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The use of ultrasonic testing for insuring quality butt welded joints is discussed. The assurance of the quality of butt welded joints is presently obtained by radiographic inspection on all California Division of Highways fabricated steel structures as specified in Test Method No. Calif. 601-E. An appreciable economic savings could be realized by substituting ultrasonic inspection in place of radiographic inspection. There are, however, many difficulties presently confronting the ultrasonic operator that, to date, have no solutions. Problems dealing with scanning interpretation when (1) welds are unground, (2) base metal plate is laminated, and (3) defect lengths are to be accurately determined are just a few.

Continued research oriented toward resolving these problems is mandatory before ultrasonic inspection can be recognized and fully accepted as assuring quality butt welded joints.

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U DND 68.39 JOINT STUDY

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STATE OF CALIFORNIA

TRANSPORTATION AGENCY

DEPARTMENT OF PUBLIC WORKS

DIVISION OF HIGHWAYS

MATERIALS AND RESEARCH DEPARTMENT

RESEARCH REPORT

NO. M & R 636210

Prepared in Cooperation with the U.S. Department of Transportation, Bureau of Public Roads July, 1968

STATE OF CALIFORNIA—TRANSPORTATION AGENCY

RONALD REAGAN, *Governor*

DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS
MATERIALS AND RESEARCH DEPARTMENT
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July 1968
Interim Report
M & R No. 636210

Mr. J. A. Legarra
State Highway Engineer

Dear Sir:

Submitted herewith is a research report titled:

ULTRASONIC WELD JOINT STUDY

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Very truly yours,

John L. Beaton

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Materials and Research Engineer

ABSTRACT

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KEY WORDS: Welding, welded joints, testing, nondestructive testing, ultrasonics, ultrasonic testing, quality control, inspection.

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This is an interim report to be issued under project titled "Ultrasonic Weld Joint Study". The work was done under the 1967-68 Work Program HPR-1/4 D-4-34 in cooperation with the United States Department of Transportation, Federal Highway Administration, Bureau of Public Roads. It should be recognized that the opinions, findings, and conclusions expressed in this publication are those of the authors and are not necessarily those of the Bureau of Public Roads.

TABLE OF CONTENTS

I. INTRODUCTION

The purpose of this project is to develop and evaluate ultrasonic inspection procedures. The principle concern is to be able to ultrasonically inspect butt welds on flange and web splices for highway steel bridge members. The ultrasonic inspection procedure and specification must insure that no detrimental weld defects will be overlooked in the examination of welded joints.

II. CONCLUSIONS

1. Ultrasonic inspection of butt welded joints can be used successfully to supplement radiographic inspection.

2. Weld flaws detected by radiographic techniques can be rapidly scanned ultrasonically for depth and length expediting defect removal.

3. Ultrasonic inspection for determining the quality of butt welded joints was made possible by:

   (a) obtaining an ultrasonic operator with technical background as well as a keen interest in ultrasonic weld inspection

   (b) applying an ultrasonic specification applicable to the objectives of this project.

4. Using instrument calibration standards to identically calibrate ultrasonic instruments allows butt welded joints to be evaluated by numerous operators with the same interpretation as to quality.

5. With proper instrument calibration, crack type weld defects are assured to be detected by ultrasonic inspection methods.

III. RECOMMENDATIONS

1. We recommend that ultrasonic inspection of butt welded joints be allowed for insuring quality welded joints on a limited basis, only, until a greater confidence level is achieved. There are many problems unsolved which need more investigation before an over-all recommendation can be given.

2. We recommend that all steel inspectors presently inspecting shop and field girder fabrication and splicing be schooled in the basic theory and practice of ultrasonics, covering both the operation of ultrasonic instruments and the interpretation of the ultrasonic specifications.

3. We recommend that the Engineer pay particularly close attention to the qualifications of the ultrasonic operator. The Engineer must insure that the appropriate specification is followed and that the operator's instrument, standard calibration blocks, and transducers conform to the specifications.

IV. DISCUSSION

The California Division of Highways, Materials and Research Department, has been experimentally using the ultrasonic specification titled "Ultrasonic Testing for Butt Welds in Highway and Railway Bridges" dated May 1968 developed by Dexter A. Olsson of Bethlehem Steel Company. This specification appears to be the most promising of all those tried or attempted. However, based upon our trial use of this specification to date, it appears there are certain problems in using this specification, some of which are characteristic of ultrasonic inspection in general and others which are due to the limitations of the specification, itself.

