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RANDOM EXCITATION OF A PANEL-CAVITY SYSTEM

by

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NOMENCLATURE

a	-	panel amplitude
$\bar{p}^2$	-	rms pressure
p_{ref}	-	reference pressure
$\Phi_p(\omega)$	-	power spectra
Φ_p^{ND}	=	$2\omega_c\ \Phi_p(\omega)/p_{ref}$, non-dimensional power spectra
ζ	-	damping ratio
ω	-	frequency
ω_c	-	center frequency
$\Delta\omega$	-	filter bandwidth
Ω	-	resonant frequency

INTRODUCTION

Most studies of sound transmission through a flexible wall have been concerned with the effect of a cavity on the vibrations of a panel under the influence of a sinusoidal external field,[1,2,3,4,5] except for some studies on the effect of sonic boom.[6,7] This investigation is concerned with both cavity pressures and panel vibrations under the influence of a random external field. Although most of the research presented here is experimental, a computer model could be constructed, using the modal approach outlined in Ref. 8, to predict the panel-cavity interaction theoretically.

The panel used was a 10" x 20" x 0.05" aluminum alloy plate that was bonded onto a rectangular frame consisting of aluminum channel members welded together at their ends. By bonding the plate to the cavity in this way, a clamped edge boundary condition was approximated. A sealed cavity was constructed beneath the panel in such a way that the cavity depth could be varied in 2" increments from 12" to 2" deep. In order to vary the cavity depth, the cavity was built in sections. Each 2" section of the cavity was bolted to the other sections with rubber gaskets between them. The cavity itself was made of 0.5" thick plexiglass and was supported by four plexiglass "feet". The panel was excited acoustically by a Wolverine LS15, 20 watt loudspeaker driven by a B & K Random Noise Generator, Type 1402. See Fig. 1.

The external sound field was measured on the panel surface, using the 6 percent bandwidth of the frequency analyzer. Since the power spectra of the external field is fairly constant, no extrapolation to zero bandwidth is necessary. See Fig. 2.

The use of a single speaker for panel excitation does present some problems, particularly in coordinating theoretical work with this experiment. The ideal external sound field would have a constant amplitude in space over the whole surface of the panel. By using a single speaker, an external field distribution that was not constant in space was obtained, but rather its amplitude was approximately 12 db lower at the point of maximum panel length, and about 5 db lower at the point of maximum panel width than at the panel center. See Fig. 3. Although this distribution is not ideal, it can be approximated in a computer simulation to obtain comparisons between theory and experiment.[9]

The panel-cavity system was placed on a laboratory bench inside a specially designed acoustic chamber. This acoustic chamber was designed to reduce the sound transmission from the laboratory to the experiment, to reduce the sound transmission from the loudspeaker into the laboratory, and thus, to isolate the experiment as much as possible from extraneous noise.

Panel Amplitude Measurement

The panel motion was measured by the use of a Bently Nevada Motion Pickup, Model 302, that was mounted on an aluminum frame located above the panel. The frame allowed movement of the pickup to any point on the surface of the panel, and also allowed variation of the distance between the pickup and the panel. Since the output of the pickup depends on the distance from the pickup to the panel, this distance must be chosen carefully so as to stay within the linear range of the pickup, and must remain constant throughout the testing procedure. To insure that the static gap distance did remain constant throughout the testing procedure, an oscilloscope was used to measure this distance in volts and to set the static gap before each run. As the panel oscillated, the voltage generated by the motion pickup was fed through an amplifier and recorded on an amplitude vs. frequency plot. Such a plot is shown in Fig. 4, for a cavity depth of 12".

For the measurement depicted in Fig. 4, the motion pickup was positioned at the center of the panel. By positioning the pickup in this way, one may obtain deflection measurements for the symmetric panel modes, i.e., the modes which have a peak at the panel center, but not for the antisymmetric modes, i.e., those modes with a node at the panel center. Notice that the dominant features of the plot are the three resonant peaks, corresponding to the first, third and fifth panel modes, occuring at 113 cps, 210 cps and 410 cps. Modes above the fifth mode have an amplitude that is negligible compared to the first three symmetric modes. Notice that, above 500 cps, the panel is essentially motionless. Also notice that, by far, the dominant panel response is at the panel fundamental mode, as in the case of sinusoidal excitation.[8]

Cavity Pressure Measurement

The pressure, or sound level, within the cavity, when the panel has been excited by the loudspeaker, was measured using a B & K 1/4" microphone, Type 4136, with a Type 2615 cathode follower and Type UA 0035 connector. This microphone was installed in holes that were drilled in the side of the cavity and that were plugged up when not in use so as to insure a near leak-proof cavity. These holes were spaced at cavity depths of 3", 5", 7", 9" and 11", so that the pressure variation with cavity depth could be studied. The voltage from the microphone due to the excitation of the cavity was analyzed using a B & K Frequency Analyzer, Type 2107.

Due to the filtering characteristics of the analyzer, the smallest bandwidth that could be obtained was 6 percent of center frequency. Also, the results obtained for cavity pressures were given in db, whereas power spectral results were preferred. In order to resolve this dilemma, a method was devised to measure power spectra from the rms decibel output of the frequency analyzer.

Using the definition for rms pressure in terms of power spectra:

$$P \equiv \bar{p}^2 \equiv \int_{-\infty}^{+\infty} \Phi_p(\omega)\, d\omega$$

one may find that, for small bandwidths,

$$P \simeq 2\Phi_p(\omega)\, \Delta\omega$$

where $\Delta\omega$ is the filter bandwidth. Therefore, non-dimensionalizing by some reference pressure, p_{ref},

$$\frac{2\ \Phi_p(\omega)\ \Delta\omega}{p_{ref}} = \frac{P}{p_{ref}}$$

Let

$$\Phi_p^{ND} \equiv \frac{2\ \omega_c\ \Phi_p(\omega)}{p_{ref}}$$

where ω_c is the center frequency of the waveform and Φ_p^{ND} is a non-dimensional power spectra. Therefore,

$$\Phi_p^{ND}\ \frac{\Delta\omega}{\omega_c} = \frac{P}{p_{ref}}$$

Taking the common logarithm of this equation, one obtains

$$\log \Phi_p^{ND} = \log \left[\frac{P}{p_{ref}}\right] - \log \left(\frac{\Delta\omega}{\omega_c}\right)$$

