CASING CORROSION EVALUATION USING ULTRASONIC TECHNIQUES
A UNIQUE APPROACH FOR WEST TEXAS WELLS

D.L. Roberts and J.W. Richards
Schlumberger Well Services

ABSTRACT

Virtually all west Texas wells possess, to varying degrees, conditions of internal and/or external casing corrosion. The majority of the corrosion problems begin when produced (or injected) fluids come in contact with the casing inner wall, or when formation fluids come in contact with the outer wall of the casing in areas not protected by adequate annular cement. Both internal and external casing corrosion problems can become more severe with time, and can, if not addressed, lead to premature demise of the well. In order to ascertain the severity of corrosion problems in any specific well, many wireline logging devices have been developed over the past several years. Basically mechanical/magnetic in makeup, quantitative interpretation from the classic tools depends largely upon assumption of unknowns that, in most cases, are very hard, if not impossible, to accurately identify.

A new corrosion evaluation procedure developed by Schlumberger uses a uniquely different approach to the challenge of quantitative casing inspection. The technique uses full ultrasonic casing resonance information recorded with a modified cement evaluation tool. Using the CET* tool, all necessary casing inspection data can be recorded simultaneously with cement evaluation information. The waveforms recorded at each of the eight (8) radially spaced CET ultrasonic transducers can be analyzed to obtain the following information regarding the condition of the casing:

- The specific internal geometry of the casing
- An internal casing roughness profile.
- A casing metal thickness profile.

A derivation of the measurements obtained at each CET transducer will be presented followed by discussion of the currently available display presentations and casing imaging techniques. The specific utilities of the ultrasonic casing inspection technique will be highlighted by citing several examples from west Texas wells.

INTRODUCTION

In most oil and gas wells in West Texas, the effects of electrochemical reactions between the downhole environment and the steel casing can initiate the corrosion process. The major cause of corrosion in west Texas wells can be attributed to corrosive formation fluids contacting the steel casing. This type of corrosion can occur on the inside or the outside of the casing. In most situations, external corrosion occurs as a result of a lack of cement in the casing-formation annular space. Along with providing mechanical support for the casing, the cement also protects the casing from coming in contact with formation fluids that may be corrosive. By insuring a good cement job, and/or implementing an adequate cathodic protection program, the problem can be greatly reduced. The main cause of internal corrosion can be related to produced formation fluids contacting the inside of the casing. If these fluids are corrosive and are allowed to contact the casing over long periods of time, internal damage to the casing may occur. Most internal corrosion problems are addressed by chemical treatments administered throughout the lifetime of the well.

* Mark of Schlumberger

If the corrosion process is allowed to proceed unabated, the overall strength and integrity of the casing could be altered. Over time, external or internal corrosion can lead to casing wall thinning. This wall thinning may cause the casing to lose its strength and can eventually lead to holes in the casing wall. The remedial work or action necessary to combat corrosion problems can be very time consuming and costly. Severe corrosion problems can lead to setting liners, replacing corroded casing, or in the worst circumstance, abandoning of the well.

CLASSIC CORROSION LOGGING DEVICES

The need to uncover corrosion problems in time for remedial action led to the development of several wireline logging devices. In the context of this paper, these devices will be referred to as "classic" corrosion logging devices. The classic devices can be divided into two general categories: electromagnetic and mechanical.

Electromagnetic

The electromagnetic tools can be used in the detection of both external and internal casing corrosion. The basic principle employed consists of detecting changes in magnetic fields induced by the logging tool as it travels in the wellbore. These changes can be related to changes in casing condition and, therefore, can be indicative of corrosion. Two basic electromagnetic tool types have been commercially available over the past several years.

The pipe analysis tool (PAL*) was developed to detect external and internal corrosion problems by noting relative response changes in any of 12 sensing pads. The sensing pads are radially spaced around the tool in order to provide 100% casing coverage (see Fig. 1). The response from a typical PAL log is shown in Fig. 1. Although qualitative in nature, the PAL tool does an adequate job of detecting holes in the casing. It can also delineate between total wall and internal corrosion sites. The device provides no information on the geometry of the casing.

The second device, the (ETT*) electromagnetic thickness tool, makes a measurement of the electromagnetic phase shift between a transmitter and a receiver coil. The measured phase shift can be related to the wall thickness of the casing. A change in phase shift can be indicative of a change in the average wall thickness of the pipe (Fig. 3). A quantitative value of average casing wall thickness can be obtained assuming that a change in phase shift is due to an actual thickness change, and not due to a change in the magnetic properties of the casing. Since casing magnetic properties are unpredictable, this type of logging device is best suited for time lapse measurements, in which a base phase shift (new casing) log can be recorded and compared with data from subsequent logging runs. (A recently developed electromagnetic device is showing promise in addressing the problem of unknown casing properites.)

Mechanical

The basic mechanical device used in corrosion detection is the multi-finger caliper tool. The device is designed to obtain information on the casing condition through the use of a series of arms or fingers, that come in contact with the inner wall of the casing. The information obtained can give good indications of internal casing geometry. However, changes in wall thickness can only be calculated by assuming a nominal external diameter. In the west Texas area, the assumption of a constant external diameter may not be valid since the most common form of corrosion occurs on the outside of the casing (see Fig. 4).

AN ULTRASONIC CASING INSPECTION DEVICE

The most recent casing inspection tool employs an ultrasonic approach to obtain quantitative answers concerning casing condition in liquid-filled boreholes. The ultrasonic device is uniquely different from any of the classic logging tools in that the answers obtained are derived from computations that depend less upon hard-to-identify parameters, and more upon solid physical measurements made by the device itself. Although the device was not intended to replace the classic logging services, it has enhanced many casing inspection interpretation situations by adding new additional information not obtained by the standard tools. Also, as a standalone logging device, the ultrasonic tool was shown to be of significant benefit when quantitative answers are desired.

The measurements pertaining to casing inspection are recorded in the wellbore using a modified cement evaluation tool, called the Digital Cement Evaluation tool. Ultrasonic travel time data, waveform amplitude data, and the information obtained from digitally recorded waveforms form the core for the casing inspection service. The approach of using a modified cement evaluation tool to obtain casing inspection information permits the convenience of gathering casing data while evaluating the condition of the cement in the casing-formation annular space.

A diagram of the digital cement evaluation tool is presented in Fig. 5. Waveform and travel time information are recorded at each of the tool's eight ultrasonic transducers. The placement of the transducers permits a radial sampling of casing condition to be obtained at any point in the wellbore.

The three casing inspection measurements taken after the firing of each ultrasonic transducer will be discussed separately below.

<u>Internal Geometry Measurements</u>

Internal geometry measurements are obtained using two-way travel time data recorded at each of the eight ultrasonic transducers. Each individual travel time measurement is defined as the time taken for sound energy to travel from the face of the ultrasonic transducer to the inner wall of the casing and then back to the surface to the transducer, as shown in Fig. 6. Each individual measurement is converted to a distance value by entering the wellbore fluid sonic velocity (a parameter measured by the tool) into the equations:

$$d = v \times T$$

where
- d = the distance from the transducer face to the casing wall (in).
- v = the velocity of sound in the wellbore fluid (in/us).
- T = one-half of the two-way travel time (us).

