

Acoustic Dissimilarities in Steel Ultrasonic Weld Inspection

Suggested Best Practices and Frequently Asked Questions in Addressing the FHWA Memorandum (December 13, 2024)

Authors: Robert Connor, PE, PhD, Glenn Washer, PE, PhD, and Curtis Schroeder, SE, PhD

Background

This white paper contains questions and answers or suggested best practices in response to the FHWA Memorandum dated December 13, 2024, "Recommendations to Account for Acoustic Dissimilarities in Steel Ultrasonic Weld Inspection," which will be referred to herein as the "Memo."

The questions are generally grouped by topic area and are intended to provide clarification regarding how to best meet the objectives of the Memo.

Industry representatives and FHWA personnel have also reviewed the questions and the responses and have found the responses to be consistent with meeting the objectives of the Memo.

August 2025

Q&A

Questions Related to Background

1 Is the information in the Memo based on a new discovery?

No. The importance of accurately knowing the velocity of shear waves is well documented in many other industries. Further, it is known that the velocity of all steels is not constant, though the differences were generally assumed to be negligible in AASHTO/AWS D1.5M/D1.5. However, the recent work reported in NCHRP Report 908 revealed that for some steels approved for use on bridges or ancillary structures, the velocity differences are significant and need to be accounted for in the calibration process.

2 Why didn't FHWA just provide revised code and commentary to integrate within the AASHTO/AWS D1.5M/D1.5 code? [It is noted that the Memo cites the 2015 AASHTO/AWS D1.5M/D1.5 code while this white paper cites the 2020 version. There are no substantive differences between the two versions as related to the items discussed herein. However, some clauses were renumbered between the 2015 and 2020 versions. FHWA cited the 2015 version incorporated by reference in 23 CFR 625.4(d)(2)(iii).]

AASHTO/AWS D1.5M/D1.5 is incorporated by reference in 23 CFR 625.4(d)(2)(iii) as a standard for use with bridges on the National Highway System. In that regard, the AASHTO/AWS D1.5M/D1.5 code is a legally binding document, and it is not within FHWA's authority to make changes to the document. To make changes to the document, AASHTO and AWS would need to make the change using their normal balloting process. Thus, the Memo is invoking Clause 8.13.2 of the code that allows discretion of the Engineer to provide variations to the ultrasonic testing (UT) procedures and equipment in Part C of Clause 8. Users should note that AASHTO/AWS is aware of the information presented in the Memo and is working to develop code language to address the issues it raises.



Smarter.
Stronger.
Steel.

Questions Related to Background

- 3** The Memo stated that the supplementary requirements are applicable to the AASHTO/AWS D1.5M/D1.5. What about applications to other highway structures fabricated to AWS D1.1/D1.1M?

The issues raised in the Memo are independent of the specification cited as they are solely due to the acoustic properties of the base metal. Hence, any specification (e.g., AWS D1.1/D1.1M) that utilizes amplitude to assess acceptance or rejection would be affected. It is noted that AWS D1.1/D1.1M is also incorporated by reference in 23 CFR 625.4(d)(2)(i). This standard is often referenced in the fabrication of pedestrian bridges and ancillary traffic structures. As these types of structures may be located within the right of way (vertically and/or horizontally) of the National Highway System, owners should strongly consider applying the same supplementary requirements to ultrasonic inspections made in accordance with AWS D1.1/1.1M. AWS D1.1/1.1M grants the Engineer approval of variations to UT procedures in Clause 8.19.2.

- 4** Does the Memo apply to all bridge members?

While not binding, the Memo has been written from the stance of providing supplemental requirements to Part C of Clause 8 of AASHTO/AWS D1.5M/D1.5, thus it is applicable to all bridge members. However, as stated in Commentary C of the Memo's Appendix A, owners can decide to apply the supplementary requirements to just a class of bridge members, e.g., fracture critical or non-redundant steel tension members as there is a higher consequence should a defect be missed during fabrication inspection and subsequently lead to member failure.

While the Memo is not binding, the concerns that it raises are real and can lead to erroneous inspection results in some cases if they are entirely ignored.

- 5** If my state elects to follow the suggestions in the Memo, must the procedures recommended in the Memo be used?

No, the Memo is a recommendation from FHWA. Additionally, there are numerous ways to measure shear wave velocity or determine the degree of acoustic anisotropy. Users may refer to other standards (DNVGL-CG-0051, JIS Z 3060, ISO 19675, ASTM E164 Annex A3, or ASTM E1961 Annex A1) which have alternative means of performing these measurements. The methods published in Appendix A of the Memo are one way this could be done, and they are modelled after a draft ballot that proposed changes to AASHTO/AWS D1.5M/D1.5, though the ballot has yet to be adopted and may still undergo modification. It is noted the recommendations contained in the Memo are very similar to those proposed during the NCHRP Report 908 research.

- 6** How does the December 13, 2024 Memo affect previous or ongoing UT of welds in T1 steel conducted as directed by the December 13, 2021, Memo "Non-Destructive Testing of Fracture Critical Members Fabricated from AASHTO M244 Grade 100 (ASTM A514/A517) Steel?"

The Memo does not have any impact on previous or ongoing UT of T1 welds as all data suggest that (1) the velocity of shear waves in quenched and tempered (Q&T) grades of steel are generally consistent with the value traditionally assumed and (2) the Q&T grades are typically acoustically isotropic.

Questions Related to Ultrasonic Waves in Solids

- 7** What is acoustic anisotropy?

