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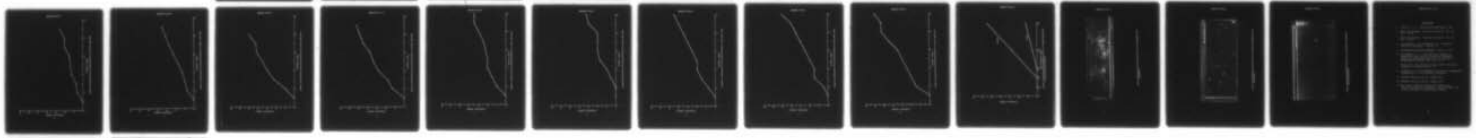

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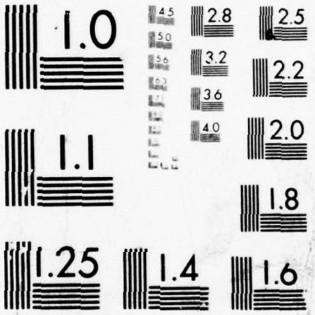

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FEASIBILITY OF ULTRASONIC RAYLEIGH WAVES FOR THE DETECTION OF CORROSION BENEATH PAINT

BY ROBERT A. YOUSHAW

RESEARCH AND TECHNOLOGY DEPARTMENT

7 FEBRUARY 1978

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Rayleigh Waves
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20. ABSTRACT (*Continue on reverse side if necessary and identify by block number*)

Rayleigh waves of ultrasonic frequency were investigated as a potential tool for detecting corrosion beneath paint on Naval ships. In certain cases, the method did detect corrosion, but in other cases known pockets of corrosion could not be detected at all. Most important, it was found that the paint is extremely attenuating to Rayleigh waves and that inspection

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distance is effectively limited to a distance of about twelve inches. For these reasons, Rayleigh waves were not considered either practical or reliable as a tool for detecting corrosion beneath paint.

SUMMARY

Rayleigh waves of ultrasonic frequency have properties which suggested a potential application in detecting corrosion beneath paint on Naval vessels. This is a matter of considerable importance to the U. S. Navy and a feasibility study in this regard was sponsored by the NSRDC/Annapolis: Task Area SF 54-501-52B, Element G276IN.

The method did not reliably detect corrosion. More important, it was found that paint in the thickness specified for ship hulls is extremely attenuating of Rayleigh waves, especially at frequencies of 2.25 MHz and higher, which are necessary for good test sensitivity. This effectively limits the inspection distance to no more than 12 inches. Considering the large area involved in ship inspection, the distance limitation makes this method impractical for the intended application.

P. R. Wessel

P. R. WESSEL
By direction

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FEASIBILITY OF ULTRASONIC RAYLEIGH WAVES FOR THE DETECTION OF CORROSION BENEATH PAINT

1. INTRODUCTION

Rayleigh waves are a type of acoustical wave that propagate only upon a surface and which may interact with irregularities on that surface to produce a reflected wave or other acoustical phenomena. Since they exist only upon a surface, penetrating no deeper than about one wave length, it has been suggested that such waves may be used to inspect a surface or a coating applied to a surface.[1]

If indeed, Rayleigh waves may be used to inspect a coating upon a surface, there is a potential application in the protective paints used on all Naval ships. Considering the large area of painted surface on Naval ships, what is required is a procedure whereby inspection may be performed along two axis to establish coordinates for pockets of corrosion within a large area. Such a system would offer not only the advantage of speed but also a capability for remote inspection thus negating the requirements for point-to-point access.

With these considerations in mind, this study was undertaken to determine the feasibility of using Rayleigh waves as a tool for detecting corrosion beneath paint.

2. RAYLEIGH WAVES

Rayleigh waves are elastic perturbations propagating near the free boundary of a solid and decaying exponentially with depth. They were first described by Lord Rayleigh in 1885 and are the ordinary vibration experienced during an earthquake. Because of their ocurrence in seismology they have been extensively studied and are described in detail elsewhere.[1,2,3].

[1] Viktorov, I.A., "Rayleigh and Lamb Waves", 1967.
[2] Mason and Thurmont, "Physical Acoustics", Vol. VI,pp.142-165.
[3] Mason & Thurmont, "Physical Acoustics", Vol VII,pp.219-272.

The velocity of the Rayleigh wave is always less than that of a transverse wave and in steel is 0.92 the transverse wave velocity.[4] Most of the energy is confined to a layer about one wave length depth.[4] In steel, the transverse velocity is 3.23×10^5 cm/sec.[5] The wave length and, therefore, depth may be calculated for several common ultrasonic frequencies using the formula:

Velocity = frequency x wave length

Frequency (MHz)	Rayleigh Wave Length
1.0	2.97 mm (.119 in.)
2.25	1.32 mm (.053 in.)
5.0	.594 mm (.024 in.)

Rayleigh waves will propagate on curved as well as flat surfaces; however, there will be some reflection from any interruption of the surface with a radius of less than one wave length with larger fractions reflected for progressively smaller radii or sharper discontinuities.[1]

Several methods exist whereby Rayleigh waves may be generated and/or detected;[1] however, the application in mind requires a sturdy, non-cemented transducer with moderately large sonic intensity. These requirements restrict the choice to the familiar wedge extensively used in shear wave ultrasonic testing. Electromagnetic methods show promise[6,7,8] and may ultimately serve well but have not yet advanced to the point where such equipment is commercially available.

In the wedge method a transducer is placed in contact with a wedge of low acoustical velocity material. The angle of the wedge is selected so as to equal or slightly exceed the critical angle as calculated from Snells law for refraction:

---

[4] Krautkramer, J., and Krautkramer, H., "Ultrasonic Testing of Materials", 1969, p. 19.

[5] Nondestructive Testing Handbook, Volume II, 43:8.

[6] Krautkramer, Dr. J. "Unconventional Methods of Generating, Receiving, and Coupling of Ultrasonic Waves for Testing Materials", British Journal of Nondestructive Testing, May 1973, p. 76.

[7] Betsco, Ron, "The Eddy Sonic Test Method", Materials Evaluation, Feb 1968, p. 21.

[8] Thomp on, R. B., "Electromagnetic Non-Contact Transducers", Proceedings of 1973 Ultrasonics Symposium.

$$\text{SIN } \theta = \frac{\text{Longitudinal velocity in wedge}}{\text{Rayleigh wave velocity in steel}}$$

The optimum angle for painted steel deviates somewhat from that for unpainted steel and was experimentally determined to be between 68° and 70°; however, Rayleigh waves were generated with almost the same efficiency at both 66° and 72° wedge angles.

In common with other types of ultrasonic waves, the transducer must be coupled to the work piece - usually by a liquid. In this work, SAE 20 oil was used.

3. EPOXY PAINTS FOR NAVAL HULLS AND CORROSION

This study was limited to the epoxy-polyamide paints specified for use on submarines. Epoxy paints consist of a two-component system. These are an epoxy resin including a pigment and a chemical hardener. Surface preparation and general painting procedure are controlled[9] and specific guide lines have been set forth for epoxy paints.[10,11] These require that the surfaces to be painted be free of rust, loose paint, dirt, scale, grease, salt deposits, moisture and other contaminants. In addition, sand blasting to a near "white" metal is required for underwater hulls.

The epoxy paint is provided in several formulations which differ mostly in the pigment. Hulls are painted with three coats which total a dry film thickness of 0.008". An antifouling paint may be added on top of the epoxy.[11]

When corrosion does take place beneath the paint, this is due to diffusion of the (salt) water into and through the paint membrane by osmotic pressure. At certain locations where the paint is imperfectly bonded, rusting begins. Since the physical nature of rust is such that the products of corrosion occupy more volume than the raw materials involved, a swelling takes place which weakens the adjacent bond which in turn accelerates further rusting. The process continues until there are blisters ultimately so large and prominent as to be visible to the naked eye.