The one item of ultrasonic inspection that can render the best specification useless is lack of interest, lack of dexterity, or lack of intelligence of the operator. This has been a major obstacle in trying to develop, evaluate, and apply ultrasonics as a routine inspection tool. The writers of this report have spent considerable time in learning the state of the art of ultrasonics as it exists today. This study began with a course on basic ultrasonic theory almost two years ago. It then progressed to simple laboratory demonstrations and finally to full evaluation of butt welded field splices. A good technical background as well as a keen interest in ultrasonics in general by the operator are considered to be an absolute must before a weld splice should even be considered for inspection by ultrasonics. The operator of the equipment is of paramount concern because what he sees and interprets on the ultrasonic screen determines what is rejectable or acceptable as outlined by any specification. He must have the ability to (1) manipulate the ultrasonic transducer while watching the screen, (2) efficiently maximize all weld flaw indications so that proper evaluation can be made, and (3) know when a particular situation gives interpretation difficulties and what corrective action should be taken. These are all operator-influenced situations that must be recognized if correct and accurate interpretations are to be made.

In the trial work to date on this project many of the operator oriented problems have been overcome, but even with a qualified operator there comes the problem of an adequate ultrasonic specification, particularly with one adequately oriented toward quality assurance of butt welded joints.

We have applied the ultrasonic specification as proposed by Bethlehem Steel Company in our inspection work with limited success to date. Our principle use of this specification has been in the area of field inspection of girder splices. The primary inspection

tool we have used to evaluate the integrity of the welded joints, in addition to continual visual inspection, is still radiography; however, a substantial amount of knowledge has been obtained by ultrasonic inspection of the identical joints prior to radiography and comparing results.

Although information on the use of ultrasonic inspection as applied to shop inspection will be included in the final report for this project, we will outline the successes and difficulties of the ultrasonic specification that we have experienced to date in evaluating field weldments.

V. INFORMATION

Since this department has begun using ultrasonics to interpret butt weld quality, we have encountered a number of areas where, prior to this study, great difficulty in using ultrasonics existed. The areas of success which have been encountered as well as some of the problems are discussed as follows:

A. Achievements

1. Reproducibility:

The ability to detect a weld flaw and evaluate its relative size and length is of little importance unless one can return a day later or even a year later and scan the same area and reproduce the same evaluation as the first. The ability of two operators evaluating an identical weld flaw the same is vitally important for controlled quality assurance of welded joints. Much of the success of being able to reproduce an interpretation of a weld joint is the result of calibration standards. It is important to be able to identically calibrate ultrasonic instruments so no matter where or when the weld joint is being evaluated, the resulting interpretation is the same. The specification Bethlehem Steel Company proposes, hereafter called the specification, has resolved many of these difficulties by using a sensitivity standard block referred to as the IIW block (International Institute of Welding). Reproducibility has been enhanced also by standardizing on three angle beam transducers along with fixed transducer frequency. The proposed specification requires that an angle beam transducer of a specified angle be used where a particular range of material thicknesses are to be scanned, e.g., for material thicknesses from 5/16" to 2" requires the use of a 70° transducer. The frequency fixed between the values 2.0 - 2.5 MHz results in a relatively constant resolving power. This implies that the characteristics of the reflected sound from a weld flaw looks approximately the same on different instruments. The frequency is also a measure of the penetrating power capabilities of the transducer. This range of frequencies is well within that penetrating power requirements necessary to satisfactorily evaluate the types of butt joints within the objectives of this project.

2. Weld Flaw Depth Evaluation:

The ability to detect and evaluate a weld flaw is only part of the total gamut of useful applications of ultrasonics. Another is after having detected a weld flaw its position can be accurately pinpointed in the weldment, expediting removal if required. The pinpointing of weld flaws has been used quite successfully both in locating the depth of defects rejected on radiographic film and as part of our ultrasonic inspection and evaluation of butt welded joints.

3. Assurance That Crack Type Defects Are Not Overlooked:

We have generated a degree of confidence such that after scanning a butt joint, crack-like weld defects are not missed. The reason for this is that the crack-type defects have greater sound reflecting characteristics for their size than any of the other weld flaw types. The ability of any NDT tool to locate and evaluate the more severe type defects as does ultrasonics places it high on the list of desirable tools to obtain and use.

4. Lightweight Portable Ultrasonic Instruments:

The state of the art is now at a point where light-weight portable ultrasonic instruments are available with battery life of from four to eight hours. This alone has greatly improved the usefulness of this tool. There is no more need to handle bulky, heavy, 110 volt powered ultrasonic instruments around, over, or under girders in either the fabrication shops or in the field. The new instruments have eliminated many of the handicaps ultrasonics have had as a field inspection tool in the past.