Acoustic anisotropy means that sound waves travel at different velocities in different directions within a plate. For example, the velocity of a wave traveling in the rolling direction is different than the velocity of a wave traveling in a direction transverse to the rolling direction or through the thickness of the plate. When waves travel at an oblique angle through the plate and parallel to the rolling direction, such as when inspecting a butt weld oriented perpendicular to the rolling direction, the wave travels at a velocity that is a combination of the velocity through the thickness and parallel to the rolling direction. If the wave is traveling in a direction that is also oblique to the rolling direction, its velocity is a combination of the through-thickness, parallel, and transverse directions, combined.

Acoustic anisotropy stems largely from elastic anisotropy, which manifests as the modulus of elasticity (E , ksi) being different depending on the direction in the plate. For example, in an anisotropic material, a tension test specimen whose axis is aligned with the rolling direction will have a slightly different modulus than a tension test specimen whose axis is aligned transverse to the rolling direction. The difference is generally negligible in terms of mechanical properties used in design to carry load but has a more significant effect on ultrasonic wave velocities. There is also a scattering component in UT that contributes to acoustic anisotropy.

Historically, carbon steel has been assumed to have isotropic properties, meaning the material only has one ultrasonic shear wave velocity, regardless of the direction the wave travels through a plate. This general assumption was revealed to be incorrect in work in Japan (Keiji, 1987) and in NCHRP Report 908, which found that the velocity of shear waves in some steels varies more than historically assumed in the three orthogonal directions, resulting in acoustic anisotropy.

Questions Related to Ultrasonic Waves in Solids

8 Are all steels acoustically anisotropic?

No. While not enough data exists to state with confidence which grade or process results in acoustic anisotropy, it does appear that Q&T carbon steels do not typically exhibit acoustic anisotropy. Based on research to date, it appears that thermo-mechanically controlled processed (TMCP) or controlled rolling processed plates are more likely to display anisotropy. In addition, ASTM A709 Grade 50CR or ASTM A1010 stainless steel has shown high levels of acoustic anisotropy. It is also noted that no correlation has been identified that suggests that the grade of steel contributes to the shear wave velocity or anisotropy issues raised in the Memo, with the exception of Q&T grades, which do not appear to be acoustically anisotropic.

9 Why is knowing the shear wave velocity in the steel plate undergoing ultrasonic inspection important?

When the shear wave velocity in the steel plate is higher than the velocity in the reference standard being used, less energy will be transmitted into the steel at high search angles and indication amplitudes will be less than if the velocities in each material were the same (Washer et. al., 2024). As a result, indications that should be rejected under the AASHTO/AWS D1.5M/D1.5 code may be rated as acceptable, meaning rejectable indications (for example, weld flaws) would not be repaired before being placed in service.

Shear waves used for UT are produced through mode conversion at the surface of the material under test. The commonly used angles of 45°, 60°, and 70° are obtained by using an acrylic wedge designed with appropriate incidence angles to produce the desired refracted shear wave within the plate. The incidence angle of the wedge is determined from applying Snell's law using the specific velocities in the acrylic wedge and the assumed velocity in the steel under test. If the steel under test has a different velocity than assumed when the wedge was produced, the refracted angle and the energy imparted into the steel will be different than expected. If the velocity in the steel plate is higher than assumed when the wedge was produced, less energy will be imparted in the steel plate due to the higher refracted angle of the wave. This effect is more pronounced at higher refracted angles (for example, 70°) as compared with lower refracted angles (for example, 45°).

10 If the shear wave velocity in the inspected plate is different than the reference standard, does that also mean the inspected object is acoustically anisotropic?

No. Steel materials naturally have variations in their acoustic velocity based on chemistry and production processes used to manufacture the plate. While the shear wave velocity in a plate may be different than the reference standard, the plate could be acoustically isotropic. Thus, there are two issues raised in the Memo—differences in the shear wave velocity between the reference standard and the test piece, and differences in the shear wave velocity in the orthogonal directions of the test piece resulting in the test piece being acoustically anisotropic.

11 Are dissimilarities in shear wave velocity large enough to significantly affect the ultrasonic test results?

Yes, in some cases, the difference can lead to complete mode conversion of the shear wave into a surface wave, particularly at higher search angles. In such cases, it may not be possible to detect a side drilled hole (typically used for calibration) in the test piece.

12 The 1% limit on anisotropy seems like a very small tolerance. Can it be increased?

The 1% limit is not a tolerance, it merely represents the difference in velocity between two orthogonal directions, and unfortunately, a small difference can result in a significant change in the energy reflected by an internal defect and affect the associated defect rating. Users can specify a higher limit (for example, 1.5% or 2%), but they must assess their own level of risk tolerance due to the potential of decreasing inspection sensitivity which could allow otherwise rejectable defects to remain in place.

13 Are these velocity issues only present in plate products?

While the existing data was obtained from plate products, there is no reason to assume that similar issues could not exist in other rolled products, such as W-shapes. In addition, acoustic anisotropy has been well-documented in other rolled products, such as steel line pipe where the rolling processes may orient the grains with a long axis parallel to the direction of rolling, and is dependent on the pipe diameter, wall thickness, and manufacturer (ASTM E1961). It is reasonable to assume that other products such as castings may have large variations in velocity compared to typical reference standards due to variations in chemistry, casting geometry, and solidification processes.

Questions Related to the Mechanical Properties of A709 Grades Identified to be Acoustically Anisotropic

- 14** Are there any concerns regarding the mechanical properties of the various ASTM A709 grades of steel that have been identified as either
(1) acoustically anisotropic or
(2) acoustically isotropic but having a shear wave velocity that is different than typically assumed?