[9] NAVSHIPS Technical Manual, Chapter 9010.

[10] NAVSHIPS Technical Manual, Chapter 9190.

[11] "Navy Epoxy Polyamide Coatings for Interior and Exterior Surfaces of Submarines", Technical Note 1-74, 29 Mar 1974.

4. RAYLEIGH WAVES ON PAINTED STEEL PLATE

A 1/4" thick steel plate was painted with epoxy paint so as to provide separate sections exhibiting one through five coats of epoxy paint. Micrometer measurements indicated paint thicknesses as follows:

One coat	0.001"
Two coats	0.002"
Three coats	0.003"
Four coats	0.005"
Five coats	0.008"

Attenuation measurements were made at 2.25 MHz, Figures 1(A-E) and 1.0 MHz, Figures 2(A-E) using the pulse-echo technique and the perpendicular edge of the steel plate as the reflector. An attempt to obtain similar data at 5.0 MHz was not successful due to extreme attenuation at that frequency. In a separate experiment, the distance was maintained constant at 10 inches and the attenuation in decibels was plotted against the paint thickness, Figure 3. The effect of frequency is readily seen and also that the full dry film thickness of eight mils is extremely absorbing at 2.25 MHz which effectively limits the inspection distance to about ten inches.

5. CORROSION SAMPLES AND RAYLEIGH WAVE TESTING

Corrosion beneath paint is induced in the laboratory by subjecting painted specimens to a warm salt water spray. In the case of epoxy paint, this was not considered practical as it was known that properly painted steel would resist corrosion for a "very" long time. Consequently, attempts were made to obtain working samples by deliberate deviation from good painting practice. To' obtain these samples, a light coat of paint (about one mil) was applied to sand blasted steel and subjected to the warm salt water spray. After about two weeks time, corrosion did occur and this is illustrated in Figure 4. Painting was then done on top of this surface to build the total thickness to 0.008". This corrosion was detected with the Rayleigh wave method but the corrosion was so general that it was not possible to distinguish between signals or determine where on the plate the corrosion was located.

This effort was repeated but the salt water spray was interrupted at the first signs of corrosion. This sample is illustrated in Figure 5.

The spots of corrosion shown here were detected with the Rayleigh wave procedure before subsequent painting, but could not be located afterwards.

From the preceding experiments, and considering the intended application, it was decided that a much larger area was needed and that the adjacent regions should be free of corrosion. To obtain a sample like this, an aluminum tube with inside diameter of two inches was bonded to a plate painted with only one mil thickness epoxy paint. The tube was filled with salt water and heated to 120°F. After two weeks, the painted surface inside the tube was generally corroded as shown in Figure 6. After adding paint to eight mils thickness, this area could not be detected with the Rayleigh wave procedure.

6. DISCUSSION OF RESULTS

The extreme attenuation of Rayleigh waves on painted steel restricts the application of this method using 2.25 MHz to "very" short distances - 12" or less. While lower frequencies can be expected to extend the range there will be a corresponding decrease in sensitivity since a much larger portion of the wave will travel in the steel and thus not be subject to interaction with flaws in the coating or bond.

The corrosion illustrated in Figure 4 was detected with Rayleigh waves after additional painting. This suggests that the method does work, but considering the examples where corrosion could not be detected after painting, Rayleigh waves do not seem sufficiently reliable for the intended application.

7. SUMMARY AND CONCLUSIONS

Rayleigh waves of ultrasonic frequency were investigated as a tool for detecting corrosion beneath paint. In certain cases, the method did detect corrosion in known locations, but in other cases, known pockets of corrosion could not be detected. Most important, it was found that paint in the thickness specified for ship hulls is extremely attenuating of Rayleigh waves, especially at the higher frequencies necessary for good test sensitivity. Because of this, the inspection distance is limited to no more than twelve inches. For these reasons, the use of Rayleigh waves to inspect for corrosion beneath paint on ship hulls cannot be considered practical.

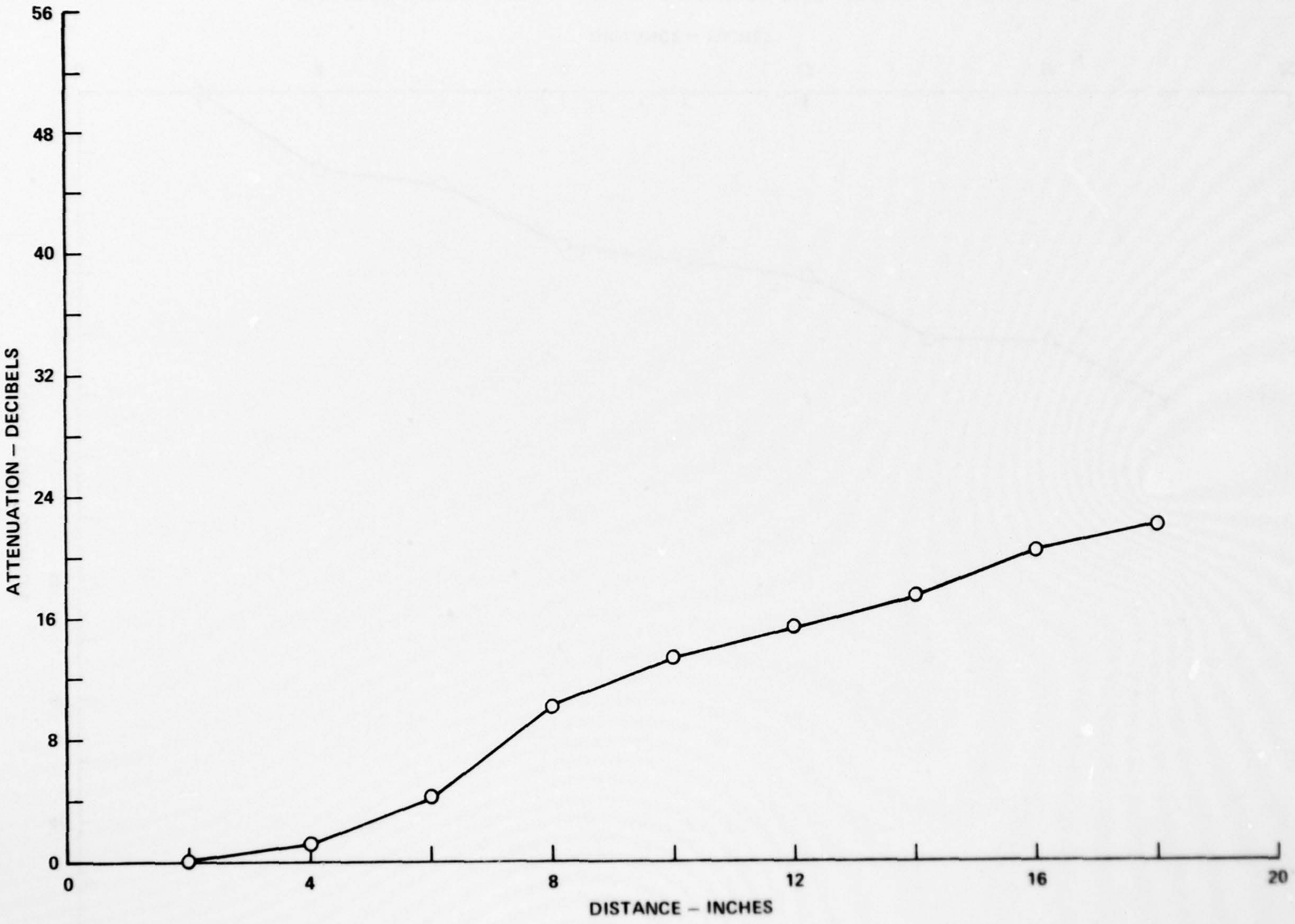

FIGURE 1A ATTENUATION OF RAYLEIGH WAVES ON STEEL AT 2.25 MHz, 0.001" PAINT.