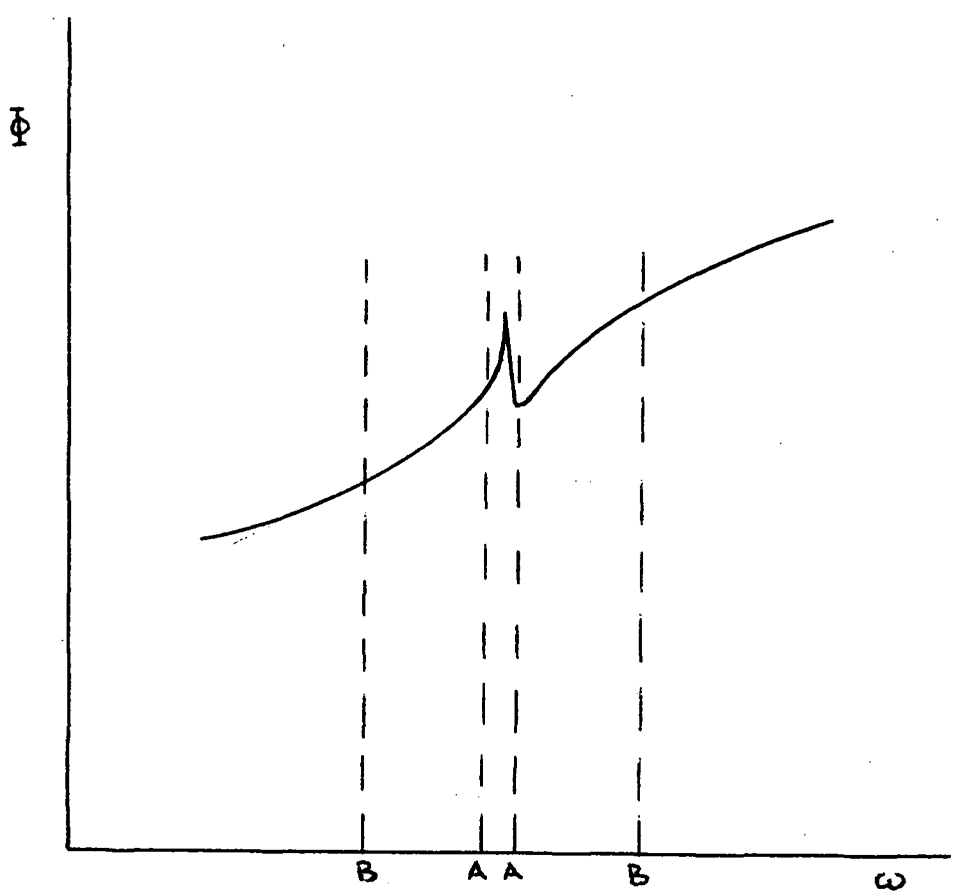
Now, choosing p_{ref} as 0.0002 μbar, the decibel reference pressure, and making use of the definition of the decibel,

$$\text{db} \equiv 20 \log (P/p_{ref})$$

the final expression for the non-dimensional power spectra, Φ_p^{ND}, in terms of the decibel level in the cavity, is obtained:

$$\Phi_p^{ND} = \log^{-1}\left(\frac{\text{db}}{20}\right) - \frac{\Delta\omega}{\omega_c}$$

Measurements were taken of the external and internal spectra at various bandwidths (6%, 8.5%, 12%, and 16% of center frequency), and the results extrapolated to obtain zero bandwidth results. A typical extrapolation graph is shown in Fig. 5. Note that, for the cavity fundamental extrapolation, the curve reaches a minimum between the largest and smallest bandwidths. This phenomena is probably due to the averaging mechanism of the frequency analyzer and the shape of the power curve:



For small bandwidths, the analyzer averages only the resonant peak of the curve, and thus as the bandwidth increases, the indicated spectrum decreases. However as the bandwidth increases from A-A to B-B, the averaging includes large responses at the higher frequencies. Thus, the indicated spectrum increases for bandwidths between A-A and B-B. The results of these measurements, shown in Fig. 6, depict a dominant resonant peak at 113 cps, the fundamental panel frequency, with smaller peaks at the third and fifth panel natural frequencies, and at the fundamental cavity frequency. Note that the difference between the internal and external pressure levels at the panel fundamental is about 12.5 db, and that this difference at the cavity fundamental is approximately zero. Both results are consistent with the sinusoidal results given in Ref. 8.

The depthwise distribution within the cavity was also measured to determine the cavity mode shapes at the fundamental frequencies. These results are shown in Figs. 7 and 8. Note that at the panel fundamental frequency, there is essentially no variation of sound pressure level with cavity depth, as predicted by theory and shown in experimental sinusoidal results.[8] Since the cavity fundamental frequency is well above the panel fundamental frequency, the cavity should respond in its "zeroth", i.e., constant pressure mode. The variation from this mode is probably due to non-rigid cavity walls (since the panel is moving greatly), or perhaps some coupling with other resonant modes.

The pressure distribution at the cavity fundamental frequency displays the traditional cosine mode shape. Although the magnitude of the cavity pressures at this frequency were measured, the phase shift was not, due to the random nature of the external excitation. Therefore, the phase shift was assumed from previous theoretical and experimental results for a sinusoidal external field.

Response Due to Varying Cavity Depth

Due to a variation in cavity depth, there are two main effects acting on the panel: the virtual mass effect and the stiffness effect.[3,4,5]

The virtual mass effect is present in all panel natural modes and is due to the mass of the air within the cavity acting as an additional mass on the panel. This additional mass causes a decrease in the natural frequencies of all of the panel modes as the cavity depth is decreased. However, this additional mass is small compared to the panel mass, and thus the effect is small.

The stiffness effect is due mainly to the compressibility of the air within the cavity. In the case of the panel fundamental mode, or any symmetric panel mode, as the panel oscillates, it forces the air in the cavity downward and, in effect, produces a volume change in the cavity. The air in the cavity, due to its compressibility, acts as an aerodynamic spring and thus stiffens the panel. Since the panel frequencies are directly related to the stiffness, this increased stiffness causes an increase in the frequencies of the symmetric panel modes.

For the antisymmetric panel modes, there is no net volume change as the panel oscillates. Therefore, the stiffness effect is not present for the antisymmetric panel modes, and thus the only effect present for these modes is the virtual mass effect, even though it is small. Since the influence of the virtual mass effect is small, the stiffness effect is the main effect acting on the symmetric panel modes, even though the virtual mass effect is present. See Fig. 9 for an example of the stiffness effect on the panel fundamental frequency.

The stiffness effect and the virtual mass effect also produce large changes in panel amplitude and cavity pressure as the cavity depth is reduced.

From Ref. 8, the ratio of amplitudes and of pressures at different cavity depths may be calculated using one term theory:

$$\frac{a_1}{a_2} = \left[\frac{\zeta_2}{\zeta_1}\right]\left[\frac{\Omega_2}{\Omega_1}\right]^2$$

$$\frac{(\Phi_p)_1}{(\Phi_p)_2} = \left[\frac{d_2}{d_1}\right]\left[\frac{\zeta_2}{\zeta_1}\right]\left[\frac{\Omega_2}{\Omega_1}\right]^2 = \frac{a_1}{a_2}\left[\frac{d_2}{d_1}\right]$$

where the subscripts 1 and 2 refer to different cavity depths. The panel damping ratio has been found experimentally and is shown in Fig. 10.

Figs. 11 and 12 show the effect of cavity depth on the panel amplitudes and cavity pressures at the panel fundamental frequency, along with the theoretical curves for constant damping and experimental damping. Notice that the panel amplitudes decrease as the cavity depth decreases, and that this results is consistent with one-mode theory. Also notice that the cavity pressures increase as the cavity depth decreases, and that this result is also consistent with theory. Furthermore, the experimental results are more accurately predicted when measured damping is used than when it is assumed constant.

Notice also that these results are consistent with the theory of the stiffness effect. Since both measurements were made at the panel fundamental frequency, which is a symmetric mode, the dominant effect will be the stiffness effect. The main feature of this effect is increasing cavity stiffness, as indicated by increased cavity pressure, at shallow cavity depths. This increased stiffness will produce decreased panel amplitudes at shallow cavity depths, as indicated in Fig. 8.

CONCLUSIONS

Based on the experimental work presented in this study, the following conclusions may be drawn:

(1) The dominant panel and cavity response occurs at the panel fundamental frequency, and is consistent with the results obtained for a sinusoidal external field.

(2) The pressure variation with depth inside the cavity at the panel fundamental frequency and at the cavity fundamental frequency is the same as that predicted by theory.

(3) The variation of panel amplitudes and cavity pressures as the cavity depth is decreased is consistent with sinusoidal results and with theory.

(4) Panel damping must be considered in order to predict panel amplitudes and cavity pressures accurately.