Using the fixed distance between diametrically opposed transducers, each distance measurement defined above can be referenced from the geometric center of the logging tool. Each measurement is then corrected to the geometric center of the casing using a best fit calculation based on the eccentricity of the tool (a measured parameter derived from the raw distance measurements). The final result yields eight internal radii measurements referenced from the geometric center of the casing. The internal geometry measurements can be presented in a variety of forms which will be discussed later in the paper.

Casing Internal Reflectivity

Internal casing reflectivity measurements are made by recording the amplitude of the first positive arrival associated with each waveform as it returns to the transducer, as shown in Fig. 7. This measured amplitude, termed W1, is representative of the amount of sound energy returning directly to the transducer after reflecting off the casing inner wall. In conditions of a smooth inner wall, each individual transducer will possess a specific return waveform amplitude. In nonsmooth conditions, certain amounts of the sound energy incident upon the casing will be scattered because of the nonsmooth wall. The scattered energy not returning to the face of the transducer will be noted as a decrease in the measured W1 value. The relative amount of W1 attenuation can be related to the amount of roughness on the inner wall of the casing. Corrosion, scale, or paraffin buildup all may be detected as decreases in the measured W1 values.

Resonance-Derived Casing Thickness

The exponential section of each digitally recorded return waveform represents the resonance, or "ringing," of the casing. By performing a frequency analysis on the exponential section of each waveform, the resonant frequency of the casing can be calculated, as in Fig. 8. Casing thickness, which is inversely related to the resonant frequency through the velocity of sound in steel, can then be calculated. Casing thickness, presented in units of inches, is calculated at each of the radially spaced transducers.

The three basic casing inspection measurements can be presented in a variety of forms, depending upon the answers desired in each particular situation.

DISPLAY PRESENTATIONS

Casing Cross Section Presentation

The casing cross section presentation is pictured in Fig. 9. The presentation consists of a two-dimensional representation of the casing taken through diametrically opposed transducers. Referring to the figure, it can be seen that Tracks 2 and 3 contain the diametrical cuts across the casing. Each individual cross section can be interpreted exactly as what it appears to be; a cutaway through the casing. The inner walls of each cross section are obtained from internal geometry information presented as internal radii values. The outer surfaces are obtained from resonance derived casing thickness values added to the internal radii values. Because each cross section is rotated 45° from adjacent sections, the presentation can be used to differentiate localized wall thinning from generalized wall thinning and to identify whether the thinning is occurring on the inside or the outside of the casing.

Track 1 contains a thickness max.-min. overlay, an internal average caliper curve, and a casing ovality curve. The max.-min thickness overlay presents the maximum and minimum resonance-derived casing thickness values calculated at each sample interval. The overlay can be used to obtain a feel for the average thickness encountered to determine the magnitude of radial thickness variations, and to highlight the thinnest section of casing. The internal average caliper curve can be used to determine casing weight to locate casing weight changes, and to highlight major changes in casing internal diameter. The casing ovality curve, defined as the difference between the maximum and minimum caliper reading, can be used to highlight out-of-round conditions occurring on the inside of the casing. High ovality readings can be identified as true ovalized casing by referring to the max.-min. thickness overlay. If the overlay indicates no change in thickness through the ovalized section, then true casing ovality, and not internal metal loss, exists.

Engineering Listing

The engineering listing presents resonance-derived casing thickness values versus depth from each of the eight transducers, along with an average casing thickness value, a max. and min. thickness, and a computation of percent metal loss between the average measured thickness and an input nominal thickness. An example is presented in Fig. 10. The engineering listing can be a valuable aid when detailed thickness values are needed in specific areas of the well. It can also be used, in a generalized manner, to obtain the overall percent of metal loss occurring versus depth. In this manner, wall thinning occurring on a macroscopic scale can be highlighted.

Acoustic Corrosion Evaluation Presentation

The acoustic corrosion evaluation presentation implements enhanced three-dimensional imaging techniques to present casing internal geometry, casing internal reflectivity, and resonance-derived casing thickness data in a very realistic manner, as if one were actually viewing the casing. An example of the presentation is pictured in Fig. 11.

In the center of the presentation, five casing images appear. Images 1 and 2 are derived from resonance thickness measurements and are defined as follows: Image 1, the gray scale image, presents resonance thickness information from all eight transducers radially from 0 - 360° across the face of the image. Depending upon the actual measured thickness, the image shading can vary from totally white (adequate thickness) to totally dark (unacceptable thickness). The amount of shading assigned to each measured casing thickness value is derived as follows: At each depth frame, the median of the measured thicknesses above, around, and below the depth frame is identified. At each particular depth in question, a totally white image would occur if an individual measured thickness were greater than or equal to the identified median thickness. Totally dark shading would occur for any individual measured thickness value equal to or less than the median thickness minus 20 percent of an input nominal thickness. The input nominal value is preselected depending upon the casing size and weight present in the well. It is this input thickness that sets the criterion for unacceptable casing thickness values. Thickness values falling between the median thickness and the median minus 20 percent of the nominal thickness will be asigned a shading between white and dark, depending on the actual measured thickness value. The complete process is repeated at the next depth frame, beginning with the identification of an updated median thickness value. The same input nominal thickness is used providing a known casing weight change has not occurred.

Image 2, the three-dimensional mesh thickness image, again presents resonance- derived casing thickness information from all eight transducers across the face of the image. The three-dimensional "fish net" image is derived by first plotting the thickness curves on the image. A grid, or mesh, system is then placed over the curves and programmed to follow the contours created by the thickness values. The thickness values are then removed from the image, leaving the mesh intact. The mesh image provides a three-dimensional effect when changes between adjacent thickness values are encountered. Basically, if a change in adjacent thickness values occurs, the mesh will spread, as it does at 1211-1215 ft in Fig. 11. In actual interpretation situations, the mesh image should be used to highlight general trends in the thickness domain, while the gray scale image should be used to spot localized defects in the thickness of the casing.

The next two images, 3 and 4, are derived from casing internal geometry measurements. The two images are generated in the same manner as the resonance-derived thickness images, with the exception that internal radii values are used in place of thickness values. The gray scale image, now representing change in internal radii measurements possess totally white shading for internal radii values equal to or less than the median radii (selected in a manner similar to the median thickness selection), and a totally dark shading for internal radii values equal to or greater than the median radius plus 20 percent of the input nominal thickness. The three-dimensional mesh internal geometry image is generated by placing a mesh over the internal radii values and then removing the radii curves. Again, in a manner similar to the resonance derived three-dimensional image, changes in adjacent internal radii values will cause a three-dimensional effect on the image.

