分割したり3次元的構造と2次元的構造に層別したりして内部データ構造を実現して居る状態ですが，著者の理論に依った場合，処理速度上の得失は如何変化するでしょうか。事例或いは今後の期待（本理論の各種基礎演算に適合するプロセッサの活用等）につき差支えない範囲で御教示頂ければ幸いです。

【回答】 処理速度は，インプリメンテーション技術によるので第二段階での検討が進まないと明確な答を出すことは不可能である。定性的には，ソリッドモデリングは，大容量のメモリーと多量の演算を必要とするので，経済性のあるシステムを構築するためには，何等かのブレークスルーが必要である。情報工学と半導体設計・生産技術の発達によって，近い将来この問題は解決出来るものと考えている。専用バックエンドプロセッサーとして，ベクトルプロセッサー，数式処理プロセッサー等の基礎技術はあるので，ローカルエリアネットワークによるネットワーク処理方式によって，実用化システムの構築は可能となるものと考えている。

25 Sloshing in Arbitrary Shaped Tanks

[Discussion] Prof. H. Miyata: The authors efforts to apply a finite-difference fluid simulation method to practical engineering purposes are very valuable. However, for further improvement the following points seem to me of importance.

(1) The effect of cell size must also be studied, since the truncation error is approximately proportional to Δx^2. When one uses very coarse cell system, the numerical viscosity, that arises from the truncation error of the convective terms, may excessively attenuates the fluid motion.

(2) The present treatment of the free-surface may restrict wave motion which can show intense nonlinearity including overturning and breaking motions depending on the conditions. Our previous work (this Journal, Vol. 156 and 157) may give useful informations on this point.

Mr. T. Misawa: We appreciate your efforts to the development of consistent and economical calculation procedure predicting the likely sloshing pressures at the design stage for arbitrary shaped tanks and their structure.

In the particular design of tanks, designers are always concerned with a structural analysis procedure as well as a prediction of sloshing pressures.

Thus, we are very much obliged if we could have some knowledge about how Lloyd's Register of Shipping is planning to introduce the computed sloshing pressures using LR FLUIDS program into a structural analysis for ensuring structural adequacy against sloshing of fluids in the design approval of particular tanks and their structure.

Dr. M. Arai: I was very impressed with the authors' new procedure, which makes use of the 'Sloshing Excitation Spectrum', to obtain the worst sloshing condition. It has the possibility to reduce computer simulation time remarkably comparing with the procedure using the harmonic forced excitation. Concerning to authors' procedure, I would like to raise a following question :

Fig. A1 is a result of numerical simulation conducted by the discusser*) using the harmonic forced excitation. The use of the harmonic excitation certainly gives the fully developed worst responses by several cycles of excitation. On the other hand, it seems to me that your procedure in Fig. 1 contains rather small number of excitation and gives smaller values for the worst responses than the harmonic excitation. I would like to hear your opinion on this point.

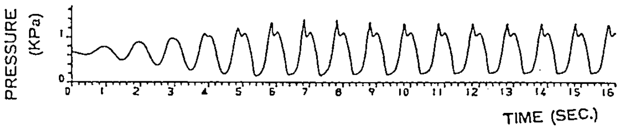


Fig. A1 An example of calculated wall pressure history of a tank with chamfers by harmonic forced excitation

*) Experimental and Numerical Studies of Sloshing Pressure in Liquid Cargo Tanks, Journal of the Society of Naval Architects of Japan, Vol. 155

Mr. T. Tanaka: I would like to congratulate you on the contribution of establishment for evaluating sloshing phenomena in arbitrary tanks by means of numerical computation.

(1) You proposed an unique procedure of

sweeping excitation frequencies near the tank's resonance frequency. And you changed the excitation periods from longer to shorter as shown in Fig. 1. Are there any other results if you change the period from shorter to longer ?