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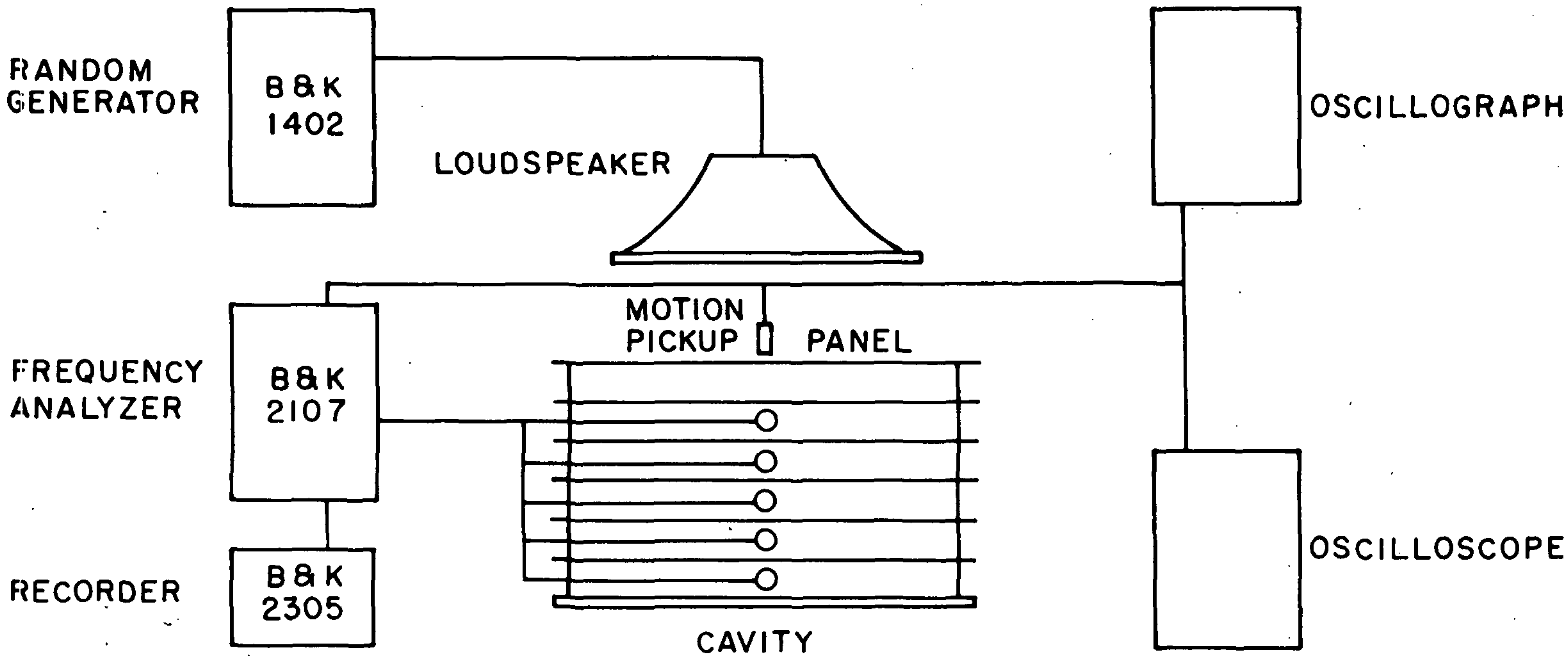
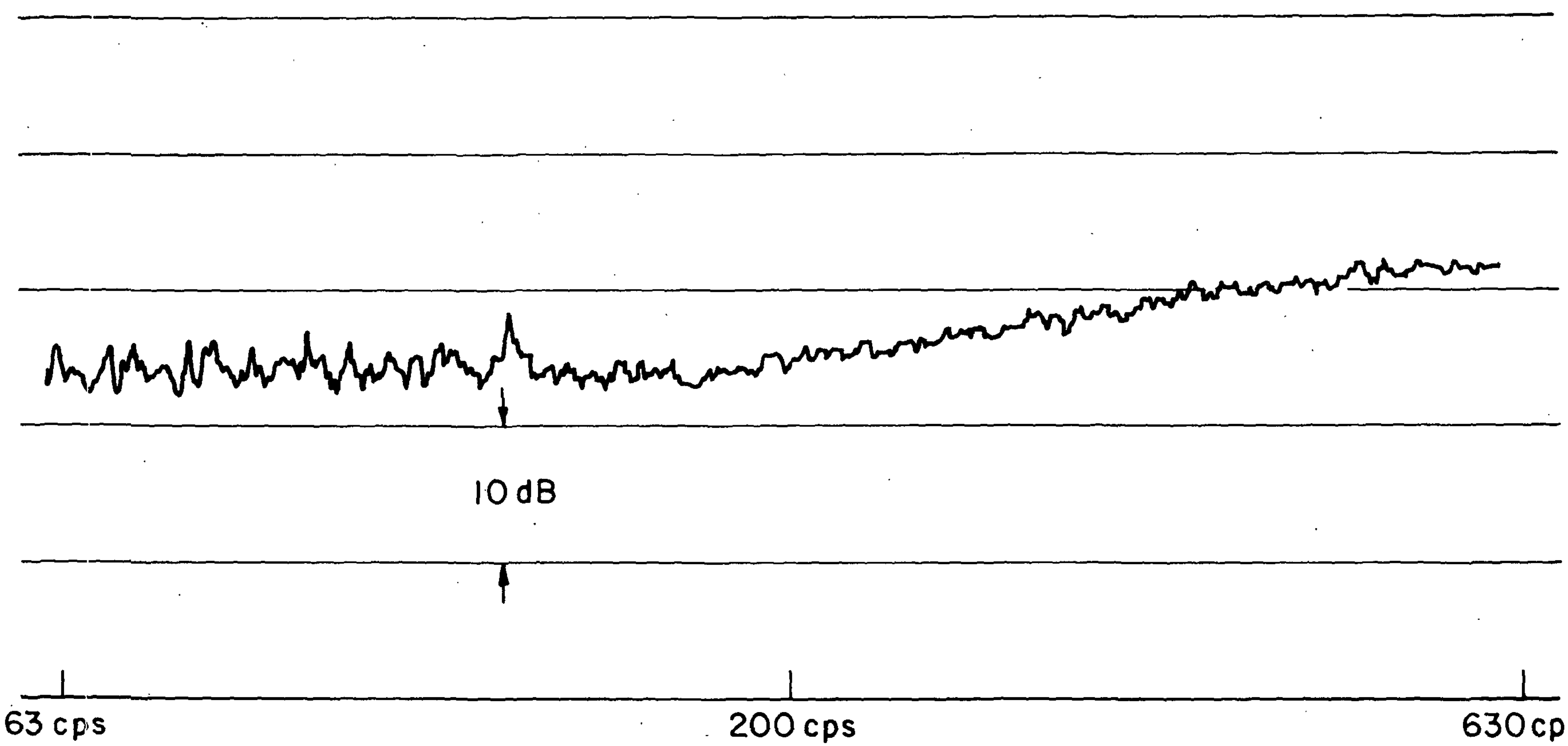