Since images 3 and 4 are generated from internal casing measurements only, they can be used in conjunction with the resonance-derived thickness images to determine whether metal loss is occurring on the inside or the outside of the casing. Specifically, if equal amounts of metal loss are seen on both sets of images, the loss can be identified as occurring on the inside of the casing. If the metal loss is identified on the resonance- derived thickness images and does not occur on the internal radii images, then the loss can be determined as taking place on the outside of the casing. If the metal loss is identified on the radii images and shows no occurrence on the resonance-derived images, then the defect can be defined as an internal geometry change and not an actual metal loss, since the resonance measurements (measuring actual metal thickness) indicate no loss of metal.

The final image, 5, represents internal casing surface reflectivity. Reflectivity values for all eight transducers are presented across the face of the image. Totally white shading will appear on the reflectivity map for reflectivity values corresponding to smooth casing, while totally dark shading will occur for reflectivity values less than 50 percent of the nominal reflectivity value (the nominal being selected in a manner similar to the selection process used in conjunction with the other measurements). Darker shading would be indicative of rough areas on the pipe inner surface.

The remaining curves on the acoustic corrosion evaluation presentation (far right track), are dimensionless pipe wall thickness change indicators. The two curves in the center of the track are calculations based on thickness change from the input nominal thickness. Both curves represent a percentage change between the median thickness and the input nominal thickness. The two curves can be used to highlight overall thickness changes from nominal, and like the image presentations, can be used to determine whether defects are on the inside or the outside of the casing. An average value, in percent of wall thickness loss, can then be obtained.

The final two curves, appearing on the far right of the track, are the maximum pipe defect indicators. The indicators, one generated from resonance measurements and one from internal geometry measurements, are defined by dividing the difference between the thinnest indicator measured at each depth interval and the median value by the input nominal thickness. The final answer is given in percent for both the resonance-derived and the internal geometry-derived indicators. Again, by comparing the two curves, it can be determined if the defects encountered occur on the inside or the outside of the casing. Also, as before, if the indicator derived from internal geometry measurements highlights metal loss and the indicator from resonance-derived measurements shows no loss, the defect can be assumed to be a change in the internal geometry of the pipe with no change in metal thicknes.

APPLICATIONS OF THE ULTRASONIC CASING INSPECTION DEVICE

The following log examples illustrate several commonly occurring situations in which the information supplied by the various presentations of the ultrasonic casing inspection service can be used to enhance knowledge of the casing condition in the well. All of the log examples presented below are from west Texas wells.

Example 1: Wall Thinning

The log example presented in Fig. 12 was generated from data recorded in a San Andres well originally drilled and cased in the late 1940's. Throughout the particular field in question, several wells had displayed symptoms related to severe casing deterioration. Workover operations were planned on several of the wells, and the well operator needed a way in which to determine if the wells possessed sufficient casing strength to maintain integrity during planned pressuring operations. It was felt that if an accurate value of casing wall thickness could be obtained, a value of casing yield strength could be calculated. The ultrasonic casing inspection device was selected as the logging service of choice because radial changes in casing thickness could be detected. This, coupled with the ability to output thickness values in units of inches, permitted the well operator to use the information supplied by the log to directly calculate yield strength in any section of the casing.

Referring to the casing cross section presentation in Fig. 12, a representative example of the type of wall thinning encountered throughout the well in question can be observed from 1504-1512 ft. Using the minimum thickness obtained from the log through this area, the well operator was able to calculate a yield strength equivalent to 30 percent of the yield strength of the casing when the well was new. It is also interesting to note that the wall thinning is very localized in both the vertical and radial direction. Using the radial spacing between CET transducers, the radial extent of the casing thinning can be calculated as covering greater than 4 but not more than 21 percent of the casing circumference. As a result of the limited radial extent of the thinning, it would be questionable whether an averaging device would have responded to the thinning.

Example 2: Internal Metal Loss

The casing cross section presentation in Fig. 13 was generated on a well in which external corrosion was suspected. In addition to discovering external corrosion in many areas of the well, an area of internal metal loss was detected from 1976 - 1985 ft. The area of internal metal loss was below the packer, and therefore most likely caused by corrosive fluids coming in contact with the inner wall of the casing. Since the metal loss is apparent only on the cut generated from transducer 3 information, it is apparent that the thinning is very localized in terms of radial extent. The defect is confirmed as occurring on the inside of the casing since the cross section inner wall shows the thinning, and the outer wall remains fairly constant. Chemical treating of the well for the purpose of inhibiting further internal corrosion was recommended as a result of the information obtained from logging.

Example 3: External Metal Loss

The subject well, drilled and cased in the early 1950's was a candidate for a workover operation. The well was to be plugged back from its original completion depth and a squeeze cement job was planned. Because of the age of the well, the well operator felt that casing deterioration was a distinct possibility, especially since the casing-formation annulus had been unprotected from corrosive formation water (San Andres) since original completion of the well. There was particular concern over the possibility of destroying the casing when setting and subsequently drilling out the cement retainer needed for the squeeze cement job. The ultrasonic casing inspection service was utilized with the objective of finding the best location for the cement retainer; i.e., avoiding any areas exhibiting wall thinning.

The resultant casing cross section presentation is shown in Fig. 14. An area of external metal loss, about 80 ft long is indicated from 1216 to 1300 ft. In particular, the most severe loss occurs from 1268 to 1300 ft. This loss appears on the section derived from Transducer 3 indicating localization in terms of radial extent. It can be identified as external metal loss since the outer surface of the cross section exhibits the thinning. From the results of the log, the decision was made to avoid the area around the loss and set the cement retainer below the area. In this manner, the thin wall would not be subject to high pressures during the cement squeeze operation, nor would the subsequent drilling of the retainer subject the area to further damage.

Example 4: External Metal Loss - Acoustic Corrosion Evaluation Presentation

The acoustic corrosion evaluation presentation example appearing in Fig. 15 was generated from information recorded in an Ector County well, drilled and cased in 1959. The primary cement job was questionable, and external casing corrosion was suspected. The Digital Cement Evaluation tool was used to evaluate the state of the cement and the casing with one trip in the hole. Cement evaluation results indicated that poor cement was indeed present, while corrosion evaluation results highlighted several areas of external casing metal loss. Pictured in Fig. 15 are two major areas of external metal loss; from 832 - 836 ft and from 838 - 843 ft. The losses can be confirmed as occurring on the outside of the casing by noting that:

- The defects occur as dark shading on the resonance-derived gray scale image, and do not appear on the internal geometry-derived gray scale image.

- Depression sites, or spreading of the mesh, are apparent on the resonance-derived three-dimensional image. The internal geometry-derived three-dimensional mesh image does not show the depression sites.

- The resonance-derived maximum thickness change from nominal curve indicates a 10-15% loss in each case, while the internal geometry-derived curve shows no correlation to the resonance-derived curve.

Because of the advanced state of external corrosion detected by the ultrasonic casing inspection service, the well operator elected to set a liner so that production from the well could continue.

