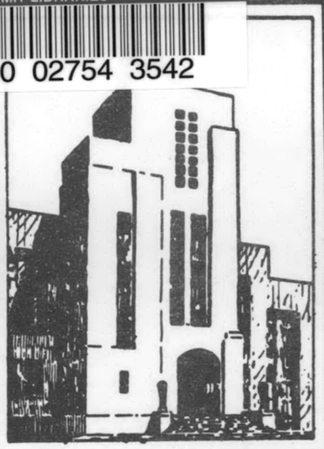

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A FULL-SCALE EVALUATION OF PASSIVE ANTIROLL TANKS ABOARD AN AK-TYPE SHIP

[redacted]

By

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HYDROMECHANICS LABORATORY

RESEARCH AND DEVELOPMENT REPORT

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ABSTRACT

A limited number of tests was made aboard an AK-type ship to determine the effectiveness of passive antiroll tanks in reducing the roll of the ship in a seaway. Comparative runs were made with the tanks operative and inoperative at two headings relative to the sea. Roll, sway, and water transfer were measured. Spectral analysis of the records indicated that the tanks reduced the rolling by a factor of two.

INTRODUCTION

The stabilization of roll in seagoing surface ships has been attempted in the past 80 years by a variety of methods. Chadwick has given a very complete chronological history and classification of such systems in his paper, "On the Stabilization of Roll."* It showed that most of the installations used either Frahm tanks, gyro stabilizers, or oscillating fins. The present vogue decidedly favors the use of activated fins, and their efficiency has been amply demonstrated. However, when a ship is forced to operate at low speeds, the stabilizing moment available with fins is sharply reduced. Such low-speed operation, although unusual in military and commercial applications, is still important for a few ships with special missions. For example, the T-AK 253, PVT JOE E MANN, has been assigned the task of tracking missiles with ship-mounted radar. Operational requirements state that it must operate with no more than 2 degrees roll while its speed is 5 knots or less.

The Bureau of Ships has designed a passive antiroll tank system for

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*Chadwick, J. H., "On the Stabilization of Roll" Transactions, Society of Naval Architects and Marine Engineers, Vol. 63, 1955.

this ship, and installation was completed in October 1958. The David Taylor Model Basin instrumented the ship to determine its rolling response to wave action, and measurements were made along the Pacific Coast during that same month. Analysis of these tests results is presented in this report.

DESCRIPTION OF INSTALLATION AND INSTRUMENTATION

The T-AK-253 has a Victory-type hull which is 450 ft long and has a beam of 62 ft. Considerable concrete ballast was poured in the No. 3 hold spaces to give a draft of 21 ft.

The passive tank system consists of two transverse pairs of rectangular tanks, as shown in Figure 1, each pair connected by a rectangular duct 6 ft wide, with two entrance nozzles, one at each end of the duct. The floor area of each of the four tanks is about 210 sq ft. The tank is on the second-deck level between Frames 40 and 48. The tank bottom is about 6 ft above the ship's center of gravity. The tank is filled with fresh water to a depth of 5 to 7 ft, the precise depth determining the tank natural frequency and therefore "tuning" the system. A door was fitted in each crossover duct so that the water transfer could be blocked and comparisons made between rolling performance with and without stabilization.

Eleven channels of information were recorded on a Consolidated string oscillograph with a Datarite magazine for immediate viewing. A Donner accelerometer was mounted on a stable-table on the ship's centerline, at Frame 38. It measured sway acceleration in a horizontal plane. A Minneapolis-Honeywell gyroscope measured ship's roll angle. Wave height was measured by a Tucker shipborne wave recorder with the pressure taps located at Frame 75 on the 10-ft waterline. To define the magnitude of the oscillation of water within the tanks, Dynisco pressure gages were mounted near the inboard and outboard edges of each of the four tanks, close to the bottom.

TRIAL AGENDA AND EXPERIENCE

The original trial agenda called for tests at speeds between 5 and 10 knots and headings varying between head and following seas. Tests were to be made with and without the duct blocked, so that the effectiveness of the tank in reducing roll could be evaluated. In addition, the water levels in each of the two parallel tank systems were to be altered to yield variable tank tuning.

On 14 October 1959, measurements were attempted outside San Francisco Bay, but the sea was too mild to yield any usable results. A further attempt was planned during a trip from San Francisco to Port Hueneme on 18 - 19 October. Unfortunately, the vagaries of the weather and the ship's operating schedule did not permit the exhaustive check on the stabilizer effectiveness originally planned in the test agenda.