EXPERIMENTAL ARRANGEMENT

Figure 1



EXTERNAL FIELD FREQUENCY SPECTRUM

Figure 2

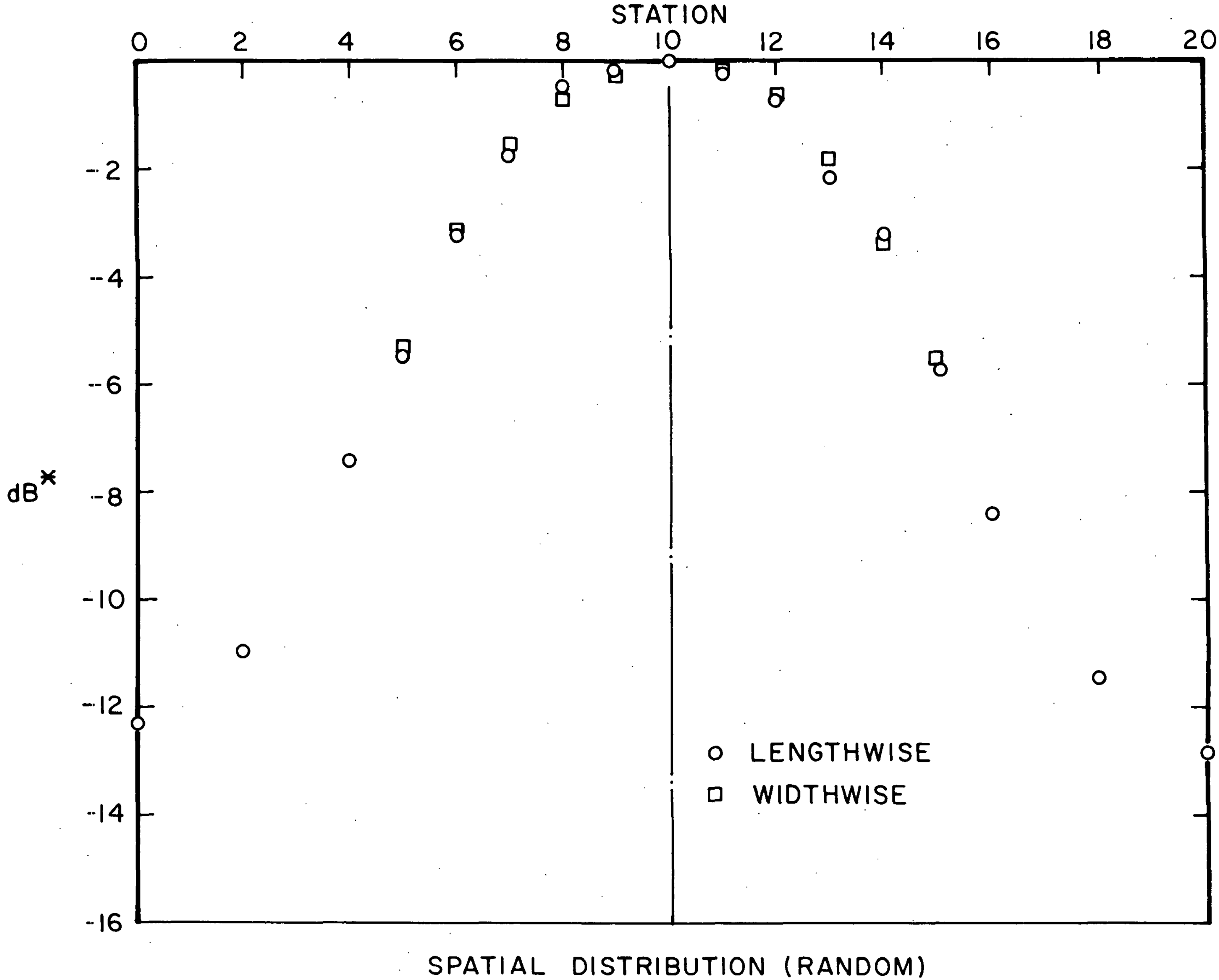
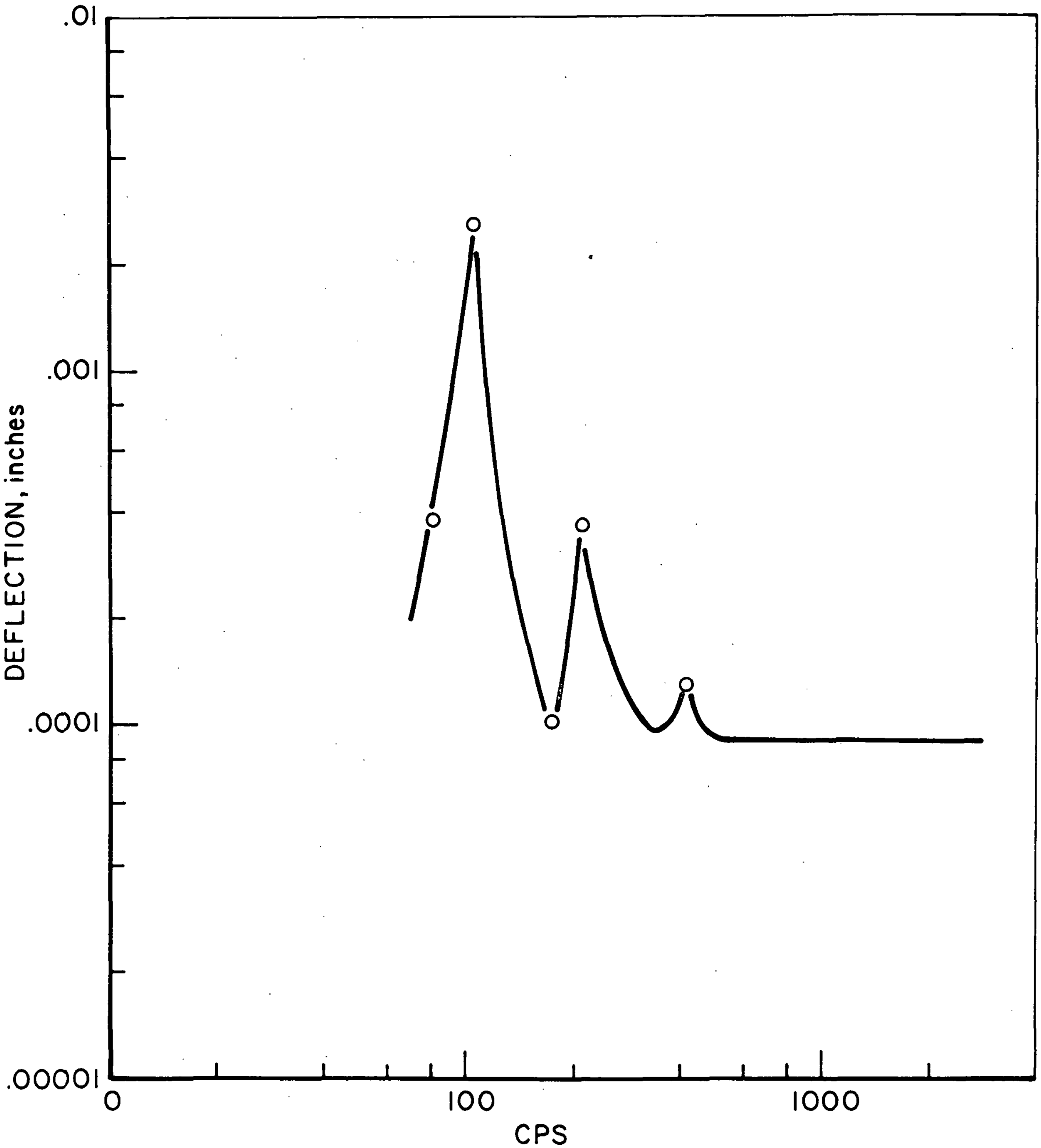
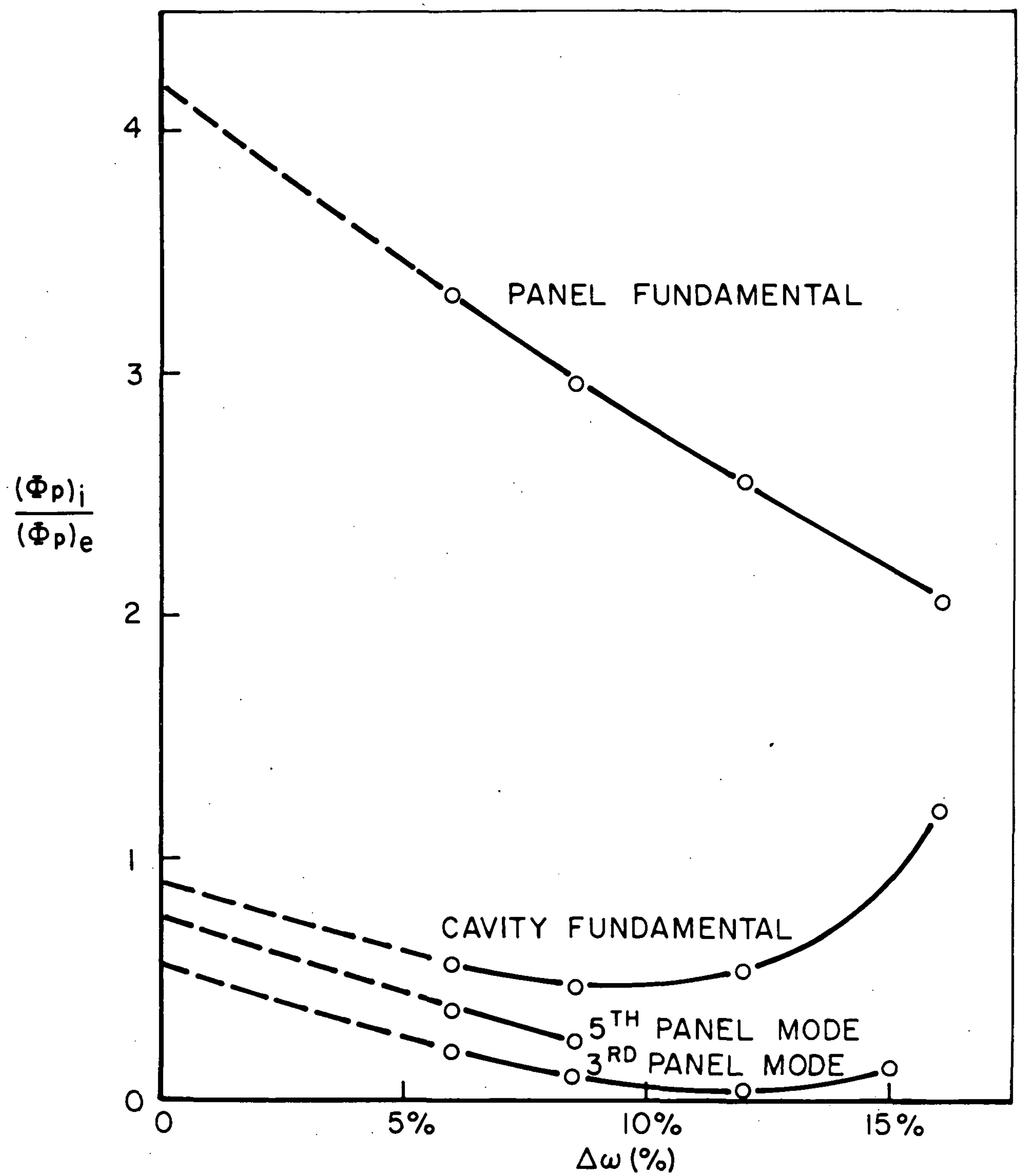

