Use of Ultrasonic Testing in the Structural Steel Industry

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It is important to note the distinction between a quality weld and a reliable weld. Many of the discontinuities which will be discussed may not be considered defective to a particular weld joint or structural member. The discontinuities may not make the weld less reliable, but merely lower the quality of the weld. When does a discontinuity become a defect? This is the question which one must ask when separating quality from reliability. The quality of a weld can be determined with ultrasonic tests; however, the reliability of a weld is established from destructive testing or welding history. Test specifications are available based on these tests.

It should be mentioned, before proceeding further, that radiography (still a primary weld inspection method), magnetic particle, and penetrant techniques are powerful inspection tools, and should not be overlooked when selecting NDT methods. It is interesting to note, for example, that a discontinuity orientated for maximum radiographic detection is in its poorest position for ultrasonic detection, and vice-versa.

THEORY AND TECHNIQUES

In order to appreciate the validity of ultrasonic testing, it is important to understand some ultrasonic theory and the techniques used to apply it. Ultrasonic weld inspection starts by testing the parent metal in the area of the weld zone. This area must be free of any discontinuities which would interfere with the inspection of the weld. Should this area contain discontinuities, the validity of the inspection results would be seriously impaired. A serious type of defect in the parent metal is lamination. In addition to contributing directly to a faulty weld, its presence prohibits an inspector from detecting or accurately pinpointing the location of detrimental defects.

Determining the location, orientation, and dimensions of a discontinuity is a prime advantage when using ultrasonic testing. In many cases the type of defect can be identified and judged to be detrimental or of such a nature as not to interfere with the reliability of the structure. Inspection may be performed immediately following the welding process. Any corrective action can be and is performed with the welder present, thereby providing immediate weld repair, reinspection of the new weld, and appraisal by the welder of his process. Such an appraisal can, in many cases, lead to a definite percent increase in the amount of quality welds made, and increase overall reliability. Rejection rates have been known to drop from 30 to 5 percent in the shop and from 10 to 3 percent in the field.

Ultrasound can be transmitted straight into a structure (normal to the entry surface) or into it at an angle. Many of the laws of light, such as the incident angle equals the reflected angle, Snell's Law, and straight line propagation also apply to ultrasound. Because its velocity in a steel member can be measured and since the dimensions of the test piece can also be measured, it is possible to accurately locate a discontinuity within a given structure or weld.

APPLICATIONS

Figures 1 and 2 show the type of applications where a straight sound beam is generally used. Laminations in plate and I-beams are depicted with the cathode ray tube (CRT) presentation an inspector would expect to see if laminations were present. Lack of penetration in a T-joint weld is also a typical straight beam application. Inspection for this type of defect is relatively simple and extremely reliable, although detection using other methods would be difficult, if not impossible. This is a prime example of a discontinuity orientated for maximum ultrasonic detection, while being in the poorest position for X-ray detection. It should be noted that inspection for laminations is being performed in the steel mills prior to fabrication or assembly into structures.

The majority of weld tests are performed using angle beams of 45°, 60°, and 70°. The angle used is dependent on the plate thickness and the type of weld to be inspected. Figure 3 shows a typical inspection tech-

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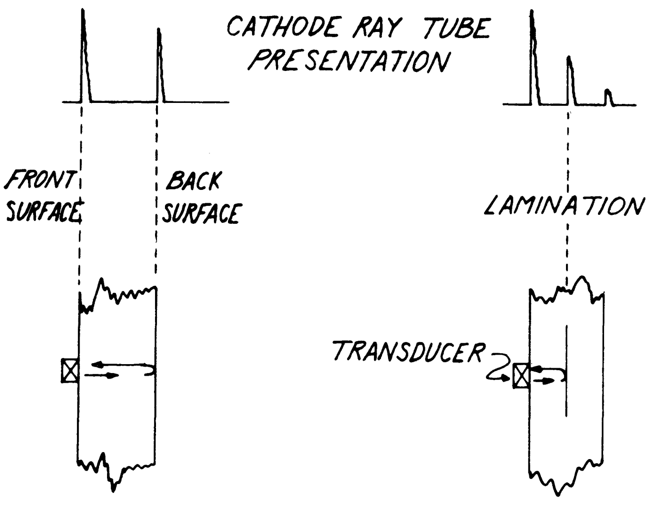