At daybreak on 19 October, just off Point Conception, Force 4 to 5 northwesterly winds were blowing, although variable and of short duration. Visual observation indicated waves from the northwest, 5 to 7 ft high and with a period of 7 to 8 sec. A subsequent hindcast by the U.S. Navy Hydrographic Office indicated that the wave system was considerably more complex. From synoptic weather charts it was deduced that a west-northwest swell of 8½-sec period and 5½-ft height was superposed on a local northwest sea, 5 ft high with 4-sec period.

Only 2 hours of testing was permitted by the ship's schedule so the agenda was sharply curtailed. Five runs were made at 5-knot speed, as shown in Table 1. The relative headings of seas-to-ship were based on the observed sea direction of 310 deg. For all tests the tanks were filled to the 6-ft water level.

TABLE 1
SCHEDULE OF TESTS

Run	Speed knots	Ship's Heading degrees	Relative Heading Seas-to-Ship	Stabilizer Condition	Duration minutes
1	5	175	Quartering	Operative	14
2	5	175	Quartering	Inoperative	14
3	5	220	Beam	Inoperative	14
4	5	265	Bow	Inoperative	9
5	5	265	Bow	Operative	9

TEST RESULTS

A portion of the oscillograph record taken during Run 1 is shown in Figure 2. The four pressure records shown at the top of the chart were taken in the forward pair of tanks, and the four at the bottom were measured in the aft set of tanks. Also indicated are the wave height, roll angle, and sway acceleration records. For all five runs these latter three channels were analyzed to obtain the power spectral density curves, and some of the pressure records were analyzed similarly for the two stabilized runs.

The records were read at 1/4-in. intervals, or every second, ship time. These readings were punched on IBM cards and fed as an input to the IBM 704 Digital Computer. The computer program determined the Fourier transform of the auto-correlation function. This yielded a tabulation of spectral densities at discrete frequency intervals.

A total of approximately 23,000 data points was utilized in the process.

The duration of these runs was, unfortunately, too short to give good statistical validity to the spectral density curves. The 9-to-14-min samples yield broad confidence limits, or, in other words the sample is not necessarily representative of the entire population. However, certain comparisons of the stabilized and unstabilized performance, such as the mean amplitudes, are still valid.

The most significant comparisons are seen in Figure 3, where the power spectral density curves for roll appear. From the area under these curves, the average roll amplitude and the average of the 1/10 highest rolls have been computed (Table 2). The roll spectra shown in Figure 3 are all sharply tuned with maximum energy at a period of about 12 sec, which can reasonably be assumed to be the ship's natural frequency. The greatest roll angles occur in the nominally quartering seas, although at this heading the west-northwest swell is very nearly abeam to the ship. The most striking aspect of Figure 3 is the sharp reduction in roll accomplished by the tank system. The summary given in Table 2 indicates that the roll angles were cut in half when the tanks were active for the two on-off tests which were run. Unfortunately, with the present state of knowledge, it cannot be said that the roll reduction would be the same in other seas, with a different frequency band of excitation, or in higher waves. However, the limited results are highly encouraging.

The so-called sway accelerometer adjacent to the tanks indicates the transverse accelerations of the tank rather than the sway acceleration of the center of gravity of the ship. Its signal partakes not only of the sway of the c.g. but also of the roll of the ship (since it is about 9 ft above the c.g.) and of yaw (since it is 110 ft forward of the c.g.). In Figure 4, the spectral density curves of sway

TABLE 2

Amplitudes of Roll, Sway, Sway Acceleration, And Water Transfer

Run	Direction of Seas	Stabilization	Average Roll degrees	Average 1/10 Highest Rolls degrees	Average Sway Acceleration ft/sec²	Average Sway Displacement feet	Average Water Transfer Outboard feet	Inboard feet
1	Quartering	Active	1.7	3.5	1.0	2.8	3.3	2.4
2	Quartering	Inactive	3.4	7.1	1.2	3.6	---	---
3	Beam	Inactive	2.7	5.6	1.7	4.0	---	---
4	Bow	Inactive	1.7	3.5	1.0	2.5	---	---
5	Bow	Active	0.9	1.9	1.0	2.4	2.1	1.5

acceleration are shown. One peak in the curve occurs at about the ship's roll frequency, and a second peak occurs at a higher frequency (between 5 and 8-sec period). This latter peak reflects the frequency of encounter between ship and wave given earlier and is prominent because the ship has no natural frequency in sway and so it simply responds directly to the oscillating wave forces. The average sway accelerations for each of the five runs are summarized in Table 2. It can be seen that the tanks do not reduce the sway acceleration at this location as they do the roll. For bow seas, the acceleration is about the same, whereas in quartering seas the reduction is only 15 percent. This is not a criticism of the tank effectiveness since this mode of motion is not an operational problem and the accelerations themselves are very low.

