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On Sloshing Force of Rectangular Tank Type LNG Carrier

(Results of Model Test)

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Summary

Many researches have been carried out on sloshing forces of liquid in a ship tank. But most of them have focused on sloshing phenomena of a tank which has considerably large gas space. And only a few results have been reported about nearly fully loaded tanks. This may come from the fact that there are some internal structural members in usual tank tops which prevent the occurrence of large impulsive pressure. But in the case of a tank which has a large flat tank top without any internal members, it is considered important to predict the magnitude of impulsive pressure.

In this report, authors present the results of model experiments focused on impulsive pressure of a nearly fully loaded tank. The experiments were carried out under the following conditions:

Filling ratio: 90~98% tank depth
Kind of ship motion: Pitch, Roll, Surge and Sway
Mode of motion: Regular and Irregular

Results are summarized as follows:

(1) Even in the case of a tank filled up to more than 90%, considerably large impulsive pressure occurs at marginal part of tank top.
(2) Considerably large impulsive pressure occurs in long period range in pitching and rolling.
(3) Large impulsive pressure occurs in a very small area at each moment.
(4) Pressure increases proportionally to the amplitude of motion in some cases, but it shows saturation in many other cases.
(5) It is considered that the probability density function of impulsive pressure shows a distribution close to Rayleigh's and truncated exponential distributions in the case of regular motion.

1. Introduction

Many researches have already been made on the motion of liquid in tanks or the load caused by sloshing. However, the main object of the researches has been the slack loading condition, that is, the loading condition in which there is a considerable void space under the tank top, and few researches have been made of the loading condition close to the full load condition. This is probably because such a high load that poses a problem does not occur in most cases under the tank top where free motion of liquid and gas is prevented by structural members installed there. However, in rectangular tanks as those of internally insulated LNG tankers having no structural members underneath flat tank top, there is a possibility that a considerably high impact pressure takes place. Especially, when panels subject to pressure are small in size and their natural frequency is high, the panels are

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likely to undergo a much higher load than ordinary hull structure panels. Under these circumstances, in designing rectangular tank type LNG tankers having insulation space inside tanks, a research was conducted, focused on the sloshing load at a high filling ratio. This is the first report on the research, outlining the results of model tests.

2. Test Method

Pitch and roll were taken up as rotary motion, and surge and sway as horizontal motion. The former was tested by Mitsubishi Heavy Industries Ltd. and the latter by Hitachi Shipbuilding & Engineering Co. Ltd.

2.1 Test Model and Measurements

Tests were conducted on a forward part tank model (No. 1 model tank) shown in Fig. 1 (a), and on a parallel part tank model (No. 2 model tank) shown in Fig. 1 (b). Fig. 1 also shows the arrangement and identification of pressure gauges. The models are 1/44 scale, made of acrylic resin. Water was used as liquid for ease of testing and measurement. Strain gauge type pressure gauges with 5.05 mm effective diameter of pressure sensitive surface were used for measurement.

The pressure gauges were installed at 11~18 points which were selected from the points shown in Fig. 1, taking into account type of motion, filling ratio, etc. The liquid motion was recorded by a video recorder and a 16 mm movie camera.