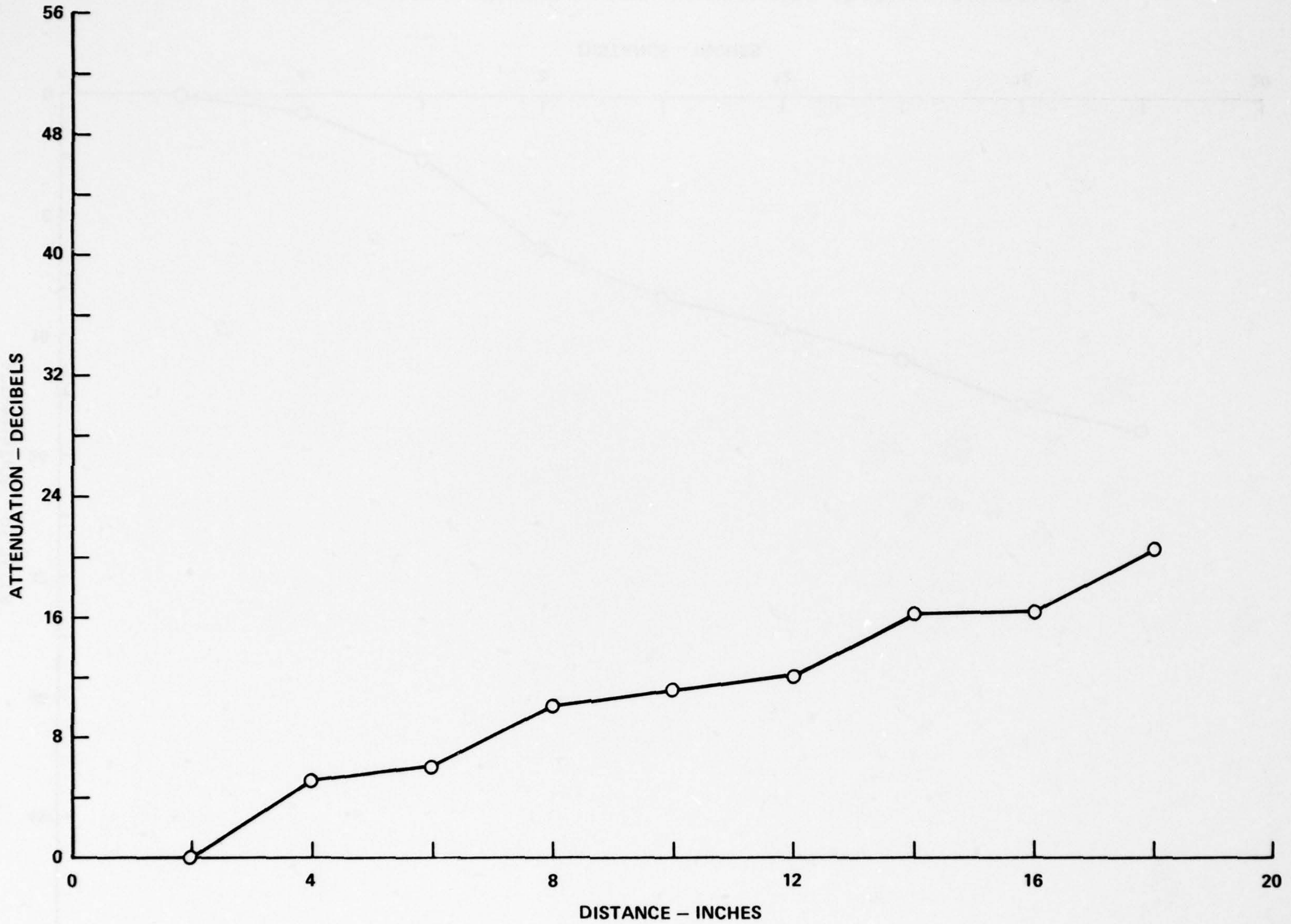

FIGURE 1B ATTENUATION OF RAYLEIGH WAVES ON STEEL AT 2.25 MHz , 0.002" PAINT.

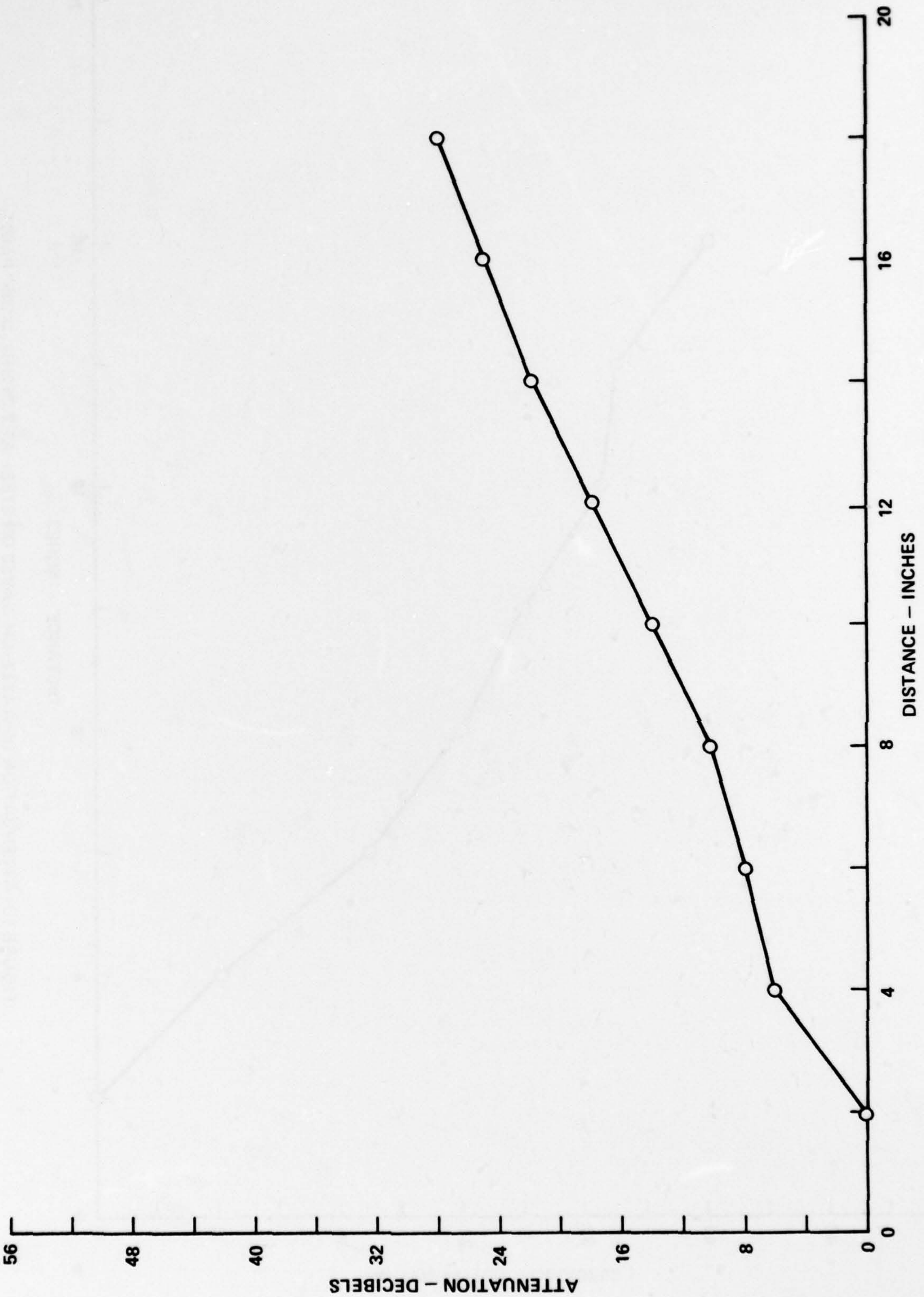

FIGURE 1C ATTENUATION OF RAYLEIGH WAVES ON STEEL AT 2.25 MHz, 0.003" PAINT.