The spectral density curves for sway displacement (Figure 5) were obtained by dividing the acceleration curves by ω^4. This frequency transformation eliminates the highest peak in the acceleration curve and causes the displacement curve to look very much like a roll spectrum; that is, sharply tuned at the natural frequency of roll. The average amplitudes of transverse displacement vary between 2 and 4 ft, and they are tabulated in Table 2. These are quite reasonable figures since the sway should be of the same order of magnitudes as the wave elevation and this is so for these tests. (Note that the usual definition of wave height gives the double amplitude of the average of the 1/3 highest waves rather than the single amplitude of the average wave). Also, a yaw about the c.g. of only 1 deg would result in a tank sway of 2 ft.

For those runs in which the tanks were active, the eight pressure records were spectrum-analyzed. Since all of the curves are so similar in shape, only a representative curve is shown in Figure 6. As would be expected, it looks very much like a narrow-band roll spectrum with the peak at the same frequency as seen in the roll spectra. We will assume that the oscillation of the ship is low enough in frequency and amplitude so that the pressure measured at the tank bottom reflects the height of water above the gages, in a hydrostatic sense. It is further assumed that the water movements in the forward and aft sets of tanks are the same since the tank dimensions differ so little. This allows us to average the statistical properties of the four outboard gages and the four inboard gages. These are summarized in Table 2 under the heading "Water Transfer." This signifies the vertical rise (or fall) of the water surface from its equilibrium position.

The wave-height records obtained from the Tucker shipborne wave recorder have not been presented because they are highly suspect. Not only did they contradict the visual observations, but the spectrum derived therefrom looked precisely like the roll spectrum, with the peak in the wave spectrum roughly proportional to the peak in the corresponding roll spectrum. Since the recorder has two vertical accelerometers, a malfunction could cause the wave-height record to partially reflect the roll signal.

In the design of passive tank stabilizers such as the present installation, the natural frequency of the tanks is chosen to be very close to that of the natural frequency of the ship in roll. Then, in beam seas, with wave frequency equal to the natural frequency (so-called resonance), the linear equations of motion show that at the instant of maximum wave slope which tends to roll the ship to starboard, the ship will be level and rolling to starboard. Also, at this instant the water in the port tanks will be at its highest elevation. In other words, a successful design would yield maximum stabilizing rolling moment to port due to the tanks, as the ship had maximum moment to starboard due to the wave.

A check of these phase relationships is not rigorously possible in these tests when simple auto-correlation techniques are used. However, it was speculated that an approximate phase relationship could be derived if the spectra of roll and water transfer were sufficiently narrow in bandwidth about the same modal frequency. Since observation of the two spectra indicate that this may be true, a very simple but perhaps unorthodox analysis was attempted. In each of the two activated tank runs, the record was inspected for intervals during which the ship appeared to be swinging easily in an almost periodic fashion. Seven such instances were chosen during Run 1, and five during Run 5. The time difference between peaks in the two records was noted for each case, as well as the apparent period of oscillation. These two values were paired to give an apparent phase difference in degrees. A remarkably small variation in phase and period was found in this sample. For Run 1, the period variation was 11.1 $\pm$ 1.1 sec and the phase variation 58 $\pm$ 15 deg. For Run 5, the period variations were 11.8 $\pm$ 1.1 sec and the phase variations were 57 $\pm$ 20 deg. The average periods of 11.1 and 11.8 sec compare reasonably well with the peak in the roll spectra at approximately 11.1 sec. Whereas the theory indicates that the water transfer should lead the roll by 90 deg at resonance for optimum design, the measurements show that for the actual design it is more nearly 60 deg.

CONCLUSIONS

Passive antiroll tanks reduced the roll by a factor of two when the ship made 5 knots in bow and quartering seas of 5-to 7-ft height. Although it cannot be said that the roll reduction would be the same in seas with a different band of excitation or in higher waves, the present limited results are highly encouraging.

ACKNOWLEDGMENTS

The assistance of Mr. K. Ripley, designer of the tank system, and Mr. A. Taplin, both of the Bureau of Ships, in the conduct of the trials is gratefully acknowledged.

Mr. J. Leahy installed and operated the instrumentation, and Mrs. F. Poole reduced the data.