All current data suggest that there is no concern or correlation regarding any negative impact on the mechanical properties (tensile strength, CVN, etc.) of ASTM A709 steels identified as having acoustic properties identified in the Memo. The same is also true for ASTM A709 grades that are acoustically isotropic yet demonstrate a different shear wave velocity than traditionally assumed.

- 15** Is the weldability of ASTM A709 grades of steel that have been identified as being acoustically anisotropic different or more challenging than acoustically isotropic steels?

There is no data that suggests that there are any negative impacts on the weldability of ASTM A709 steels identified to be acoustically anisotropic or acoustically isotropic steel with a different shear wave velocity than traditionally assumed.

- 16** Do shear wave velocity effects, and the possibility of anisotropy, also need to be checked for the weld metal?

The issues addressed in the Memo only apply to base metal, but UT inspection of the welds themselves will be affected as it relies on transmission of ultrasound through the adjacent base metal. The welds of anisotropic materials are formed in a similar manner to those of isotropic materials. Therefore, there is no reason to believe that the acoustic properties of weld metal used to join two anisotropic materials would significantly differ from welds metal used to join isotropic plates. Hence, there is no need to make specific velocity measurements in the deposited weld metal or consider the weld metal velocities when applying the guidance of the Memo or the recommendations contained in herein.

- 17** Can the level or degree of acoustic anisotropy be specified when an order is placed from the steel mill or in project special provisions like other mechanical properties?

Current ASTMs do not require mills to identify or target acoustic properties for any grade of ASTM A709 steel (or any grade of structural steel used in civil engineering applications for that matter). It is believed that imposing limits on the acoustic properties would likely result in unnecessary rejection of plate that otherwise would meet the mechanical requirements and increase cost. Therefore, the industry focus has been to adapt ultrasonic inspection to the potential conditions of A709 steels.

While some production processes appear to be more prone to the issues raised in the Memo (for example, TMCP or controlled rolling) current research suggests that any grade and process other than steel produced by the Q&T process could be susceptible. Currently, mill certifications are not required to specify the rolling process such as TMCP or controlled rolling. Therefore, steel rolled using these processes could be sold as multiple different grades. Steels rolled with conventional rolling processes, typically described as “hot-rolled” or “as-rolled” that have been tested have not shown anisotropic properties exceeding 1%.

- 18** Once it is determined that the steel is acoustically anisotropic, should it be rejected?

As stated, the mechanical properties and weldability of such steels are not negatively impacted. Hence, rejection of an acoustically anisotropic plate based solely on the acoustic properties is not warranted. Alternative NDT methods or special calibration procedures may be necessary to properly inspect components with differences in shear wave velocity or anisotropic characteristics when UT is required. This will likely require consideration of the member classification (redundant or non-redundant), weld type (butt joint, T-joint, etc.), and weld orientation with respect to the rolling direction.

Questions Regarding UT Inspection of Welds

19 How can I determine if the shear wave velocity in my reference standard is different than in the steel I am using?

The most direct way to assess the shear wave velocity in a material is to use a normal incidence shear wave transducer to measure the velocity through the thickness of the reference standard (calibration block) and the steel plate being inspected, both polarized in the scanning direction. Normal incidence shear wave transducers are available commercially from many vendors that sell ultrasonic transducers. The normal incidence shear wave transducer can be used with typical ultrasonic flaw detectors but requires a high-viscosity couplant specified by the probe manufacturer to transmit shear waves directly from the transducer to the steel component. The shear wave velocity can be calculated from timing the measurements of multiple backwall reflections and using the actual (not nominal) thickness of the component. Annex A1 of ASTM E1961 provides a framework of the method to calculate acoustic velocity, except that it utilizes reflections from machined notches in a steel sample cut from a section of pipe rather than multiple backwall reflections in the test object.

20 How can I determine if my steel is acoustically anisotropic?

The simplest way to determine if a material is anisotropic is to measure the velocity of a shear wave polarized in the rolling direction and the velocity of a shear wave polarized transverse to the rolling direction. If the velocity varies by greater than ~1% (~32 m/sec, 0.0013 in./microsecond), the material can be considered anisotropic. Timing measurements of the orthogonally-polarized waves alone may be used, since the material thickness is the same for each wave.

Measured anisotropic ratios (AR) vary somewhat spatially along the length or width of the plate, and it is recommended that at least three measurements at different locations be averaged to assess the nominal anisotropic ratio.

21 How difficult is it to determine if my steel is acoustically anisotropic?

The normal incidence shear wave transducers produce a polarized shear wave. The transducer simply needs to be placed on the material with the polarization direction (which is marked on the transducer) aligned with the rolling direction to determine one velocity, then rotated 90° to determine the second velocity. These two velocities can then be compared to assess the anisotropy.

22 Will using phased array ultrasonic testing (PAUT) solve these issues?

No. The same physics principles that affect UT with a single element transducer also affect phased array that consists of multiple individual elements within the transducer. The underlying focal laws used to determine the direction of the wave produced from the phased array assume the material under test is isotropic, and therefore waves are all traveling at the same velocity regardless of direction. When the material is anisotropic, waves travel at different velocities depending on direction, causing errors between the angle intended and the angle produced in the materials by the focal laws (Holloway and Ginzel, 2021). Additionally, the amplitude of the wave imparted into the material under test and the reference standard will be different, causing errors in the rejection level used to assess indications.

PAUT may help with acoustically isotropic materials that differ in velocity from standard materials since the focal laws can be generated using the correct velocity rather than needing a specialized wedge to be machined like conventional UT. Note that the calibration process will still require use of a reference standard that is acoustically similar to the test object.

