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Diffraction About Acoustically Soft Panels

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Preface

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Reviewed and Approved: 8 March 1990

A handwritten signature in black ink, appearing to read "B. F. Cole". The signature is fluid and cursive, with the first letters of the first and last names being capitalized and prominent.

B. F. Cole
Head, Environmental and Tactical Support Systems Department

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DIFFRACTION ABOUT ACOUSTICALLY SOFT PANELS

INTRODUCTION

In an ideal situation, baffles can be made large enough so that acoustic testing will not be contaminated by diffraction. For material testing at the Naval Underwater Systems Center (NUSC), baffles initially were made 5λ square at the lowest frequency of interest. As the need to test different material configurations expanded and lower frequencies were encountered, costs and the limitation of the size of the test facility necessitated exploring diffraction discrimination techniques.

SLIDE 1

**DIFFRACTION ABOUT ACOUSTICALLY SOFT
SQUARE PANELS**

OBJECTIVE: DETERMINE DIFFRACTION FLOOR FOR
TRANSMISSION LOSS MEASUREMENTS WITH RESPECT TO

- FREQUENCY
- HYDROPHONE POSITION
- ARRAY SIZE
- ARRAY GEOMETRY
- ARRAY SHADING

In the 1970's, Wayne Strawderman, Roger Maple, and John Libuha of NUSC designed and built shaded and summed hydrophone arrays to reduce diffraction during insertion loss testing of acoustically soft, resonant compliant tube baffles. Designing a beam pattern with minimum sidelobes was expected to improve discrimination against diffraction. During that period, Sachs (D. Sachs, "Edge Diffraction Interference in Baffle Performance Measurements," JASA, vol. 68, S85, 1980) and Radlinski (R. P. Radlinski, "Diffraction About an Acoustically Soft Panel," NUSC Technical Memorandum 801141, September 1980) made calculations to estimate the performance of these measurement arrays; however, no attempt was made to optimize the configurations. In this paper, these early studies are revisited in order to explore optimum configurations with respect to array size and array geometry and to investigate tradeoffs as a function of frequency.

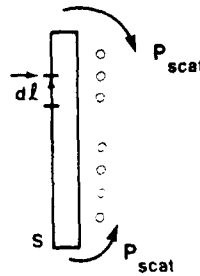
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SLIDE 2



DIFFRACTION ABOUT A STRIP

TWO-DIMENSIONAL SOURCE STRENGTH INTEGRAL SOLUTION TO WAVE EQUATION



$$P_{\text{TOTAL}} = P_{\text{inc}} + P_{\text{scat}}$$

$$= e^{i\vec{k} \cdot \vec{r}} + \int_S A(s) H_0(s, r) d\vec{l}$$

WHERE

$\vec{k}$ - WAVENUMBER VECTOR

$\vec{r}$ - POSITION VECTOR

$A(s)$ - SOURCE DISTRIBUTION

$H_0(s, r)$ - ZEROTH-ORDER HANKEL FUNCTION

$d\vec{l}$ - DIFFERENTIAL ELEMENT IN CLOSED LINE INTEGRAL

To calculate diffraction about an acoustically soft baffle, a two-dimensional boundary element integral method was employed. A plane wave P_{inc} is assumed to be incident on a strip of perimeter S , and a diffracted field P_{scat} is calculated behind the strip. The total field is the sum of the incident and diffracted wave. The diffracted field is described by the simple source integral. Here, $A(s)$ is the unknown source distribution that is determined from the boundary conditions, and the size of the element of integration dl is chosen to be a fraction of a wavelength. $H_0(s, r)$ is the zeroth-order Hankel function that is proportioned to the two-dimensional Green's function.

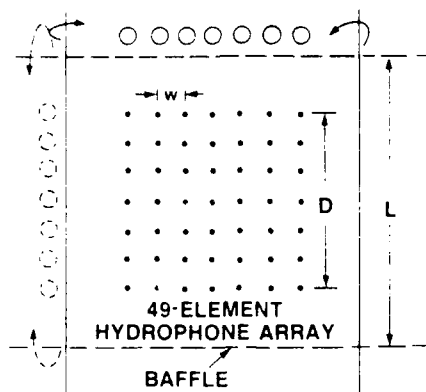
From previous studies, this integral method works well with soft boundary conditions at low frequencies. For rigid boundaries (R. P. Radlinski, "Modeling of

Line-Array Transducers Near Finite-Width Soft Reflectors," NUSC Technical Report 4583, 1973), calculations with baffles that are thin with respect to an acoustic wavelength resulted in numerical problems. At high frequencies, one must either avoid or numerically correct for the Dirchelet eigenfrequencies.