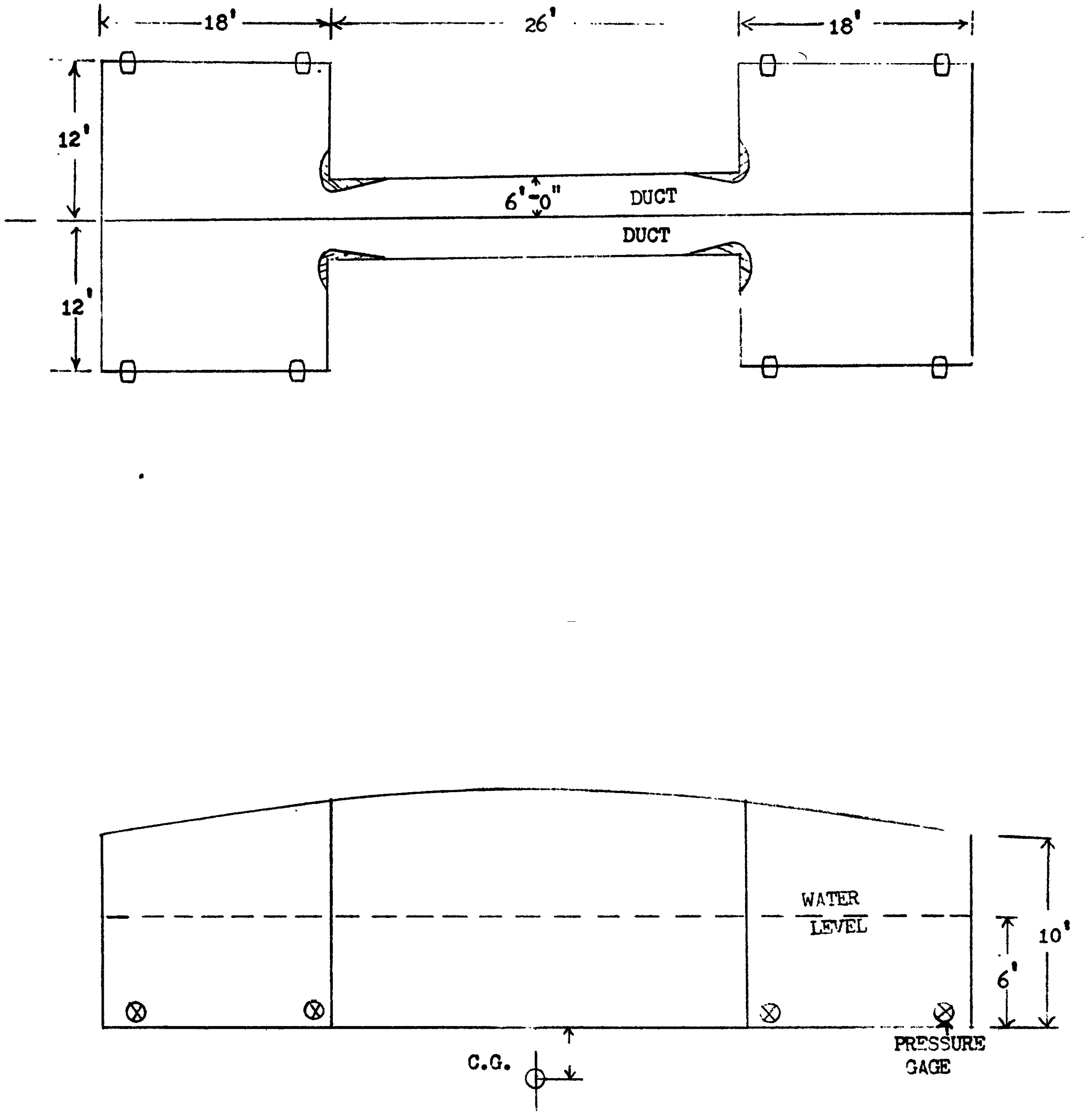

FIGURE 1

SCHEMATIC REPRESENTATION OF TANK SYSTEM

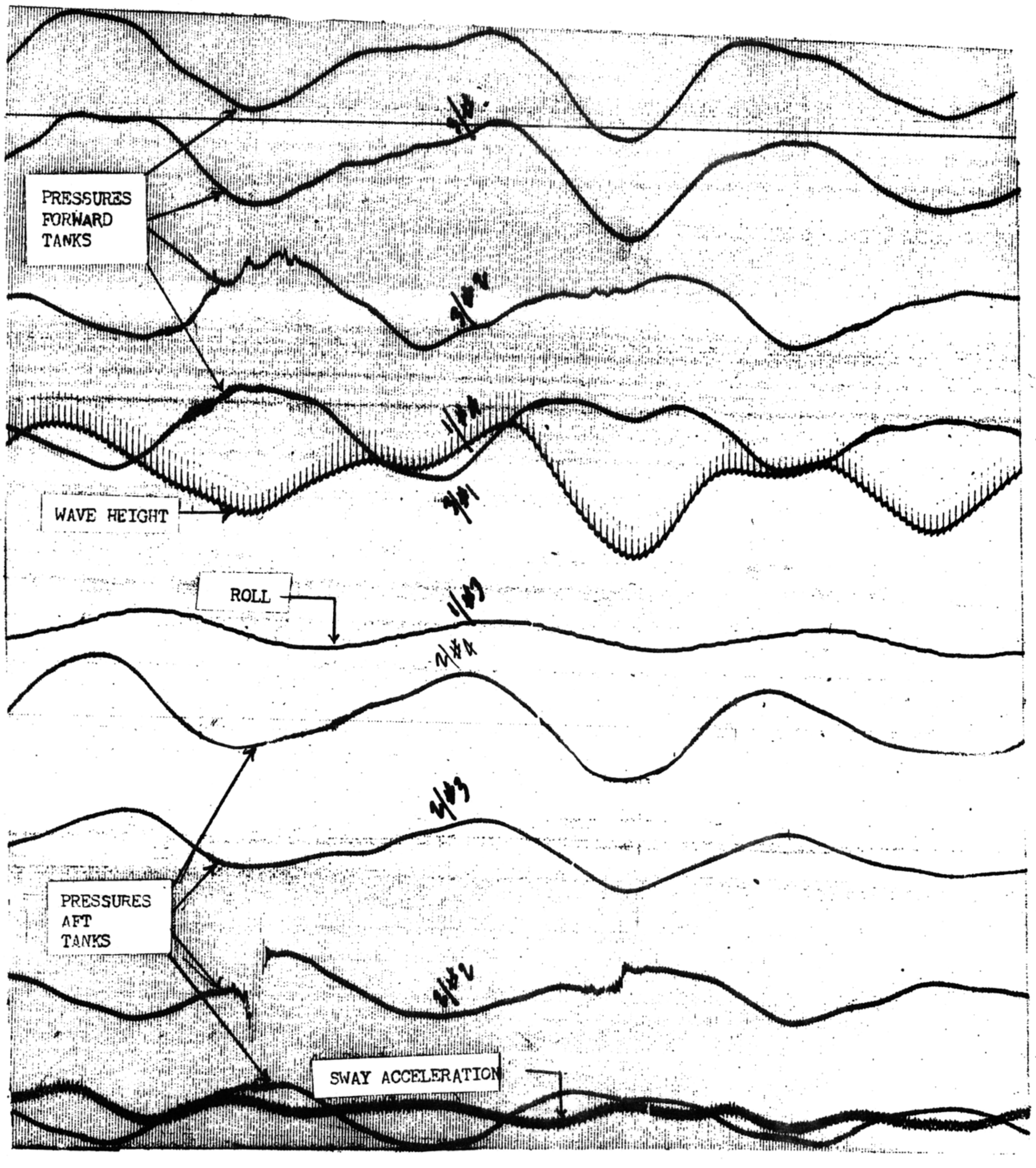

