TECHNICAL NOTE R-185

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A SURVEY OF RING BAFFLE DAMPING IN CYLINDRICAL TANKS

by G. P. Stricklin
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RESEARCH LABORATORIES

BROWN ENGINEERING COMPANY, INC.

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A SURVEY OF RING BAFFLE DAMPING IN CYLINDRICAL TANKS

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STRUCTURES DIVISION
PROPULSION AND VEHICLE ENGINEERING LABORATORY
GEORGE C. MARSHALL SPACE FLIGHT CENTER

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Prepared By

G. P. Stricklin
J. A. Baird

ABSTRACT

A survey of Miles' method for determining the damping produced by ring baffles in cylindrical tanks was conducted. O'Neill's modification of Miles' equation which eliminates free surface wave height from this equation is discussed. Experimental investigations from several sources which determine the damping and frequency of liquid oscillation in ring baffled cylindrical tanks are surveyed. These experimental investigations give an indication of the conditions for which Miles' equation is applicable.

Approved:

E. J. Rodgers

E. J. Rodgers
Manager
Mechanics and Thermodynamics Department

Approved:

R C Watson Jr

R. C. Watson, Jr.
Vice President
Advanced Systems & Technologies

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LIST OF SYMBOLS

a	Radius of circular cylindrical tank
C_D	Local drag coefficient
d	Depth of baffle below equilibrium surface
E	Energy of motion
F	Force on tank wall in lateral direction
$\overline{F}$	Dimensionless force coefficient, $F/\rho g a^3$
F_c	Correction factor in Miles' equation
g	Acceleration due to gravity
h	Height of liquid equilibrium surface measured from tank bottom
J_1	Bessel function of first kind of order one
k	$= 1.84/a$
P	Pressure on the baffle
r, θ, z	Cylindrical coordinates
S	Cross sectional area of tank, πa^2
T	Period
t	Time
U_m	Timewise maximum velocity
v_n	Velocity normal to a surface
W	Baffle width
w	Vertical component of velocity

LIST OF SYMBOLS (Continued)

Greek Symbols

α	Ratio of baffle area to cross-sectional area of the tank
γ	Damping ratio
δ	Logarithmic decrement
ζ	Free surface height
ρ	Mass density
ϕ	Velocity potential
ω	Circular frequency of liquid oscillation

INTRODUCTION

In the study of the structural dynamics of space vehicles the effect of fuel sloshing is normally introduced by means of a mechanical model. These mechanical models usually include the effects of damping which is introduced in the form of a quantity called the damping factor or damping ratio. In order that the model properly represent the fuel sloshing it is important to be able to accurately predict the value of the damping ratio for various types of tanks. The purpose of this report is to give a survey of Miles' method for predicting the damping ratio for cylindrical tanks with ring baffles. Miles' method of analysis is discussed along with certain modifications to it. A discussion of some experimental results and their comparison to Miles' analysis is also included.

DESCRIPTION OF MILES' METHOD

Miles[1] determines an expression for the damping produced by ring baffles in a cylindrical tank based upon potential flow theory and experimental observations. The tank and baffle configuration is shown in Figure 1.

Miles solves Laplace's equation, subject to appropriate boundary conditions, for free oscillation of a liquid in a rigid unbaffled tank using the linearized free surface condition. The solution is subject to several assumptions listed as follows:

- The ring width is small compared to the tank radius, $\alpha << 1$.
- Local flow in the neighborhood of the baffle is not affected by the free surface or the bottom of the tank.
- The first mode of sloshing persists except in the immediate vicinity of the ring.

A velocity potential function satisfying Laplace's equation and the boundary conditions is

$$\phi = J_1(kr)\,\frac{\cosh[k(z+h)]}{\cosh(kh)}\,\sin\omega t\,(A\sin\theta + B\cos\theta) \quad , \tag{1}$$

where A and B are constants to be evaluated. This potential function is valid only for the first sloshing mode where the frequency is given by

$$\omega = [\,kg\ \tanh(kh)]^{\frac{1}{2}} \tag{2}$$

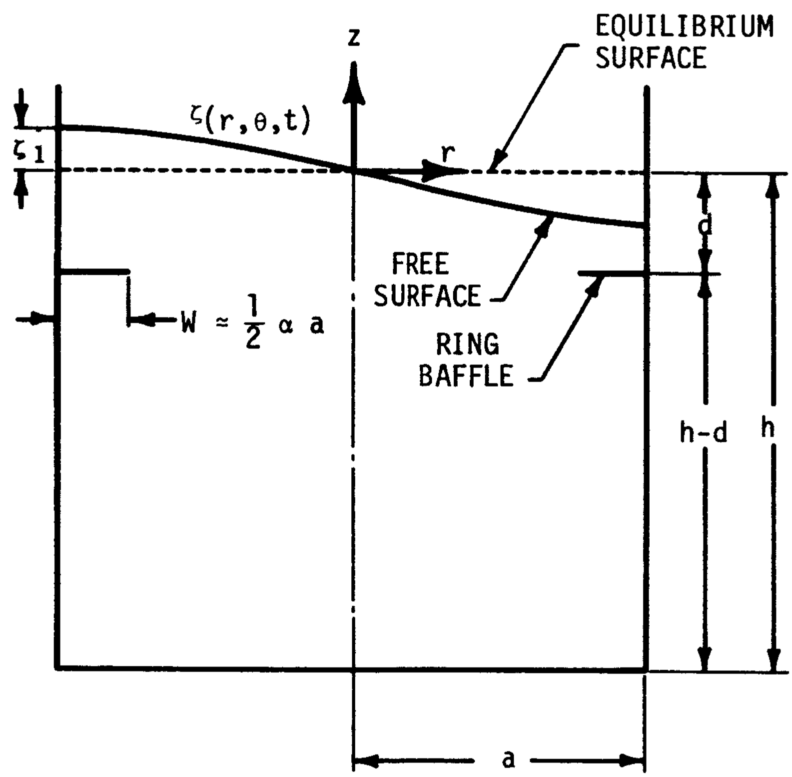

Figure 1. Sectional View of Cylindrical Tank with Ring Baffle.

and $ka = 1.84$. The free surface height ζ is found from the expression

$$\zeta = -\frac{1}{g}\frac{\partial \phi}{\partial t} \qquad \text{on} \qquad z = 0 \quad , \tag{3}$$

which yields

$$\zeta = -\frac{\omega}{g} J_1(kr) \cos(\omega t)(A \sin\theta + B\cos\theta) \tag{4}$$

The constants A and B are evaluated from knowledge of the free surface shape. ζ is zero at $\theta = \pi/2$ and $3\pi/2$; therefore, the constant A is zero. If ζ_1 is defined as the maximum wave height at the tank wall over a cycle, $[\zeta_1 = \zeta(r = a,\ \theta = 0,\ t = 0)]$, then Equation 4 may be written as

$$\zeta = \zeta_1 \frac{J_1(kr)}{J_1(ka)} \cos\theta \cos(\omega t) \quad . \tag{5}$$

Equation 1 can now be written as

$$\phi = \frac{\zeta_1 g}{\omega} \frac{J_1(kr)}{J_1(ka)} \frac{\cosh[k(z+k)]}{\cosh(kh)} \cos\theta \sin(\omega t) \tag{6}$$

For the undamped case ζ_1 is a constant; however, if damping is present ζ_1 is reduced to a lower value for the next cycle $(t = 2\pi/\omega)$.

Miles gives the damping ratio in the form

$$\gamma = \frac{1}{2\omega E} \overline{\frac{dE}{dt}} \quad . \tag{7}$$

The total energy of motion, E, exhibited at the free surface is found from classical theory to be

$$E = \frac{1}{4} \rho g \zeta_1^2 S \left[1 - \frac{1}{(ka)^2} \right] . \tag{8}$$

where S is the cross-sectional area of the tank. The mean rate of energy dissipation, $(\overline{dE/dt})$, is found by evaluating the integral

$$\overline{\frac{dE}{dt}} = -\frac{\omega}{2\pi} \int_0^{\frac{2\pi}{\omega}} \int \int_{\alpha S} P \, v_n dS \tag{9}$$

at z = -d. The pressure on the ring is $(\rho w^2 C_D/2)$, where C_D is the drag coefficient and the vertical velocity component at z = -d, r = a is found from Equations 2 and 6 to be

$$w = -\omega \zeta_1 \; f(-d) \cos(\theta) \sin(\omega t) \quad , \tag{10}$$

where

$$f(-d) = \frac{\sinh[k(h-d)]}{\sinh(kh)} \quad .$$

In the evaluation of Equation 9, C_D is assumed constant in integrating over θ, and ζ_1 as constant in integrating over t. The result is

$$\overline{\frac{dE}{dt}} = -\frac{1}{2} S \rho \alpha C_D [\omega \; f(-d) \zeta]^3 \left(\frac{4}{3\pi}\right)^2 \quad . \tag{11}$$

Substitution of Equations 8 and 11 into Equation 7 yields

$$\gamma = 0.473 \; \exp[-5.52 (d/a)] \; \alpha \left(\frac{\zeta_1}{a}\right) C_D \quad , \tag{12}$$

after the hyperbolic tangent is approximated by unity and f(-d) by exp (-kd).