(2) Generally speaking, for design of tanks in an LNG carrier, it is considered that three-dimensional (3D) effects may be important. You state that the two-dimensional approach may be applicable to most tank designs, if suitable calibration was conducted. From my experience of 3D random excitation model tests, it seems to me that it is not easy to calibrate in order to find some relationships between 2D computed results and 3D tests. If you have some sorts of ideas, please teach us.

【Reply】 We would agree with Professor H. Miyata that cell size is important and consequently, to determine a practical optimum, we conducted numerical experiments where we saw that further grid refinement did not result in significant alterations to either pressures or free surface motions. The only exception was from computed pressures on sloping boundaries, where, due to modelling the slope by steps, a smaller cell size tends to reduce the predicted pressures. As Professor Miyata points out, LR. FLUIDS employs a single valued representation of the free surface distribution along the tank and thus cannot model overturning and breaking waves. However, it should be stressed that LR. FLUIDS accounts for all dnon-linearities in the Navier-Stokes equations. Modelling breaking waves would require a considerably smaller cell size and consequently larger computational time and it is therefore not justified in our opinion for a numerical sloshing design evaluation and classification procedure.

We would like to thank Mr. T. Misawa for raising the important subject of the use of sloshing pressures to assess structural adequacy. Although the paper concentrates on the hydrodynamic phenomenon itself, we briefly state that at present at Lloyd's Register the pressures are used in a static plastic collapse structural analysis. The procedure that has been adopted uses a moving average numerical filter on the pressure time histories so as to obtain an appropriate static equivalent to the computed impulse signals. A study of the dynamic structural response to impact loads is presently underway and will be reported in the future.

Dr. M. Arai, as ourselves, recognises the need for an excitation scheme which would bring about computational efficiency. From his experience however from harmonic excitation runs he points out that a number of cycles are needed before the pressure signals fully develop to their maximum values, as seen on figure A1. Whereas in harmonic excitation the tank is started from rest with the free surface horizontal, the "Sloshing Excitation Spectrum" at any one instance produces pressure and free surface responses, not from rest, but from fluid motions which would have been fully developed if the excitation had not been continuously changing. Since in our Excitation Spectrum the motion starts with a large period, and thus little violence in the fluid, and slowly becomes faster, we achieve nearly fully developed pressure signals at all periods in the range under examination. We have satisfied ourselves that the rate at which we change the period does not significantly affect the derived responses, by performing numerical experiments using different rates of period variation and also purely harmonic excitation tests. Finally, we wish to point out that using the Excitation Spectrum we ensure that the resonant period is picked, whereas in the case of harmonic testing this would necessitate a number of experiments or computations. The first question by Mr. T. Tanaka is covered in the reply to Dr. Arai. Here we only wish to point out that on one occasion we examined an excitation spectrum with the reverse period variation, ie starting from fast motion and slowing down with time. Contrary to expectation we did not record significant differences in the fluid's response compared to the corresponding computation which used the adopted period reducing excitation.

Mr Tanaka also raises the interesting question of calibration between Two and Three dimensional results. The limited model experiments we carried out do not allow us to offer a definite formula for this calibration. However, we have simply made the hypothesis that if the generally accepted technique, of taking the square root of the sum of squares of pressures from two separate Two dimensional runs, is to be adopted, then we have proposed that this form of addition should employ pressures which are obtained at the same period of excitation. In other words, for a tank in which the liquid has distinctly different natural periods in the two principal horizontal directions, then it must surely be unrealistic to combine pressures from two tests which were performed at different resonant periods. Sloshing model tests could be purposely conducted to address the question of calibration by the square root technique and the viability of our hypothesis. As more designers become convinced on the practicality of sloshing computations and, furthermore, in view of the computational expense associated with a Three dimensional numerical simulation we believe that such model tests are worthwhile and should therefore be encouraged.

Finally, we would like to thank all the contributors for their kind words of encouragement and for discussing this paper. The interest shown in our work and the warm reception we received by members of the Society are truly appreciated.