FIGURE 2 - SAMPLE OF OSCILLOGRAPH RECORD

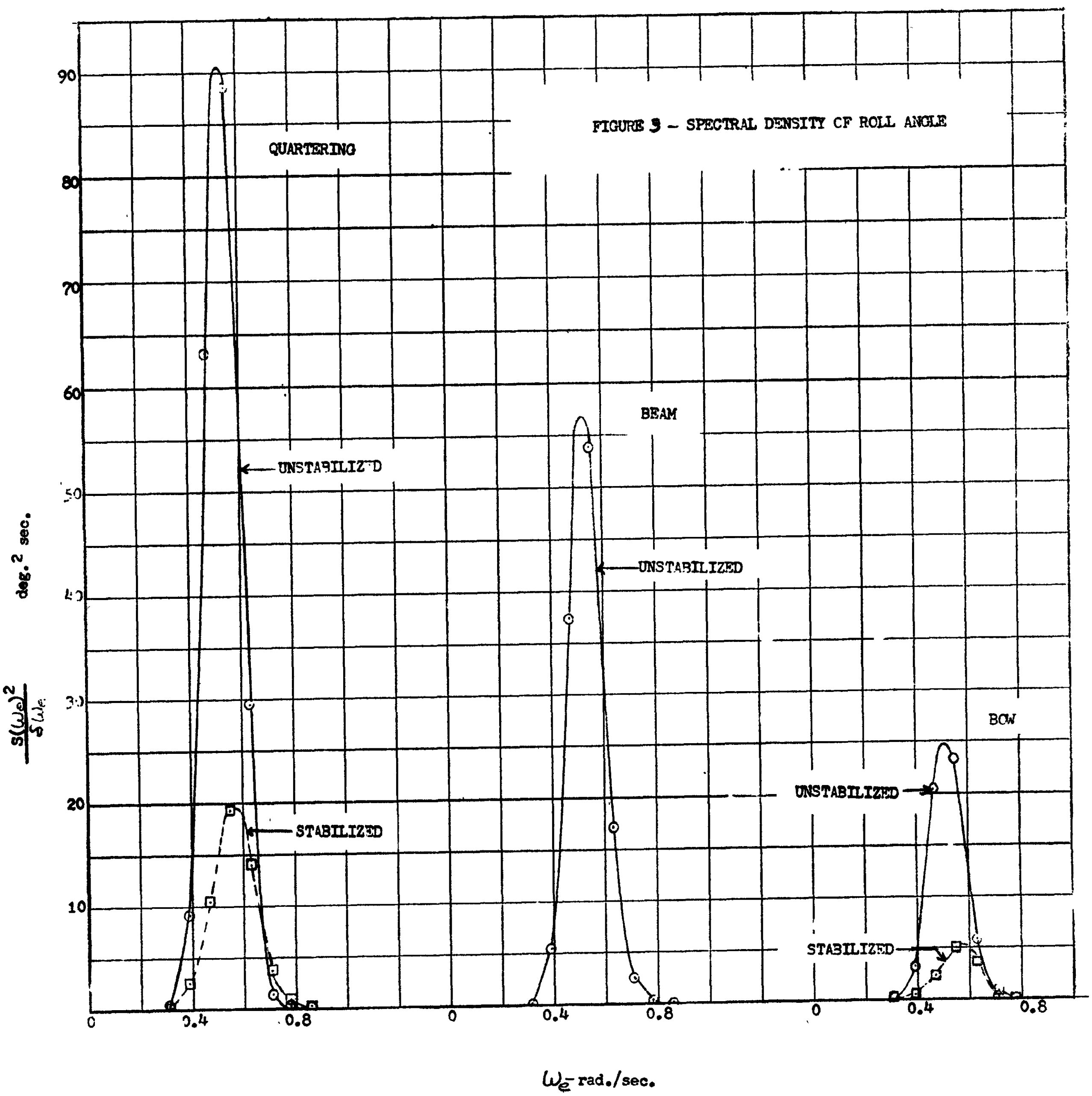

FIGURE 3 – SPECTRAL DENSITY OF ROLL ANGLE
QUARTERING
BEAM
BOW
UNSTABILIZED
STABILIZED
90
80
70
60
50
40
30
20
10
0
0.4
0.8
$\frac{S(\omega_e)^2}{\delta\omega_e}$ deg.^{2} sec.
ω_e - rad./sec.