Based on an experimental study of Keulegan and Carpenter[2] for flat plates in oscillating flow, the drag coefficient is taken as a function of the period parameter, $(U_m T/D)$, where

U_m - timewise maximum velocity,

T - period,

D - double baffle width.

The expression for C_D is

$$C_D = 15 \left(\frac{U_m T}{D}\right), \quad 2 \leq \frac{U_m T}{D} \leq 20 \quad . \tag{13}$$

The drag coefficient in Equation 13 is found by substitution of Equation 10 with the same assumptions used for tanh (kh) and f(-d) as in obtaining Equation 12. The result is

$$C_D = 15 \left[\frac{2\pi \exp\left[-1.84\,(d/a)\right]}{\alpha} \left(\frac{\zeta_1}{a}\right) \cos\theta \right]^{-\frac{1}{2}} \quad . \tag{14}$$

Substitution of Equation 14 into Equation 12 with $\cos\theta$ set equal to unity yields Miles' final result for the damping ratio:

$$\gamma = 2.83\, \alpha^{\frac{3}{2}} \exp\left[-4.60\,(d/a)\right] \left(\frac{\zeta_1}{a}\right)^{\frac{1}{2}} F_c \quad , \tag{15}$$

where F_c is a correction factor to account for the inexactness in the determination of C_D. Miles gives evidence based upon experimental observations of Howell and Ehler[3] that the correction factor is approximately 1.5. Subsequent investigators have used Equation 15 with $F_c = 1$ to correlate their experimental results; the agreement will be discussed in later sections.

MILES' EQUATION IN MODIFIED FORM

O'Neill[4] modified Miles' expression (Equation 15) to enhance its use in actual situations. O'Neill states that the lateral slosh force is of greater interest to the designer than the wave amplitude at the wall, ζ_1. The lateral force is more easily measured in experimental slosh facilities than wave heights. O'Neill makes use of the dimensionless force coefficient defined as

$$\overline{F} = \frac{F}{\rho g a^3} \quad . \tag{16}$$

The lateral force, F, is found from linear slosh theory and the maximum wave amplitude can be expressed in terms of $\overline{F}$ as

$$\overline{F} = 1.71 \left(\frac{\zeta_1}{a}\right) \tag{17}$$

For the first mode for $h > a$. Substitution of Equation 17 into Equation 15 with the correction factor set to unity yields

$$\gamma = 2.16\, \alpha^{\frac{3}{2}} \exp\left[-4.60\,(d/a)\right] \quad (\overline{F})^{\frac{1}{2}} \quad . \tag{18}$$

The discussion of Equation 18 with respect to experiment observations is presented in a later section.

EXPERIMENTAL INVESTIGATIONS

INVESTIGATION OF SILVEIRA, STEPHANS, AND LEONARD[4]

This investigation was performed to determine the damping effect of baffles on liquid oscillating in its fundamental nonsymmetric mode for cylindrical tanks and the effect of baffles on the frequency of oscillation. Various baffle configurations were tested with the results indicating that ring baffles provide the greatest damping for a given baffle surface area. The subsequent discussion will be limited to the observed characteristics of ring baffles.

The two tanks studied were 12 and 30 in. in diameter. The 12-in. tank was fitted with various width ring baffles ($W/a = 0.076, 0.123, 0.157, 0.241$). The baffle thickness for this tank was 0.125 in. The data of interest to this investigation was mostly obtained using the 12-in. tank. A study showing the effects of tank diameter employed data from both 12- and 30-in. tanks. The baffle thickness for the 30-in. tank was 0.25 in. The test liquid was water. The liquid in the cylinder was excited in its fundamental nonsymmetric mode by a paddle. When the wave height was sufficient, the paddle was removed and the motion allowed to damp out.

If a linear system is assumed, the logarithmic decrement may be written as

$$\delta = \frac{1}{n} \ln \frac{M_o}{M_n}$$

where M_o is the amplitude of the initial moment and M_n is the moment amplitude after n cycles. Moments were measured for the 12-in. tank by a torsion bar, strain gage arrangement. The 30-in. tank was supported by three legs, one of which was a load cell. These signals were amplified and read into a dampometer from which moment and frequency data were obtained.

The 12-in. tank was tested for four different baffle widths, and the logarithmic decrement was found as a function of baffle depth below the equilibrium surface. This data with baffle width as a parameter is plotted in Figure 2. Due to difficulty in exciting the fundamental mode for the range of maximum damping, the plotted data in this range is doubtful. In this uncertain region the curves of Figure 2 are shown as dashed lines. The general shape of all the curves are similar. The damping increases with baffle depth until the entire ring is submerged throughout the slosh cycle; then the damping decreases with depth until the condition of an unbaffled tank is reached. An attempt to correlate this data with Miles' formula for damping was not made.

The effect of surface-wave height on the logarithmic decrement was examined for the 12- in. diameter tank. The baffle width and depth below the equilibrium surface were held constant at $W/a = 0.076$ and $d/a = 0.333$, respectively. The amount of water in the tank was varied. The results of this study appear in Figure 3. A divider baffle was present in addition to the ring baffle for some of the data points of Figure 3. Data was also obtained for the ring baffle without the divider.

Miles' equation in terms of the logarithmic decrement,

$$\delta = (2\pi)\, 0.283 \exp\left[-4.60\, (d/R)\right] \alpha^{\frac{3}{2}} \left(\frac{\zeta_1}{R}\right)^{\frac{1}{2}} \quad , \tag{19}$$

was compared to the experimental data of this test. The initial value of the wave amplitude is the value plotted in Figure 3. The higher values of damping obtained for the ring with the divider as compared to the data for the ring without the divider indicate that the excess damping was produced by the divider. Comparison of Miles' equation to the experimental data shows good agreement.