B. Problems

Unfortunately, the successes have been small in number when compared with the difficulties. There are still many unanswered questions and unsolved problems with respect to ultrasonic inspection of butt welded joints. A brief description of the difficulties are discussed, all of which have no immediate answers at this time.

1. Comparing Ultrasonic With Radiographic Interpretations:

So far as we have witnessed, there is little or no consistency when an ultrasonic butt weld joint interpretation is compared with the radiographic interpretation of

the same joint. Obviously there are more flaws in weldments than have been shown using conventional radiographic techniques. Questions needing further study are (a) are weld flaws detected by ultrasonic inspection more detrimental to the life of the structure than flaws detected by radiography?,(b) can we ever accept a weld joint whose ultrasonic interpretation is "acceptable" but has a rejectable radiographic film indication?

2. Scanning With Weld Reinforcement Partially Ground:

There is substantial difficulty in adequately interpreting a weld joint when the reinforcement is unground or partially ground. The problem is greatly enhanced as the joint becomes thinner as generally exist on web butt welds. The principle concern are defects that lie within the weld but whose interpretations are made impossible because of reflected sound off the weld reinforcement. The reinforcement also prevents thorough examination of the weld area with a direct sound path unless the operator is capable of scanning upside down as would be required on flange welds. When scanning from the top side of the flange, which is most common, and when evaluating the upper area of the weldment, the operator needs to back away from the weld to a distance sufficient to have the sound beam reflected off the bottom of the plate and back up into the upper part of the weld. Even with the sound beam reflected from the bottom, there still occurs indications from the upper weld reinforcement. What makes the problem even more troubling is that some weld reinforcement will not reflect the sound beam for the ultrasonic transducer to detect, resulting in no indication on the screen. Question: How can an operator interpret indications coming from near the surface area when the weld is only partially ground and evaluate them properly?

3. Scanning Close to Surface Defects:

We have witnessed that ultrasonic interpretation of defects lying near the surface of smooth ground butt welds can easily be missed. This has been proven when comparing radiographic interpretation with ultrasonic. An ultrasonic evaluation of a particular joint showed the joint was clean and free of defective weld. The radiographic evaluation showed the joint was rejectable with a slag line as the reason. Rescanning of these joints still revealed no ultrasonic indications. We

were able to verify the existence of the slag defect as its removal was witnessed by the ultrasonic operator, the radiographer, the field welding inspector, and the welder. The slag was near the surface in each case. Question: How can the scanning technique be improved so that defects close to the surface are not missed?

4. Scanning Over Web Fillet Welds:

In scanning girder flange butt welds, the operator encounters difficulties when trying to evaluate the weld length in the area of the web cope-hole. The problem arises from the partial penetration fillet welds which tie the girder web to the flanges. Spurious indications are always evident on the ultrasonic instrument screen when scanning flange butt welds over flange to web fillet welds. The operator cannot rely on any sound indications returning from or near the flange surface where the web fillet welds terminate at the web cope-hole. For a complete examination of the flange welds, the transducer is normally backed away from the weld to a point where the sound beam is reflected from the bottom surface allowing careful examination of the upper part of the weldment. In the area of the cope-hole, only a small portion of the sound beam is allowed to reflect from the opposite side, that being the part of the sound beam that strikes the unfused land where the web to flange fillet welds tie the two together. The portion of the sound beam that strikes the land and reflects properly is of an insufficient amount for any evaluation. Most of the beam is either absorbed by or reflected erratically back from the fillet welds. Little or no evaluation of the flange weld in the area of the cope hole can be made when scanning from the web side on the girder flange. Question: How can scanning techniques be changed so as to allow satisfactory interpretation of the flange butt weld in the web cope area?

5. Scanning Weld With Laminated Base Metal:

Laminations in steel have the properties of disrupting the sound path of the ultrasonic transducer. The proper evaluation of a weldment requires absolute awareness of the location of the sound beam while penetrating the base material, weld material or both. Any distortion of the sound path, which can occur easily when scanning on laminated plate, results in utter confusion and renders the tool useless. Question: How badly laminated can plate become before the operator

should disqualify his tool as not being able to satisfactorily inspect the weld area?

6. Scanning Over Harshly Ground or Wavily Ground Surfaces:

Oftentimes the operator is required to ultrasonically scan a joint that was ground with a power grinder that leaves the surface with rough grind marks or leaves the surface smooth but very wavy. The ability of the transducer sound beam to penetrate the surface is dependent on its ability to hold sufficient couplant between the transducer and the work piece. Rough or wavily ground surfaces result in loss of couplant, subsequently no sound enters the steel, which gives an invalid interpretation of the weld area. Question: How rough or wavy can a surface be before no interpretation of the weld joint should be attempted?