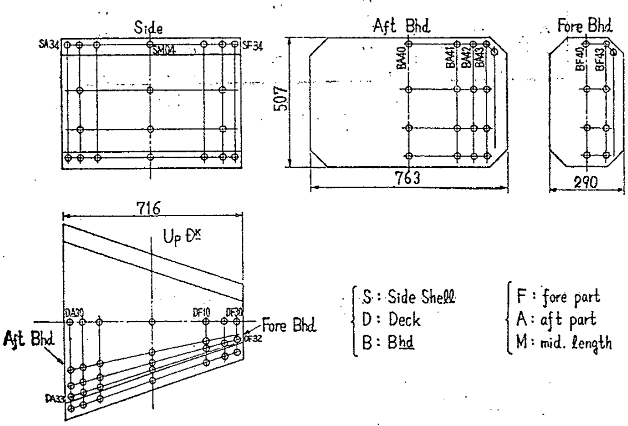

Fig. 1 (a) Model Tank No. 1

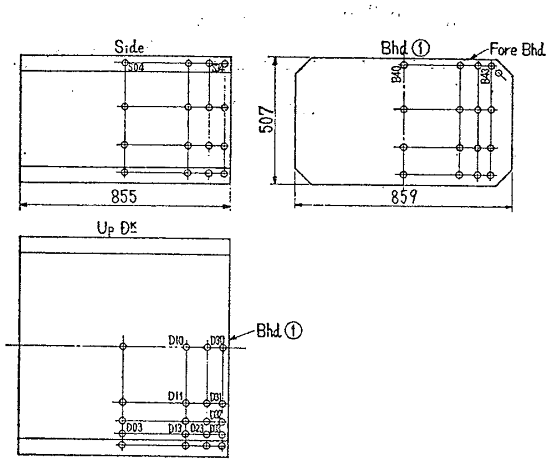

Fig. 1 (b) Model Tank No. 2

2.2 Test Conditions

(1) Regular Motion Tests

The following conditions were combined as considered appropriate.

i) Type and amplitude of motion

Tests were conducted at 8° pitch, at 12° roll, and at 40 mm surge and sway. For some conditions, tests were conducted at different amplitude to obtain their relation with amplitude.

ii) Liquid level (Filling ratio, h/D)

Liquid level was varied at an increment of 2% between 90 and 98%. For some conditions, tests were conducted at 30~60% also.

iii) Period of motion

Period of motion was varied between 0.8~2.8 sec. Increments of variation were smaller near the resonance period than in the other periods.

(2) Irregular Motion Tests

The motion of a ship running on the sea which can be expressed by ISSC sperctum was calculated, and the oscillation table was driven by a tape which was prepared so as to possess the same spectrum. The tests can be classified into the following two types.

i) Pitch

Tests were conducted at 94% liquid level and 5° significant value of pitching amplitude. Average encounter period was varied between 1.51 and 2.41 sec.

ii) Surge

Tests were conducted at 94% liquid level and 44 mm significant value of motion amplitude. Average surge period was varied between 1.00 and 1.25 sec.

2.3 Recording and Reading of Data

Pressure gauge outputs were recorded on a magnetic tape data recorder through an amplifier. In processing data, a method of directly reading the data of an oscillograph transferred from the data recorder (for rotary motion) and a method of reading the data by means of an electronic computer after A/D conversion (for horizontal motion) were used. When the two methods were compared under the same conditions, the former showed a slightly higher value, but the difference was not significant.

3. Test Results and Considerations

(1) Pressure Time History

Fig. 2 shows an example of pressure time history obtained from the tests. It indicates that peak pressure amplitudes scatter very widely, sometimes showing vibration type. The axis of time