STATION
0
2
4
6
8
10
12
14
16
18
20
-2
-4
-6
-8
-10
-12
-14
-16
dB*
LENGTHWISE
WIDTHWISE
SPATIAL DISTRIBUTION (RANDOM)

Figure 3



PANEL RESPONSE TO RANDOM NOISE

Figure 4



TYPICAL BANDWIDTH CORRECTION

Figure 5

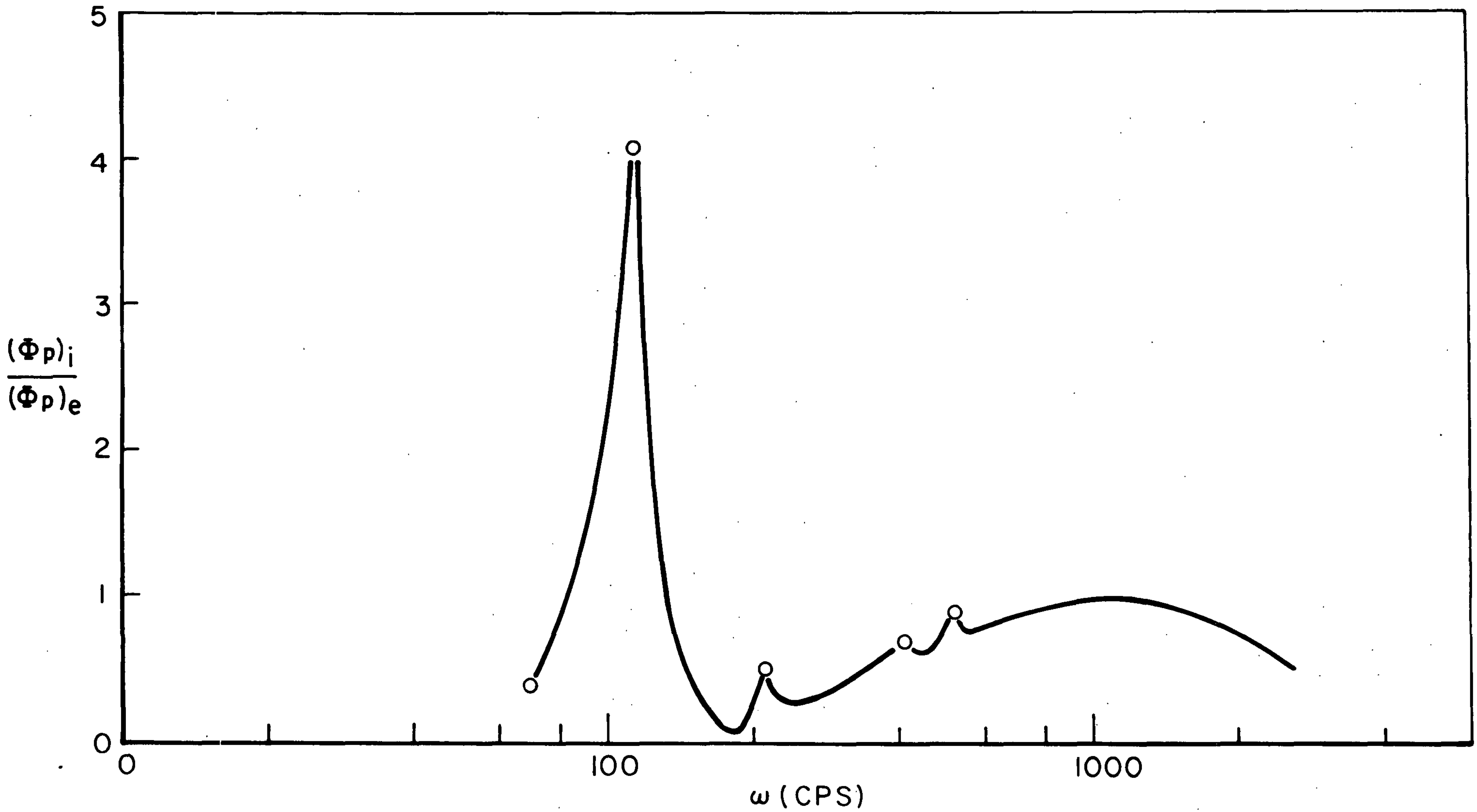
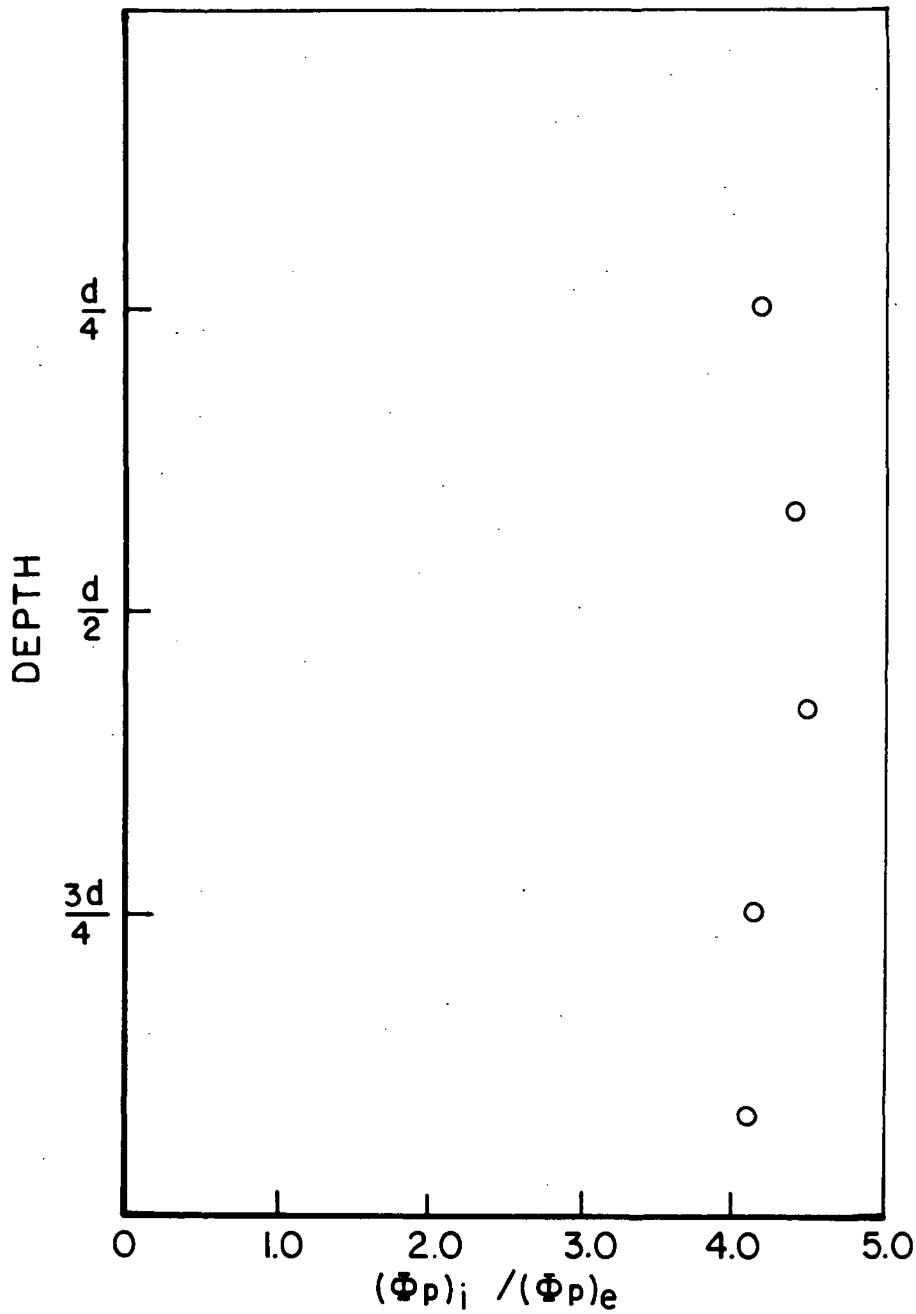