7. Scanning Stacked Defects:

We have experienced when comparing ultrasonic and radiographic interpretation that stacked defects are always a point of disagreement. The ultrasonic specification does not cover the possibilities that more than one defect can occur in the vertical plane of the weld throat at one time. This is a little idealistic as it is quite possible and very probable from our experience that weld flaws do occur and have occurred in this fashion. The evaluation of two or more weld flaws lying in a vertical plane of the weld throat, even though beyond the scope of the ultrasonic specification, requires responsible corrective action when they are detected. The problem arises where two stacked defects occur in the weldment, either one existing alone in the weld section would be acceptable by present radiographic specifications; however, their geometrical orientation relative to the radiographic source and the radiographic film results in their being superimposed on the film and radiographically interpreted as (1) one defect longer than acceptable by the radiographic specification or (2) one very dark indication that is also not acceptable by the radiographic specification. Questions: If both flaws are interpreted ultrasonically as being small, (1) is it to the best interest and safety of the structure to repair only one, (2) if one should be repaired, should it be the one that is interpreted ultrasonically or radiographically more severe, and (3) should they be repaired at all?

8. Evaluating Defect Lengths:

We believe a given defect should be evaluated first for its relative amplitude indication and secondly for its

length. The amplitude indication can now be evaluated quite easily. It is compared to the indication from the 1/16" diameter drilled hole in the IIW block. Evaluating the flaw length is more difficult. There are defects in welds that should be accepted provided they are short in length. There are, on the other hand, the same type flaws with appreciable length that should be repaired. The ability of ultrasonics to measure defect lengths, without special calibration, to within plus or minus 1/16 inch is unrealistic. We would hope a final ultrasonic specification will have weld flaw lengths as a part of its acceptance-rejection criteria. Question: Can ultrasonics be expected to evaluate weld flaw lengths to the degree described in the American Welding Society's D2.0 titled, "Specifications for Welded Highway and Railway Bridges", Figure 409?

9. Elements:

We have found that there are many elements of nature that greatly hinder the performance of the ultrasonic operator and his interpretation of weld quality. They are:

(a) Sun: the sun reflects from the cathode ray tube to an extent that no sweep is visible on the screen.

(b) Wind: the wind blows the record sheet on which the ultrasonic data is recorded. The wind also blows grinding dust and dirt on the couplant greatly reducing the scanning confidence. On occasion, light scaffolding on which the ultrasonic operator stands has been felt to move as the result of wind gusts.

(c) Heat: when the temperature of the steel on which the operator is scanning becomes hot due to sun exposure or early scanning after welding, the couplant becomes very fluent and tends to evaporate rapidly. As the couplant thins out it becomes more and more difficult to retain adequate couplant between the transducer and the work piece. The fluent couplant resulting from hot steel greatly restricts the ultrasonic interpreting of vertical or overhead surfaces. We have witnessed that heat also accelerates fatigue of the ultrasonic operator.

(d) Cold: cold weather restricts the dexterity of the operator. Ultrasonic inspection oriented toward

the objectives of this project do not lend themselves to the operator wearing gloves while scanning.

(e) Rain: rain presents problems as most ultrasonic equipment is not waterproof. The rain also hampers the operator's enthusiasm toward documenting each flaw observed as it requires his working with wet record sheets.

(f) Noise: noise caused from automatic impact wrenches is common as girder stiffeners and sway bracing are installed. The noise is quite distracting to the operator and in some cases a condition arises under which a satisfactory inspection cannot be conducted.

10. Inspection Conditions:

Inspection conditions can be broken down into four groups: (a) the operator must be reasonably comfortable while scanning, (b) he must be able to see the screen clearly while manipulating the transducer, (c) he must put up with frequent couplant loss particularly while scanning upside down, and (d) he must be capable of scanning whether on the ground, on the girder, on the welder's scaffolding or on the welder's floats. These conditions can adversely affect the satisfactory evaluation of the joint by the degree with which they individually exist.

One last point that is important for satisfactory evaluation of butt welds is the physical and mental condition of the operator. Basically he must have good eyesight and feel physically healthy. Any discomfort or illness will affect the proper performance of the ultrasonic operator resulting in a loss of confidence and most likely an invalid weld joint evaluation. There is no reason for ultrasonic inspection to be conducted unless it can assure at least the minimum confidence level demanded by its presence.