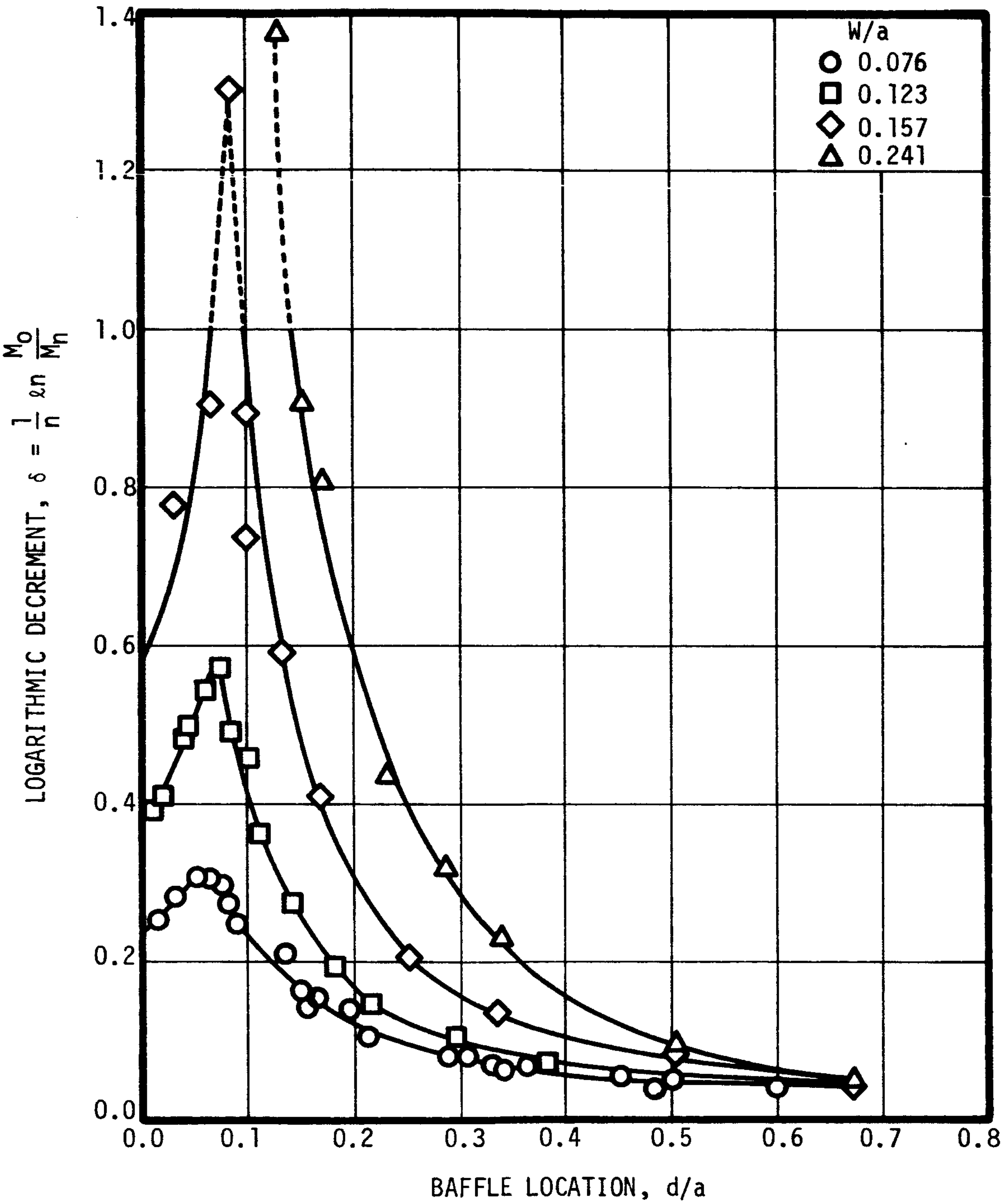

Figure 2. Variation of Logarithmic Decrement with Baffle Location for Fixed-Ring Baffle. a = 6 inches; h/a = 2. (from Reference 4)

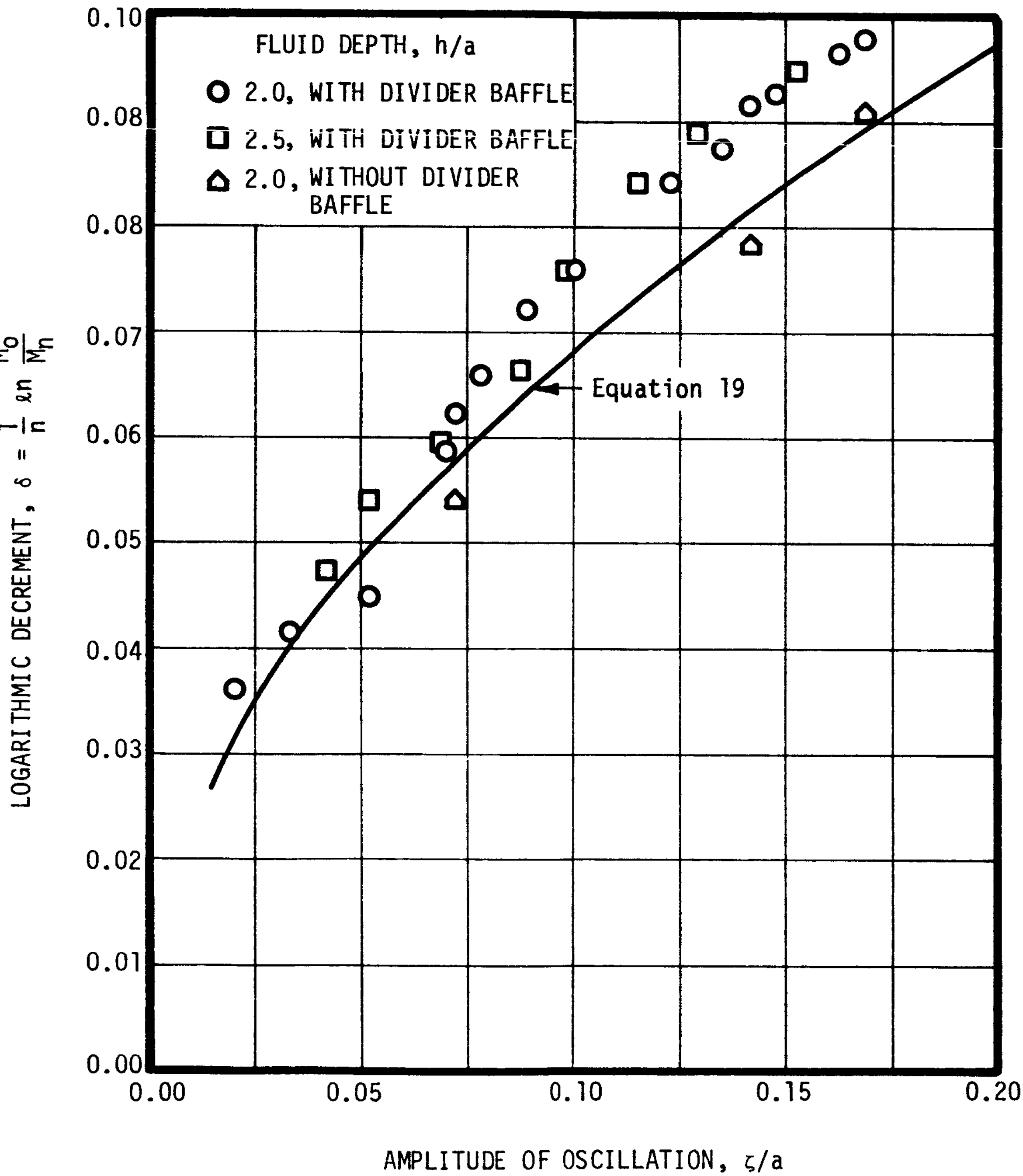

Figure 3. Variation of Logarithmic Decrement with Amplitude of Oscillation For Fixed-Ring Baffle. $W/a = 0.076$; $d/a = 0.333$ (from Reference 4)

The effect of tank diameter on the damping produced by ring baffles was examined by comparing data for the 12- and 30-in. diameter tanks. The same width baffle, $W/a = 0.076$, was used in both tanks. The results of this test are shown in Figure 4. The factor,

$$\alpha^{\frac{3}{2}} \left(\frac{\zeta_1}{a}\right)^{\frac{1}{2}} ,$$

was evidently maintained at a constant value for both tanks. Miles' equation is also plotted in Figure 4 and shows good agreement except at baffle depths of $d/a > 0.1$.

The effect of ring baffles on the natural frequency of the fundamental mode was measured for the four baffle widths in the 12-in. tank. The results are shown in Figure 5. These data indicate that the maximum frequency is obtained when the baffle is at the equilibrium surface. At depths below the equilibrium surface the frequency drops to a minimum value which is below that of an unbaffled tank, and with further reduction in baffle depth the frequency approaches that of an unbaffled tank.

INVESTIGATION OF O'NEILL[5]

The objectives of O'Neill's study were to provide more reliable experimental data on ring damping in cylindrical tanks, and to determine the applicability of Miles' equation for conditions which are beyond the limiting assumptions of this equation. Wave amplitudes are difficult to measure and in some cases difficult to define. As has been shown previously, O'Neill derives the dimensionless force coefficient,