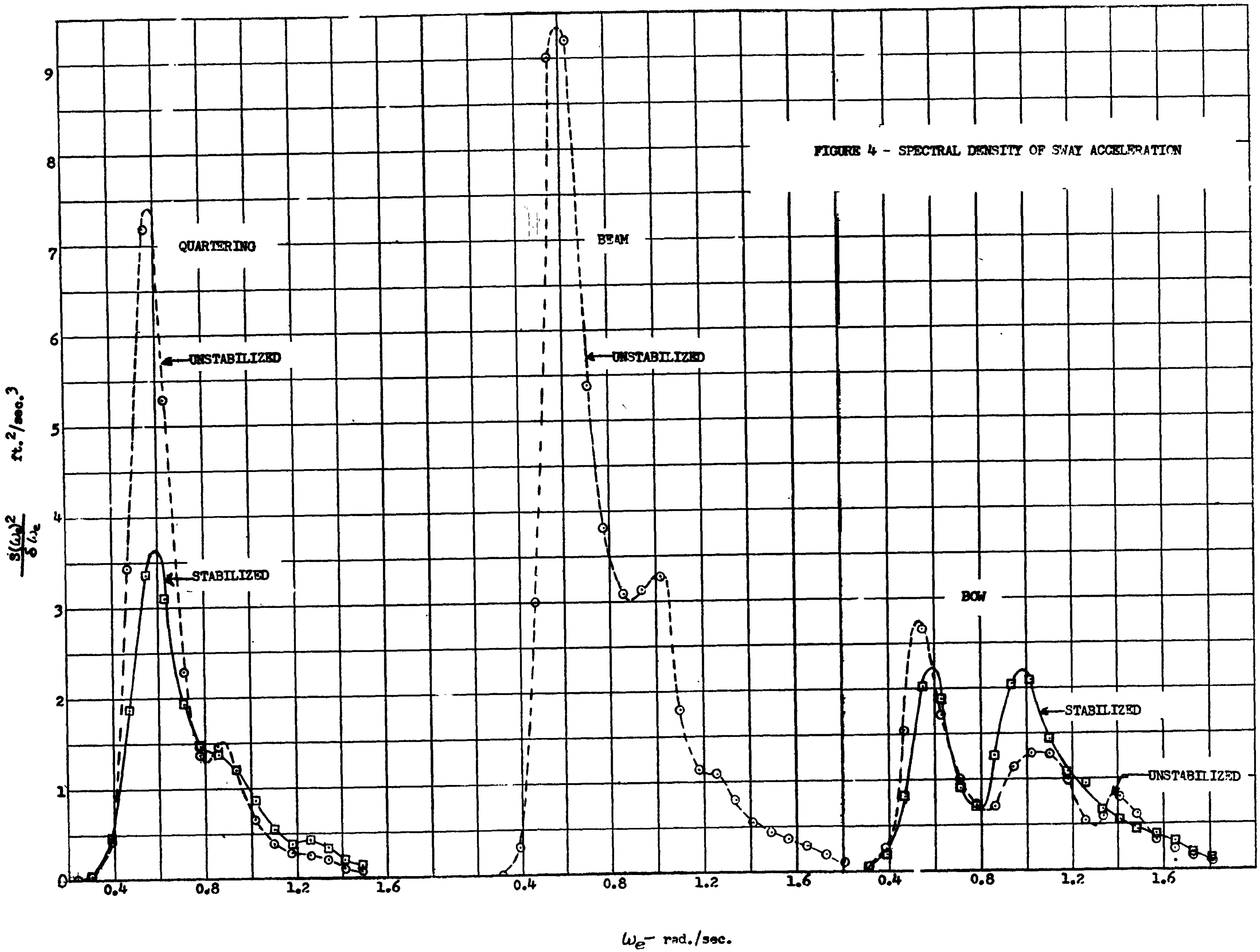

FIGURE 4 - SPECTRAL DENSITY OF SWAY ACCELERATION

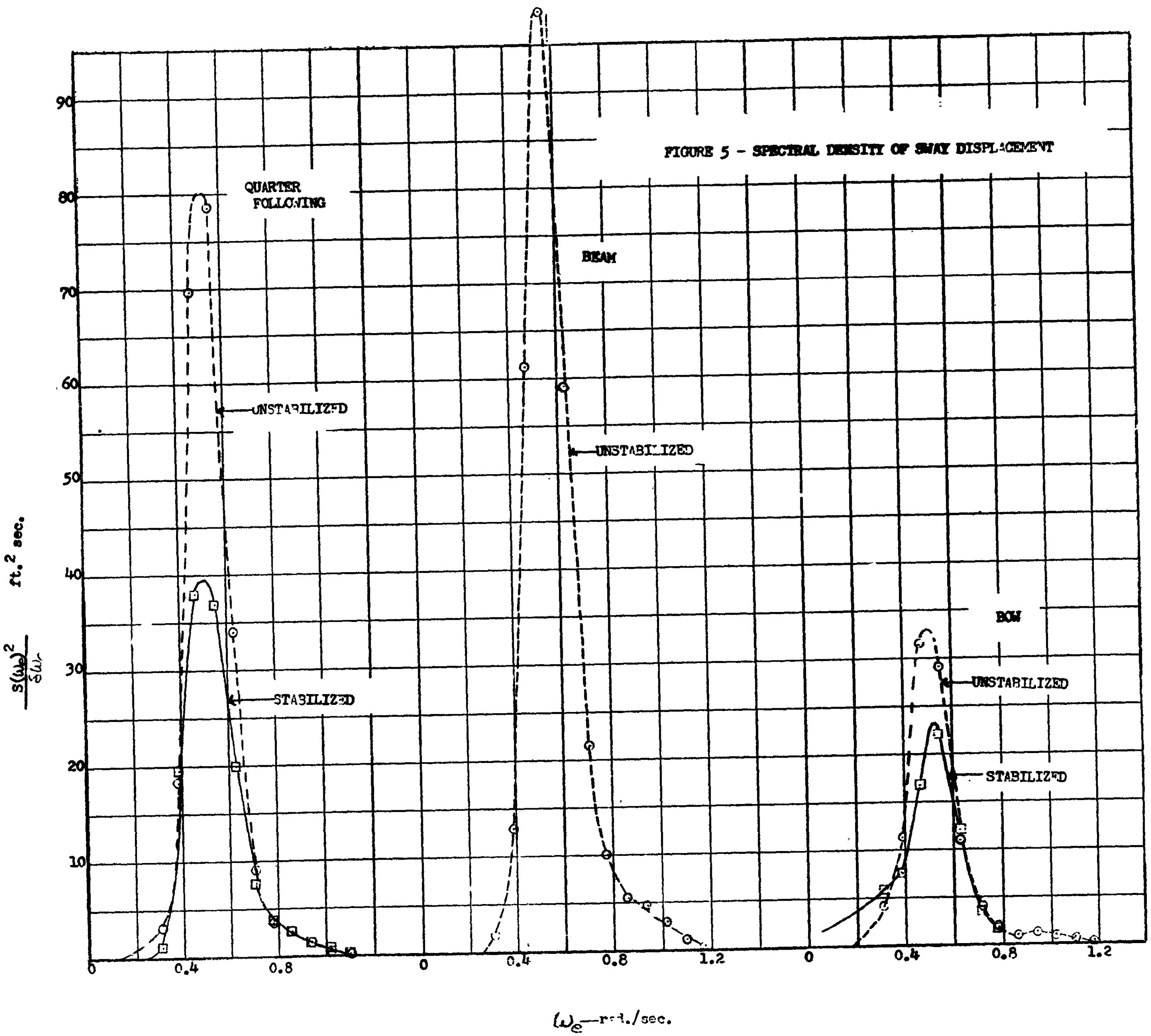

FIGURE 5 - SPECTRAL DENSITY OF SWAY DISPLACEMENT