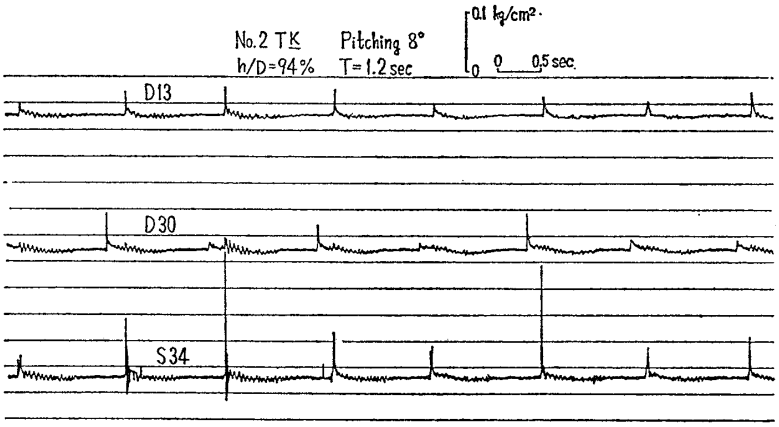

Fig. 2 Typical time histories of pressure

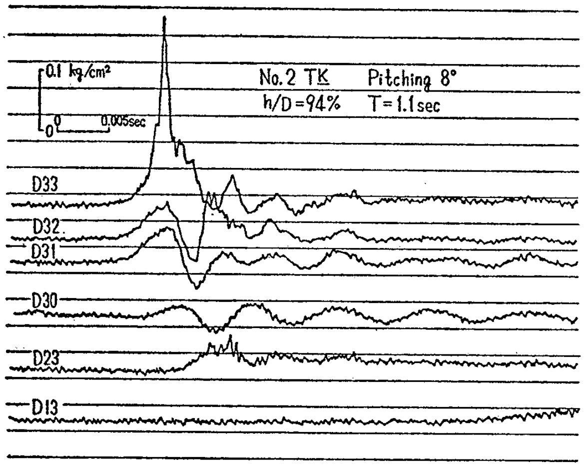

Fig. 3 (a) Typical time histories of pressure

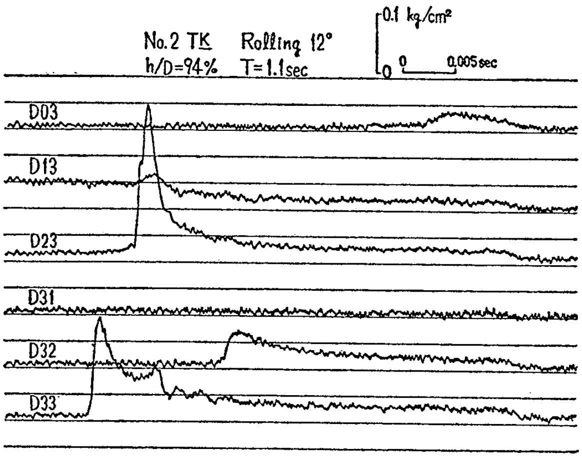

Fig. 3 (b) Typical time histories of pressure

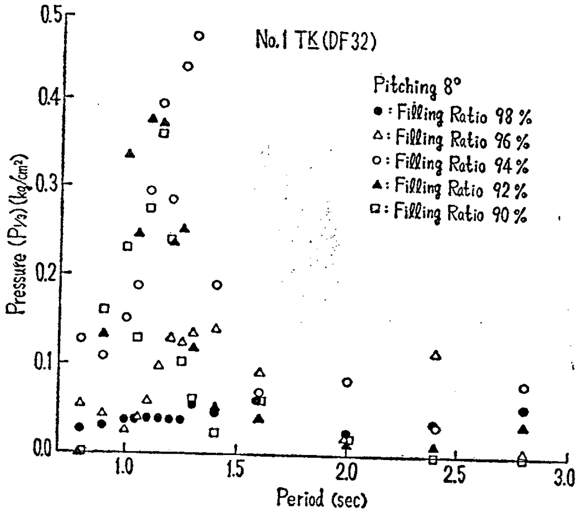

Fig. 4 (a) Example of pressure response (Pitch)

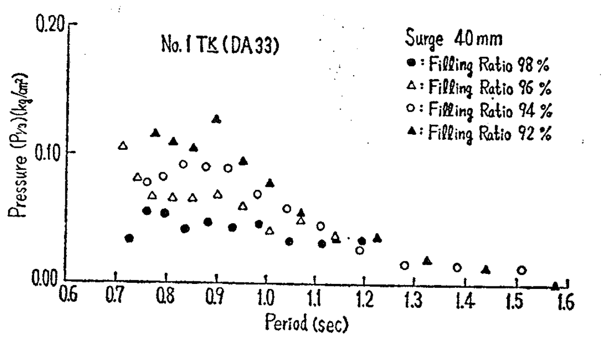

Fig. 4 (b) Example of pressure response (Surge)

in the part of impact pressure is expanded in Figs. 3 (a) and (b). Fig. 3 (a) shows a case in which pressures of the same phase appear in the adjacent part, and it seems that this is apt to occur in the case of vibration type pressure time history. On the other hand, in Fig. 3 (b), a peak is seen separately in each pressure gauge, and a band of high pressures seems to have swept along the tank top at a high speed.

(2) Periodic Response of Pressure

Examples of pressure response in regular motion are given in Figs. 4 (a)～(d). Pressure response to variation of period is sharp in rotary motion while it is dull in horizontal motion. Response is dull in irregular motion as a matter of course, and even in rotary motion, it produces