$$\overline{F} \approx 1.71 \left(\frac{\zeta_1}{a}\right) ,$$

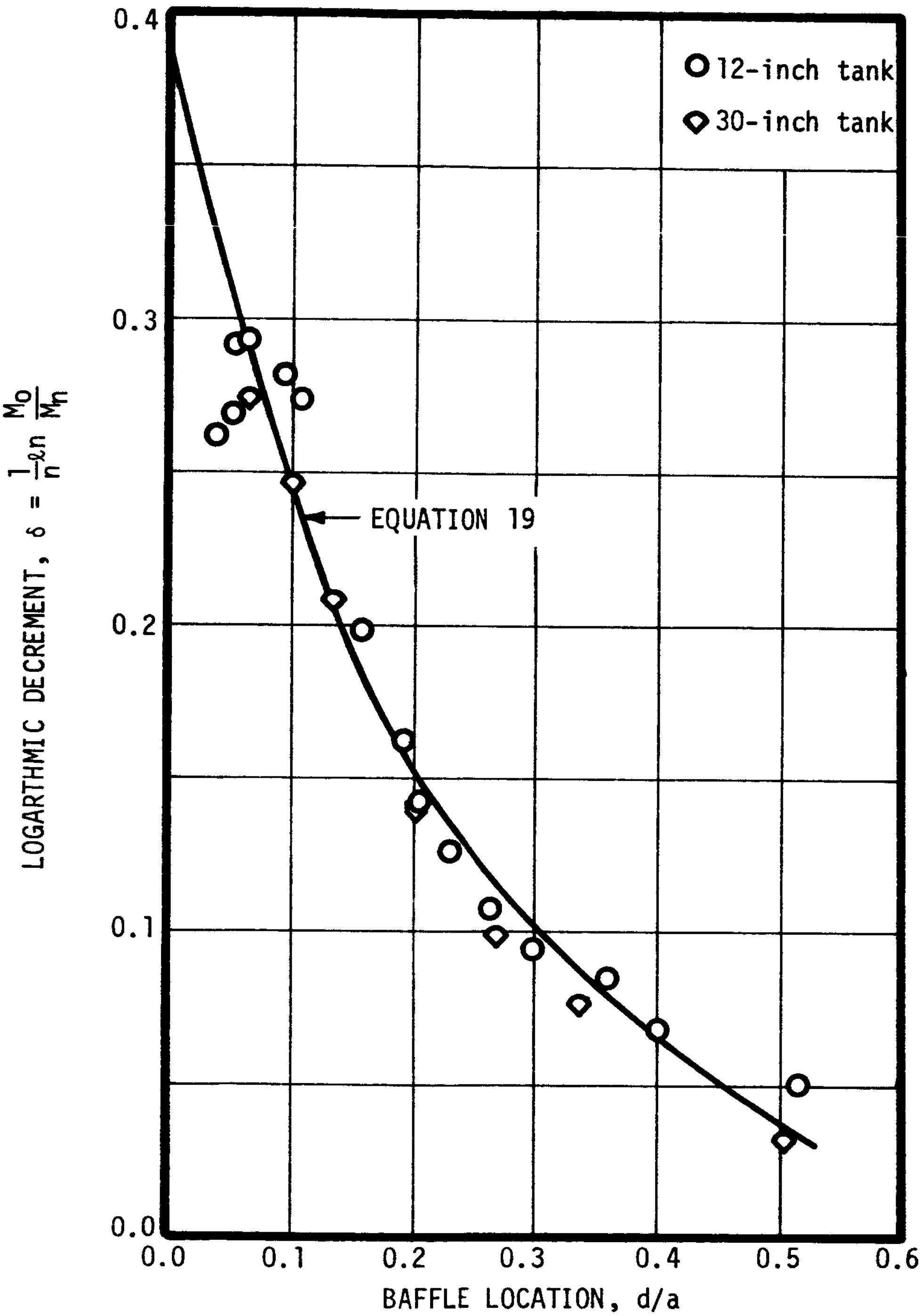

Figure 4. Variation of Logarithmic Decrement with Baffle Location in the 12- and 30-inch Diameter Tanks (from Reference 4)

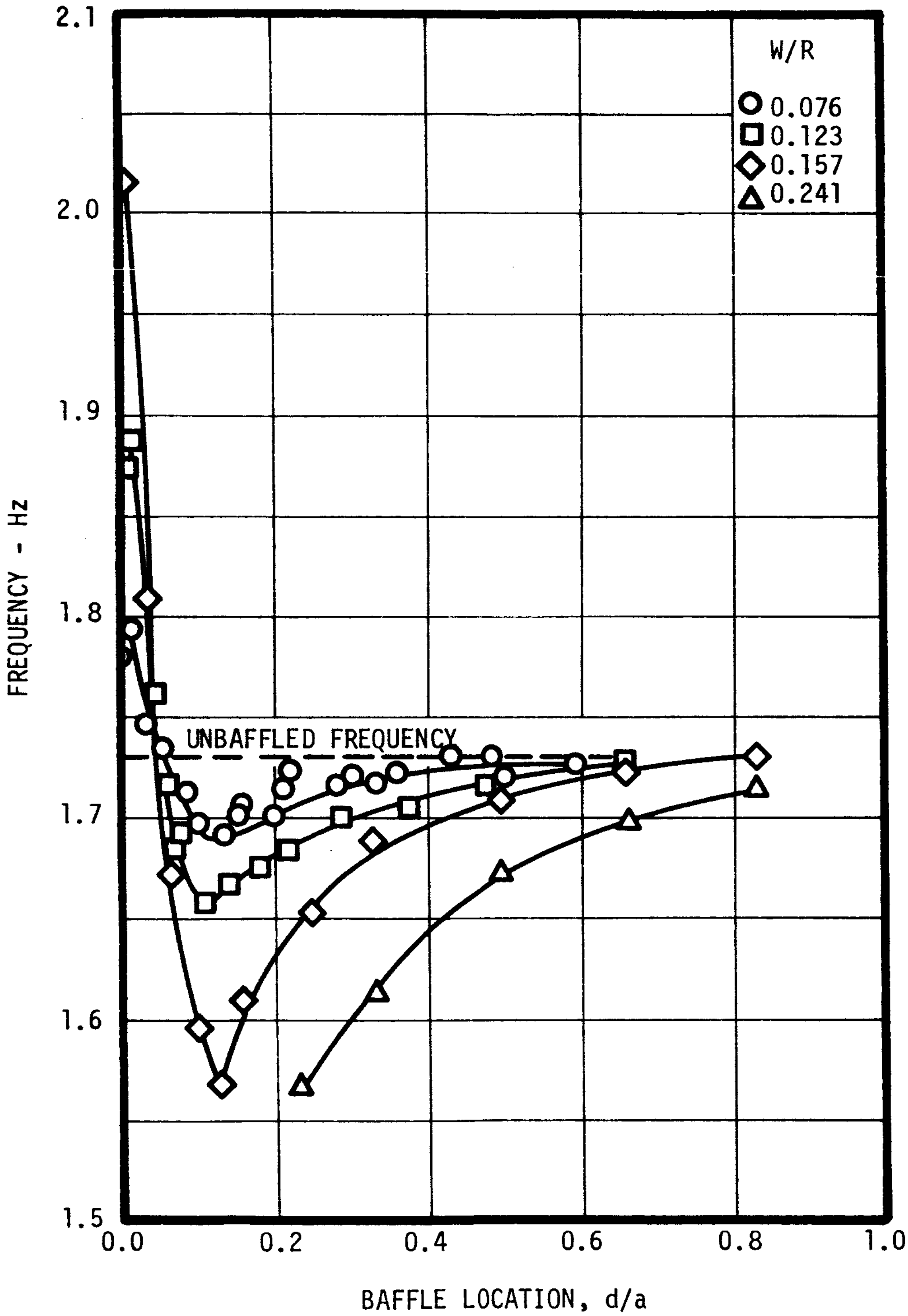

Figure 5. Variation of Frequency with Baffle Location for Fixed-Ring Baffle.

based upon classical potential theory. By substitution of this expression into Miles' formula, the damping is given as a function of lateral force which is more easily measured than wave amplitude and is a more valuable parameter for design purposes.

The slosh facility was designed such that there was only one degree of freedom along the drive axis. A scotch-yoke mechanism was employed to produce sinusoidal lateral motion of the tank. The drive was supplied by a variable speed motor. The quantities measured as a function of time were: the force in the drive link, lateral displacement of the tank and platform, amplitude of the surface wave at the wall, and the vertical force on the ring baffle. The frequencies of the drive and surface were measured when necessary.

Five different methods of measuring ring damping were used in this study. A method (or methods) was sought to yield damping data for situations which were thought more apt to occur in actual missile flight; i.e., in situations where sloshing occurs, the ring breaks the surface, and the baffle area is not small as compared to the cross-sectional area of the tank. The five methods used to experimentally determine the damping are outlined below.

Ring Force Method

The vertical force required to anchor the ring to the tank wall is measured; the component of ring force which is out of phase with the vertical velocity is used to determine the energy dissipation over a cycle of motion. The ring damping is obtained by comparing this energy dissipation to the total energy of motion found by applying classical theory using measured wave amplitudes. The tank is driven at or near the frequency of the mode of interest. Continuous records are taken to determine the phase relation between the vertical velocity of the liquid and the ring force. This method gives the damping ratio due to the ring alone exclusive of the viscous damping for an unbaffled tank. The ring damping has been found to be the predominant percentage of the total damping.

Drive Force Method

The tank is oscillated laterally at a frequency close to the natural frequency of the contained liquid's first mode. After steady-state sloshing is obtained, a record is made of the force in the drive link. If the damping of the tank support mechanism is negligible as compared to the ring damping the steady-state energy input to the system is equivalent to the energy dissipated by the ring baffle. This energy input is determined from the force in the drive link. The total energy of motion is calculated from the wave amplitudes at the tank wall using classical theory. The comparison of the dissipated energy to the total energy gives the damping ratio.

Wave Amplitude Response Method

This method employs the bandwidth technique to determine the damping ratio. The tank is driven at a constant excitation amplitude through a frequency range which includes the resonant frequency of the dominant slosh mode. A typical data curve is shown in Figure 6.