23 Does this issue only affect complete joint penetration (CJP) welds?

The issue affects any joints inspected ultrasonically. While the majority of welds that are inspected using UT are CJP welds, anytime UT is used, the issues regarding velocity differences or anisotropy must be addressed. Hence, proper calibration for these effects must be considered when inspecting T-joints, corner joints, or PJP welds that are sometimes solely inspected using UT. Fillet welds are typically inspected with other methods such as magnetic particle testing (MT) or liquid penetrant testing (PT) that are not affected by shear wave velocity.

24 Once it is determined the steel is acoustically anisotropic or there are sufficient differences in the shear wave velocity compared to the reference standard, can the welds be inspected per the AASHTO/AWS D1.5M/D1.5 using UT?

AASHTO/AWS D1.5M/D1.5 requires radiographic inspection (RT) in many scenarios, or the option of UT in lieu of RT with approval. The physics of RT are not affected by shear wave velocity, and no adjustments are required when conducting RT. However, the need for UT will be unavoidable in the following scenarios per AASHTO/AWS D1.5M/D1.5:

Questions Regarding UT Inspection of Welds

- Per Clause 6.22.13 and Table 8.1, CJP groove joints under any loading condition made with the electroslog or electrogas welding process shall be RT and UT tested.
- Per Clause 8.7.1, all CJP groove joints in T- and corner configurations and under any loading condition of redundant members shall be UT tested.
- Per Clause 12.16.2.1, CJP butt joints in nonredundant steel tension members (NSTMs) in tension and repaired groove welds under any loading condition require RT and UT.
- Per Clause 12.16.2.2 all CJP groove T- and corner joints in NSTMs in tension and repaired groove welds under any loading condition shall be UT tested.

25 In cases where some form of UT of a weld either must be performed or is preferred, what can be done to account for these issues?

Research is currently underway at the University of Missouri-Columbia with the objective of developing procedures on how to address the issues raised in the Memo. However, that work will not be completed until late 2025. In the meantime, the authors suggest the following strategies in specific applications when a shear wave velocity mismatch greater than 1% occurs, or anisotropic ratio exceeds 1%. The suggested strategies were developed for carbon steels with velocity or anisotropy differences compared to typical reference standards. These strategies should not be applied to stainless steel such as ASTM A709 Grade 50CR without further study on the velocity and anisotropy effects for those materials. Six different cases are presented as follows.

Case 1

CONDITIONS

- The measured shear wave velocity ratio between the test object and the reference standard is less than or equal to 1%.
- The measured anisotropic ratio of the test piece is less than or equal to 1%.

RECOMMENDATION

No changes to the current AWS approach are necessary and the original acceptance criteria, as shown in Tables 1a and 1b of the Appendix of this white paper, are applicable.

Case 2

CONDITIONS

- The measured shear wave velocity ratio between the test object and the reference standard is greater than 1% but less than or equal to 2.5%.
- The measured anisotropic ratio of the test piece is less than or equal to 1%.

RECOMMENDATION

The authors recommend following the guidance contained in Section B of the table found in Appendix A of the FHWA Memo. If the measured shear wave velocity ratio is greater than 1% but less than or equal to 2.5%, the UT operator can restrict inspection angles to 60° and less and use the modified acceptance criteria as shown in Tables 2a and 2b of the Appendix of this white paper. Because the anisotropic ratio is less than or equal to 1%, section C of the table found in Appendix A of the FHWA Memo does not apply. Alternatively, the user may perform a more detailed calibration to account for amplitude variations resulting from the differences in shear wave velocity between the reference standard and the test piece or use a different reference standard with a shear wave velocity ratio less than or equal to 1%. If the measured shear wave velocity ratio is greater than 2.5%, the user should obtain a different reference standard that more closely matches the shear wave velocity of the test object.

Case 3

CONDITIONS

- The measured shear wave velocity ratio between the reference standard and the test piece is less than or equal to 1%.
- The measured anisotropic ratio of the test piece is greater than 1% but less than or equal to 1.75%.
- The CJP butt, T-, or corner joint is aligned within $\pm 10^\circ$ of either parallel or perpendicular to the rolling direction of the plate.
 - Examples may include a CJP web-to-flange weld in an I-shaped girder, a CJP weld in a corner of a box girder, or a CJP weld of a vertical connection plate.
- The intent is to preclude UT of welds that are oriented at an oblique angle between 10° and 80° from the rolling direction.

RECOMMENDATION

In this case, the measured shear wave velocity ratio less than or equal to 1% and inspection angles do not need to be restricted as recommended in Section B of the table found in Appendix A of the FHWA Memo. However, the anisotropic ratio is greater than 1% and the FHWA Memo would not recommend using this test plate with a CJP groove weld. As stated above, the work at the University of Missouri is currently underway. While that work is not completed, based on the data obtained to date, the authors are recommending an interim working solution to serve as a stop-gap measure where UT of CJP butt welds, T-, or corner joints must be performed. In the interim, for anisotropic ratios greater than 1% but less than or equal to 1.75%, the test sensitivity should be increased by +4 dB for test angles 60° and larger (in other words, +4 dB additional sensitivity should be applied to the test object as compared to the reference standard). The modified acceptance criteria are shown in Tables 3a and 3b of the Appendix of this white paper.

Case 4**CONDITIONS**

- The measured shear wave velocity ratio between the reference standard and the test piece is greater than 1% but less than or equal to 2.5%.
- The measured anisotropic ratio of the test piece is greater than 1% but less than or equal to 1.75%.
- The CJP butt, T-, or corner joint is aligned within $\pm 10^\circ$ of either parallel or perpendicular to the rolling direction of the plate.