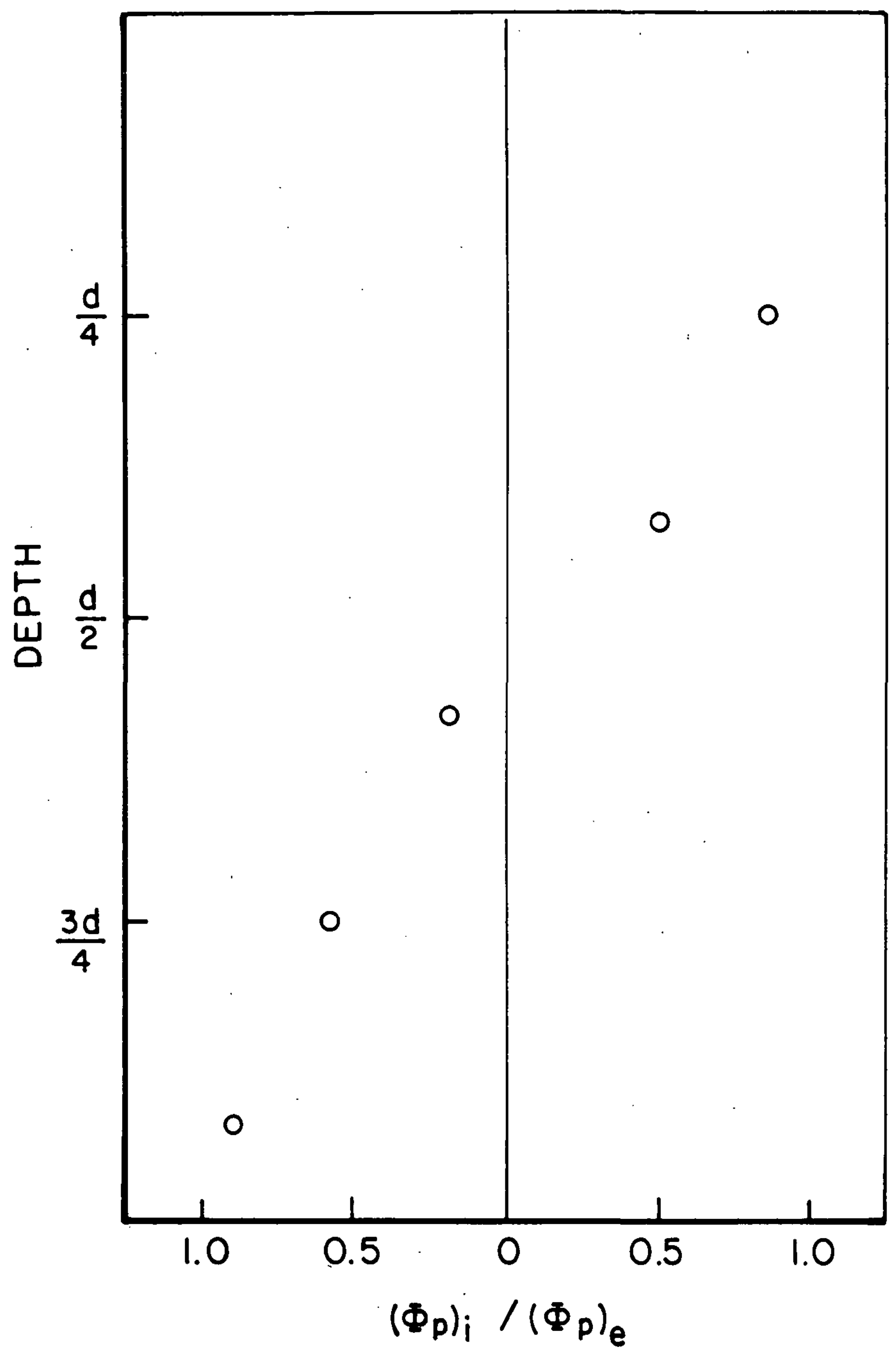
Figure 6

CAVITY RESPONSE TO RANDOM FIELD



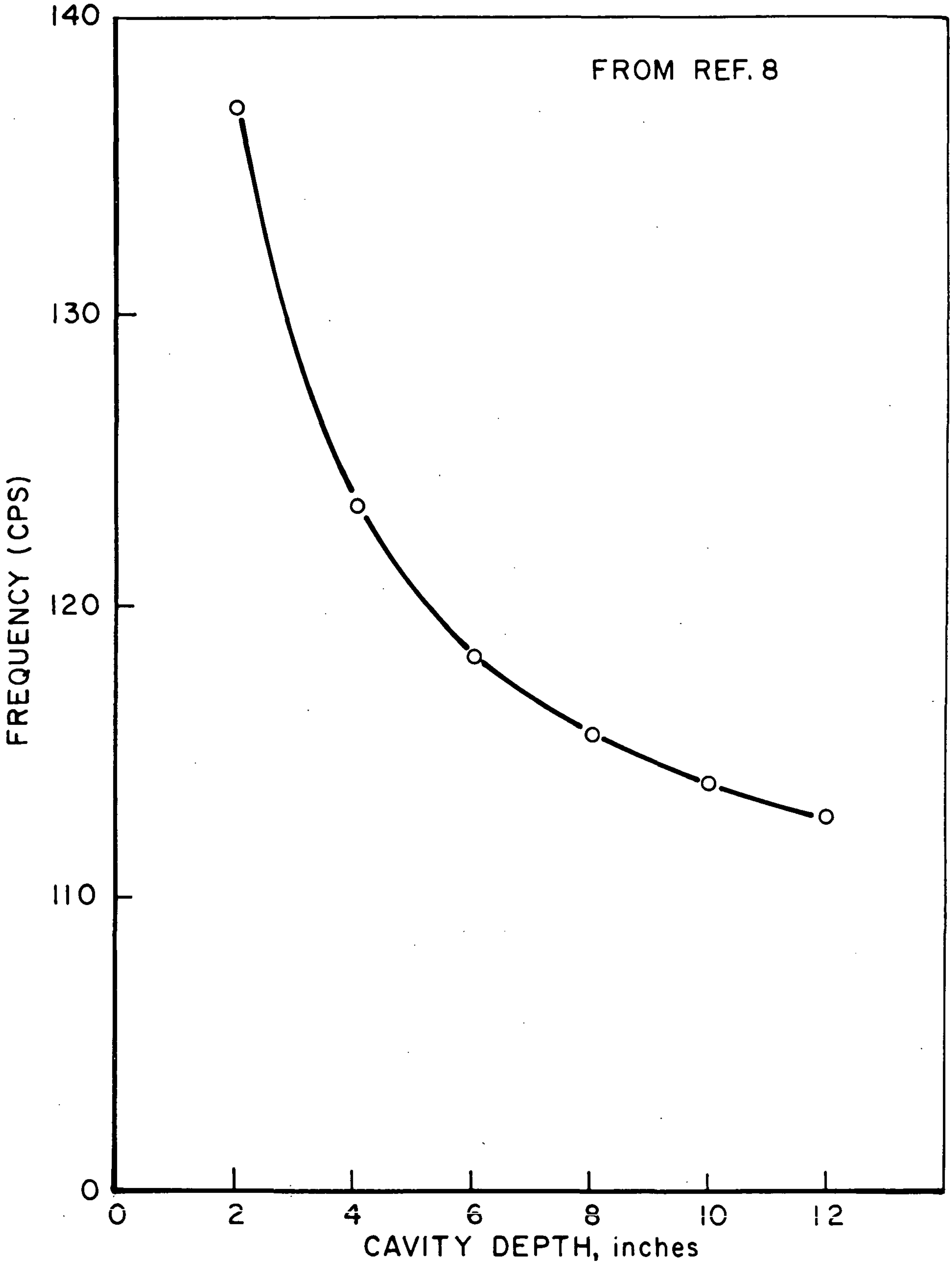
PRESSURE DISTRIBUTION