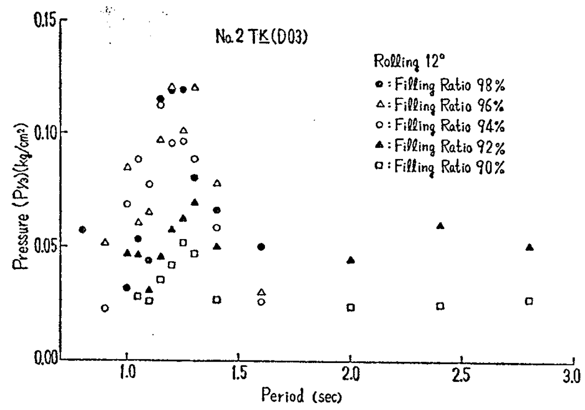

Fig. 4 (c) Example of pressure response (Roll)

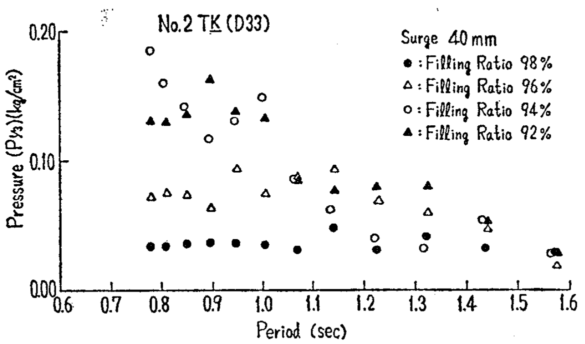

Fig. 4 (d) Example of pressure response (Sway)