RECOMMENDATION

The authors recommend following the guidance contained in Section B of the table found in Appendix A of the FHWA Memo due to the measured shear wave velocity ratio being greater than 1% but less than or equal to 2.5%, thus it would be easiest for the UT operator to restrict inspection angles to 60° and less. Since the anisotropic ratio is greater than 1% but less than or equal to 1.75%, the test sensitivity should be increased by +4 dB for the 60° acceptance criteria. Thus, only 45° and 60° inspection angles should be used, and the modified acceptance criteria are shown in Tables 4a and 4b of the Appendix of this white paper.

Case 5**CONDITIONS**

- The measured shear wave velocity ratio between the reference standard and the test piece is greater than 1% but less than or equal to 2.5%.
- The measured anisotropic ratio of the test piece is greater than 1.75% but less than or equal to 5%.
- The CJP butt, T-, or corner joint is aligned within $\pm 10^\circ$ of either parallel or perpendicular to the rolling direction of the plate.

RECOMMENDATION

In scenarios where the shear wave velocity ratio is greater than 1% but less than or equal to 2.5% and the anisotropic ratio is greater than 1.75% but less than or equal to 5%, the authors recommend limiting inspection angles only to 45°. The following adjustments need to be made:

- For weld thicknesses where the AASHTO/AWS D1.5M/D1.5 Bridge Welding Code has a 45° acceptance criteria, the reference gain should be increased by +2 dB (in other words, +2 dB additional sensitivity should be applied to the test object as compared to the reference standard).
- For weld thicknesses where the AASHTO/AWS D1.5M/D1.5 Bridge Welding Code only has 70° acceptance criteria, an additional +5 dB correction should be applied to account for the typical difference between the 45° and 70° acceptance criteria (in other words, a total correction of +7 dB).

The revised acceptance criteria are shown in Tables 5a and 5b of the Appendix of this white paper.

Case 6**CONDITION**

This case covers situations not included in Cases 1 through 5.

RECOMMENDATION

Due to the limited data that exists, simple generalized recommendations cannot be made at this time. Unique calibrations using samples obtained from the test piece or with reference standards with acoustic properties in the direction of shear wave propagation that are identical, or representative of the actual test pieces must be used.

When the reference standard is made from the steel obtained directly from the test piece (such as from a drop), the direction of polarization of the shear wave for calibration should be identical to that which will be utilized in the test piece to inspect the weld. For example, if the CJP weld is oriented along a path 30° from the rolling direction, the reference standard should include a reflector (such as a side drilled hole) that is also 30° from the rolling direction. Consideration should be given to attenuation, mode conversion, and beam splitting when developing the calibration procedures and adjustment factors.

Commentary

1. There is a possibility that plates on either side of the weld could fall into different percentage ranges. If this occurs, as a conservative approach, the highest percentage may be used to determine the required action. While this approach is conservative, unnecessary rejections could result. As an alternative, specific calibrations can be made on either side of the weld.
2. The criteria in AASHTO/AWS D1.5M/D1.5 Bridge Welding Code assigns +3 dB and +5 dB of sensitivity for refracted angles of 60° and 45°, respectively, as compared to a 70° refracted wave (Shenefelt, 1971). This is intended to compensate for signal loss when the wave is less favorably aligned with a vertical discontinuity (such as a crack). Therefore, when a 60° refracted wave is to be used in place of a 70° refracted wave, +3 dB of sensitivity is added. When a 45° refracted wave is used in place of a 70° refracted wave, the adjustment is +5 dB. These values are reflected in the tables where appropriate.

References

- AASHTO/AWS (2020), D1.5M/D1.5:2020 *Bridge Welding Code*, 7th ed., American Welding Society, Miami, Fla.
- ASTM (2024), *Standard Specification for Structural Steel for Bridges*, ASTM A709-24, ASTM International, West Conshohocken, Pa.
- Connor, R. J., Schroeder, C.J., Washer, G.A., Crowley, and M., Fish, P.E. (2019), “Acceptance Criteria of Complete Joint Penetration Steel Bridge Welds Evaluated Using Enhanced Ultrasonic Methods,” *NCHRP Report 908*, Washington, D.C., June.
- Holloway, P. and Ginzel, E. (2021), “Calibration for anisotropic effects on shear wave velocity for improvements of weld inspections in TMCP steels,” *e-Journal of Nondestructive Testing*.
- Keiji, I. (1987), “Method of Ultrasonic Angle Beam Examination for Welds of Ferritic Steels with Acoustic Anisotropy Activity Report of Non-destructive Inspection Subcommittee, Quality Control Committee, The Joint Research Society, ISIJ,” *Transactions of the Iron and Steel Institute of Japan*, Vol. 27, No. 11, pp. 898–909.
- Japanese Standards Association (2015), JIS Z 3060:2015, *Method for Ultrasonic Testing for Welds of Ferritic Steel*, Tokyo, Japan.
- National Academies of Sciences, Engineering, and Medicine (2019), “Acceptance Criteria of Complete Joint Penetration Steel Bridge Welds Evaluated Using Enhanced Ultrasonic Methods,” *NCHRP Report 908*, The National Academies Press, Washington, D.C., doi.org/10.17226/25494
- Shenefelt, G. A. (1971), “Ultrasonic Testing Requirements of the AWS 1969 Building Code and Bridge Specifications,” *Welding Journal*, Vol. 50, pp. 342–349.
- Washer, G., Agbede, J., Yadav, K., Connor R., and Turnbull, R. (2024), “Acoustic Wave Velocities in Bridge Steels and the Effects on Ultrasonic Testing,” *Journal of Nondestructive Evaluation*, Vol. 43, No. 4, p. 115.