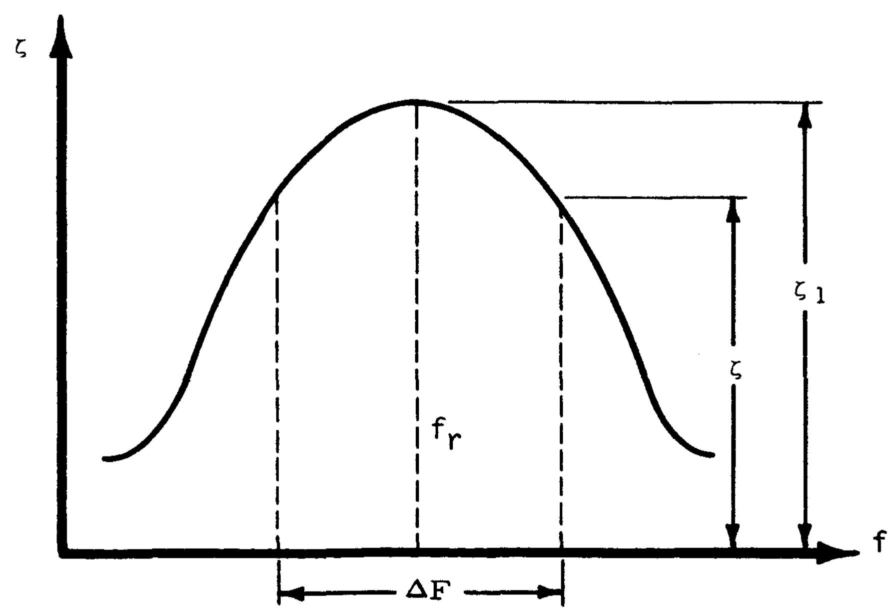

Figure 6. A Typical Data Curve

The expression for the damping ratio is

$$\gamma = \frac{1}{2} \frac{\Delta f}{f_r} \left[\left(\frac{\zeta_1}{\zeta} \right)^2 - 1 \right]^{-\frac{1}{2}} \quad .$$

If the ratio $(\zeta_1/\zeta) = 2/\sqrt{2}$ is substituted in the above equation, the result is

$$\gamma = \frac{1}{2} \frac{\Delta f}{f_r} \quad .$$

Damping ratios obtained by this method are reliable only if the resonant frequencies of the oscillating fluid are not close. For a linear system lateral forces may be used instead of wave amplitudes.

Wave Amplitude Decay Method

In this method the free surface wave heights at the wall are measured after the excitation has ceased. From the ratio of successive wave heights the logarithmic decrement and damping ratio are obtained.

Wave Force Decay Method

The tank is driven at a frequency close to the resonant frequency of the principal slosh mode. The motion of the tank is abruptly stopped after the wave height is sufficient and the drive link firmly anchored. The force in the drive link is recorded. If the system is assumed to be linear, then the peak wave amplitudes are proportional to the peak force amplitudes. The ratio of successive peak forces can be used to give the damping ratio.

Tests were run using the five methods of determining the damping for a 0.495-ft diameter tank fitted with two different width single baffles. Three baffle submergence depths were examined for each width baffle.

Data for two submergence depths which more nearly conforms with Miles' assumptions is plotted in Figure 7. Miles' equation in the modified form as presented by O'Neill is also plotted.

For d/a = 0.505 the wave force decay and wave amplitude decay methods give results in agreement with theory. The ring force and drive force methods give damping values below the theoretical curve. The data obtained by the wave amplitude response method is considerably higher than predicted; the data for the other four methods is considered in acceptable agreement within experimental scatter of the predicted values.

For the shallower depth data recorded in Figure 7 where the damping by the ring baffle is more predominant, the four acceptable methods for deeper submergence were found to be in fair agreement with the theoretical curve. The wave amplitude response method again gave high values. Data for this submergence shows more scatter than that for the deeper submergence ring.

O'Neill states that a knowledge of lateral forces on the tank wall is of more value than wave heights. The wave force decay method was improved and used exclusively in subsequent tests.

Experiments to determine the damping of two ring baffles in a 0.729-ft radius tank were carried out for three submergence depths. Records include the condition of zero submergence, (d/a) = 0, in which the smooth surface of the fundamental mode is difficult to obtain. This condition of wave-splashing is obviously beyond the assumptions of Miles' equation. The results of these tests using the wave force decay method of testing along with appropriate theoretical curves are shown in Figures 8 and 9.

Some of the measured values of the damping ratio are above the theoretically predicted values. Notice that when both width baffles are at the deepest recorded depth that the measured values more nearly match the theoretical prediction. This is the condition for which the assumptions of the theory are more nearly met.

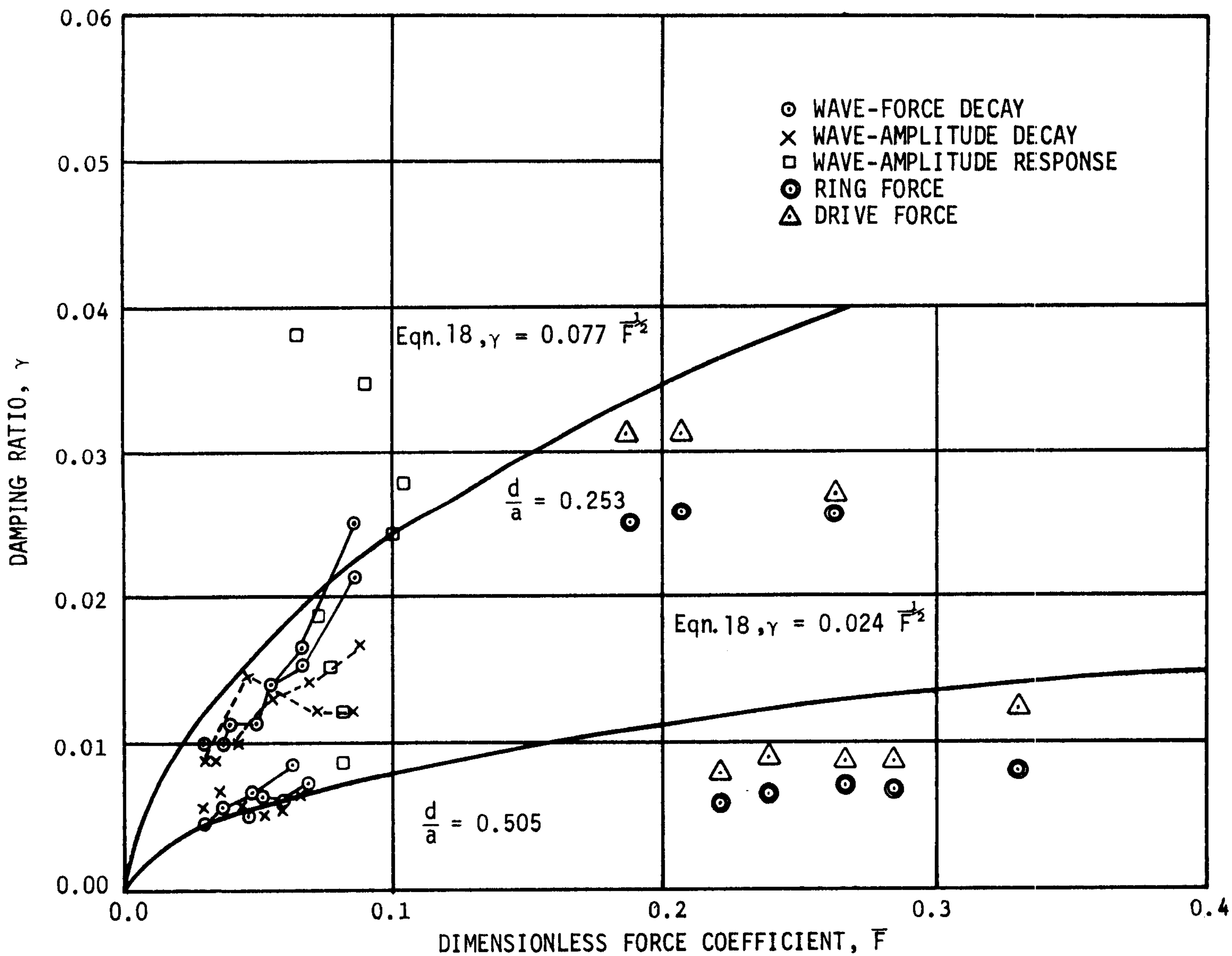

Figure 7. Damping Ratios for Cylindrical Tank with Flat Bottom and Annular Damping Ring. Ring position $(h-d)/a = 2.11$; ring-width parameter $\alpha = 0.235$ (from Reference 5)

