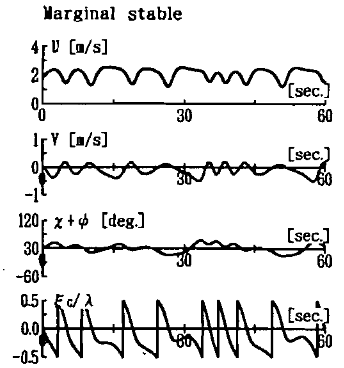

Fig. D　Course keeping of purse seiner model ($\lambda/L=1.5$, $H/\lambda=1/15$, $F_n=0.4$, $\chi=30°$)

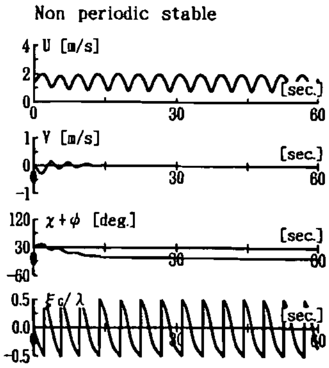

Fig. E　Course keeping of purse seiner model ($\lambda/L=1.5$, $H/\lambda=1/15$, $F_n=0.3$, $\chi=30°$)

	k_{zz}/L_{pp}
Container model	0.314
Purse seiner model	0.316

	$K_P(\delta/\psi)$	$K_D(\delta/\dot{\psi})$
Container model	0.5～2.0	0.14～1.14
Purse seiner model	1.0	0.32

にヨー角の周期的な変動は見られません。これはコンテナ船がまき網漁船に比べ針路安定性に劣るためと考えます。

（2）　今回行った計算では自動操舵による保針は行っておらず，舵角を0度に保ったままの状態で，Fig. A の様に船と波との偏角が指数関数的に増大する場合をブローチングとしています。

（3）　船首揺れ慣性モーメントは以下の通りです。
自動操舵系の角度に対するゲイン K_P，角速度に対するゲイン K_D は，以下に示す範囲で，速度に応じてその設定を変更しています。

10　Non-Linear Periodic Motions of a Ship Running in Following and Quartering Seas

【Discussion】 Dr. K. J. Spyrou （1）In a recent paper, [D 1], a classification of four fundamental broaching mechanisms has been proposed, two of which relate with surf-riding while the other two are inherent of the periodic mode. Further studies about certain characteristics of these mechanisms are now underway. The Authors state in their Introduction that broaching occurs at the transition between periodic motion and surf-riding. This is indeed one of the possible broaching mechanisms, [D 2], but as explained in [D 1] it is not the only one. The term 'broaching' characterizes generally a type of behaviour for which however there might be a variety of causes. It would be interesting if the Authors wished to contrast their findings in the light of this classification.

（2）The nonlinear dynamics of the periodic mode have been analysed also in [D 3] on the basis of a numerical approach featuring automatic periodic-static identification methods. On the other hand, the Authors have followed here, at least for the initial stage of their study, the analytical method. A basic difficulty with any analytical formulation of the broaching problem, lies in the fact, that, due to a number of necessary simplifying assumptions from the outset, analytical methods cannot provide very accurate predictions neither for the actual frequency of encounter between the ship and the wave, nor for the components of the state-vector. In addition, the derivation of the corresponding state-space form is laborious and the actual expressions as proven from equations (36) to (47), are very complicated. Coming into terms with this fact, the Authors correctly have decided to identify numerically the steady-states corresponding to the system of equations (36), instead of making further simplifications in order to proceed analytically. But the question naturally arising here is, if numerical methods had to be used at a later stage, why the Authors haven't done so from the beginning of their analysis. Methods of numerical analysis of periodic solutions are rather widespread in modern dynamical systems' theory and in [D 3] it was attempted to introduce some of these methods into the study of nonlinear ship motions. It appears that, nowadays, analytical solutions of complex multi-degree problems are very rarely sought. So perhaps the Authors would like to justify why they have chosen an analytical approach in the first place, since existing numerical methods are easier and they give much more accurate results.

(3) The Authors have focused their attention on a mathematical model which is basically a non-autonomous system with no restoring terms. Much of the innovation of their method lies in the treatment of this model on the basis of the so-called averaging method. However, strictly speaking, such a formulation is possible to be avoided, as was shown in [D 3], this model can be transformed into an equivalent autonomous form where the wave related terms play the role of restoring. This happens due to the attracting or repelling properties of the wave yaw moment in relation to the direction of wave propagation, at different positions of the wave. Had the Authors selected the latter formulation would their task had been in any sense easier ?

(4) The Authors are commended for including finally in their text a check to verify that the derived periodic solutions are 'contained' within the [−35 deg, +35 deg] range of rudder. As has been pointed out in [D 1] and [D 3] this is an essential check; because, although the periodic motion appears some times stable, if the maximum allowed rudder deflection is reached, and unless the ship's commanded heading is suitably adjusted, the oscillation will 'break' and broaching is possible to occur. However attention should be raised here on the actual gain values for which the analysis is carried out, because these are very influential for the amplitude of the oscillatory motion. It is interesting here that higher gain values, which are thought by many as desirable, can lead to unacceptable oscillation of the rudder and thus increase the risk of broaching.

Based on many exciting recent developments it appears now that the solution of the broaching problem, at least at the theoretical level, is not very far away. It is hoped that these developments will lead also to improved focus of future experimental efforts so that to be able, in the not so distant future, to produce specific design and operational guidelines for minimising the risk of broaching.

<References>

[D 1] K. J. Spyrou (1996) Dynamic Instability in Quartering Seas; The Behavior of A Ship during Broaching, Journal of Ship Research, (accepted).

[D 2] K. J. Spyrou (1995) Surf-Riding, Yaw Instability and Large Heeling of Ships in Following/Quartering Seas, Ship Technology Research,/Schiffstechnik, pp 103-112, 42/1.

[D 3] K. J. Spyrou (1995) Surf-Riding and Oscillations of A Ship in Quartering Waves, Journal of Marine Science and Technology, pp 24-36, 1/1.

[Reply] (1) The discusser classified broaching under the following four scenarios.

(i) A ship under a periodic motion is attracted by an unstable equilibrium of surf-riding and then settles into a turning motion.

(ii) A ship captured at a stable equilibrium of surf-riding tends to a turning motion.

(iii) The rudder angle of a ship reaches the maximum rudder angle during her periodic motion.

(iv) A overtaking-wave periodic motion loses its stability.

The author would like to point out that the scenario (i) does not always result in turning. Because of an auto-pilot, a ship completing broaching can rather proceed to a periodic motion around a certain course or successively repeatable broaching besides capsizing. His conclusion seems to be based on his unrealistic assumption that a rudder should be frozen once it reaches its physical limit.

Apart from this point, the conclusion (4) of this paper explains why a periodic motion can tend to surf-riding equilibrium during the scenario (i). The first author [Refs 1-2] has mainly engaged in investigating the scenario (i) known as a "true broach" [A 1] and results obtained in this paper dealt with its trigger. For the scenario (ii), the first author had shown the danger of reducing propeller revolution during surf-riding. [A 2] For the scenarios (iii-iv), known as a "cumulative yaw motion" [A 1], some simulated results are available. [for example, A 3] Since the method of this paper is capable to identify also these scenarios, they were not found within the current parameter set as shown in Fig. 29. And also in the corresponding model experiment these scenarios were not observed. [Ref. 12] However, the possibility of these scenarios under different auto-pilot parameters still remains. In our