Appendix

AWS Tables with proposed changes in amplitude criteria.

Table 1a.

Original AASHTO/AWS D1.5M/D1.5 Table 8.4

Table 8.4
UT Acceptance-Rejection Criteria – Tensile Stress (see 8.26.3.1)

Flaw Severity Class	Weld Thickness ^a (mm [in.]) and Search Unit Angle										
	8 [$\frac{5}{16}$] through 20 [$\frac{3}{4}$]	>20 [$\frac{3}{4}$] through 38 [$1\frac{1}{2}$]	>38 [$1\frac{1}{2}$] through 60 [$2\frac{1}{2}$]			>60 [$2\frac{1}{2}$] through 100 [4]			>100 [4] through 200 [8]		
	70°	70°	70°	60°	45°	70°	60°	45°	70°	60°	45°
Class A	+10 and lower	+8 and lower	+4 and lower	+7 and lower	+9 and lower	+1 and lower	+4 and lower	+6 and lower	-2 and lower	+1 and lower	+3 and lower
Class B	+11	+9	+5 +6	+8 +9	+10 +11	+2 +3	+5 +6	+7 +8	-1 0	+2 +3	+4 +5
Class C	+12	+10	+7 +8	+10 +11	+12 +13	+4 +5	+7 +8	+9 +10	+1 +2	+4 +5	+6 +7
Class D	+13 and up	+11 and up	+9 and up	+12 and up	+14 and up	+6 and up	+9 and up	+11 and up	+3 and up	+6 and up	+8 and up

^a Weld thickness shall be defined as the nominal thickness of the thinner of the two parts being joined, given in mm [in.].

Table 1b.

Original AASHTO/AWS D1.5M/D1.5 Table 8.5

Table 8.5
UT Acceptance-Rejection Criteria – Compressive Stress (see 8.26.3.1)

Flaw Severity Class	Weld Thickness ^a (mm [in.]) and Search Unit Angle										
	8 [$\frac{5}{16}$] through 20 [$\frac{3}{4}$]	>20 [$\frac{3}{4}$] through 38 [$1\frac{1}{2}$]	>38 [$1\frac{1}{2}$] through 60 [$2\frac{1}{2}$]			>60 [$2\frac{1}{2}$] through 100 [4]			>100 [4] through 200 [8]		
	70°	70°	70°	60°	45°	70°	60°	45°	70°	60°	45°
Class A	+5 and lower	+2 and lower	-2 and lower	+1 and lower	+3 and lower	-5 and lower	-2 and lower	0 and lower	-7 and lower	-4 and lower	-1 and lower
Class B	+6	+3	-1 0	+2 +3	+4 +5	-4 -3	-1 0	+1 +2	-6 -5	-3 -2	0 +1
Class C	+7	+4	+1 +2	+4 +5	+6 +7	-2 to +2	+1 +2	+3 +4	-4 to +2	-1 to +2	+2 +3
Class D	+8 and up	+5 and up	+3 and up	+6 and up	+8 and up	+3 and up	+3 and up	+5 and up	+3 and up	+3 and up	+4 and up

^a Weld thickness shall be defined as the nominal thickness of the thinner of the two parts being joined, given in mm [in.].

Table 2a.

FHWA Recommendations for 1% < Velocity Ratio ≤ 2.5% for Tensile Stress
(modifications shown with ~~strikethrough~~ and **bold** text)

Table 8.4
UT Acceptance-Rejection Criteria – Tensile Stress (see 8.26.3.1)

Flaw Severity Class	Weld Thickness ^a (mm [in.]) and Search Unit Angle										
	8 [⁵ / ₁₆] through 20 [³ / ₄]	>20 [³ / ₄] through 38 [1½]	>38 [1½] through 60 [2½]			>60 [2½] through 100 [4]			>100 [4] through 200 [8]		
	70° 60°	70° 60°	70°	60°	45°	70°	60°	45°	70°	60°	45°
Class A	+13 and lower	+11 and lower	+4 and lower	+7 and lower	+9 and lower	+1 and lower	+4 and lower	+6 and lower	-2 and lower	+1 and lower	+3 and lower
Class B	+14	+12	+5 +6	+8 +9	+10 +11	+2 +3	+5 +6	+7 +8	-1 0	+2 +3	+4 +5
Class C	+15	+13	+7 +8	+10 +11	+12 +13	+4 +5	+7 +8	+9 +10	+1 +2	+4 +5	+6 +7
Class D	+16 and up	+14 and up	+9 and up	+12 and up	+14 and up	+6 and up	+9 and up	+11 and up	+3 and up	+6 and up	+8 and up

^a Weld thickness shall be defined as the nominal thickness of the thinner of the two parts being joined, given in mm [in.].

Table 2b.