Fig. 1. Cathode ray tube presentation illustrating the time/distance relationship using a straight beam transducer

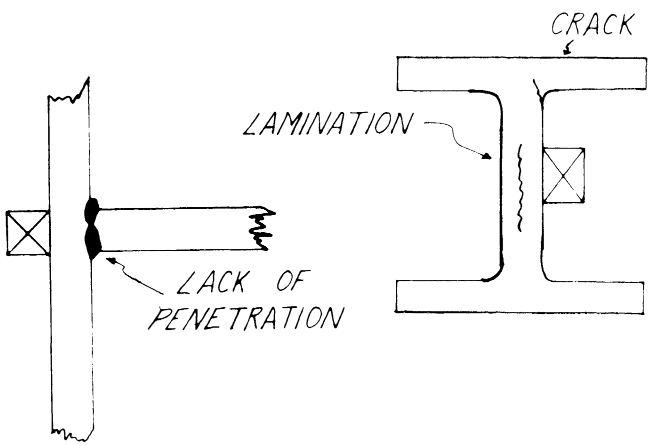

Fig. 2. T-joint weld penetration and I-beam integrity are easily inspected using a straight beam ultrasonic transducer

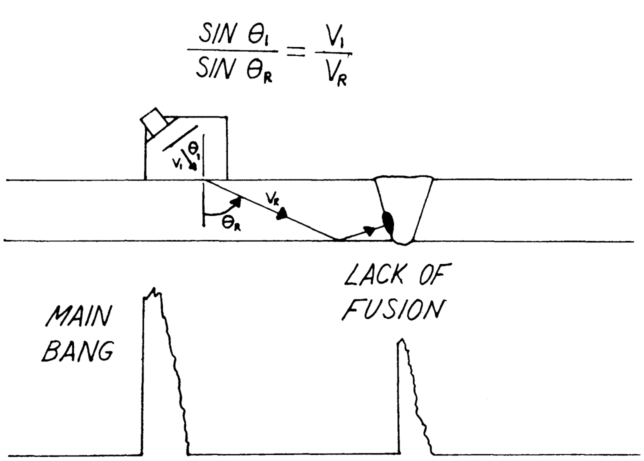

Fig. 3. The presentation from lack of fusion using an angle beam transducer. The angle beam generated illustrates the use of Snell's Law

nique used to test a single-V butt weld. Since the maximum amount of sound energy will be reflected from a discontinuity when the incident sound beam is normal to the plane of the discontinuity, the complementary angle of the anticipated defect angle should be used. A prime example is the case of lack of fusion. The signal from this defect would be large when detected at the proper angle, making its detection extremely reliable.

Since a distance relationship can be presented on the cathode ray tube of an ultrasonic test instrument, we can locate discontinuities along the parent metal or in the weld zone with either a straight or angle beam. Various methods are available to calculate this distance, dependent on the angle used and the beam location for various transducer positions. Such a method is shown in Fig. 4.

The signals received and displayed on the CRT supply the test operator with a vast amount of information for his interpretation. The human mind, acting as a highly functional computer, can readily sort this information and relate it to discontinuity location, orientation, and in many cases the type of defect or discontinuity. The signal shape also supplies information. The basic pattern for a gas inclusion, as an example, will give a relatively small indication from all inspection directions because of its spherical shape. See Fig. 5. A slag inclusion has an irregular shape and its reflections will vary with change in test direction. The indication is likely to be irregular or grassy in nature, much the same as it would be for porosity and other irregular multi-reflector surfaces. Longitudinal defects such as cracks or lack of penetration present a maximum reflection when the sound beam is perpendicular to the discontinuities' general direction. Any change in the incidence angle will decrease the amplitude of the reflected signal abruptly.