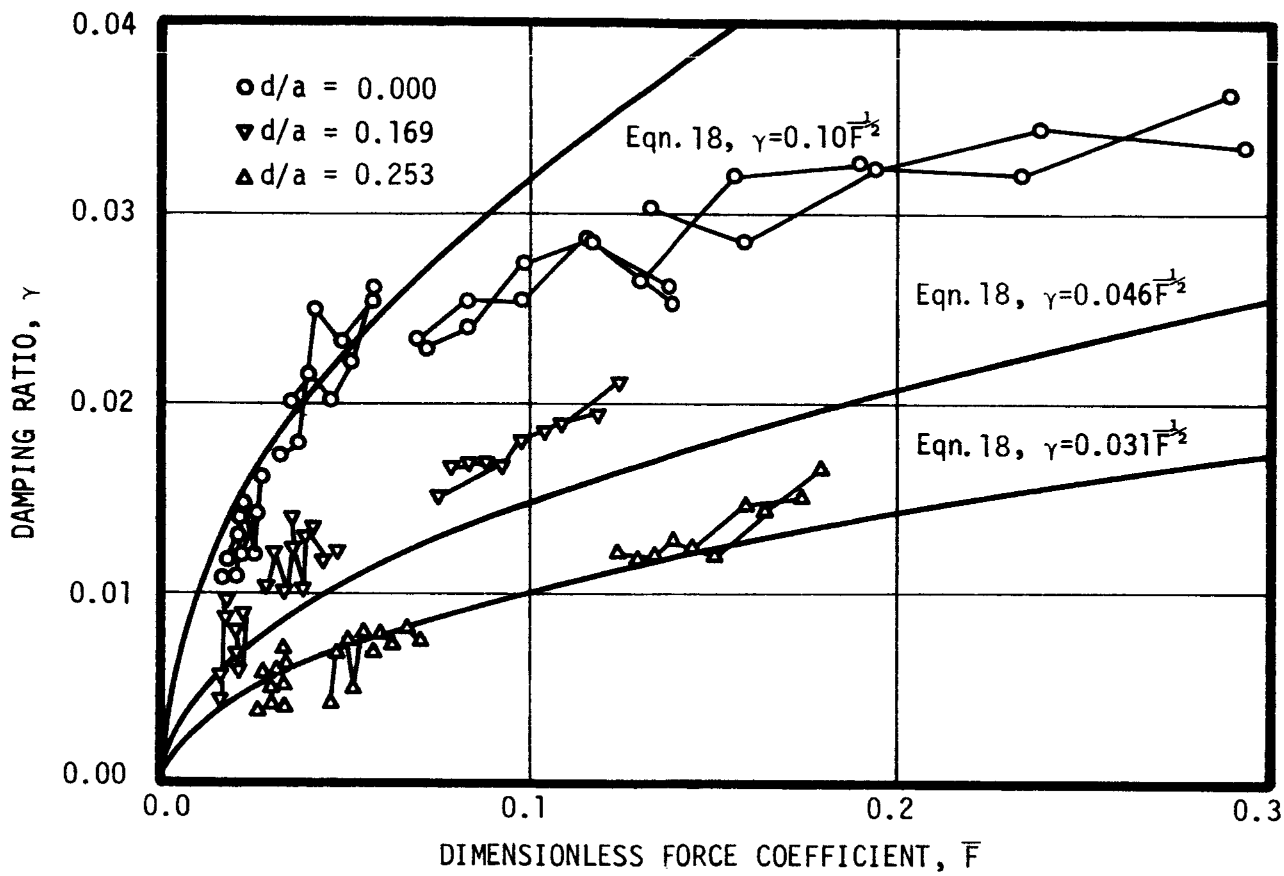

Figure 8. Damping Ratios by the Wave-Force Method for Cylindrical Tank with Flat Bottom and Annular Damping Ring. Ring position $(h-d)/a = 2.11$; ring-width parameter $\alpha = 0.118$ (from Reference 5)

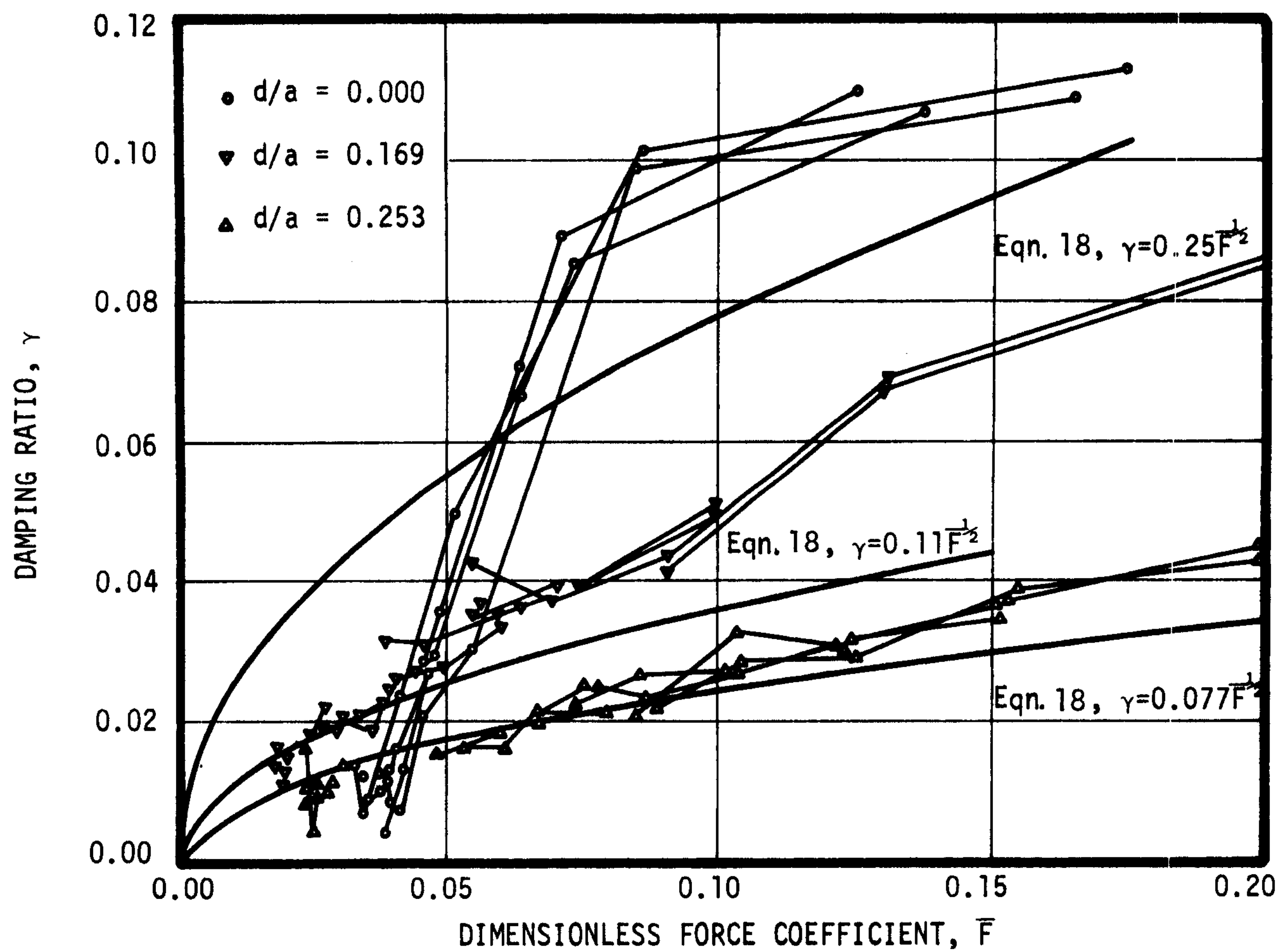

Figure 9. Damping Ratios by the Wave-Force Method for Cylindrical Tank with Flat Bottom and Annular Damping Ring. Ring position $(h-d)/a = 2.11$; ring-width parameter $\alpha = 0.235$ (from Reference 5)

The data for both ring widths show that the greatest damping is obtained when the ring is at the equilibrium surface. At $(d/a) = 0$ when a small force coefficient or wave amplitude was observed, the damping was below that predicted. Observations of the free surface indicated the fluid motion was confined to a surface area which effectively excluded the baffle. This was not considered to be of consequence since the wave amplitudes were smaller than could be expected in actual circumstances, and the frequency of oscillation was higher than that of the first mode for an unbaffled tank.

O'Neill concluded his investigation by stating that Miles' theoretical formula gives adequate results within ±30% of the experimentally observed values.

INVESTIGATION OF ABRAMSON AND GARZA[6]

The purpose of this investigation was to extend the results presented by Silveira to include the effects of baffle perforation on damping and the frequency of the oscillating liquid. Also the damping of a single ring baffle was compared to the theoretical prediction of Miles. In this investigation the tank was undergoing forced oscillations.