FHWA Recommendations for 1% < Velocity Ratio ≤ 2.5% for Compressive Stress
(modifications shown with ~~strikethrough~~ and **bold** text)

Table 8.5
UT Acceptance-Rejection Criteria – Compressive Stress (see 8.26.3.1)

Flaw Severity Class	Weld Thickness ^a (mm [in.]) and Search Unit Angle										
	8 [⁵ / ₁₆] through 20 [³ / ₄]	>20 [³ / ₄] through 38 [1½]	>38 [1½] through 60 [2½]			>60 [2½] through 100 [4]			>100 [4] through 200 [8]		
	70° 60°	70° 60°	70°	60°	45°	70°	60°	45°	70°	60°	45°
Class A	+8 and lower	+5 and lower	-2 and lower	+1 and lower	+3 and lower	-5 and lower	-2 and lower	0 and lower	-7 and lower	-4 and lower	-1 and lower
Class B	+9	+6	-1 0	+2 +3	+4 +5	-4 -3	-1 0	+1 +2	-6 -5	-3 -2	0 +1
Class C	+10	+7	+1 +2	+4 +5	+6 +7	-2 to +2	+1 +2	+3 +4	-4 to +2	-1 to +2	+2 +3
Class D	+11 and up	+8 and up	+3 and up	+6 and up	+8 and up	+3 and up	+3 and up	+5 and up	+3 and up	+3 and up	+4 and up

^a Weld thickness shall be defined as the nominal thickness of the thinner of the two parts being joined, given in mm [in.].

Table 3a.

AWS Table 8.4 for Case 3: $1\% < AR \leq 1.75\%$, Velocity Ratio $\leq 1\%$ **PROPOSED INTERIM WORKING SOLUTION**(modifications shown with **bold** text)Table 8.4
UT Acceptance-Rejection Criteria – Tensile Stress (see 8.26.3.1)

Flaw Severity Class	Weld Thickness ^a (mm [in.]) and Search Unit Angle										
	8 [$\frac{5}{16}$] through 20 [$\frac{3}{4}$]	>20 [$\frac{3}{4}$] through 38 [$1\frac{1}{2}$]	>38 [$1\frac{1}{2}$] through 60 [$2\frac{1}{2}$]			>60 [$2\frac{1}{2}$] through 100 [4]			>100 [4] through 200 [8]		
	70°	70°	70°	60°	45°	70°	60°	45°	70°	60°	45°
Class A	+14 and lower	+12 and lower	+8 and lower	+11 and lower	+9 and lower	+5 and lower	+8 and lower	+6 and lower	+2 and lower	+5 and lower	+3 and lower
Class B	+15	+13	+9 +10	+12 +13	+10 +11	+6 +7	+9 +10	+7 +8	+3 +4	+6 +7	+4 +5
Class C	+16	+14	+11 +12	+14 +15	+12 +13	+8 +9	+11 +12	+9 +10	+5 +6	+8 +9	+6 +7
Class D	+17 and up	+15 and up	+13 and up	+16 and up	+14 and up	+10 and up	+13 and up	+11 and up	+7 and up	+10 and up	+8 and up

^a Weld thickness shall be defined as the nominal thickness of the thinner of the two parts being joined, given in mm [in.].

Table 3b.

AWS Table 8.5 for Case 3: $1\% < AR \leq 1.75\%$, Velocity Ratio $\leq 1\%$ **PROPOSED INTERIM WORKING SOLUTION**(modifications shown with **bold** text)Table 8.5
UT Acceptance-Rejection Criteria – Compressive Stress (see 8.26.3.1)

Flaw Severity Class	Weld Thickness ^a (mm [in.]) and Search Unit Angle										
	8 [$\frac{5}{16}$] through 20 [$\frac{3}{4}$]	>20 [$\frac{3}{4}$] through 38 [$1\frac{1}{2}$]	>38 [$1\frac{1}{2}$] through 60 [$2\frac{1}{2}$]			>60 [$2\frac{1}{2}$] through 100 [4]			>100 [4] through 200 [8]		
	70°	70°	70°	60°	45°	70°	60°	45°	70°	60°	45°
Class A	+9 and lower	+6 and lower	+2 and lower	+5 and lower	+3 and lower	-1 and lower	+2 and lower	0 and lower	-3 and lower	0 and lower	-1 and lower
Class B	+10	+7	+3 +4	+6 +7	+4 +5	0 +1	+3 +4	+1 +2	-2 -1	+1 +2	0 +1
Class C	+11	+8	+5 +6	+8 +9	+6 +7	+2 to +6	+5 +6	+3 +4	0 to +6	+3 to +6	+2 +3
Class D	+12 and up	+9 and up	+7 and up	+10 and up	+8 and up	+7 and up	+7 and up	+5 and up	+7 and up	+7 and up	+4 and up

^a Weld thickness shall be defined as the nominal thickness of the thinner of the two parts being joined, given in mm [in.].

Table 4a.

AWS Table 8.4 for Case 4: 1% < AR ≤ 1.75%, 1% < Velocity Ratio ≤ 2.5%

PROPOSED INTERIM WORKING SOLUTION

(modifications shown with ~~strikethrough~~ and **bold** text)

Table 8.4
UT Acceptance-Rejection Criteria – Tensile Stress (see 8.26.3.1)

Flaw Severity Class	Weld Thickness ^a (mm [in.]) and Search Unit Angle										
	8 [⁵ / ₁₆] through 20 [³ / ₄]	>20 [³ / ₄] through 38 [1½]	>38 [1½] through 60 [2½]			>60 [2½] through 100 [4]			>100 [4] through 200 [8]		
	70° 60°	70° 60°	70°	60°	45°	70°	60°	45°	70°	60°	45°
Class A	+17 and lower	+15 and lower	+8 and lower	+11 and lower	+9 and lower	+5 and lower	+8 and lower	+6 and lower	+2 and lower	+5 and lower	+3 and lower
Class B	+18	+16	+9 +10	+12 +13	+10 +11	+6 +7	+9 +10	+7 +8	+3 +4	+6 +7	+4 +5
Class C	+19	+17	+11 +12	+14 +15	+12 +13	+8 +9	+11 +12	+9 +10	+5 +6	+8 +9	+6 +7
Class D	+20 and up	+18 and up	+13 and up	+16 and up	+14 and up	+10 and up	+13 and up	+11 and up	+7 and up	+10 and up	+8 and up

^a Weld thickness shall be defined as the nominal thickness of the thinner of the two parts being joined, given in mm [in.].

