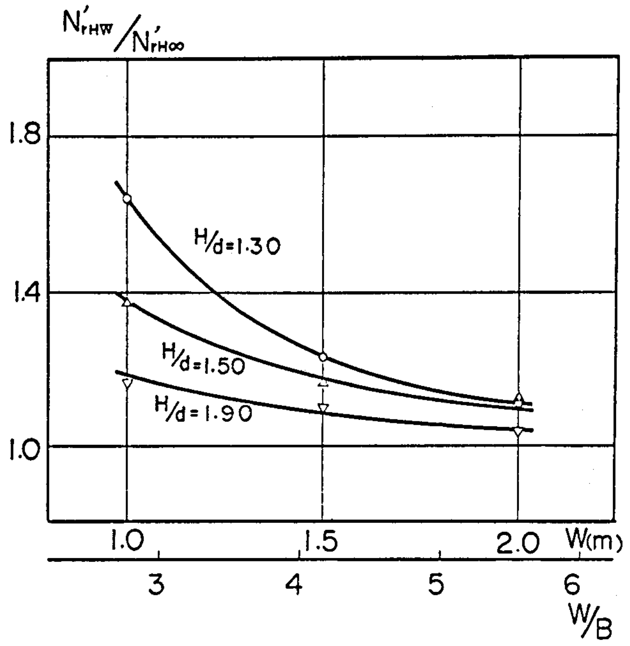

Fig. 2.22. Mariner type ship: Finite width effect on rotary derivative N'_r

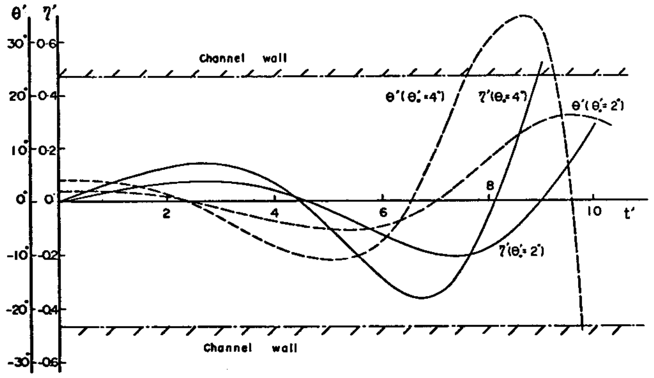

Fig. 2.23. Mariner type ship: The calculated ship motion, θ' and η', with respect to the case with initial directional angle θ'_0. H/d = 1.50, W/B = 5.55 (W = 2.0 m)

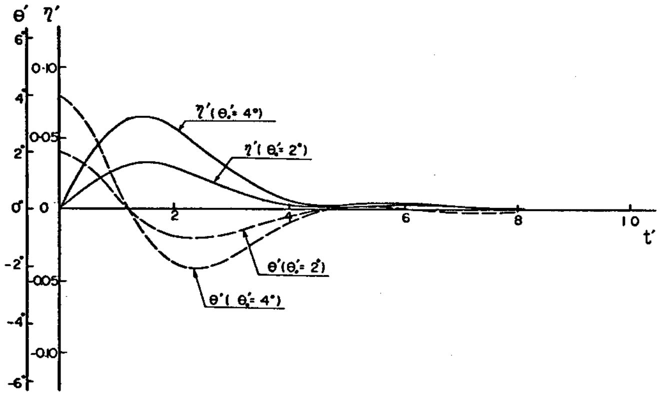

Fig. 2.24. Mariner type ship: The calculated ship motion with initial directional angle θ_0, θ' and η', in case of introducing the automatic directional control $\delta = 2\theta'$.
H/d = 1.50, W/B = 5.55 (W = 2.0 m)

2.2.2. *Experiments with Constrained Models*

In the rotating-arm basin of the Ship Research Institute the hydrodynamic force and moment acting on the naked hull of the model of a large oil-tanker were measured in shallow water and deep water with variation of drift angle, β, and yaw angular velocity, r. The test results are shown in Fig. 2.11, where the hydrodynamic force is non-dimensionalized by dividing by $\frac{1}{2}\rho\, L^2\, U^2$; cf. Ref. 5.