METHODS

The methods used to inspect various types of welds are shown in the following figures. Figure 6 depicts three examples where inspector interpretation is necessary. Test validity will be lost if position **B** in Diagram 1 is used to determine the presence of defects near the "drop through." Signals from the "drop through" will hide any defects present as shown. The correct technique is from position **A**. Likewise, excessive weld bead and the use of back up plates can mask defects if not approached properly. A good ultrasonic weld inspector will probe the weld zone from more than one side whenever possible, in order to prohibit natural weld characteristics from masking defects.

This points out the necessity for trained ultrasonic inspectors. The validity of inspection is only as good as the capability of the inspector. The human element,

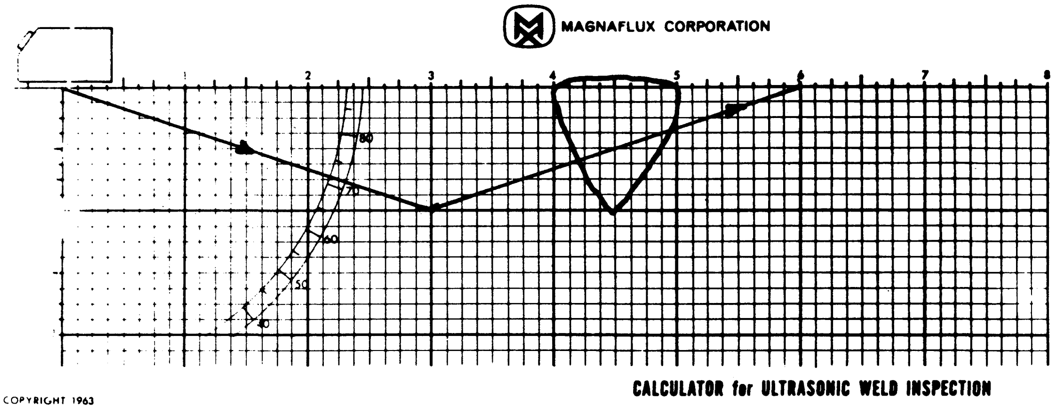

Fig. 4. Location of a discontinuity within the weld zone can be determined easily with the use of a calculator card

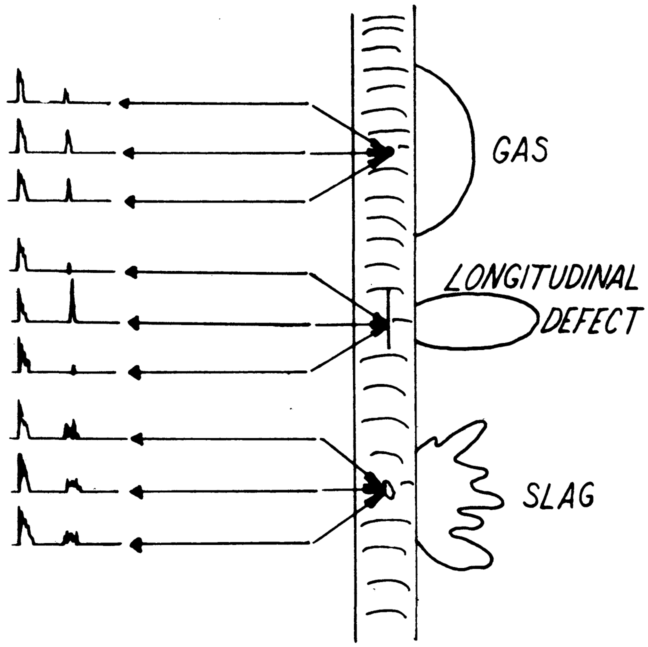

Fig. 5. The shape of an ultrasonic signal provides needed information to an inspector for proper determination of the defect type