@ PANEL FUNDAMENTAL MODE

Figure 7



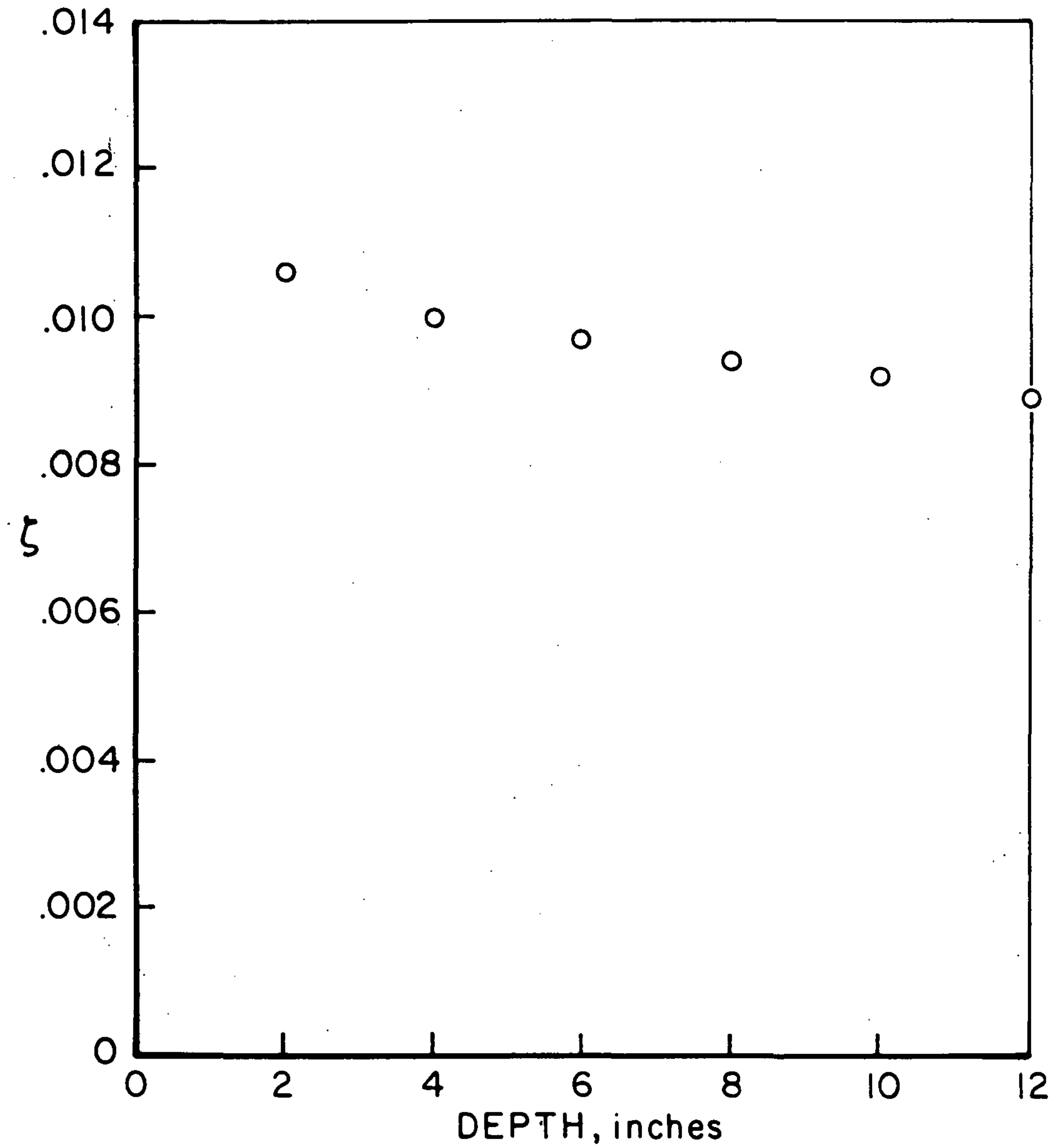
PRESSURE DISTRIBUTION
@ CAVITY FUNDAMENTAL MODE