Example 5: Nonmetallic Buildup on the Inside of the Casing

The subject well, drilled and cased in 1952, was originally completed in the Canyon Sand formation. The well was purchased by the current operator with the intent of plugging off the Canyon section and recompleting in the Wolfcamp. Since an acidizing operation was planned for the new zone, knowledge of the cement and casing quality were desired. To fulfill this need, the Digital Cement Evaluation tool was employed.

Fig. 16 presents the resultant acoustic corrosion evaluation presentation. Two conclusions can be made from the information on the presentation:

1) The condition of the casing, in terms of metal thickness, is very good. This can be concluded by observing the low value of average metal loss indicated by the resonance-derived pipe wall thickness from nominal curve (exhibiting only 1-5% metal loss), and also by the low values of the resonance-derived maximum thickness change from nominal curve.

2) A nonmetallic buildup, most likely paraffin, exists on the inner wall of the casing. This can be identified by noting the relatively rough surface of the internal geometry-derived three-dimensional mesh image, the rough internal geometry-derived gray scale image, the dark shading of the internal reflectivity map, and finally by the fact that the internal geometry-derived average metal loss from nominal curve is indicating a thickness value <u>greater</u> than the nominal thickness (the individual measured radii values are responding to the surface of the buildup rather than to the casing).

Since the results of cement evaluation confirmed that adequate cement existed above, below, and through the prospect zone, the operator proceeded with workover plans with the added knowledge that all was well with the casing and cement.

SUMMARY

The ultrasonic casing inspection service can be used in liquid-filled boreholes where casing degradation from corrosion or wear is suspected to:

- Determine actual casing metal thickness.
- Determine, in areas exhibiting metal loss, whether the loss is occurring on the inside or outside of the casing.
- Obtain information concerning the surface quality of the casing inner wall.
- Determine the overall geometry present on the inside of the casing.

Since the ultrasonic casing inspection information is recorded using the Digital Cement Evaluation tool, the transducer arrangement permits the aforementioned casing information to be recorded radially at any point in the casing. The inspection service is well suited for determining cement quality while simultaneously gathering casing inspection information.

Used in conjection with other casing inspection tools, the ultrasonic casing inspection service, along with the various presentations, can greatly enhance the total amount of information obtained concerning detailed casing condition by adding new, quantitative measurements to those obtained from conventional tools. In this manner, the solid answers obtained can be used in a more efficient manner to make decisions concerning the best course of action applicable to the individual well in questions.

ACKNOWLEDGEMENTS

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2. Alain Dumont, Jean-Bernard Patin, Gilles Le Floch: **" A SINGLE TOOL FOR CORROSION AND CEMENT EVALUATION."** SPE Paper 13140, presented in Houston, Texas, September 16-19, 1984.