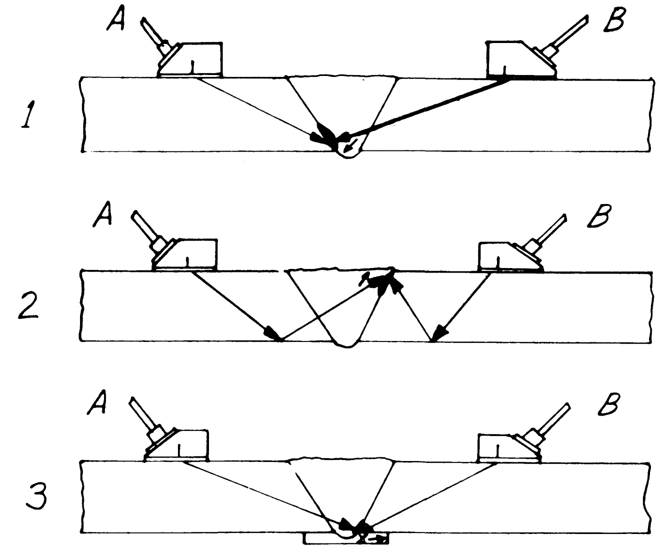

Fig. 6. Weld configuration must be considered prior to inspection. The correct ultrasonic technique must be used to prohibit natural weld characteristics from masking defects

as in other test methods, can make the difference between a valid test and a completely erroneous one. Training and experience with proper supervision are the only answers to this problem today.

The correct approach to weld testing is extremely important, not only in regard to signal interpretation, but from the standpoint of knowing the path the sonic energy has followed. Figure 7 shows the correct approach for inspecting various weld configurations. The opposite approach would offer the sound more than one path of travel, which would lead to erroneous results.

The figures presented show some limitations to ultrasonic inspection dependent on flaw orientation and weld configuration. Radiography, magnetic particle, and penetrants have been used in weld testing for many years and are still the primary test methods.

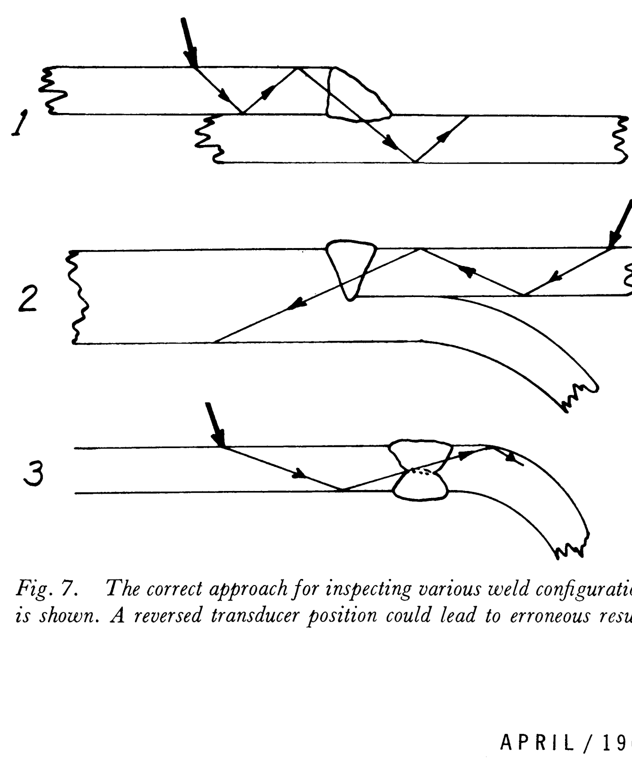

Fig. 7. The correct approach for inspecting various weld configurations is shown. A reversed transducer position could lead to erroneous results

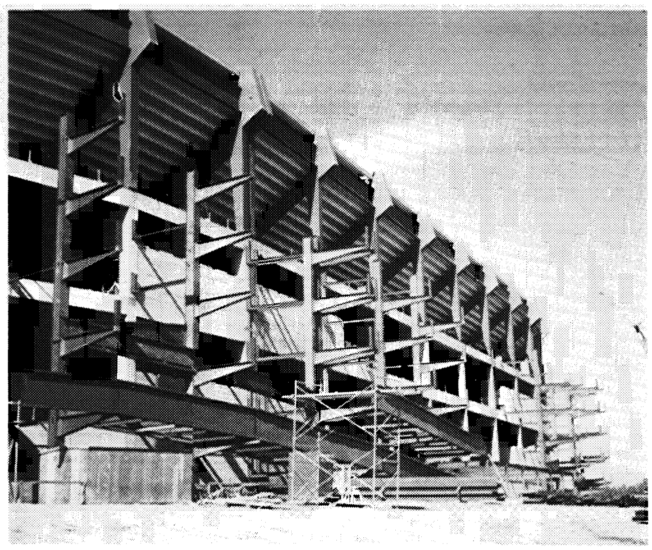

Fig. 8. Over 700 butt welds in this cantilevered construction of Angel's Stadium were inspected with ultrasound. Weld integrity was assured in joints that would have been difficult to inspect by other methods