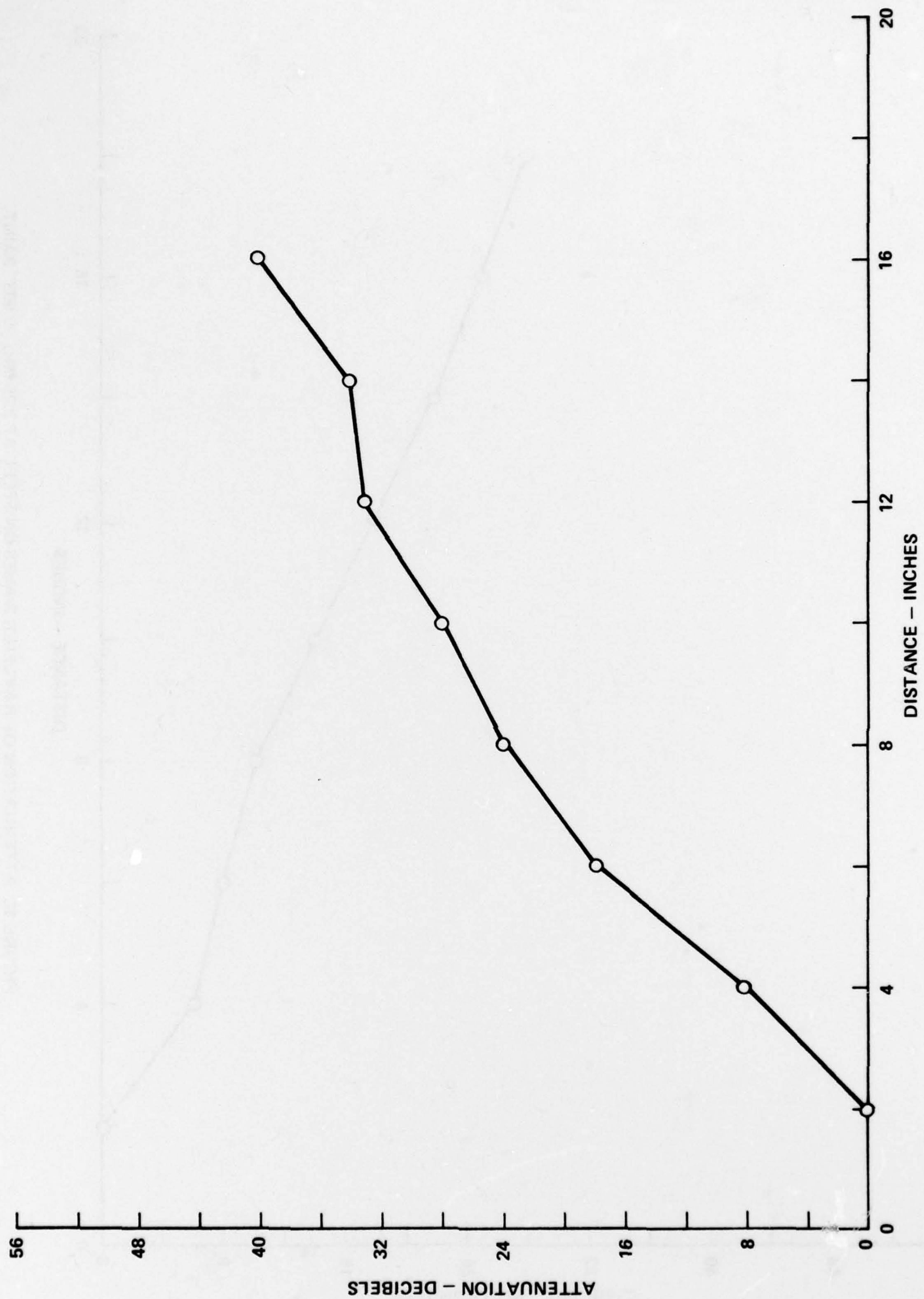

FIGURE 1D ATTENUATION OF RAYLEIGH WAVES ON STEEL AT 2.25 MHz , 0.005'' PAINT.

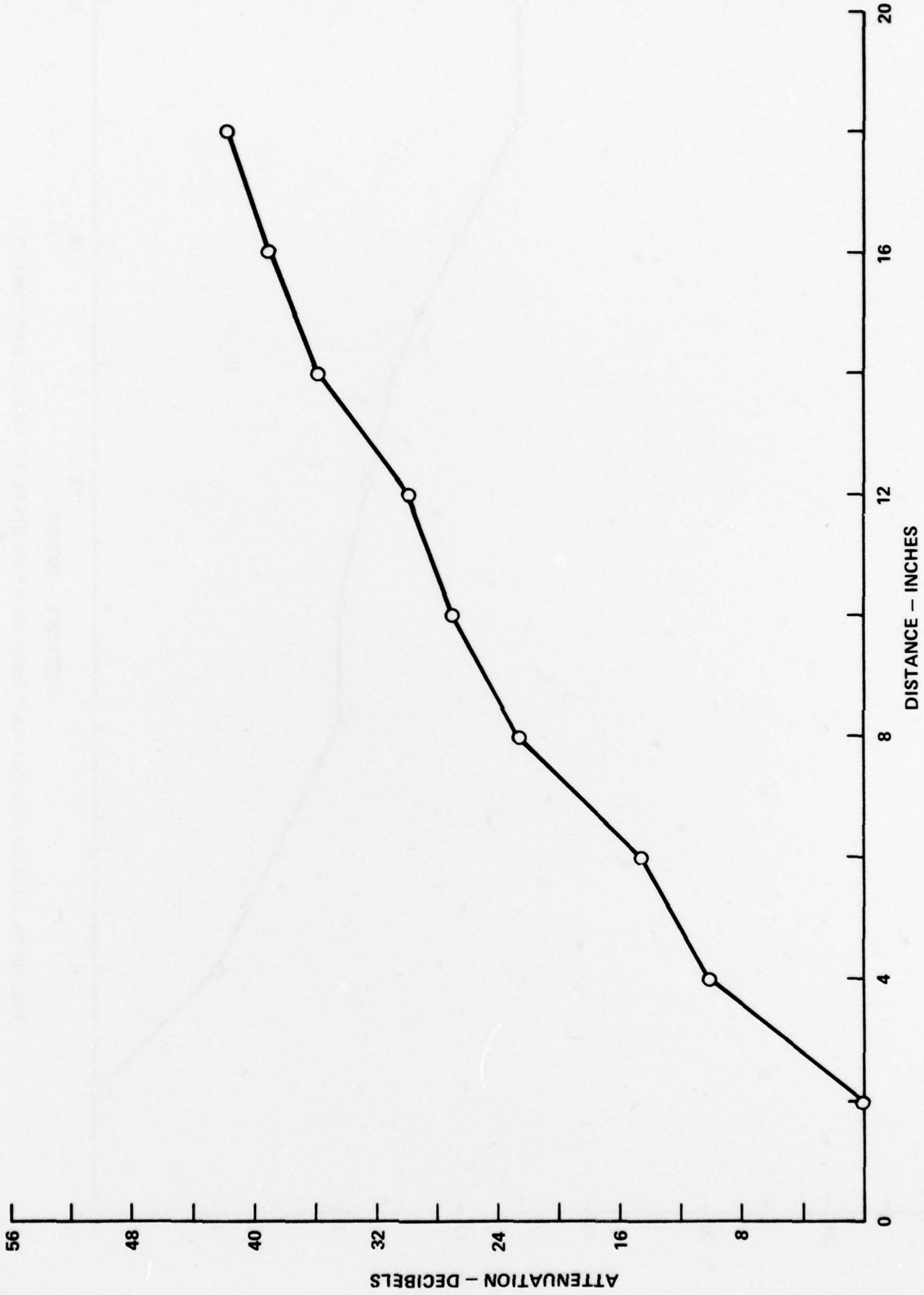

FIGURE 1E ATTENUATION OF RAYLEIGH WAVES ON STEEL AT 2.25 MHz , 0.008'' PAINT.