SLIDE 3

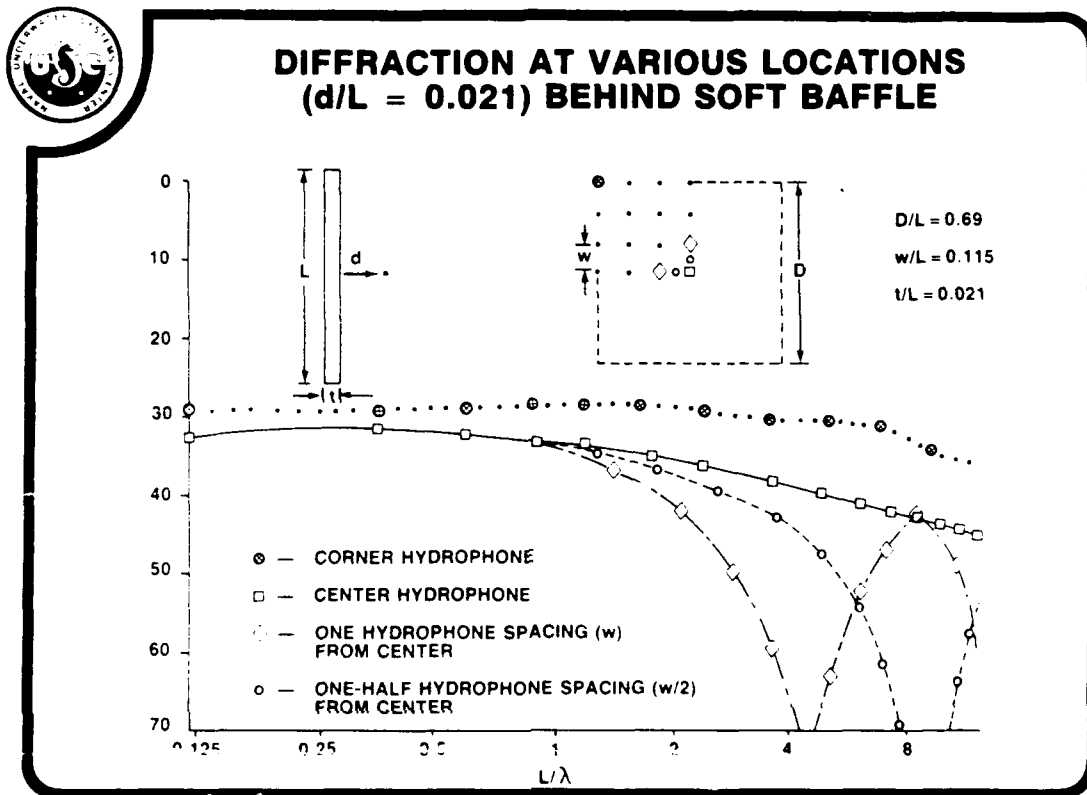


APPROXIMATE DIFFRACTION SOLUTION FOR HYDROPHONE ARRAY BEHIND BAFFLE



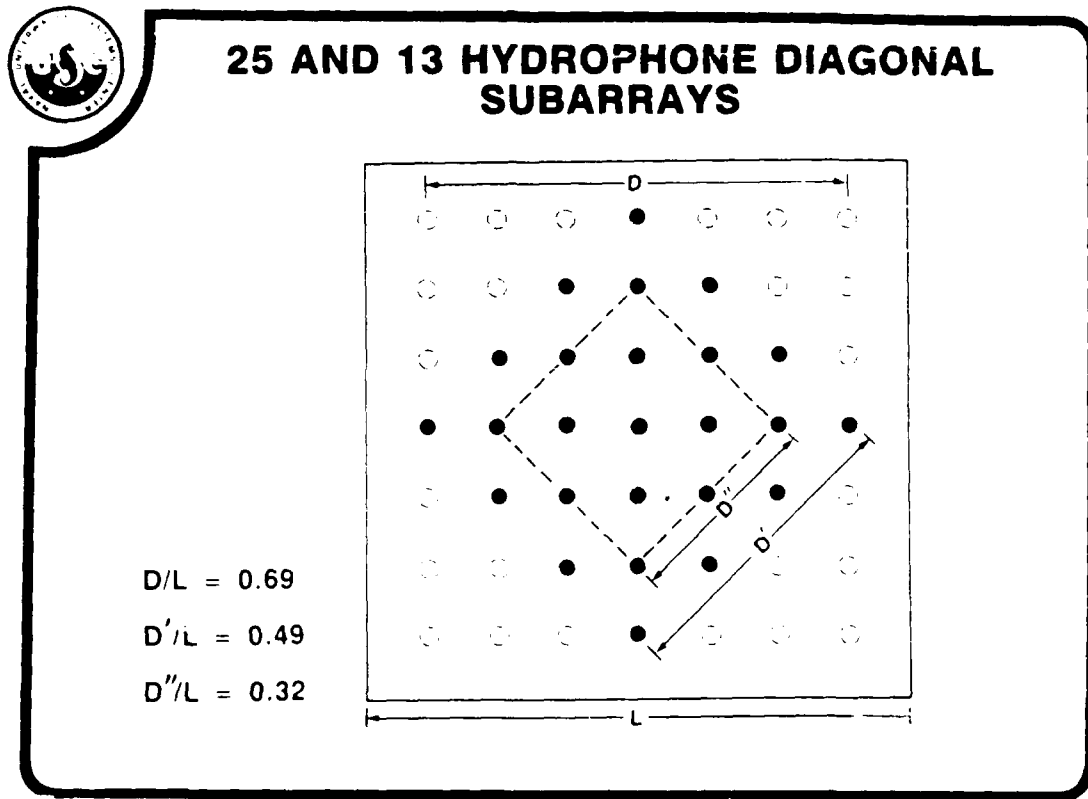
- ADD CONTRIBUTIONS FROM TWO STRIPS TO APPROXIMATE PRESSURE AT ARRAY ELEMENTS
- PRESSURE DOUBLING FOR DIAGONAL ELEMENTS
- CORNER EFFECTS NEGLECTED