A 1.2-ft diameter rigid wall cylindrical tank was excited in translational motion with amplitudes in the range, $0.00184 \leqq X_o/2a \leqq 0.00823$. One baffle width was used for all the experiments. The baffle thickness was varied from 0.018 to 0.030 inches. The baffle width ratio was maintained at $(W/a) = 0.157$ for all experiments. The height of the equilibrium surface was held at $(h/a) = 2$. The damping ratio, γ, and resonant frequency parameter, $(2\omega^2 a/g)$, were determined as a function of baffle submergence ratio, d/a. Due to significant effects of excitation amplitude the data presented was in terms of rms values of excitation amplitude. Damping was determined by the half-bandwidth technique using the resonance peaks of the experimental force response curves.

Experimentally determined values of damping ratio versus baffle depth are plotted in Figure 10. Miles' equation based on observed surface wave heights at the wall with $F_C = 1$ is plotted to give a comparison. The agreement is poor for $(d/a) < 0.125$, and good for $(d/a) > 0.125$. The author states that the surface wave shape is quite complex and not in agreement with the theoretical assumptions.

Two experiments were performed to find the effects on damping and frequency characteristics after reducing the baffle area by perforation. In one experiment the area was reduced from 0 to 30% by 0.079 in. holes. The effect is shown in Figure 11a. A curve for 23% area reduction by 0.020 in. holes is included for comparison purposes. The baffle with the smaller holes gives much greater damping than the baffle with the same area reduction by larger holes. This is probably due to the greater effect of viscosity with respect to the smaller holes. The trend is that a reduction in baffle area yields a corresponding reduction in damping.

Figure 11b shows the effect of different hole sizes on the damping at 30% reduced area. These curves indicate that the baffles with smaller holes are more effective in damping.

The liquid resonant frequencies were determined as a function of the baffle depth. The resonant frequency is plotted as the dimensionless resonant frequency parameter. This data is shown in Figures 12a and 12b. The resonant frequency is a maximum at $(d/a) = 0$ and decreases to a minimum at approximately $(d/a) = 0.10$. With further reduction in baffle depth the frequency gradually increases to that of an unbaffled tank. Figure 12a shows that the minimum frequency is lowest for the solid baffle and as the percentage perforation increases this minimum increases. Figure 12b shows that in general with 30% reduction in baffle area the large hole sizes give higher frequencies through most of the depth range.

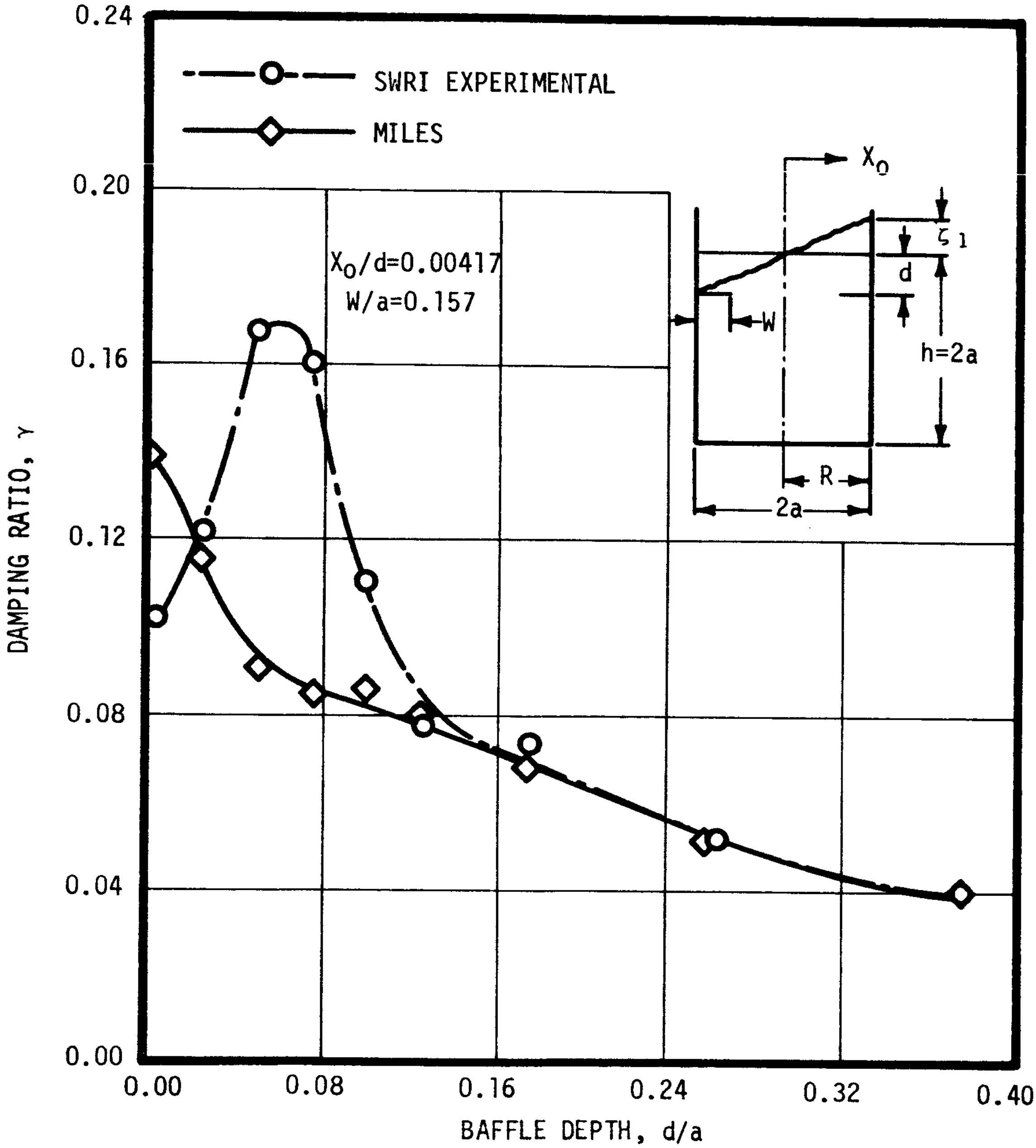

Figure 10. Comparison of Theory and Experiment for Damping Provided by a Flat Solid Ring Baffle as a Function of Baffle Depth (from Reference 6)