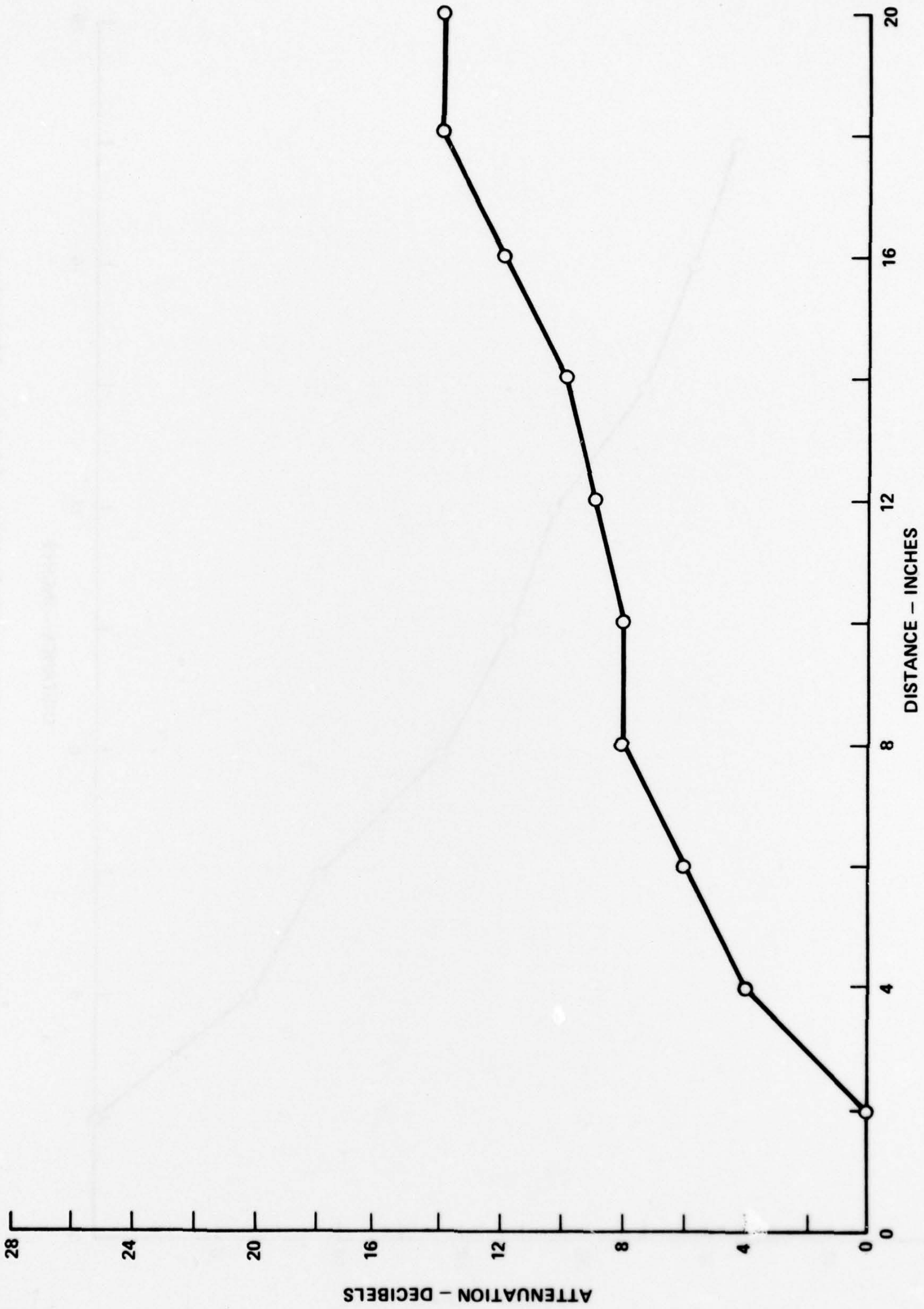

FIGURE 2A ATTENUATION OF RAYLEIGH WAVES ON STEEL AT 1.0 MHz , 0.001″ PAINT.

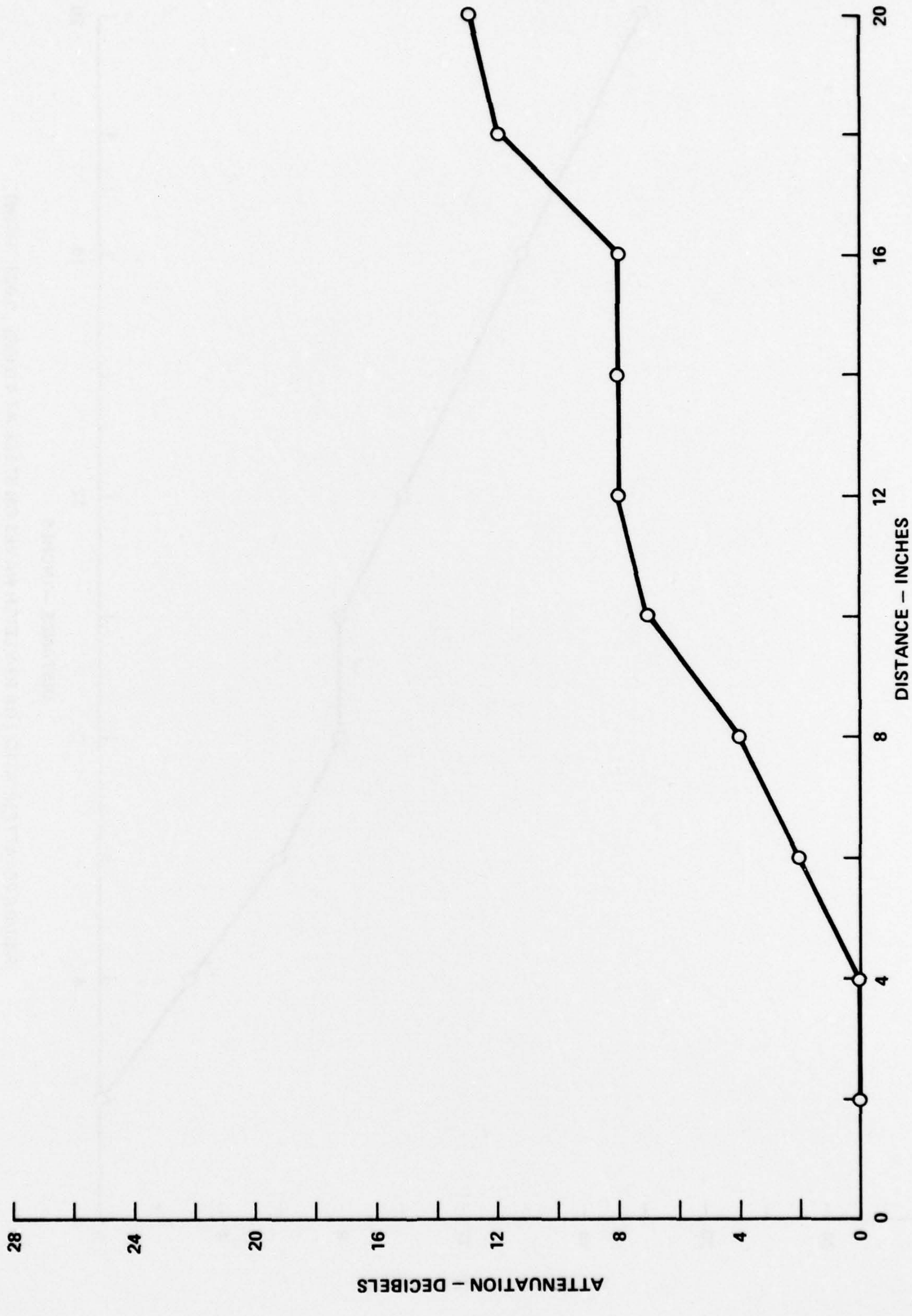

FIGURE 2B ATTENUATION OF RAYLEIGH WAVES ON STEEL AT 1.0 MHz, 0.002" PAINT.