To obtain a solution for a two-dimensional array behind an acoustically soft square baffle (pressure equals zero at the boundary surfaces), the diffracted field is first calculated, at the locations shown by the open circles, for two strips at right angles to each other. An approximate solution is obtained by adding the contributions from the two acoustically soft strips. This approximation results in the effects of corners being neglected and pressure doubling (6 dB) along the diagonal elements of the 49-element square array shown by solid dots in the slide. The 49 hydrophone elements correspond to one of the originally constructed arrays. In the examples that will be discussed, L is the length of the edge of the soft square baffle, D is the length of the side of the hydrophone array, and w is the hydrophone spacing of the array.



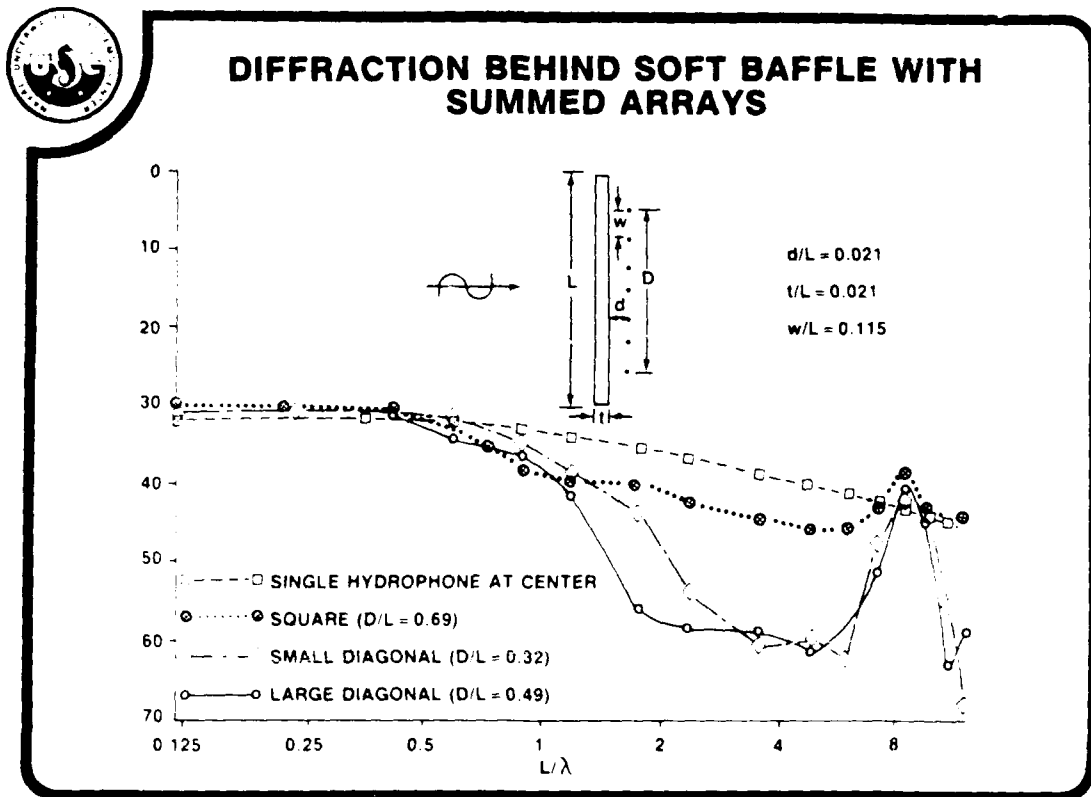
The diffraction at various locations behind the acoustically soft baffle is shown here as a function of the baffle length (L) to an acoustic wavelength (λ). The thickness of the baffle (t) and distance behind the baffle (d) are identical in this example. The length of the hydrophone array (D) is about 0.7 of the baffle length L . For the locations shown, the corner element of the array has the highest diffraction floor at about 30 dB and the center element is consistently lower than the corner element. Interestingly, the diffracted pressure at the hydrophone for one-element spacing from the center and the pressure at one-half element spacing are out of phase at about L/λ of 3. These pressure oscillations suggest an optimum phase cancellation from summing a tighter packed array than the originally constructed 49 hydrophone measurement array with a D/L of ~ 0.7 .