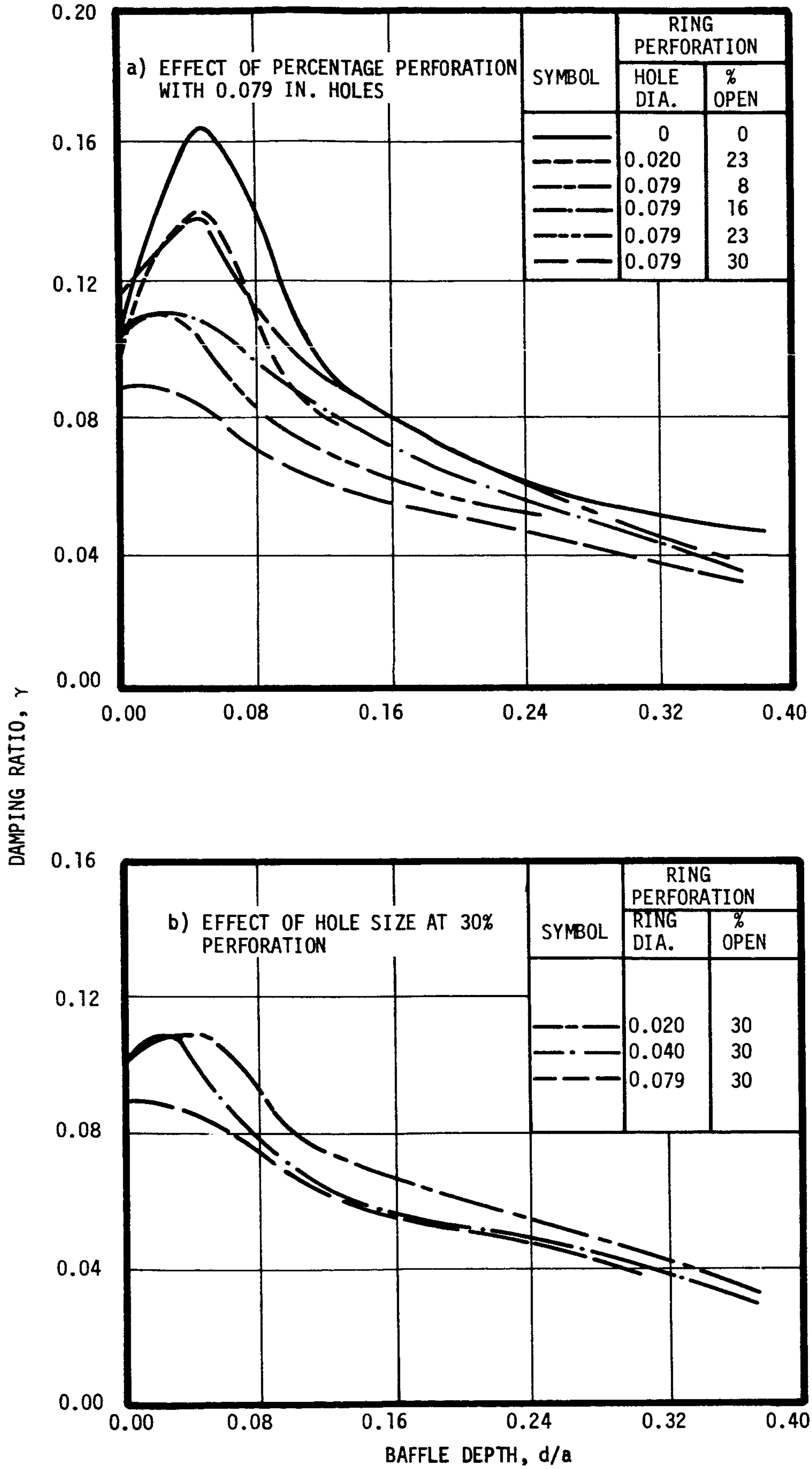

Figure 11. Damping Effectiveness as a Function of Baffle Depth (from Reference 6)

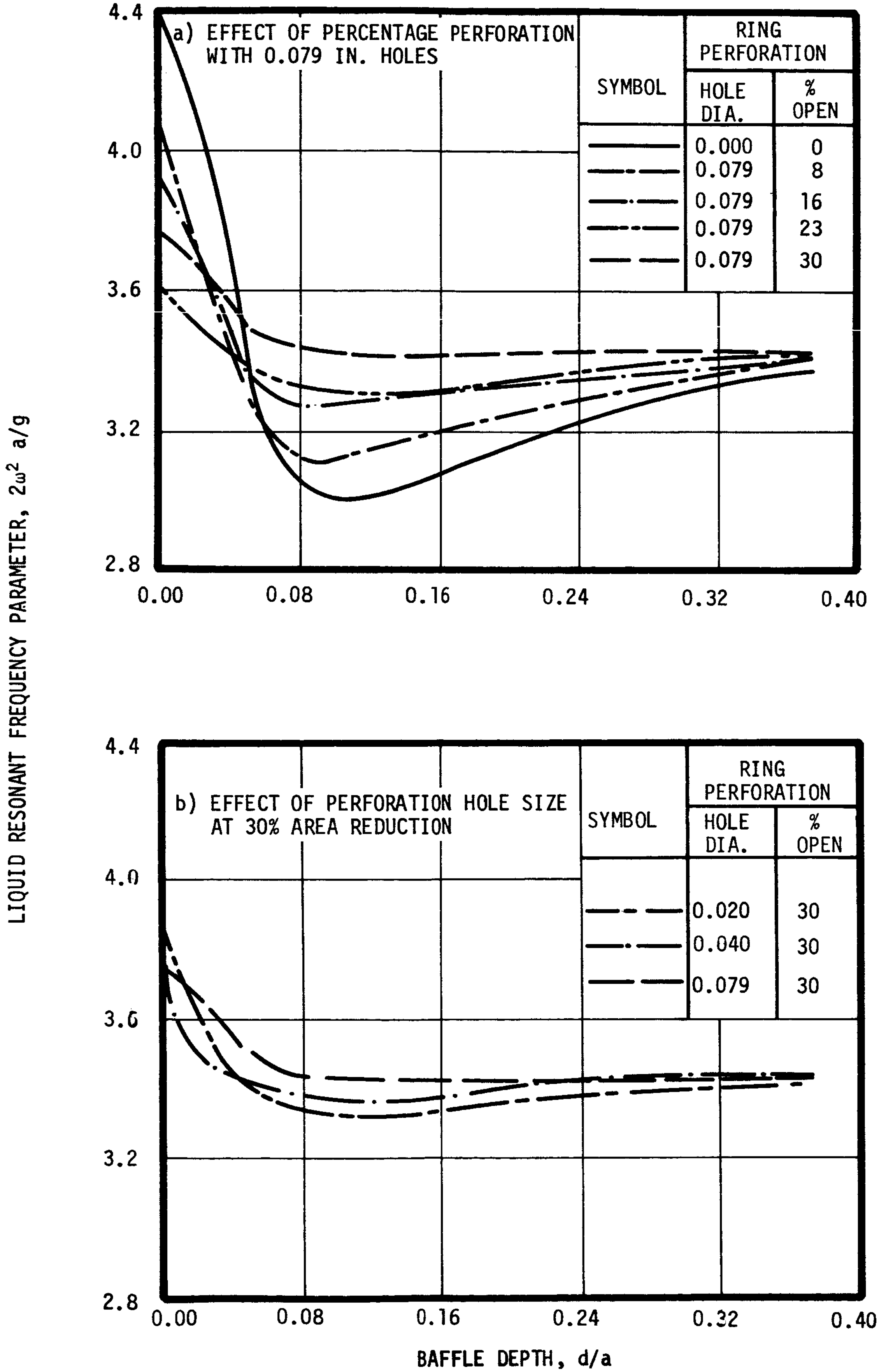

Figure 12. Liquid Resonant Frequencies as a Function of Baffle Depth (from Reference 6)

SUMMARY AND CONCLUSIONS

Miles formulates a semi-empirical expression for the damping produced by ring baffles in cylindrical tanks:

$$\gamma = 2.83\, \alpha^{\frac{3}{2}} \exp[-4.60\,(d/a)] \left(\frac{\zeta_1}{a}\right)^{\frac{1}{2}} F_c$$

The assumptions used in obtaining this expression include that the surface wave height be small with respect to the tank radius, the baffle width small, and the surface oscillation is that of the first asymmetric mode.

Experimental investigators have shown that Miles' equation with $F_c = 1$ gives acceptable results for damping provided the baffle is not at or slightly under the equilibrium surface. Experimental methods of obtaining the damping ratio vary and in some instances are questionable. Based upon the literature available the experimental method of O'Neill which uses lateral tank force appears to be the most reliable, but his test results are the least extensive. O'Neill rewrites Miles' equation in terms of lateral tank force by employing classical theory which eliminates surface wave height ζ_1 as follows:

$$\gamma = 2.16\, \alpha^{\frac{3}{2}} \exp[-4.60\,(d/a)]\ \bar{F}$$

O'Neill's experimental results show that this prediction of the damping ratio gives an answer which approximates observed values even if the baffle is wide ($\alpha < 0.25$), the baffle is at the equilibrium surface and splashing occurs.

All the experimental studies showed that the damping increases as the baffle approaches the equilibrium surface. This is the condition when Miles' equation gives the least reliable results. The investigations of

Silveira and O'Neill show that the damping increases as the baffle width increases. Abramson's study shows that baffle perforation reduces the liquid damping, but a limiting amount of baffle weight can be removed and the baffle remain effective. The damping results were not compared to Miles' theory nor was a perforation factor introduced into Miles' equation.

Studies of Silveira and Abramson on the effect of ring baffles on the resonant frequency of slosh show that when the baffle is at the equilibrium surface that the frequency of oscillation is increased above that of an unbaffled tank. This is thought to be due to the ring baffle effectively reducing the tank diameter. As the baffle depth is increased, the resonant frequency drops suddenly to a minimum value below that of an unbaffled tank. Abramson suggests that if the slosh frequency is critical, that another motion suppression mechanism be considered, such as compartmented tanks.

Experimental studies on multiple ring baffles are limited. Since the damping produced by a single baffle decreases to that of an unbaffled tank with increasing depth, O'Neill suggests that the damping be calculated based on the one baffle at an effective depth and damping contributions of baffles sufficiently below the equilibrium surface be neglected. Abramson states that a baffle is effective only when it is at a distance $|d/a| < 0.125$ above the equilibrium surface or when the baffle is submerged at a depth $d/a < 0.375$ below the equilibrium surface. Abramson gives no indication of the wave heights involved in making this suggestion.

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13. ABSTRACT

A survey of Miles' method for determining the damping produced by ring baffles in cylindrical tanks was conducted. O'Neill's modification of Miles' equation which eliminates free surface wave height from this equation is discussed. Experimental investigations from several sources which determine the damping and frequency of liquid oscillation in ring baffled cylindrical tanks are surveyed. These experimental investigations give an indication of the conditions for which Miles' equation is applicable.

14. KEY WORDS

Fluid
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