Questionable areas as cited should definitely be inspected with other NDT methods. These general limitations of ultrasonics can also be the limitations of other NDT methods, but are offset by the many advantages of ultrasound, such as:

1. High sensitivity to internal reflectors
2. Capability of penetrating many inches of steel
3. Inspection from one surface of specimen possible
4. Equipment portability
5. Rapid and inexpensive method
6. Precision in the determination of discontinuity location, orientation, and dimension; eliminating excessive material removal from the weld area during repair
7. Testing can be performed during construction, with no danger to nearby personnel

It is easy to understand why many contractors are using ultrasonic techniques as a powerful back-up method where other methods are not sufficient.

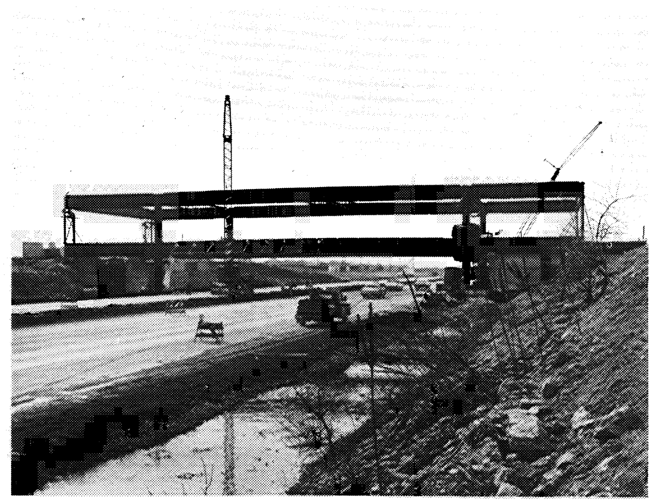

Fig. 9. The Abraham Lincoln Oasis has no center support, leaving a 135-ft clear span. Four cruciform columns with 32 butt welds support the entire structure

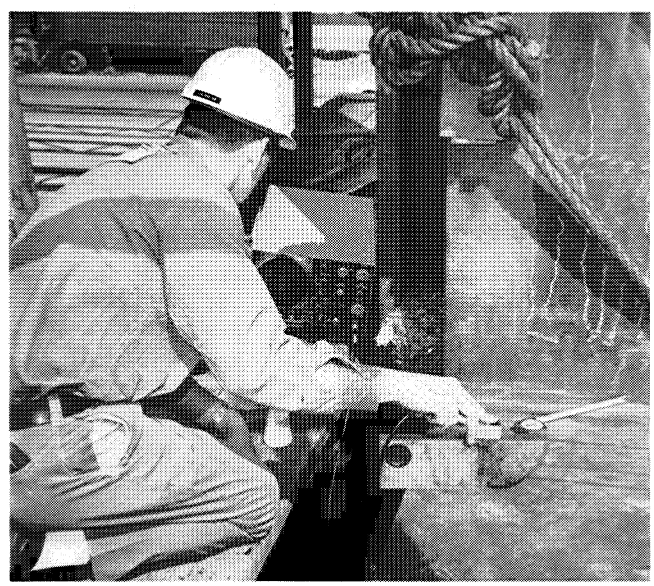

Fig. 10. A test block (IIW Block) is used to calibrate the ultrasonic instrument for proper defect location determination. Guidelines help locate the sound beam within the weld zone

EXAMPLES

The $16 million stadium at Anaheim, Calif. (Fig. 8), Angels Stadium, was inspected with ultrasonics. More than 700 highly stressed tension welds at vital butt joints were tested. 500 of these welds were inspected during fabrication of 42 rigid frames. 210 welds were field inspected. The plates varied in thickness from ⅝-in. to 2½ in. The major defect which was detected was lack of penetration. Others included porosity and slag inclusions. The 210 field inspections took a total inspection and reading time of about 650 minutes. The benefits from ultrasonic testing were derived primarily from the speed and accuracy of the tests. Immediate repair could be performed, since the depth, size, and location of the defect could be determined. Weld integrity was assured in joints that would have been difficult to inspect by other methods.