SLIDE 5



The first examples that employ hydrophone arrays for diffraction discrimination will examine uniformly summed outputs for two geometrical arrangements of diagonal subarrays versus the standard 49-element square array of length D. The two diagonal subarrays consist of 25 and 13 hydrophones, and they are differentiated by solid circles in the slide. The length of these subarrays is about $1/2L$, as designated by D' ; for the shaded region in the slide, the length is about $1/3L$, as designated by D'' .

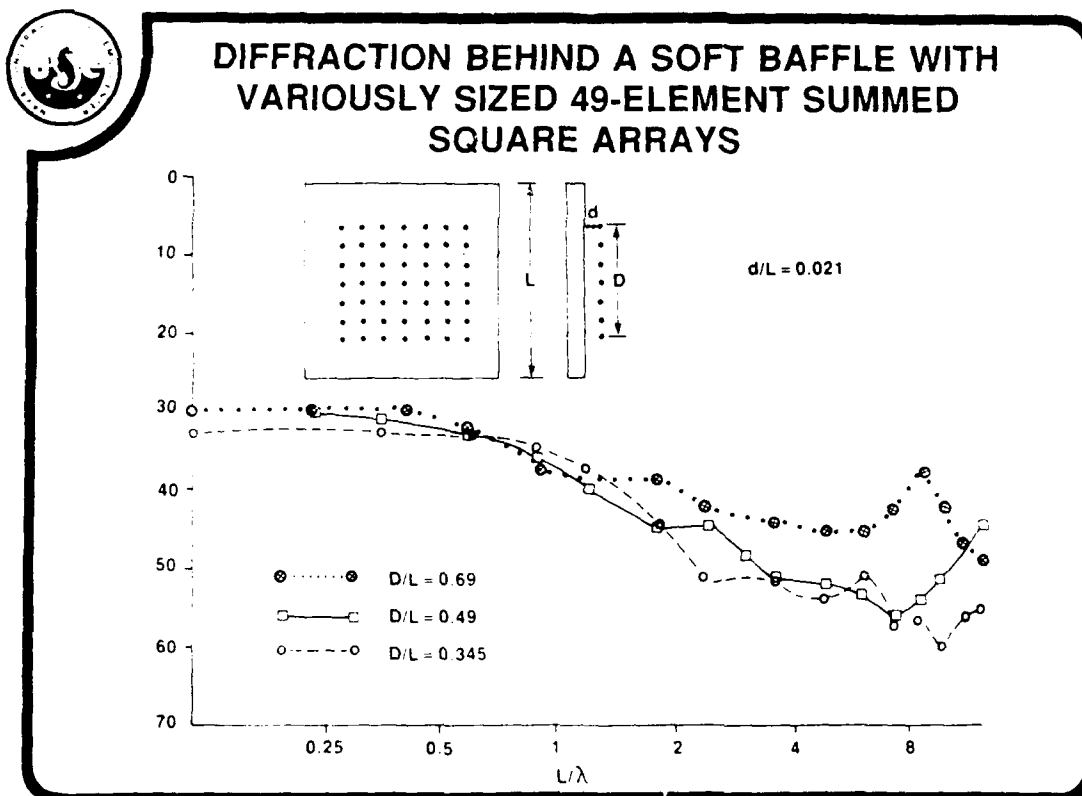
SLIDE 6



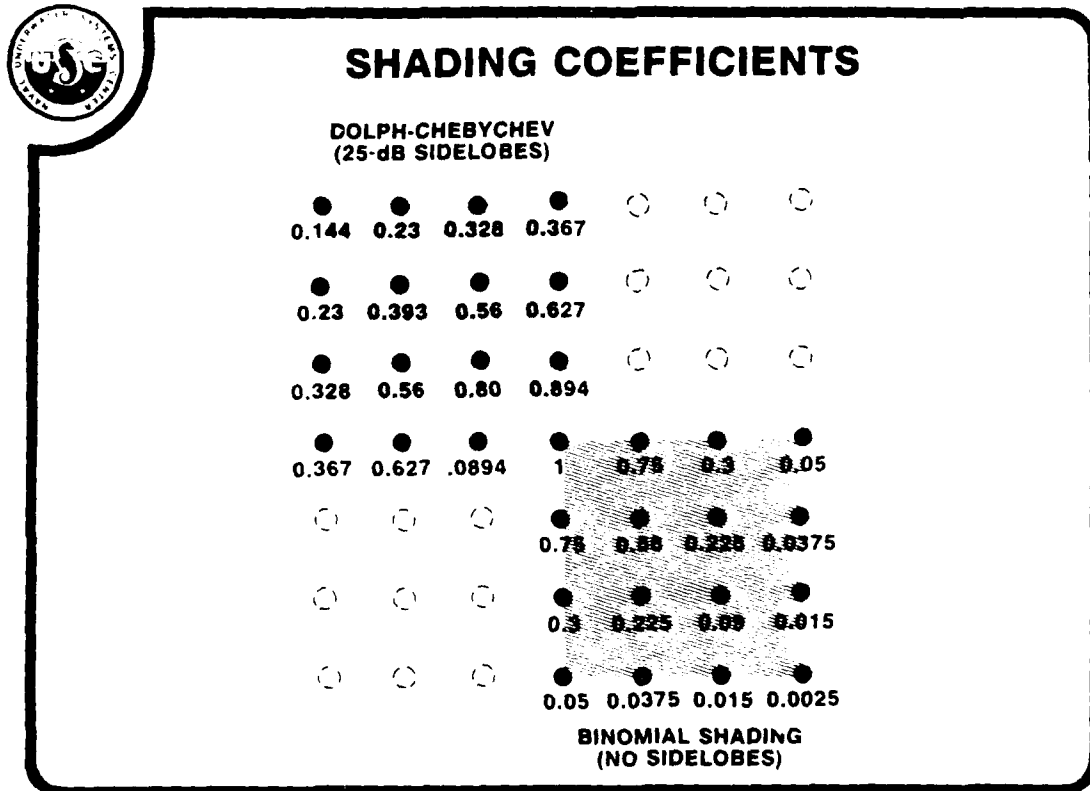
The diffraction floor for the three configurations of uniformly summed arrays shown in the previous slide is compared here with the diffracted field observed by a single hydrophone at the center. Below L/λ of 1, there is no significant advantage to using a summed array for any of the illustrated configurations. For $1.25 \leq L/\lambda < 8$, both smaller diagonal arrays outperform the standard larger 49-element square array.

In the region from $L/\lambda = 0.5$ to 3, the narrower beamwidth of the larger diagonal array allows for significant discrimination against diffraction. For all arrays, at about L/λ of ~ 8 , the hydrophone spacing is equivalent to a wavelength, and aliasing of the arrays severely degrades array performance. Because this example includes both array size and geometry, we next look only at array size.