Similary, using the model of an ore-carrier of the Great Lakes, the hydrodynamic force and moment in shallow water ($H/d = 1.36$) were measured with forced yawing technique by the author, and some of the results are shown in Figs. 2.12 and 13[6]. In these figures, the test results in deep water are also shown for the purpose of comparison with shallow water test data.

In Fig. 2.14 are shown the results of the spiral test of an ore-carrier "Benjamin Fairless" of the Great Lakes, for both shallow water ($H/d = 1.36$) and deep water[6].

The course stability of ships is determined by the relative positions of the points of application of sway damping force and yaw damping force. Then, in order to investigate the course stability in shallow water, the points of application of the sway damping force $\ell'_\beta\, (= N'_\beta/Y'_\beta)$ and yaw damping force $\ell'_r\ (= N'_r/(-(m' + m'_z) + Y'_r))$ were measured by forced yawing technique by Fujino. The test results are shown in Figs. 2.15 ~ 18, of which Figs. 2.15 and 16 give the resulys of the Mariner type ship and the remainder those of an oil-tanker, "Tokyo Maru"[7].

During 1964–1966, the bodily sinkages of ships in shallow water were measured at Kobe University of Mercantile Marine, and one example of them is shown in Fig. 2.19[8].

2.2.3. *Shallow Water Effect on Lateral Resistance and Turning Moment*

In the case of handling large ships in ports or shallow bays it comes into question to what extent the lateral resistance and turning moment required to bring the ship to the prescribed position are affected by finite water depth.

To solve this problem a 3 m model of a large oil-tanker was towed by the towing carriage with drift angle 0°–180° and the lateral force and turning moment were measured in various cases of water depth at the Ship Research Institute[9].

2.2.4. *Effect of Restricted Width on the Manoeuvrability*

Fujino[7] conducted an extensive experiment on the hydrodynamic force and moment acting on a model navigating through a channel varying its width and depth. Forced yaw technique making use of a planar-motion-mechanism was employed. Therefore, effect of restricted width on the added mass, added mt. of inertia, linear derivatives and rotary derivatives as well as the asymmetric side force and moment were obtained. Fig. 2.20 is an example of measured side force and moment acting on a Mariner ship model navigating offset position of a channel. Figs. 2.21 and 22 are measured rotary derivatives of the same model. Using these derivatives it was found that the Mariner ship model which is marginally stable in deep water tends to be very unstable in a channel, even if the channel width is fairly large. Ship's behaviour in a channel with an initial yaw angle is calculated as shown in Fig. 2.23 where θ' is the angle of yaw and η' is the offset distance/ship's length.

It was also shown that this directional instability in a channel can easily be overcome by applying a simple automatic control by yaw angle deviation as shown in Fig. 2.24.

REFERENCES

1) YAMANOUCHI, Y. and MORI, N., "Manoeuvrability on Shallow Water", The Nautical Society of Japan, 1968.
2) KAN, M. and HANAOKA, T., "Analysis for the Effect of Shallow Water upon Turning", Journal of Zosen Kiokai, Vol. 115, 1964.
3) KOSEKI, N., YAMANOUCHI, Y., MATSUOKA, S. and YAMAZAKI, Y., "Some Model Experiments on Shallow Water Effects upon Turning Ability", Journal of Zosen Kiokai, Vol. 117, 1965.
4) THE SHIPBUILDING RESEARCH ASSOCIATION OF JAPAN, "Experimental Studies on Navigation of Large Ships", (translated from Japanese title), Report of Research Section No. 98, 1968.
5) MORI, N., "Studies on Shallow Water Effects by Constrained Models" (translated from Japanese title), unpublished.
6) MOTORA, S. and COUCH, R.B., "Manoeuvrability of Full Bodied Ships in Restricted Waters", SNAME, Great Lakes and Great Rivers Section, 1961.
7) FUJINO, M., "Experimental Studies on Ship Manoeuvrability in Restricted Waters", IPS Vol. 168, 1968, Journal of Zosen Kiokai, Vol. 124, 1969.
8) KOBE UNIVERSITY OF MERCANTILE MARINE, "Studies on the Bodily Sinkage of Ships in the Inland Sea of Japan" (translated from Japanese title), Reports I, II, III, 1964–1966.
9) THE JAPAN DREDGER TECHNICAL SOCIETY, "Report of Research and Investigation into Tag Boat for Large Ships" (translated from Japanese title), 1968. Summarized in the formal contribution to the 12th ITTC, 1969.