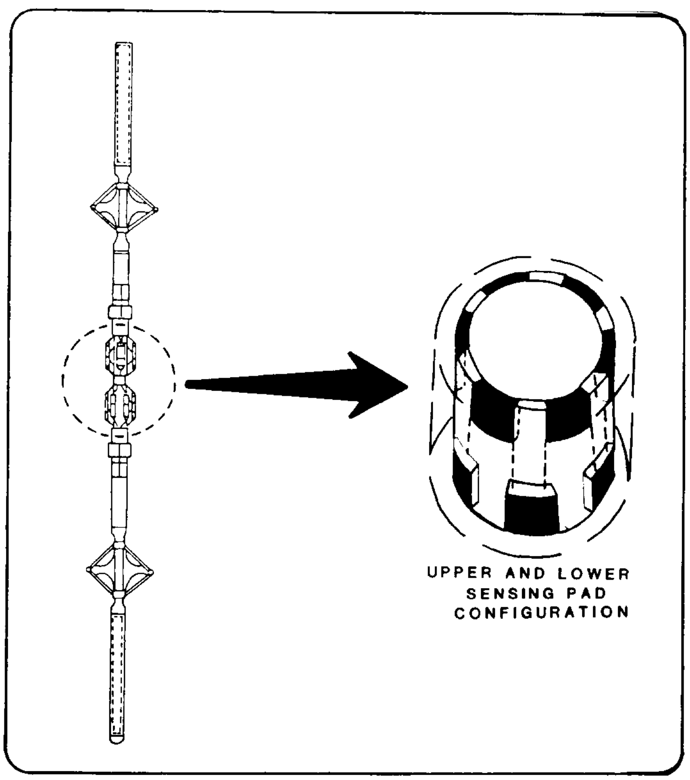


Figure 1—The pipe analysis tool

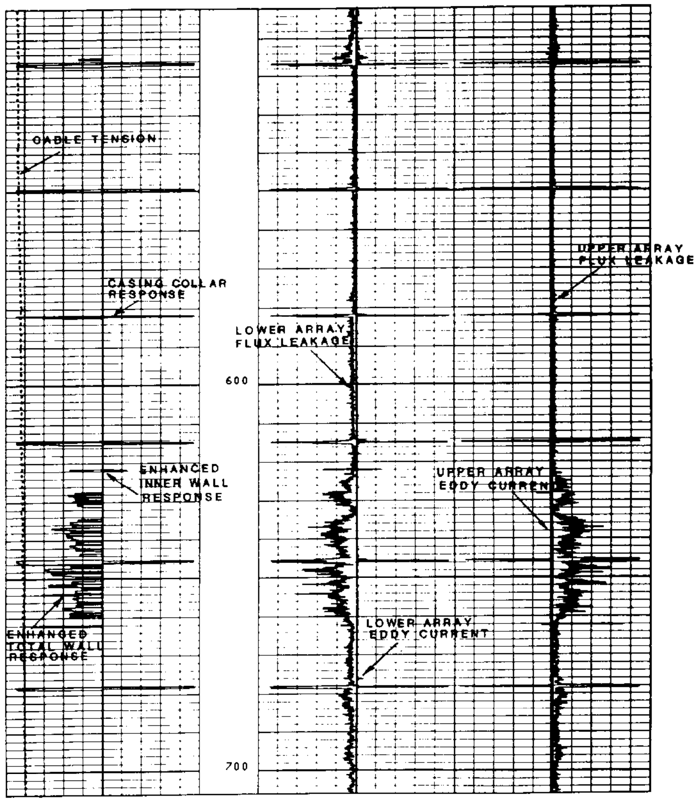


Figure 2—Standard pipe analysis log presentation

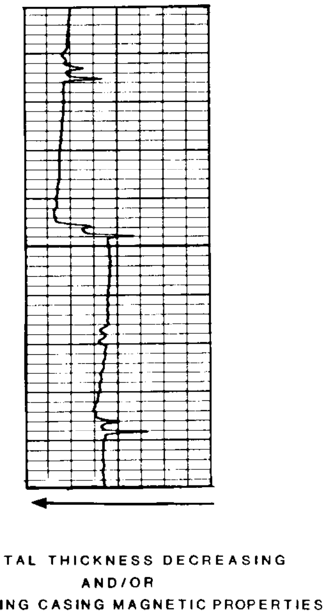


Figure 3—Electromagnetic thickness tool phase shift response

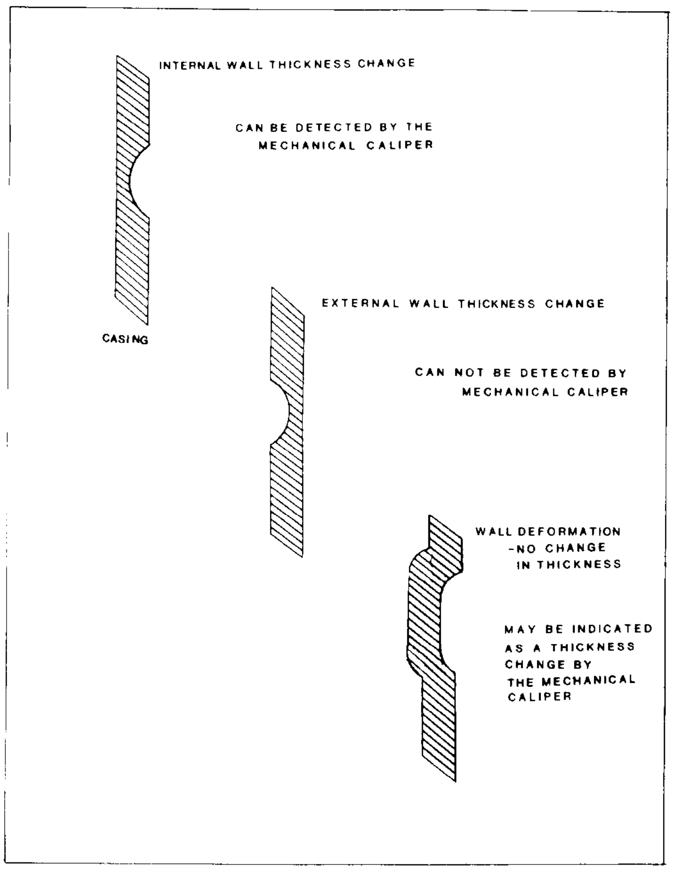


Figure 4—Mechanical caliper responses

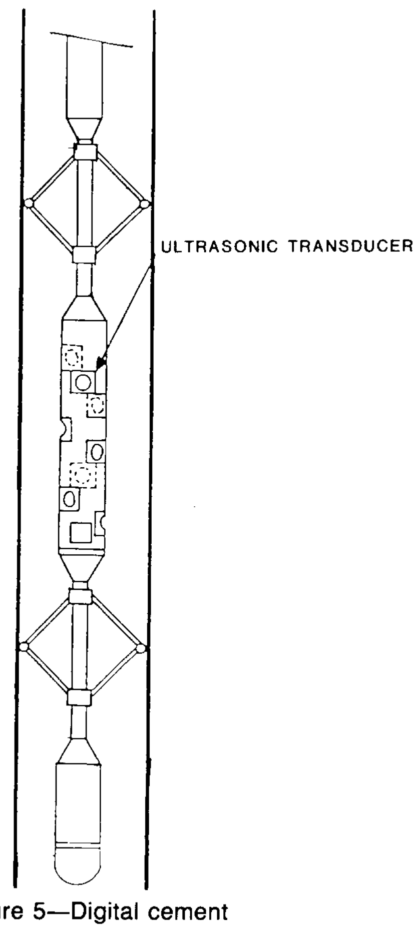


Figure 5—Digital cement evaluation tool

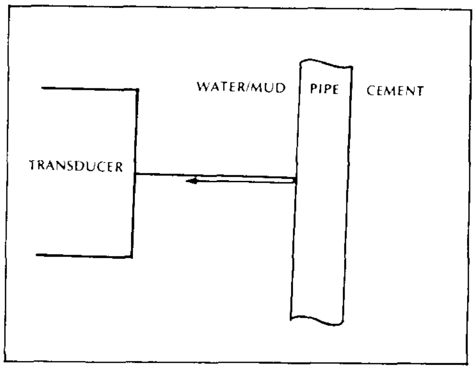


Figure 6—Two-way travel time path

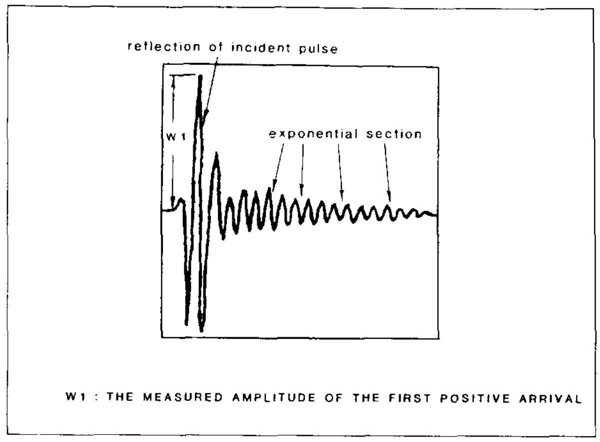


Figure 7—Return waveform at the transducer

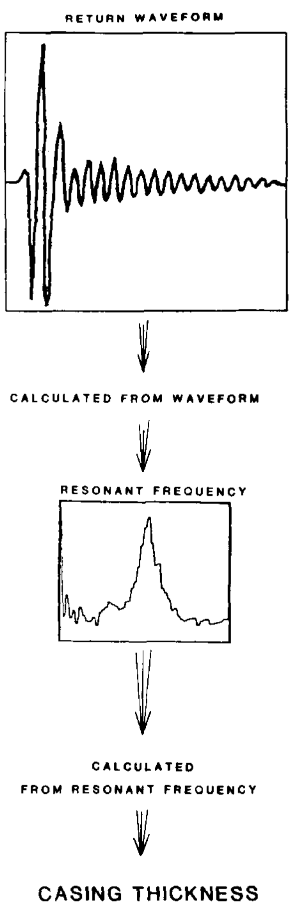
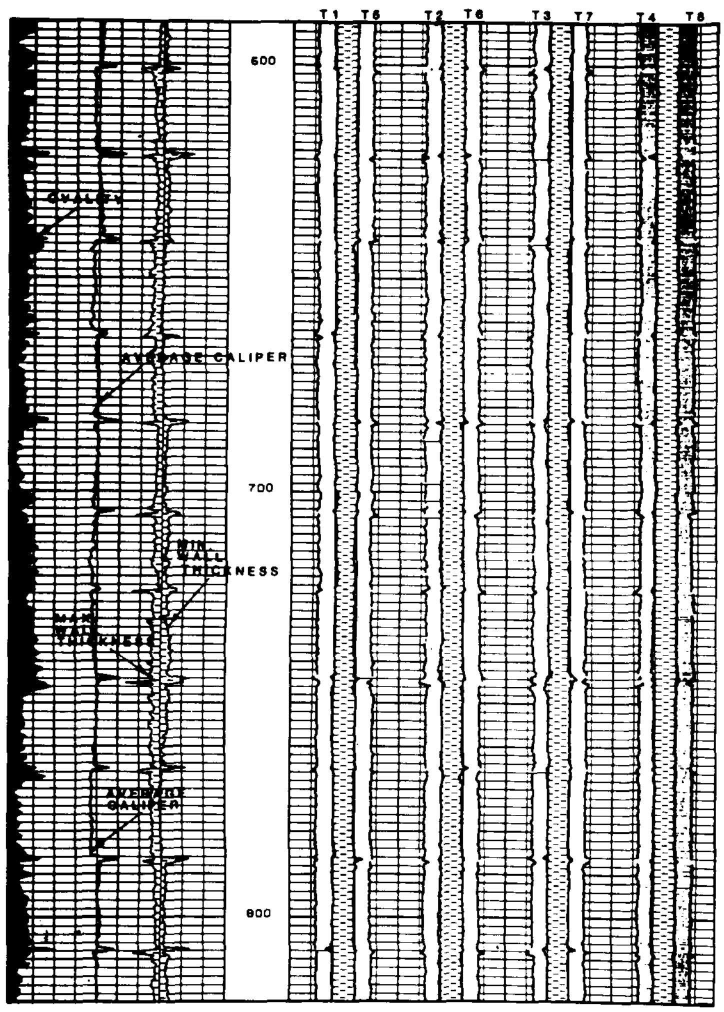
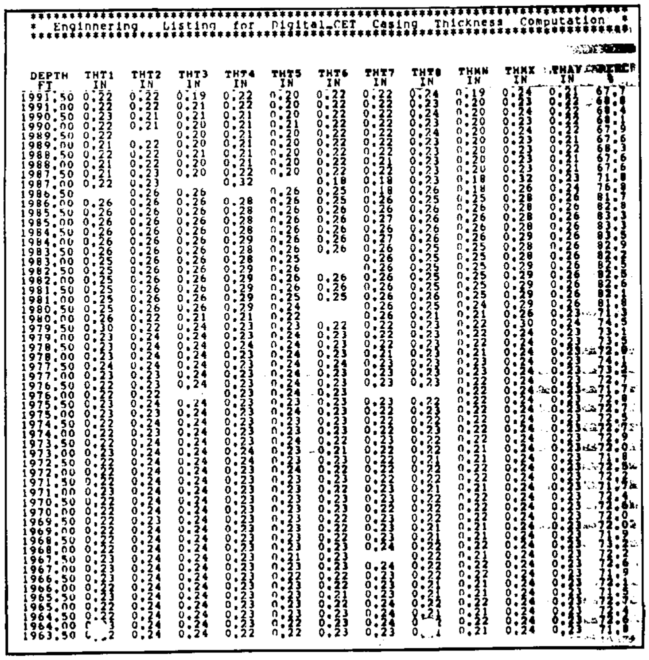


Figure 8—Resonance-derived casing thickness



CASING CROSS SECTIONS
(EACH SECTION ROTATED 45 DEGREES)

Figure 9—Casing cross section presentation



* Enginnering Listing for Digital_CET Casing Thickness Computation *

DEPTH FT	THT1 IN	THT2 IN	THT3 IN	THT4 IN	THT5 IN	THT6 IN	THT7 IN	THT8 IN	THMN IN	THMX IN	THAV IN	[illegible] %
1991.50	0.22	0.22	0.19	0.22	0.20	0.22	0.22	0.24	0.19	0.24	0.21	67.7
1991.00	0.22	0.22	0.21	0.22	0.20	0.22	0.22	0.23	0.20	0.23	0.22	68.8
1990.50	0.23	0.21	0.21	0.21	0.20	0.22	0.22	0.24	0.20	0.24	0.22	68.4
1990.00	0.22	0.21	0.20	0.21	0.21	0.22	0.22	0.23	0.20	0.23	0.22	68.1
1989.50	0.22		0.20	0.21	0.20	0.22	0.22	0.24	0.20	0.24	0.22	67.9
1989.00	0.21	0.22	0.20	0.21	0.20	0.22	0.22	0.23	0.20	0.23	0.21	67.6
1988.50	0.22	0.22	0.21	0.21	0.20	0.22	0.22	0.23	0.20	0.23	0.22	68.3
1988.00	0.21	0.22	0.20	0.21	0.20	0.22	0.21	0.23	0.20	0.23	0.21	67.6
1987.50	0.21	0.23	0.20	0.22	0.20	0.22	0.22	0.23	0.20	0.23	0.21	67.6