SLIDE 7

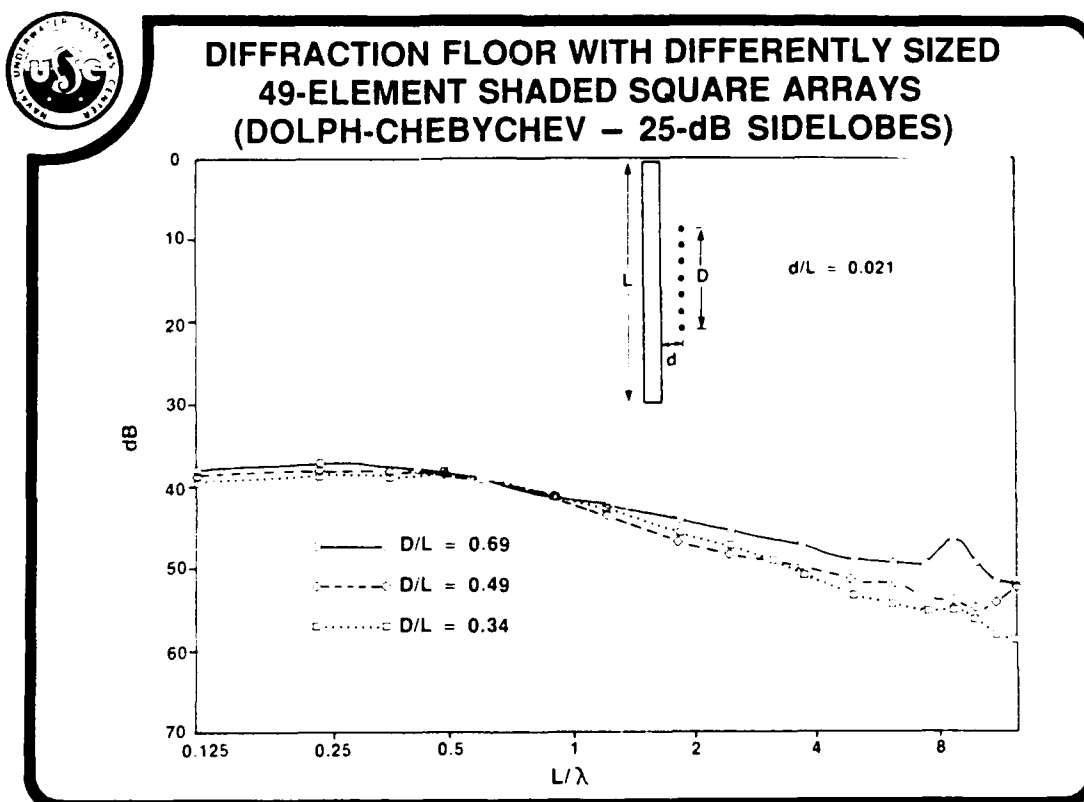


In this example, the array size is varied for 49 hydrophone square arrays that are uniformly summed. In general, both of the smaller arrays perform better than the largest standard array, where D/L is ~ 0.7 . Again, near $L/\lambda = 1$, the larger of the two smaller arrays is somewhat better against diffraction. Neither of the smaller arrays has the aliasing problem near $L/\lambda = 0.8$, but evidence of aliasing at higher frequencies is seen with the midsized array.