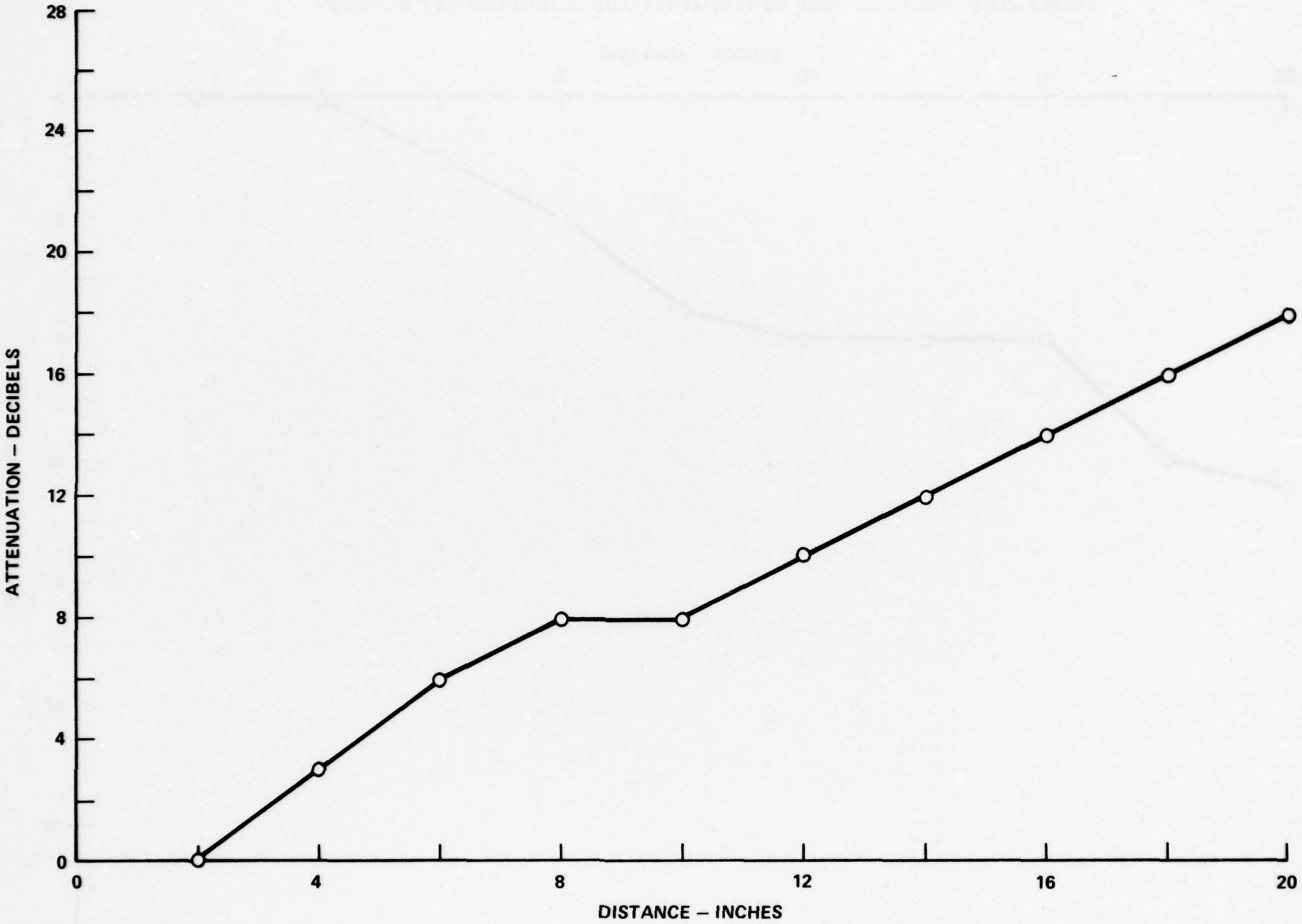

FIGURE 2C ATTENUATION OF RAYLEIGH WAVES ON STEEL AT 1.0 MHz , 0.003 " PAINT.

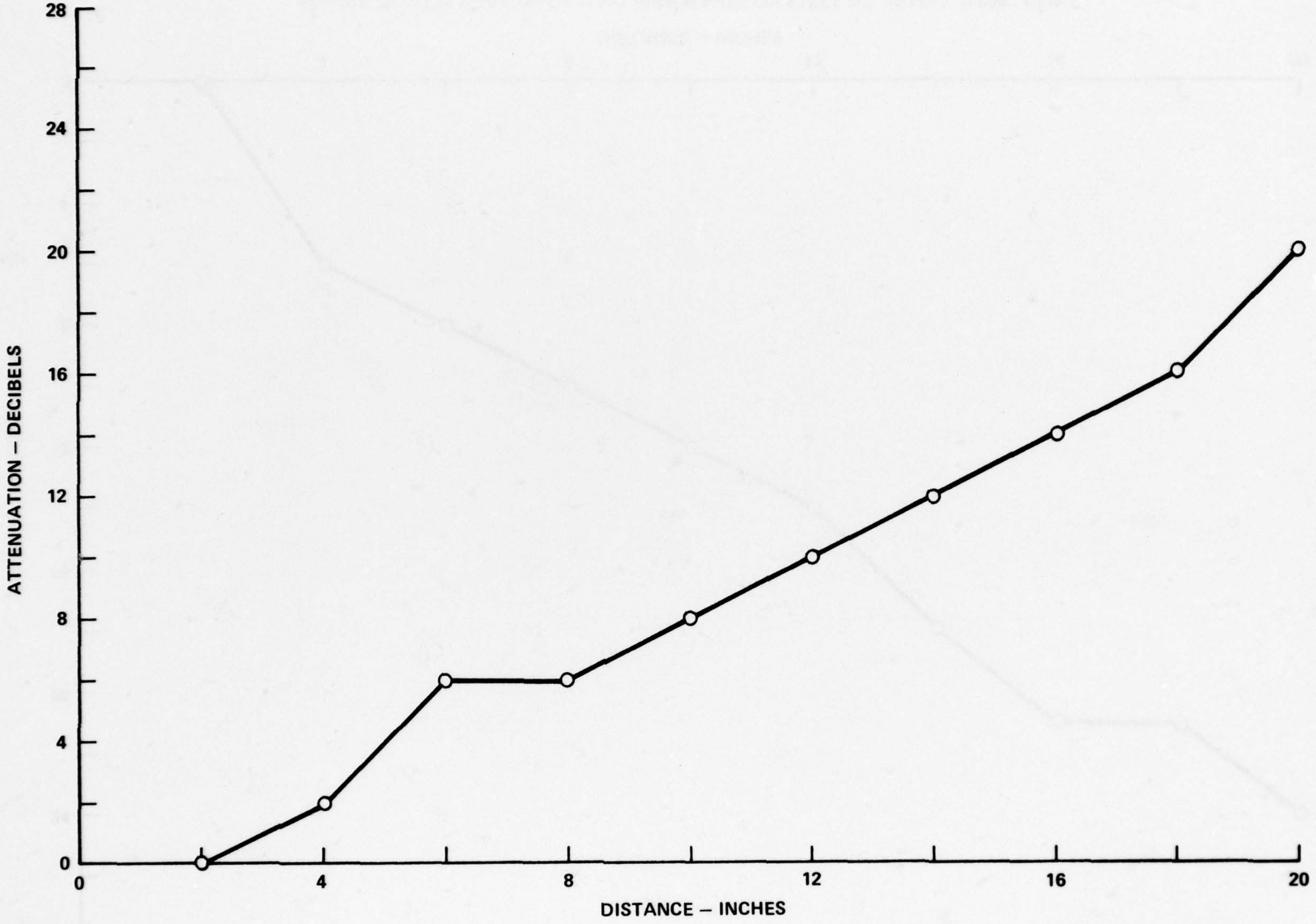

FIGURE 2D ATTENUATION OF RAYLEIGH WAVES ON STEEL AT 1.0 MHz , 0.005 " PAINT.