1987.00	0.22	0.23		0.32		0.18	0.18	0.23	0.18	0.32	0.23	71.8
1986.50		0.26	0.26		0.26	0.25	0.18	0.26	0.18	0.26	0.24	76.8
1986.00	0.26	0.26	0.26	0.28	0.26	0.25	0.26	0.25	0.25	0.28	0.26	81.7
1985.50	0.26	0.26	0.26	0.28	0.26	0.26	0.26	0.26	0.26	0.28	0.26	82.8
1985.00	0.26	0.26	0.26	0.28	0.26	0.26	0.27	0.26	0.26	0.28	0.26	83.3
1984.50	0.26	0.26	0.26	0.28	0.26	0.26	0.26	0.26	0.26	0.28	0.26	83.3
1984.00	0.26	0.26	0.26	0.29	0.26	0.26	0.27	0.26	0.26	0.29	0.26	83.5
1983.50	0.26	0.26	0.26	0.28	0.26	0.26	0.26	0.25	0.25	0.28	0.26	82.9
1983.00	0.25	0.26	0.26	0.28	0.25		0.26	0.25	0.25	0.28	0.26	82.2
1982.50	0.25	0.26	0.26	0.29	0.26		0.26	0.25	0.25	0.29	0.26	82.5
1982.00	0.25	0.26	0.26	0.29	0.26	0.26	0.26	0.25	0.25	0.29	0.26	82.5
1981.50	0.25	0.26	0.26	0.29	0.26	0.26	0.26	0.25	0.25	0.29	0.26	82.6
1981.00	0.25	0.26	0.26	0.29	0.25	0.25	0.26	0.26	0.25	0.29	0.26	82.1
1980.50	0.25	0.26	0.26	0.29	0.24		0.26	0.25	0.24	0.29	0.26	81.8
1980.00	0.26	0.22	0.21	0.21	0.22		0.26	0.21	0.21	0.26	0.23	71.3
1979.50	0.30	0.22	0.24	0.23	0.23	0.22	0.22	0.23	0.22	0.30	0.24	74.5
1979.00	0.23	0.24	0.24	0.23	0.24	0.23	0.22	0.23	0.22	0.24	0.23	73.1
1978.50	0.23	0.24	0.24	0.24	0.24	0.23	0.22	0.23	0.22	0.24	0.23	73.5
1978.00	0.23	0.24	0.24	0.23	0.24	0.23	0.21	0.23	0.21	0.24	0.23	72.8
1977.50	0.24	0.24	0.24	0.23	0.24	0.24	0.23	0.23	0.23	0.24	0.23	74.1
1977.00	0.23	0.23	0.24	0.23	0.24	0.23	0.23	0.23	0.23	0.24	0.23	73.3
1976.50	0.22	0.23	0.24	0.23	0.24	0.23	0.23	0.23	0.22	0.24	0.23	72.7
1976.00	0.22	0.22		0.23	0.24	0.23			0.22	0.24	0.23	71.7
1975.50	0.23	0.24	0.24	0.23	0.23	0.23	0.23	0.22	0.22	0.24	0.23	72.8