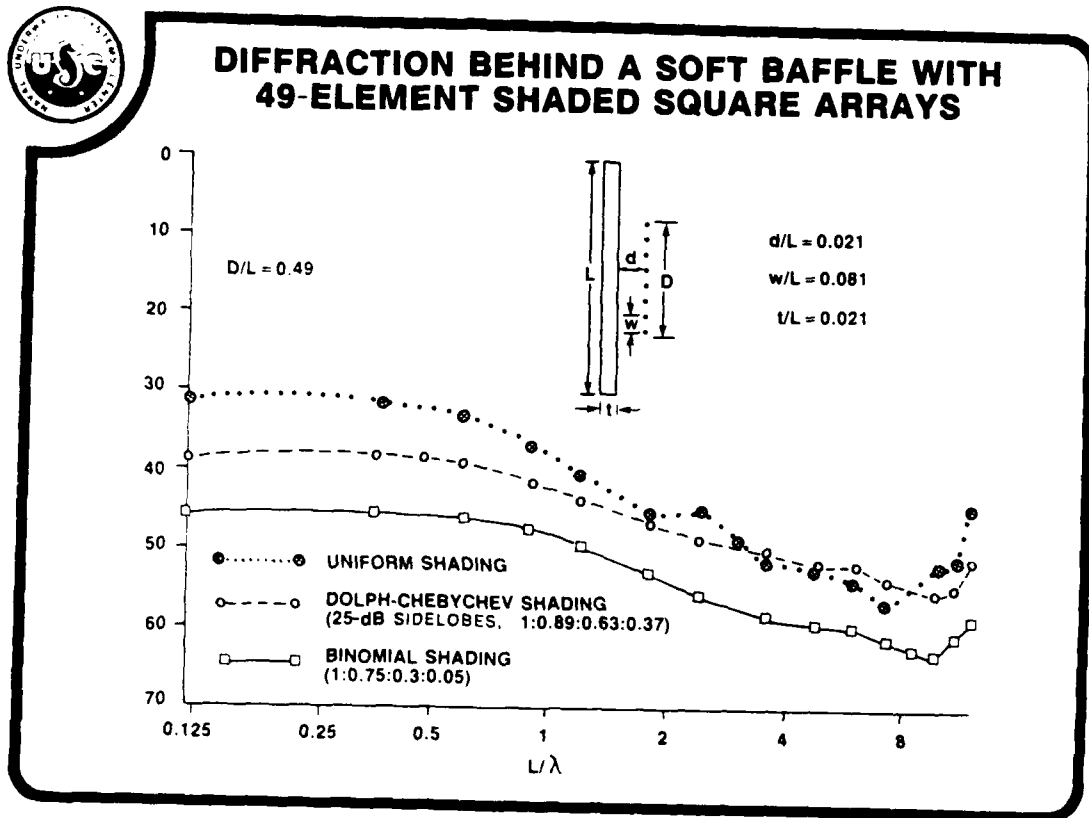


Besides the uniform shading that already has been considered, two examples of Dolph-Chebyshev shading will now be studied. This type of shading gives the minimum beam broadening for designated sidelobe levels. The coefficients for the 25-dB sidelobe Dolph-Chebyshev case, which was employed in an actual measurement array, is shown in the upper left-hand quadrant. The limiting case of no sidelobes for Dolph-Chebyshev shading is referred to as binomial shading, and these coefficients for a 49-element array are shown in the lower right-hand quadrant. Because of the wider numerical spread for the binomial coefficients, this shading is sensitive to noise fluctuations in the corner elements. For these studies, binomial shading might be viewed as an optimistic lower diffraction bound.

SLIDE 9



Initially, the Dolph-Chebyshev shading with 25-dB sidelobes is compared for different array sizes to verify that, as with the uniformly shaded arrays, there is an optimum array size with respect to the panel size. The array size where D/L is ~ 0.69 represents that used for the originally constructed 49-element array with shading. As with the uniformly shaded array, the array where D/L is ~ 0.5 tends to have better performance for $L/\lambda > 1$ and similar performance for $L/\lambda < 1$. The smallest array, where D/L is ~ 0.34 , has reduced performance with respect to the midsized array for $0.8 < L/\lambda < 3$. Again, with the shaded arrays, an array size where D/L is ~ 0.5 is optimum for the frequency range under consideration.

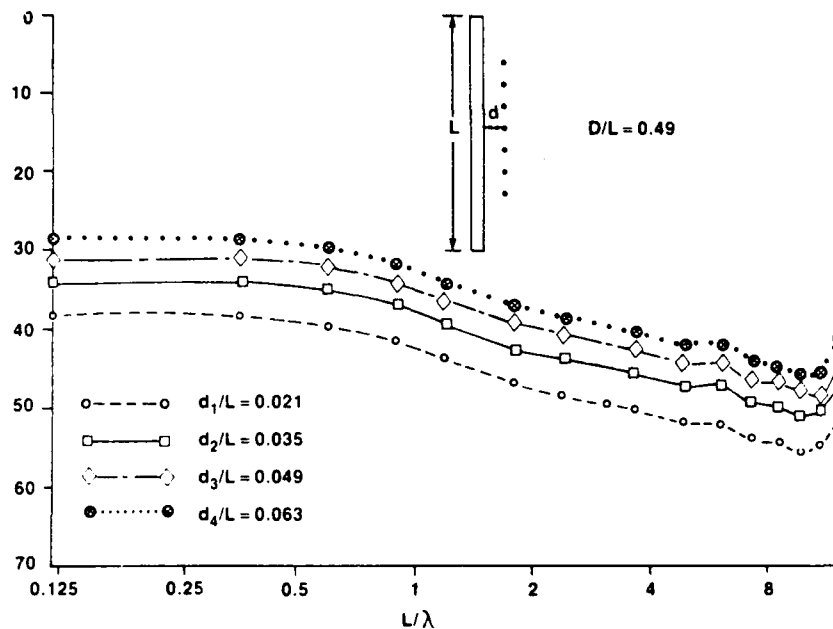


The uniformly shaded rectangular array of $D/L = 0.49$ is compared with the Dolph-Chebyshev shading with 25-dB sidelobes and with binomial shading. For the 25-dB sidelobe shading, improvement is found with respect to uniform shading below $L/\lambda \leq 1$. With binomial shading, about a 5-dB improvement in diffraction, with respect to 25-dB sidelobe shading, is realized over the entire frequency band.