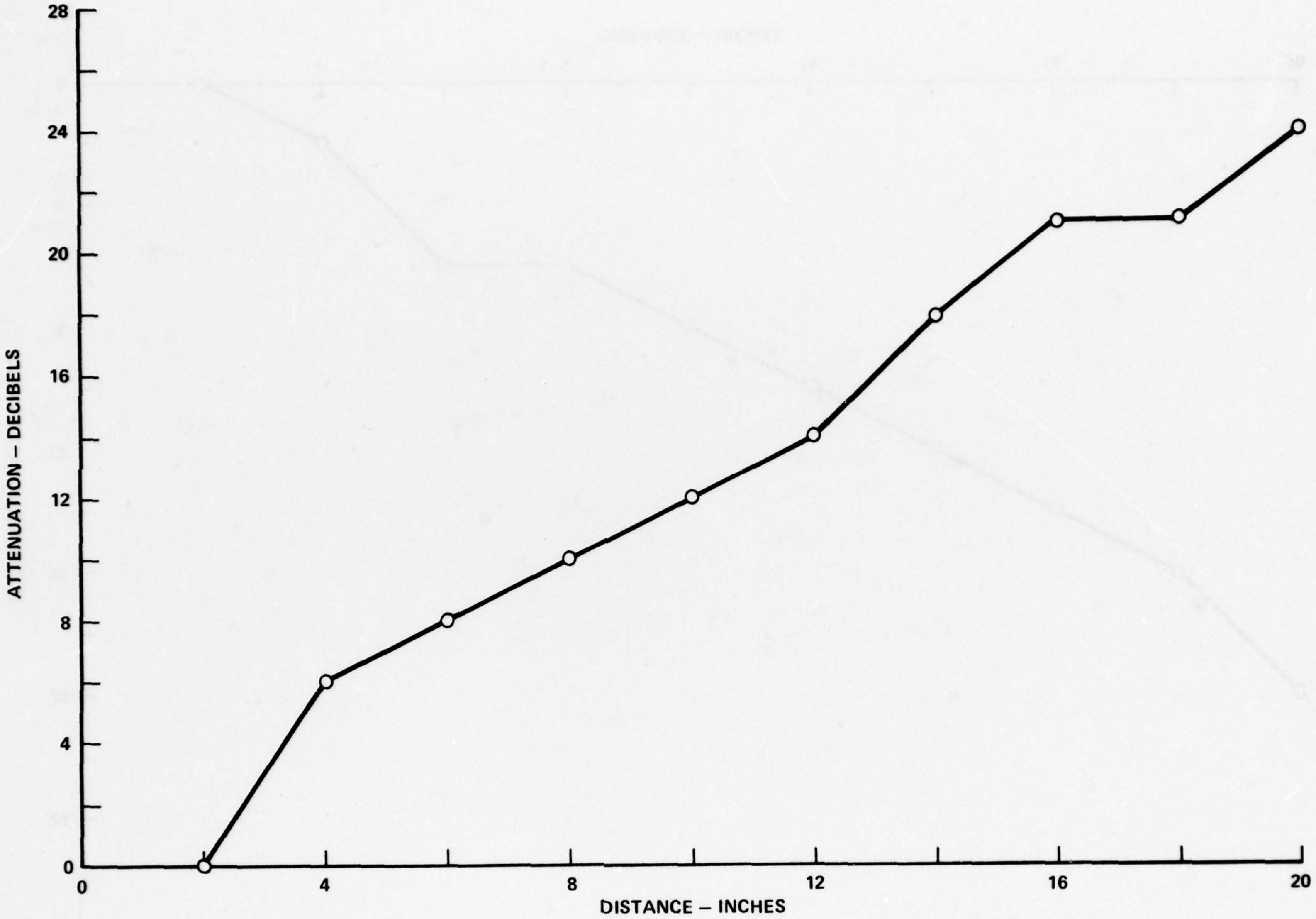

FIGURE 2E ATTENUATION OF RAYLEIGH WAVES ON STEEL AT 1.0 MHz , 0.008" PAINT.

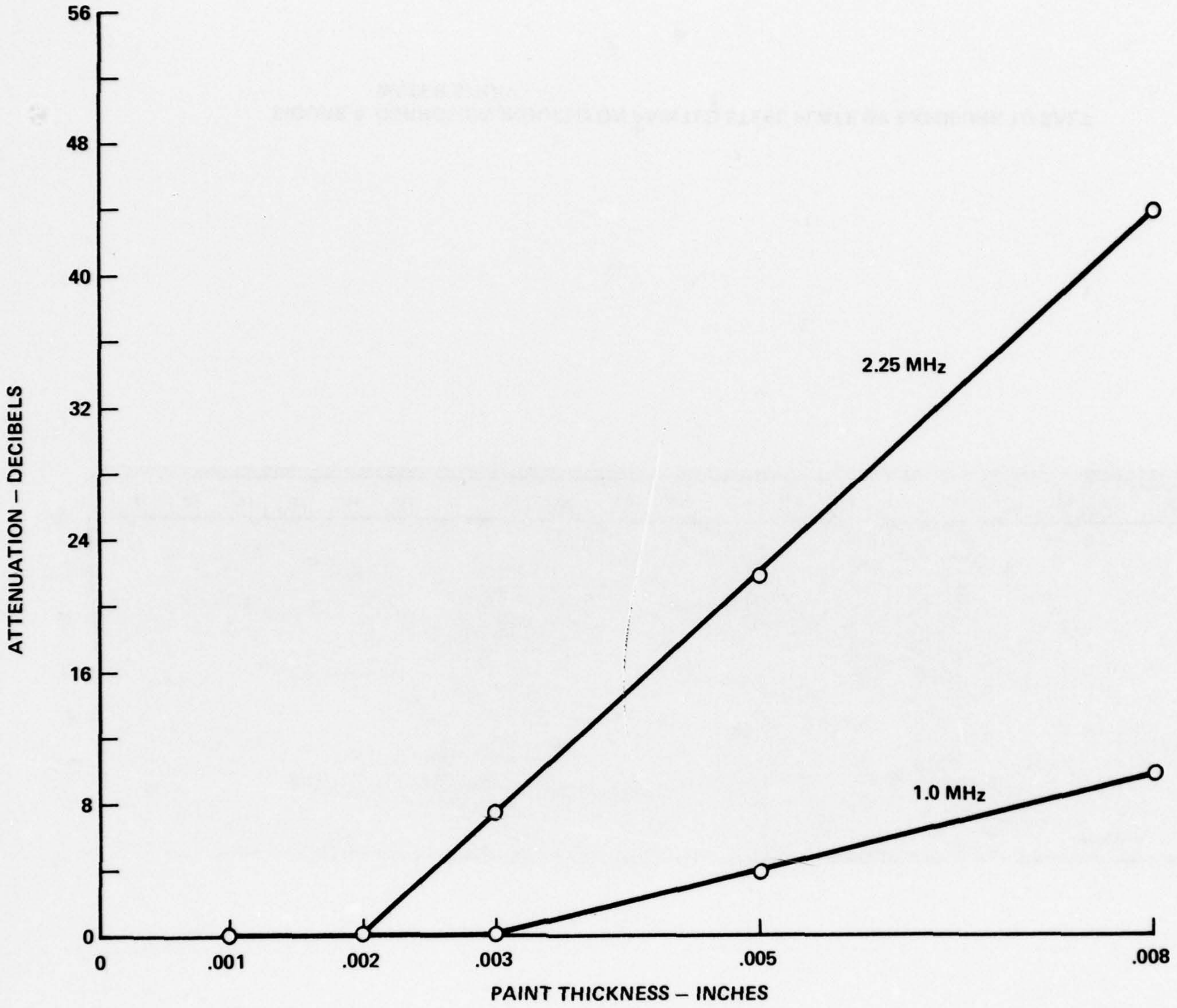

FIGURE 3 ATTENUATION OF RAYLEIGH WAVES ON STEEL AT 10 INCHES DISTANCE FOR 1.0 MHz AND 2.25 MHz FREQUENCIES.