Figure 8



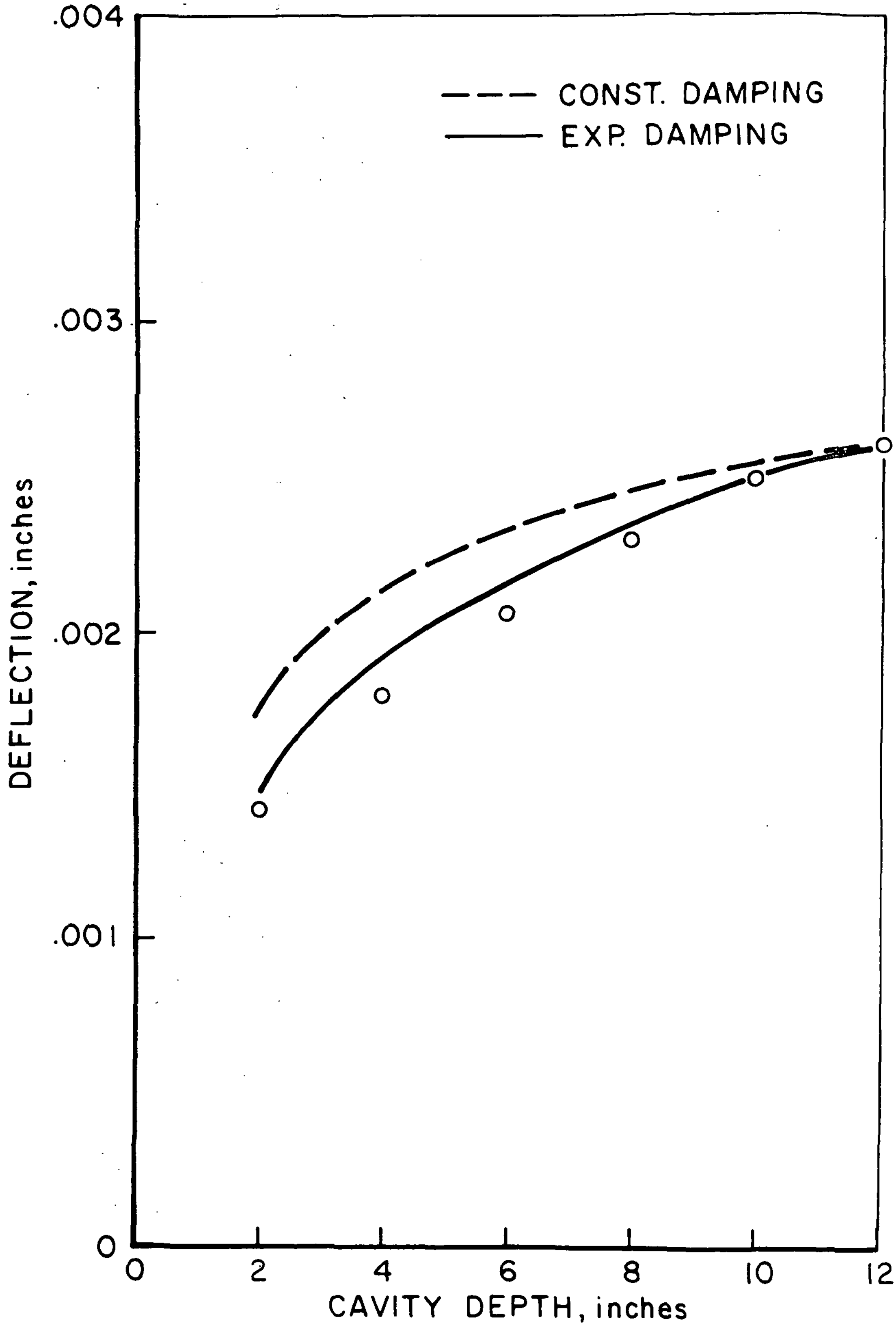
FUNDAMENTAL PANEL FREQUENCY VS CAVITY DEPTH

Figure 9



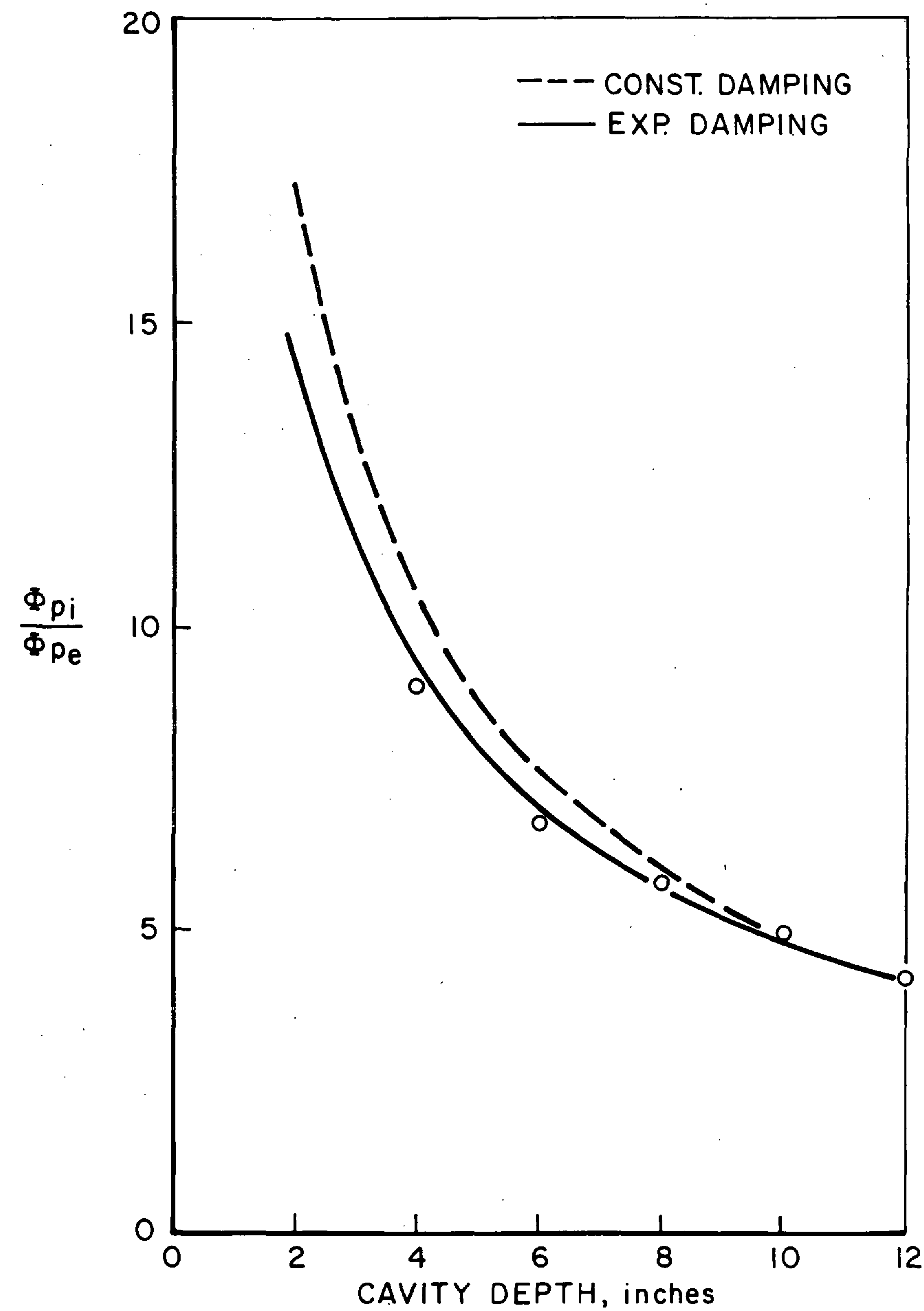
PANEL DAMPING RATIO VS CAVITY DEPTH
(PANEL FUNDAMENTAL MODE)

Figure 10



PANEL AMPLITUDE VS CAVITY DEPTH

Figure 11



CAVITY PRESSURE VS CAVITY DEPTH

Figure 12