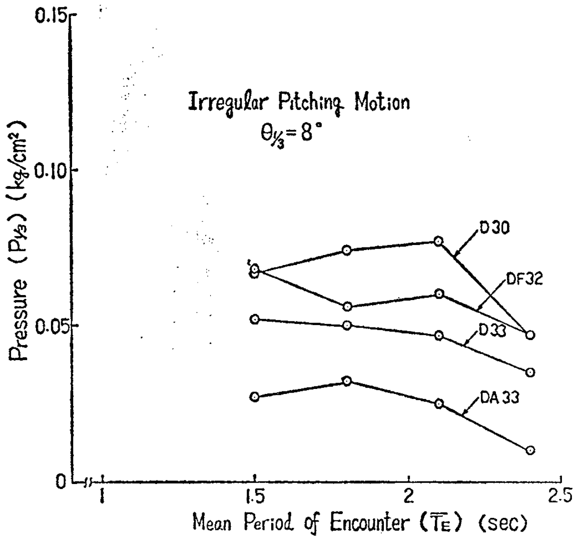

Fig. 4 (e) Example of pressure response at irregular pitch motion

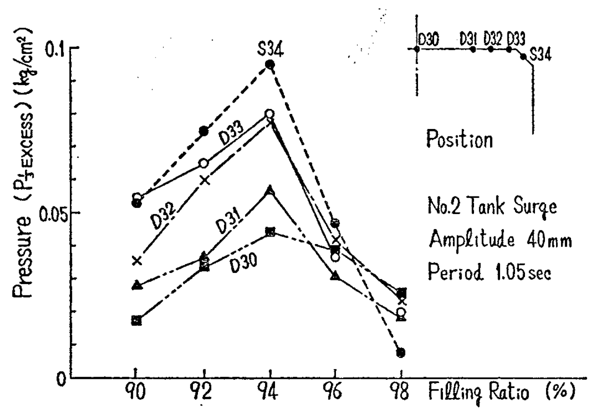

Fig. 5 (a) Influence of filling ratio

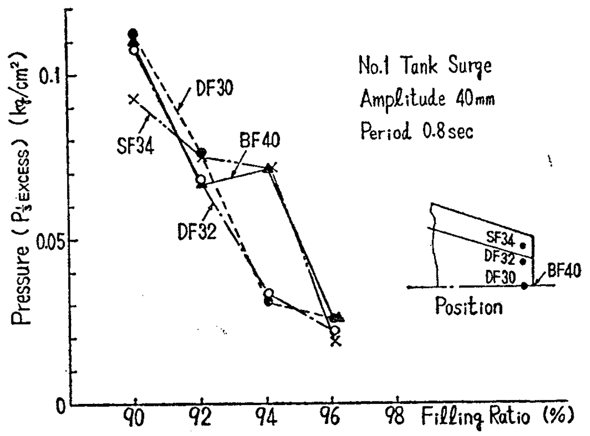

Fig. 5 (b) Influence of filling ratio

such a gentle curve as shown in Fig. 4 (e). (At $\bar{T}_E = 1.5$ sec. in the figure, a considerable amount of resonance region components is included.) In the case of rotary motion a relatively high pressure is produced in a long period region far away from the resonance period. This is because even when liquid is not moving, the rotation of a tank tends to cause the tank top to strike smooth liquid surface, and this is a distinctive feature in rotary motion at a high filling ratio. On the other hand, in the case of horizontal motion, a high pressure is produced in short period region. This is because the acceleration in horizontal direction increases in inverse proportion to the square of motion period. (The gravity component in the direction of tank length (breadth) which is predominant in rotary motion has no relation with period.) In 8° pitch motion, the maximum pressure was close to 5 t/m² in significant value. Since this is a value obtained in a test using a 1/44 scale model and liquid with specific gravity of 1, it becomes a very high value, 100 t/m², when simply converted in terms of a full-scale LNG tanker.

(3) Effect of Filling Ratio

The effect of filling ratio observed in regular motion tests is given in Figs. 5 (a)~(c). In the Fig. 5 (a), the maximum value is seen at 94% filling ratio while in Fig. 5 (b), pressure tends to increase as filling ratio decreases. However, there are some instances in which a considerably high pressure is produced even at 98% as seen from Fig. 5 (c), and so it is difficult to give a general tendency.

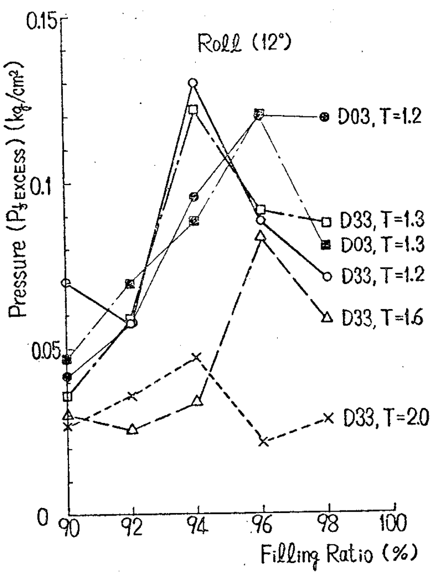

Fig. 5 (c) Influence of filling ratio

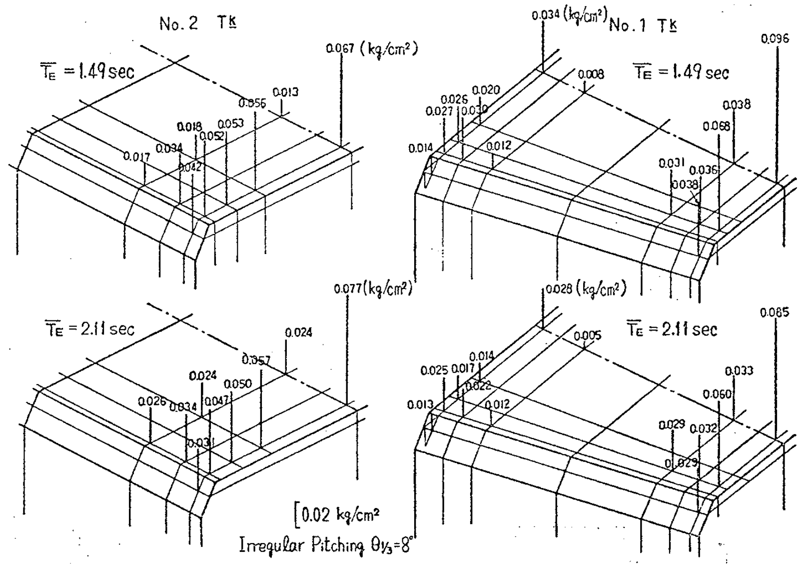

Fig. 7 Distribution of maximum impulsive pressure

(4) Effect of Amplitude

An example of regular motion tests is given in Fig. 6 (a). The effect of amplitude increases almost proportionally in surge while it is hardly seen in sway. The only difference between surge and sway is whether there is a small oblique part between the side wall and the tank top, so it would be premature to say definitely that it indicates an intrinsic difference due to difference of motion type. It should rather be considered as an indication of the complexity of the phenomenon. The effect of amplitude in irregular motion of surge is shown in Fig. 6 (b). In the case of DA33, pressure increases nearly in proportion to amplitude in the range of amplitude shown, but in the case of D33, a tendency of saturation has already appeared.