26　波浪衝撃荷重と船体の応答に関する実船計測（第1報）

【討論】国武吉邦君　（1） Fig. 6 を見ますと，縦揺より求めた波スペクトルが，波高計による値と良く一致していますが，他の船体運動より，もしくは他の波出会い角で，波スペクトルを求めた例がありましたらご教示下さい。

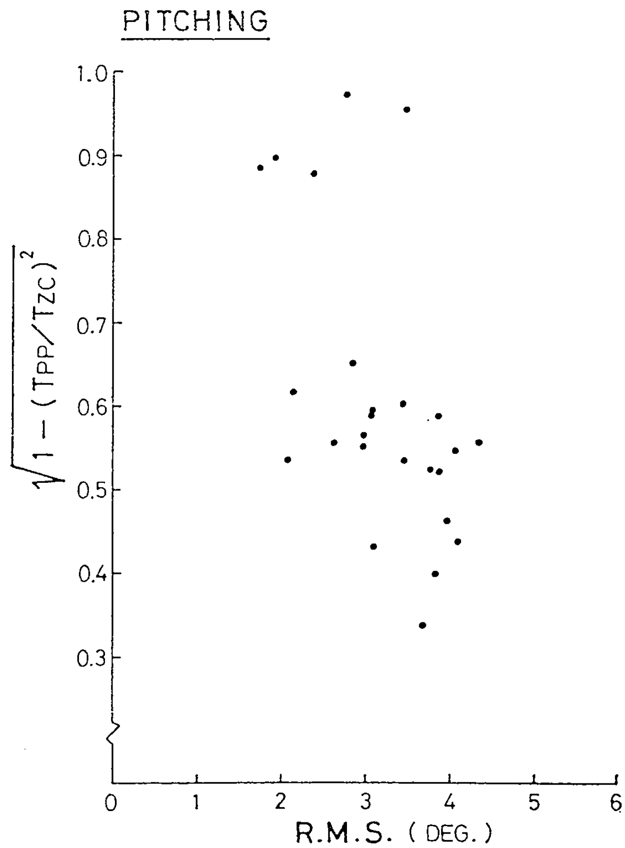
（2） Fig. 8（a）（b）あるいは Fig. 13 は，縦揺，船首上下加速度およびバウフレア部の水圧が，かなり大きな応答をしている範囲まで，その全振幅が Rayleigh 分布に近いという貴重なデータですが，応答の大きさによってバンド幅パラメータはどう変化したか，データがあればお示し願います。

（3） 設計の立場から，本論にあるスラミング時におけるバウフレア部の衝撃水圧と船体縦曲応力の強い相関には大いに関心がありますが，船舶の大きさが異なる場合でも同じ相関があるものでしょうか，ご意見をお聞かせ下さい。

【回答】（1） 直接，波スペクトルを他の船体運動から求めた例はありませんが，縦揺および上下揺の計測データを用いて波の時系列データを求めた例はあります。両者は位相はよくあっていますが，振幅はわずかに上下揺によるものの方が大きいという結果を得ています。

（2） 縦揺のバンド幅パラメータの例を付図に示します。バンド幅パラメータはかなりバラツキますが，振幅（ここでは RMS 値をとっています）との相関はないようです。上の方の点は追い波 ($\chi=0°$, $\chi=45°$) のものです。

（3） 衝撃水圧は運動と同様に Froude 則に従うとしても矛盾は生じないと考えられます。したがって，大型船においても相似の条件が満されれば，今回と同じように衝撃水圧を生じ，その分布状態も相似になり衝撃力も相似則に従うことになるので，これにより高い縦曲げ応



力が生じると考えられます。したがって大型船においてもバウフレア部の衝撃水圧と縦曲応力には強い相関があると思われます。

【討論】荒井　誠君　（1） 討論者らが実施した船首部断面模型の水面落下実験では，船首フレア部の衝撃圧として，鋭いピークはもたないが高い圧力が比較的長く持続する特徴をもつ圧力を計測しました（文献(A)）。本研究ではフレア部に作用する圧力を Wagner の式を用いて整理していますが，Fig. 10（a）の PS-3 の計測