FIGURE 4 CORROSION INDUCED ON PAINTED STEEL PLATE BY EXPOSURE TO SALT WATER SPRAY.

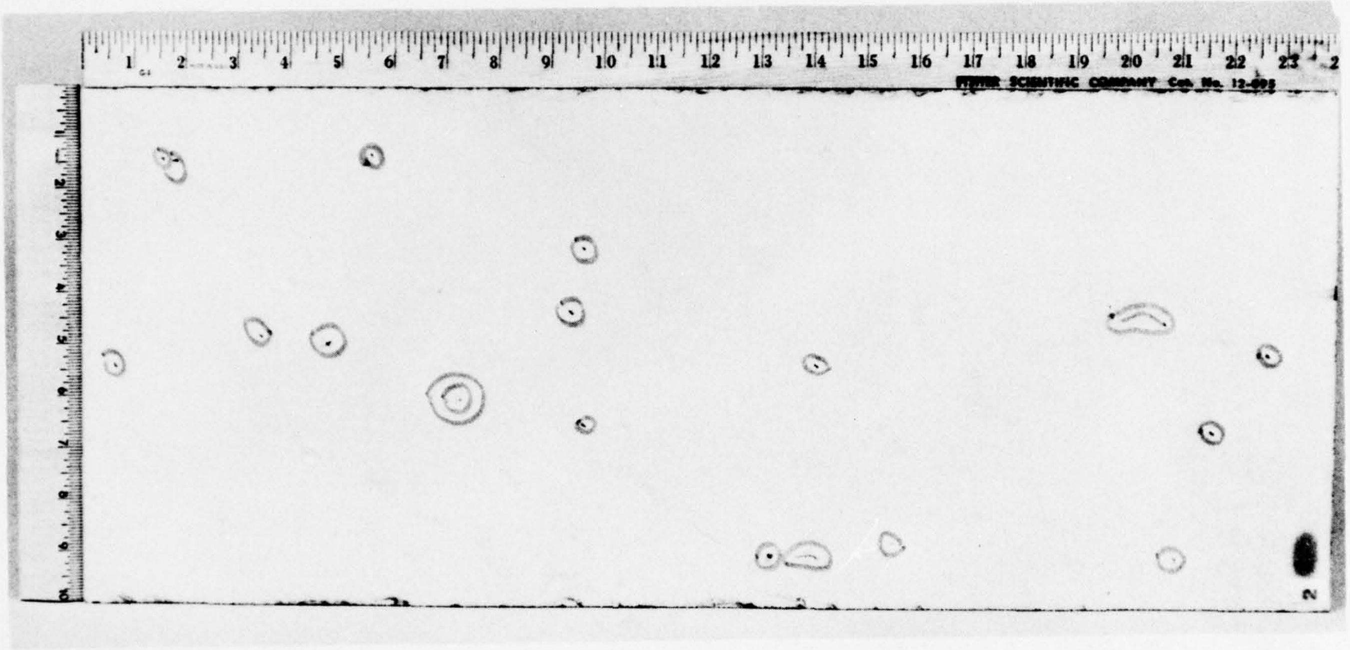

FIGURE 5 MINOR CORROSIN ON PAINTED STEEL PLATE INDUCED BY EXPOSURE TO SALT WATER SPRAY.

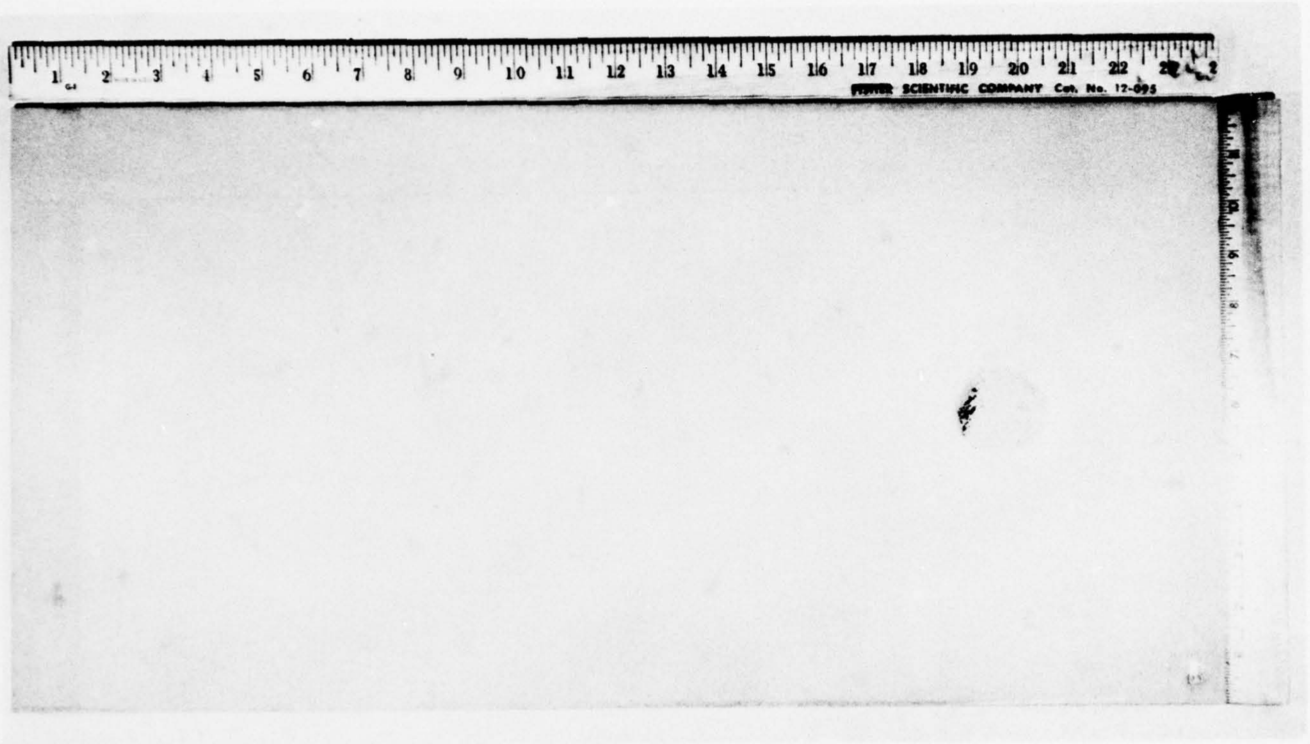

FIGURE 6 LOCALIZED CORROSION ON PAINTED STEEL PLATE INDUCED BY EXPOSURE TO SALT WATER SOLUTION.

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4. Krautkramer J., and Krautkramer, H., "Ultrasonic Testing of Materials", 1969, p. 19.

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9. NAVSHIPS Technical Manual, Chapter 9010.

10. NAVSHIPS Technical Manual, Chapter 9190.

11. "Navy Epoxy Polyamide Coatings for Interior and Exterior Surfaces of Submarines", Technical Note 1-74, 29 Mar 1974, Naval Ship Engineering Center.

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