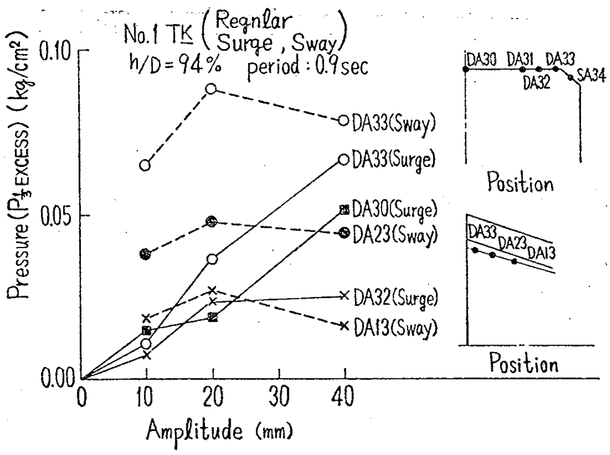

Fig. 6 (a) Influence of amplitude

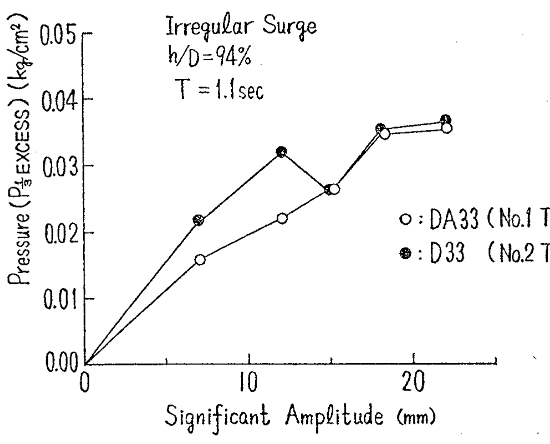

Fig. 6 (b) Influence of amplitude

(5) Distribution of Pressure

To know in what part of a tank a high impact pressure occurs is an important task in designing. Fig. 7 shows distribution of peak values of impact pressure obtained in irregular pitch motion tests. In the figure, a high pressure is seen in the middle part of a side. At a corner, the pressure will be much higher actually, combined with a pressure caused by perpendicular motion such as roll. The pressure decreases significantly as the distance from a tank wall increases.

(6) Simultaneous Distribution of Pressure

In the preceding paragraph, the place where pressure becomes high irrespective of time was discussed. In examining tank strength, it is also important to know pressure distribution at each moment. Fig. 8 shows how much pressure occurred in adjacent part at a moment when the maximum pressure was observed on a pressure gauge. It is seen from the figure that the range in which high impact pressures occur simultaneously is very small.

(7) Probability Distribution of Pressure

Scattering of pressure will be studied in more details at the next opportunity. Here, the results