Table 4b.

AWS Table 8.5 for Case 4: 1% < AR ≤ 1.75%, 1% < Velocity Ratio ≤ 2.5%

PROPOSED INTERIM WORKING SOLUTION

(modifications shown with ~~strikethrough~~ and **bold** text)

Table 8.5
UT Acceptance-Rejection Criteria – Compressive Stress (see 8.26.3.1)

Flaw Severity Class	Weld Thickness ^a (mm [in.]) and Search Unit Angle										
	8 [⁵ / ₁₆] through 20 [³ / ₄]	>20 [³ / ₄] through 38 [1½]	>38 [1½] through 60 [2½]			>60 [2½] through 100 [4]			>100 [4] through 200 [8]		
	70° 60°	70° 60°	70°	60°	45°	70°	60°	45°	70°	60°	45°
Class A	+12 and lower	+9 and lower	+2 and lower	+5 and lower	+3 and lower	-1 and lower	+2 and lower	0 and lower	-3 and lower	0 and lower	-1 and lower
Class B	+13	+10	+3 +4	+6 +7	+4 +5	0 +1	+3 +4	+1 +2	-2 -1	+1 +2	0 +1
Class C	+14	+11	+5 +6	+8 +9	+6 +7	+2 to +6	+5 +6	+3 +4	0 to +6	+3 to +6	+2 +3
Class D	+15 and up	+12 and up	+7 and up	+10 and up	+8 and up	+7 and up	+7 and up	+5 and up	+7 and up	+7 and up	+4 and up

^a Weld thickness shall be defined as the nominal thickness of the thinner of the two parts being joined, given in mm [in.].

Table 5a.

AWS Table 8.4 for Case 5: $1.75\% < AR \leq 5\%$, Velocity Ratio $\leq 2.5\%$ **PROPOSED INTERIM WORKING SOLUTION**(modifications shown with ~~strikethrough~~ and **bold** text)Table 8.4
UT Acceptance-Rejection Criteria – Tensile Stress (see 8.26.3.1)

Flaw Severity Class	Weld Thickness ^a (mm [in.]) and Search Unit Angle										
	8 [$\frac{5}{16}$] through 20 [$\frac{3}{4}$]	>20 [$\frac{3}{4}$] through 38 [$1\frac{1}{2}$]	>38 [$1\frac{1}{2}$] through 60 [$2\frac{1}{2}$]			>60 [$2\frac{1}{2}$] through 100 [4]			>100 [4] through 200 [8]		
	70° 45°	70° 45°	70°	60°	45°	70°	60°	45°	70°	60°	45°
Class A	+17 and lower	+15 and lower	+8 and lower	+11 and lower	+11 and lower	+5 and lower	+8 and lower	+8 and lower	+2 and lower	+5 and lower	+5 and lower
Class B	+18	+16	+9 +10	+12 +13	+12 +13	+6 +7	+9 +10	+9 +10	+3 +4	+6 +7	+6 +7
Class C	+19	+17	+11 +12	+14 +15	+14 +15	+8 +9	+11 +12	+11 +12	+5 +6	+8 +9	+8 +9
Class D	+20 and up	+18 and up	+13 and up	+16 and up	+16 and up	+10 and up	+13 and up	+13 and up	+7 and up	+10 and up	+10 and up

^a Weld thickness shall be defined as the nominal thickness of the thinner of the two parts being joined, given in mm [in.].

Table 5b.

AWS Table 8.5 for Case 5: $1.75\% < AR \leq 5\%$, Velocity Ratio $\leq 2.5\%$ **PROPOSED INTERIM WORKING SOLUTION**(modifications shown with ~~strikethrough~~ and **bold** text)Table 8.5
UT Acceptance-Rejection Criteria – Compressive Stress (see 8.26.3.1)

Flaw Severity Class	Weld Thickness ^a (mm [in.]) and Search Unit Angle										
	8 [$\frac{5}{16}$] through 20 [$\frac{3}{4}$]	>20 [$\frac{3}{4}$] through 38 [$1\frac{1}{2}$]	>38 [$1\frac{1}{2}$] through 60 [$2\frac{1}{2}$]			>60 [$2\frac{1}{2}$] through 100 [4]			>100 [4] through 200 [8]		
	70° 45°	70° 45°	70°	60°	45°	70°	60°	45°	70°	60°	45°
Class A	+12 and lower	+9 and lower	+2 and lower	+5 and lower	+5 and lower	-1 and lower	+2 and lower	+2 and lower	-3 and lower	0 and lower	+1 and lower
Class B	+13	+10	+3 +4	+6 +7	+6 +7	0 +1	+3 +4	+3 +4	-2 -1	+1 +2	+2 +3
Class C	+14	+11	+5 +6	+8 +9	+8 +9	+2 to +6	+5 +6	+5 +6	0 to +6	+3 to +6	+4 +5
Class D	+15 and up	+12 and up	+7 and up	+10 and up	+10 and up	+7 and up	+7 and up	+7 and up	+7 and up	+7 and up	+6 and up

^a Weld thickness shall be defined as the nominal thickness of the thinner of the two parts being joined, given in mm [in.].



Smarter. Stronger. Steel.

National Steel Bridge Alliance
312.670.2400 | www.aisc.org