Another example is the Abraham Lincoln Oasis, spanning the Illinois State Tollway near South Holland, Ill. (Fig. 9). Four cruciform columns with 32 butt welds support the entire structure. The welds on this structure were tested for lack of penetration, lack of fusion, and cracks in the weld area. Any gas pockets, slag inclusions, incomplete fusion, inadequate penetration, or similar

Fig. 11. Argus Island, situated in approximately 190 ft of water, was ultrasonically inspected in 1963

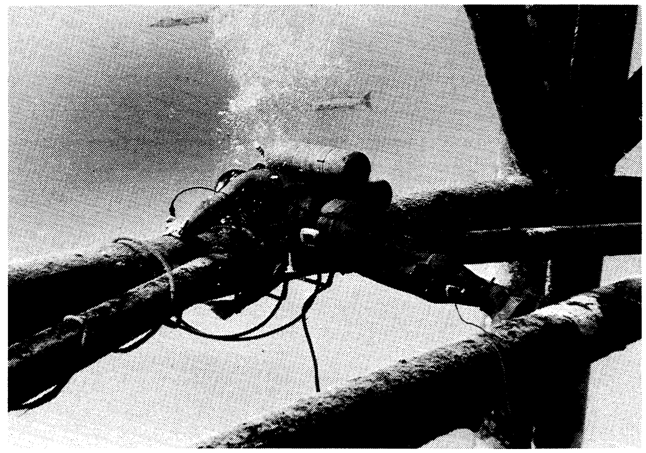

Fig. 12. A diver probes a weld with water acting as a continuous scaffold and a sonic couplant

defects 1/16-in. wide and 1/2-in. long or larger had to be removed and repaired. Speed offered a prime advantage again. Since the welds are 20 in. long x 4 in. deep at a 45° angle, it is important to be able to pin point defect locations when the repair of a weld this size has to be performed. See Fig. 10.

Off-shore platforms such as those used for oil drilling, research, weather, and defense purposes can also be inspected with ultrasonics. Structures such as these are often exposed to severe storms, creating high stresses in many of the weld joints. Testing becomes increasingly important at periodic intervals or at times immediately following such storms. In tests of this sort, communications are maintained between a diver and persons monitoring the ultrasonic test equipment. Since water is a sound conductive media, it is used as a couplant to transfer the sound from the transducer into the test piece. The diver positions the transducer at various points about the weld, while the reflected signals are displayed and monitored by means of video recorders, pen recorders, and TV cameras. The first complete underwater structure survey using ultrasound was conducted on Argus Island in 1963. This U. S. Navy research platform, located approximately 30 miles southwest of Bermuda, is situated in approximately 190 ft of water. Barring delays caused by unusual circumstances, such as barracuda and sharks in the immediate area, it is possible to test the welds on an 8-pile tower down to a depth of 100 ft in four to five days. See Figs. 11 and 12.

The validity of ultrasonic inspection on off-shore structures was demonstrated in Houston on June 22, 1965. An obsolete off-shore structure, which had been above water for several years, was inspected. Seven welds were selected for the demonstration, and five of these yielded ultrasonic indications of a serious nature. The welds were then sectioned in the areas indicated by the ultrasonic tests. All five defects were found at the locations indicated, and all five defects were of the type as had been determined from the ultrasonic evaluation.

The use of ultrasonic testing has increased the reliability of structural welds with its acceptance as a powerful inspection method. Past history related to the examples mentioned, along with many others, coupled with positive results from sectioning analysis of ultrasonically inspected welds, is proving the validity of ultrasonic weld inspection as a means to weld reliability.