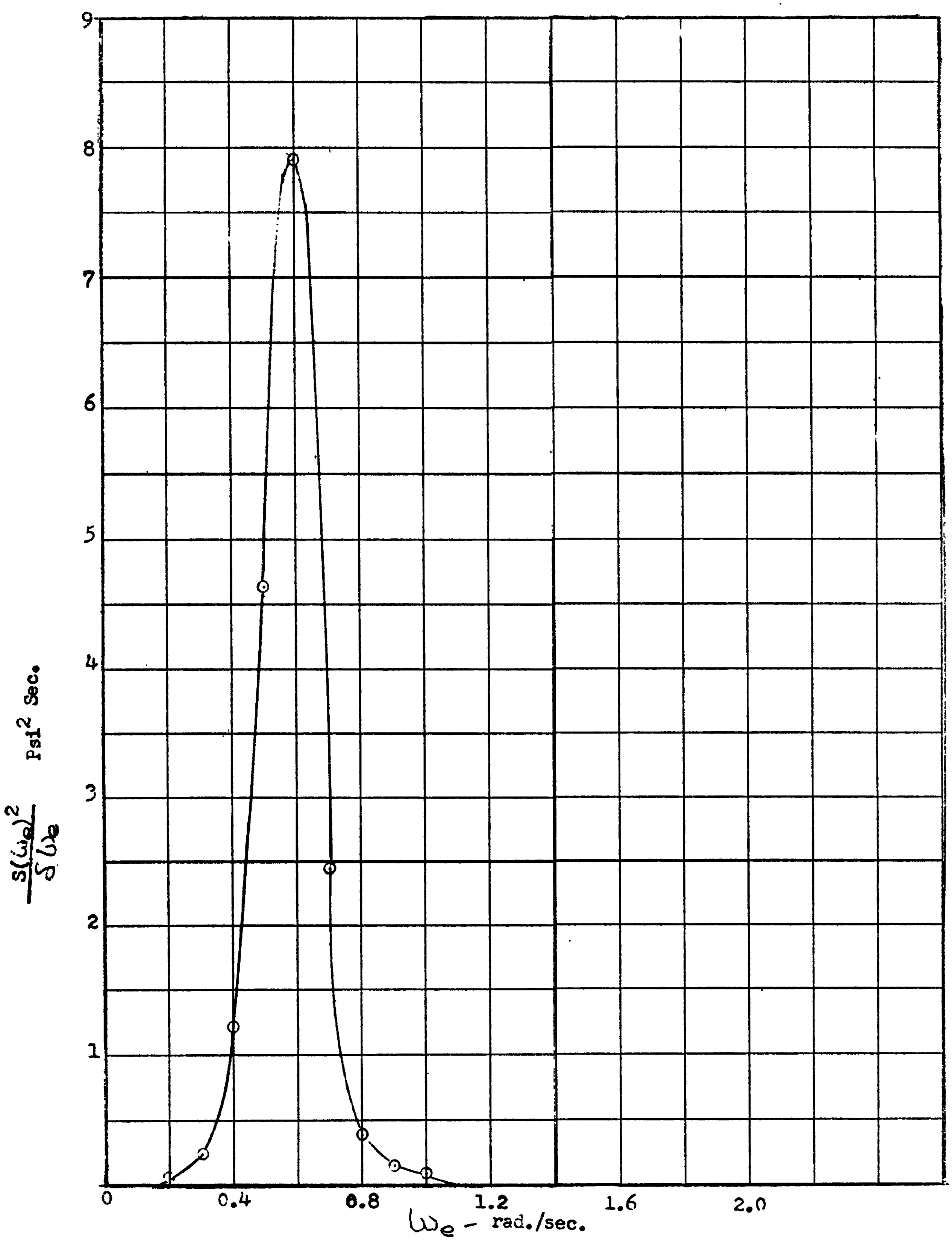

FIGURE 6 - SPECTRAL DENSITY OF A REPRESENTATIVE PRESSURE RECORD

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