1975.00	0.23	0.23	0.24	0.23	0.24	0.23	0.22	0.23	0.22	0.24	0.23	72.7
1974.50	0.22	0.24	0.24	0.23	0.23	0.23	0.22	0.22	0.22	0.24	0.23	72.5
1974.00	0.22	0.23	0.24	0.23	0.23	0.23	0.22	0.23	0.22	0.24	0.23	72.7
1973.50	0.22	0.24	0.24	0.23	0.24	0.22	0.23	0.22	0.22	0.24	0.23	72.9
1973.00	0.23	0.24	0.24	0.24	0.23	0.21	0.22	0.22	0.21	0.24	0.23	72.0
1972.50	0.22	0.24	0.24	0.24	0.23	0.23	0.22	0.21	0.21	0.24	0.23	71.8
1972.00	0.22	0.24	0.24	0.23	0.24	0.22	0.22	0.22	0.22	0.24	0.23	72.8
1971.50	0.22	0.24	0.24	0.23	0.23	0.23	0.22	0.22	0.22	0.24	0.23	72.2
1971.00	0.23	0.24	0.24	0.23	0.23	0.22	0.23	0.21	0.21	0.24	0.23	71.7
1970.50	0.22	0.24	0.24	0.23	0.23	0.23	0.23	0.22	0.22	0.24	0.23	72.4
1970.00	0.22	0.24	0.24	0.23	0.23	0.23	0.22	0.22	0.22	0.24	0.23	72.6
1969.50	0.22	0.23	0.24	0.23	0.23	0.22	0.23	0.22	0.22	0.24	0.23	72.0
1969.00	0.22	0.24	0.24	0.23	0.23	0.22	0.23	0.21	0.21	0.24	0.23	72.0
1968.50	0.22	0.24	0.24	0.23	0.23	0.22	0.23	0.21	0.21	0.24	0.23	71.9
1968.00	0.22	0.24	0.24	0.23	0.23	0.23	0.24	0.22	0.22	0.24	0.23	73.2
1967.50	0.23	0.24	0.24	0.23	0.21	0.23		0.22	0.21	0.24	0.23	72.2
1967.00	0.23	0.24	0.24	0.23	0.23	0.23	0.24	0.22	0.22	0.24	0.23	72.6
1966.50	0.23	0.24	0.24	0.23	0.22	0.22	0.23	0.22	0.22	0.24	0.23	71.9
1966.00	0.22	0.24	0.24	0.23	0.23	0.22	0.23	0.21	0.21	0.24	0.23	72.1
1965.50	0.22	0.24	0.24	0.23	0.23	0.21	0.23	0.21	0.21	0.24	0.23	71.5
1965.00	0.22	0.24	0.24	0.23	0.23	0.22	0.24	0.22	0.22	0.24	0.23	72.3
1964.50	0.22	0.24	0.24	0.23	0.23	0.23	0.24	0.21	0.21	0.24	0.23	72.4
1964.00	[illegible]	0.24	0.24	0.23	0.22	0.23	0.24	[illegible]	0.22	0.24	0.23	72.6
1963.50	[illegible]	0.24	0.24	0.22	0.22	0.23	0.23	[illegible]	0.21	0.24	0.23	71.8