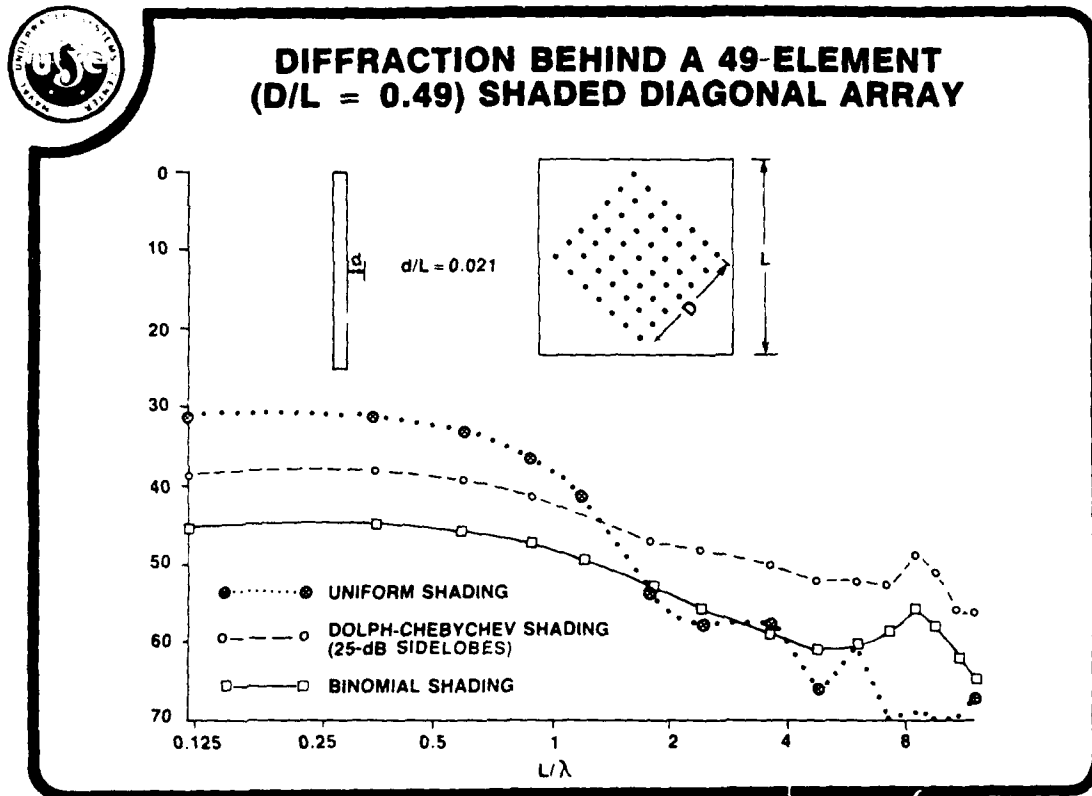
SLIDE 11



**DIFFRACTION FLOOR WITH A 49-ELEMENT SHADED
SQUARE ARRAY AT VARIOUS DISTANCES BEHIND A
SOFT BAFFLE (DOLPH-CHEBYCHEV - 25-dB SIDELOBES)**



The increase in diffraction as the array is placed farther away from the baffle is illustrated for the 49-element rectangular baffle where D/L is ~ 0.5 and for the 25-dB sidelobe Dolph-Chebyshev shading. As the distance of the array behind the baffle increases by a factor of three, the diffraction increases by about 10 dB over the entire frequency range.



The final example illustrates differences between uniformly summed diagonal arrays and shaded diagonal arrays with $D/L = 0.49$. As with the square arrays, the shading increases the performance at frequencies where L/λ is less than 1. However, for the 25-dB sidelobe shading, the performance is significantly degraded with shading for L/λ greater than 1. In this case, the optimum performance occurs for shading applied only for frequencies where L/λ is less than 1.

CONCLUSIONS

For uniform shading, diagonal arrays of sizes $1/3 < D/L < 1/2$ perform better against diffraction than a rectangular array (D/L of ~ 0.7) above $L/\lambda > 1$. Uniform shading is optimum for all diagonal arrays where $L/\lambda > 1$. Dolph-Chebyshev shading increases performance for $L/\lambda < 1$ in all configurations. The optimum size for an array of hydrophones for the frequencies investigated is D/L equal to ~ 0.5 . The use of the approximate solution by coherent addition of the contributions of two-dimensional strip analysis should be checked by a full three-dimensional calculation. The three-dimensional calculation could most easily be performed at small values of L/λ .

SLIDE 13



CONCLUSIONS

- UNIFORM SHADING
 - DIAGONAL ARRAYS SUPERIOR TO SQUARE ARRAYS FOR $L/\lambda > 1$
- DOLPH-CHEBYCHEV SHADING
 - INCREASES PERFORMANCE FOR $L/\lambda < 1$
 - DECREASES PERFORMANCE OF DIAGONAL ARRAYS FOR $L/\lambda > 1$
- SIZE
 - $D/L \sim 0.5$ OPTIMUM FOR BOTH DIAGONAL AND SQUARE ARRAYS
- TWO-DIMENSIONAL APPROXIMATIONS SHOULD BE VERIFIED WITH THREE-DIMENSIONAL ANALYSIS

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