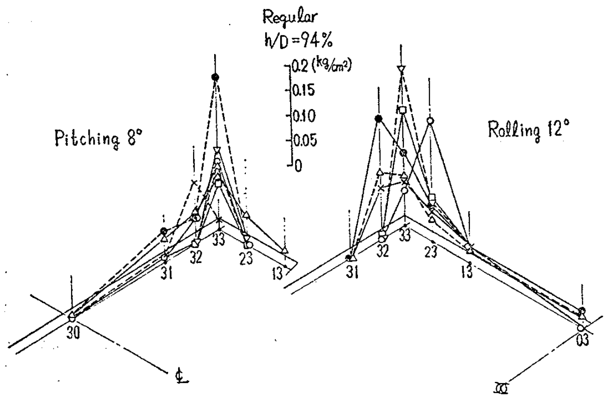

Fig. 8 Simultaneous distributions of pressure

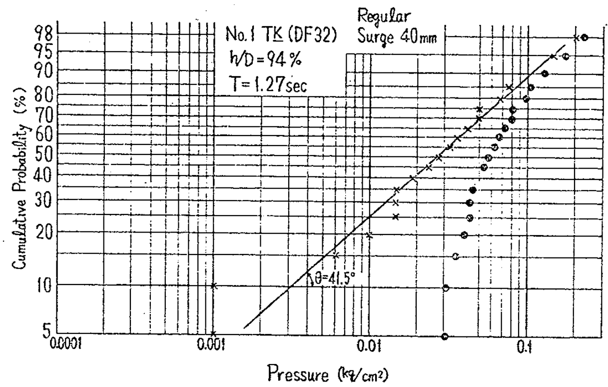

Fig. 10 (a) Probability distribution of impulsive pressure

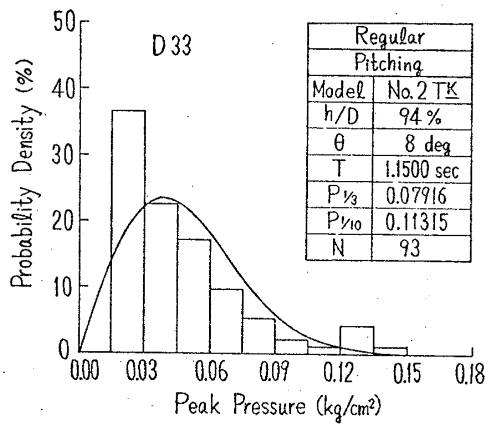

Fig. 9 Probability distribution of impulsive pressure

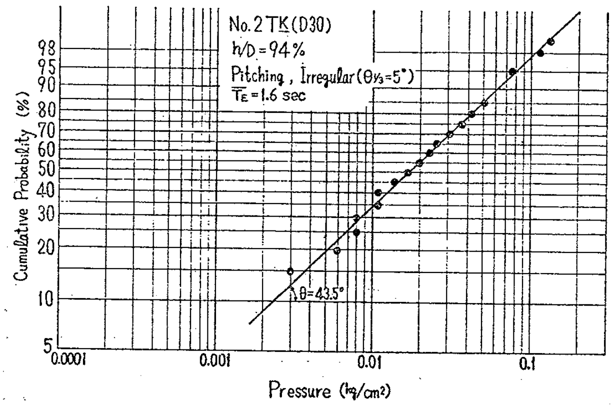

Fig. 10 (b) Probability distribution of impulsive pressure

of tests are briefly explained. Fig. 9 shows a histogram of an example of probability distribution in regular motion. It is close to Rayleigh distribution but gives slightly higher probability in high pressure part. For further examination, the cumulative value was plotted on probability paper as shown in Fig. 10 (a). Points marked with "•", which show pressures directly plotted form a curve, and the higher the pressure, the gentler the slope, which means a distribution pattern with poor convergence. However, when P-30 g/cm² is plotted instead of P, pressures fall in a nearly straight line as marked with "x", in the figure, producing a pattern close to an exponential distribution. On the other hand, when the results of irregular motion tests are plotted in Fig. 10 (b) in the same manner, points showing P directly plotted form a linear pattern, and its slope is very close to an exponential distribution. More data should be examined to know general characteristics, but an examination of the above figures alone leads us to consider that distribution pattern will be different in a part where probability of occurrence is very low, and that it is very complex in nature.

4. Conclusion

Introduced above were tests results on the sloshing load at a high filling ratio on which few researches had been made. It is important to determine the characteristics of the sloshing load by examining these data and to establish a method of estimating the load taking them into account, but this point was not discussed here. Preparations are under way to publish at the next opportunity a method of taking into account the scatter and saturation of load, together with a comparison between irregular motion test and regular motion test. Thus, this report is merely a summary of model test results, but the following have been found.

(1) In regular motion test, resonance appears more clearly in rotary motion than in horizontal motion. In rotary motion, a relatively high pressure occurs even in long period region, which in horizontal motion, a high pressure occurs in short period region.

(2) The effect of liquid level varies with period, etc. in a complex manner. A considerably high impact pressure sometimes occurs even in a condition close to the full load condition,

which requires due attention.

(3) The effect of amplitude is also complex. There are a case in which it increases in proportion to amplitude and a case in which it saturates in a relatively small amplitude.

(4) The distribution of the maximum values of pressure is limited to a part close to side walls at tank top (ship sides and transverse bulkheads), and pressure decreases markedly as the distance from them increases.

(5) The range in which high impact pressures are distributed simultaneously is small.

(6) A distribution close to Rayleigh distribution or truncated exponential distribution was obtained from an examination of several examples of pressure. In the case of irregular motion, a distribution close to an exponential distribution was obtained.

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Reference

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