Figure 10—Engineering listing

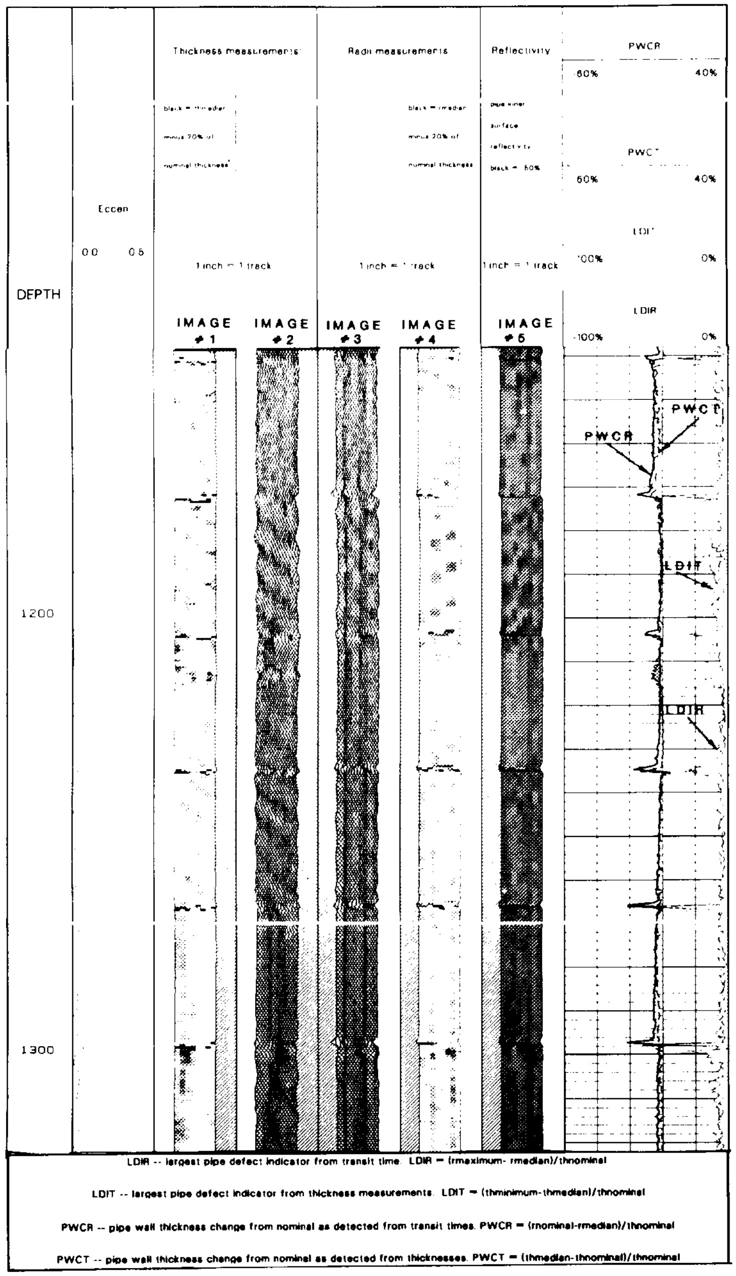


Figure 11—Acoustic corrosion evaluation presentation

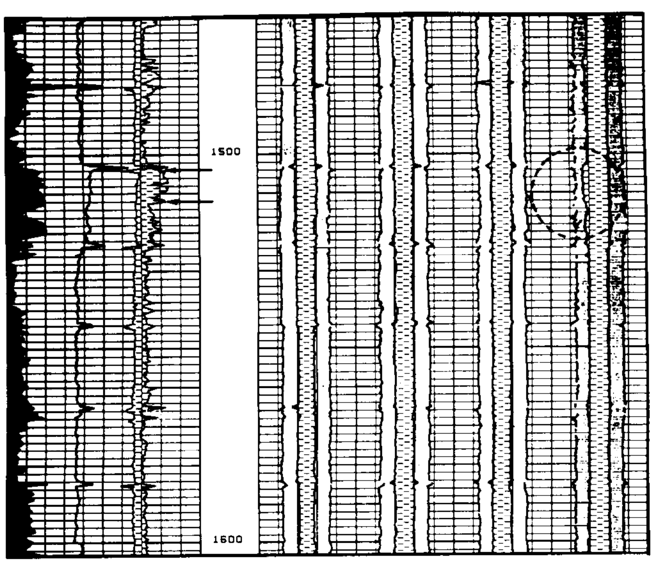


Figure 12—Casing wall thinning

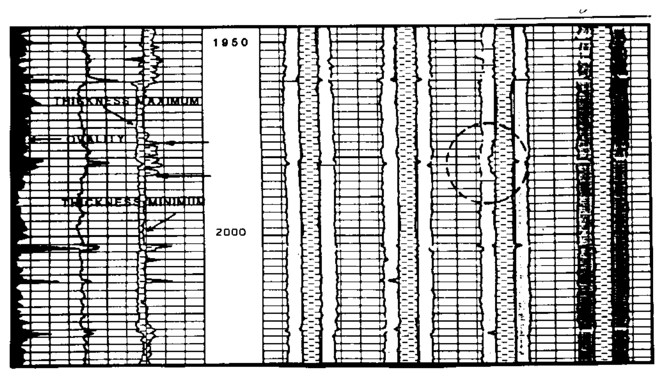


Figure 13—Internal metal loss

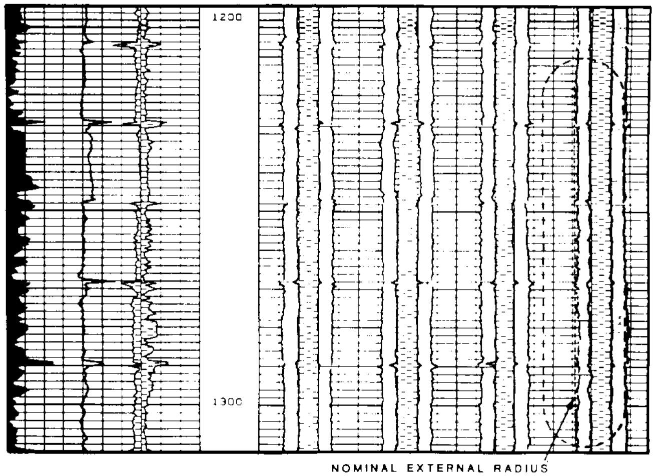


Figure 14—External metal loss

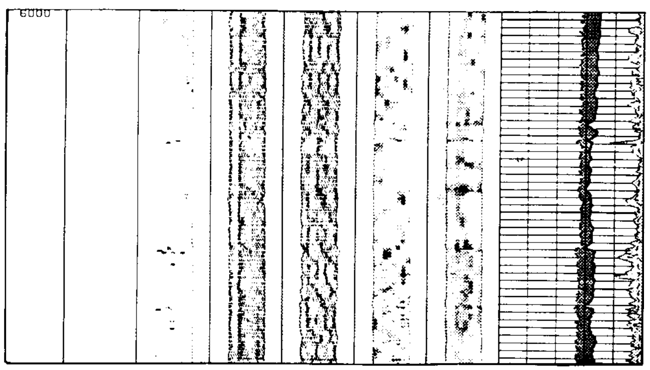


Figure 16—Non-metallic buildup on inner wall of casing

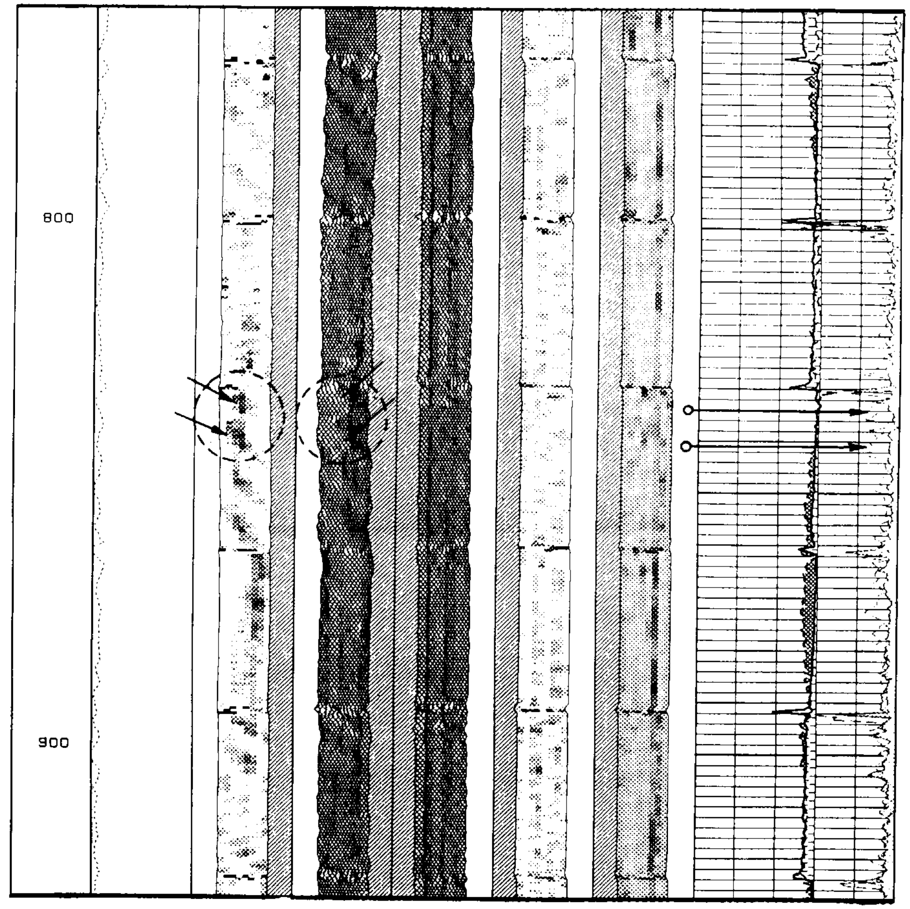


Figure 15—External metal loss - acoustic corrosion evaluation presentation