U.S. Department of Transportation
Federal Highway Administration

FHWA Memorandum

Recommendations to Account for Acoustic Dissimilarities in Steel Ultrasonic Weld Inspection

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Acronyms and Notation

AASHTO: American Association of State Highway and Transportation Officials

AWS: American Welding Society

CJP: complete joint penetration

dB: decibel units

FHWA: Federal Highway Administration

IIW: International Institute of Welding

NCHRP: National Cooperative Highway Research Program

NISWT: normal incidence shear wave transducer

TA: technical advisory

UT: ultrasonic testing

v_a = velocity in wedge

v_b = velocity in test object or reference standard

v_1 = acoustic shear wave velocity in direction of sound propagation of reference standard

v_2 = acoustic shear wave velocity in direction of sound propagation of test object

$v_{transverse}$ = acoustic shear wave velocity transverse to direction of sound propagation in test object

ϕ_1 = Angle of transducer relative to vertical

ϕ_2 = Angle of wave relative to vertical

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References

1. AASHTO/AWS. (2015). “*Bridge Welding Code*,” AASHTO/AWS D1.5M/D1.5:2015-AMD1, American Association of State Highway and Transportation Officials and American Welding Society, Washington, DC.
2. Connor, R. J., Schroeder, C. J., Crowley, B. M. Washer, G. A and Fish, P. E.. (2019) “*Acceptance Criteria of Complete Joint Penetration Steel Bridge Welds Evaluated Using Enhanced Ultrasonic Methods*.” National Cooperative Research Program (NCHRP) Report 908. Transportation Research Board. Washington D. C.
3. Washer, Agbede, Yadav, Connor, and Turnbull (2024). “Acoustic Wave Velocities in Bridge Steels and the Effects on Ultrasonic Testing.” *Journal of Nondestructive Evaluation.* Vol. 43, no. 4. https://doi.org/10.1007/s10921-024-01109-1.

Today's Presenter

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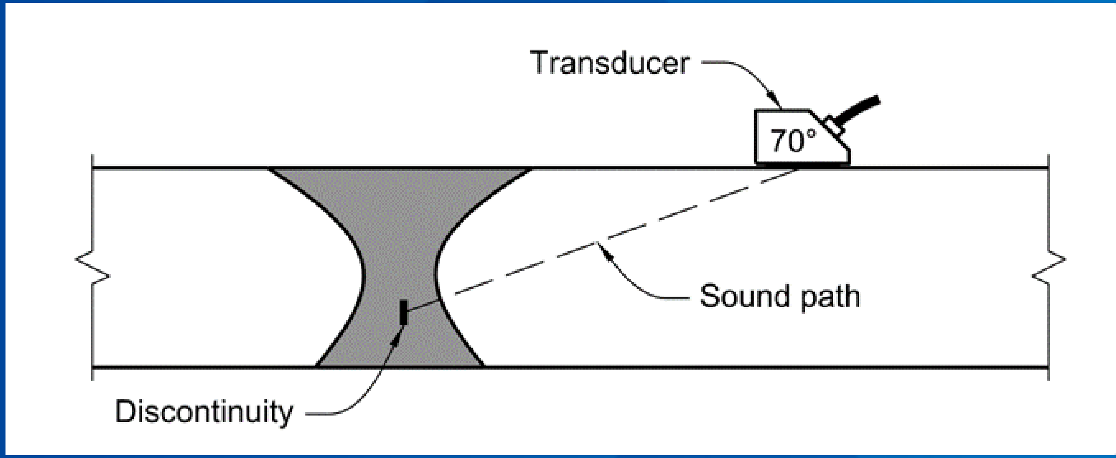
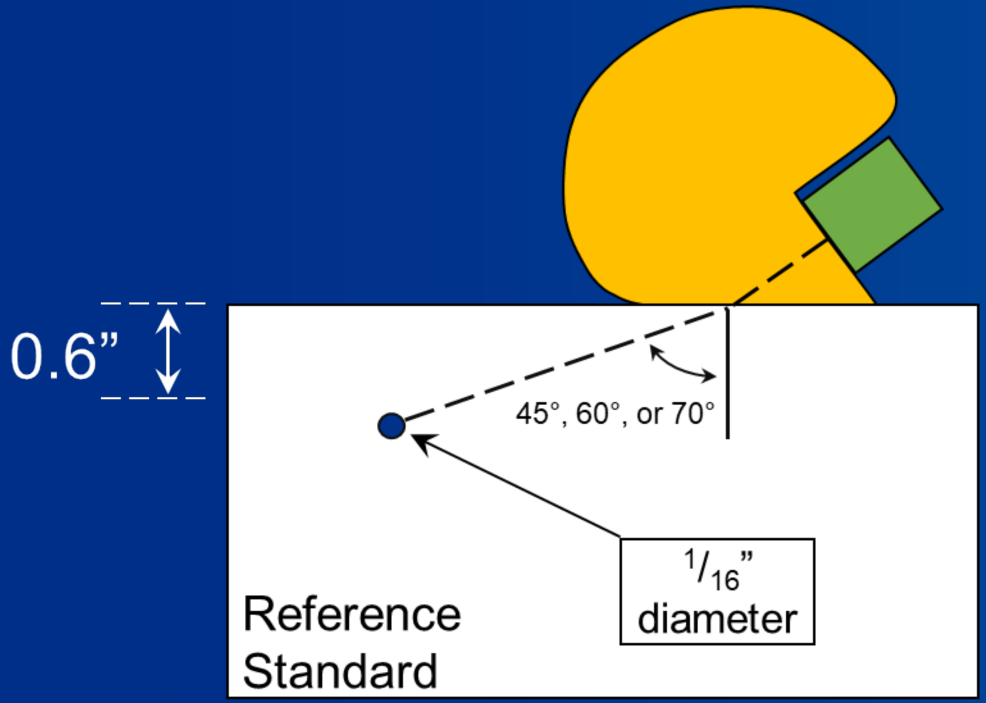
Ultrasonic Testing (UT)

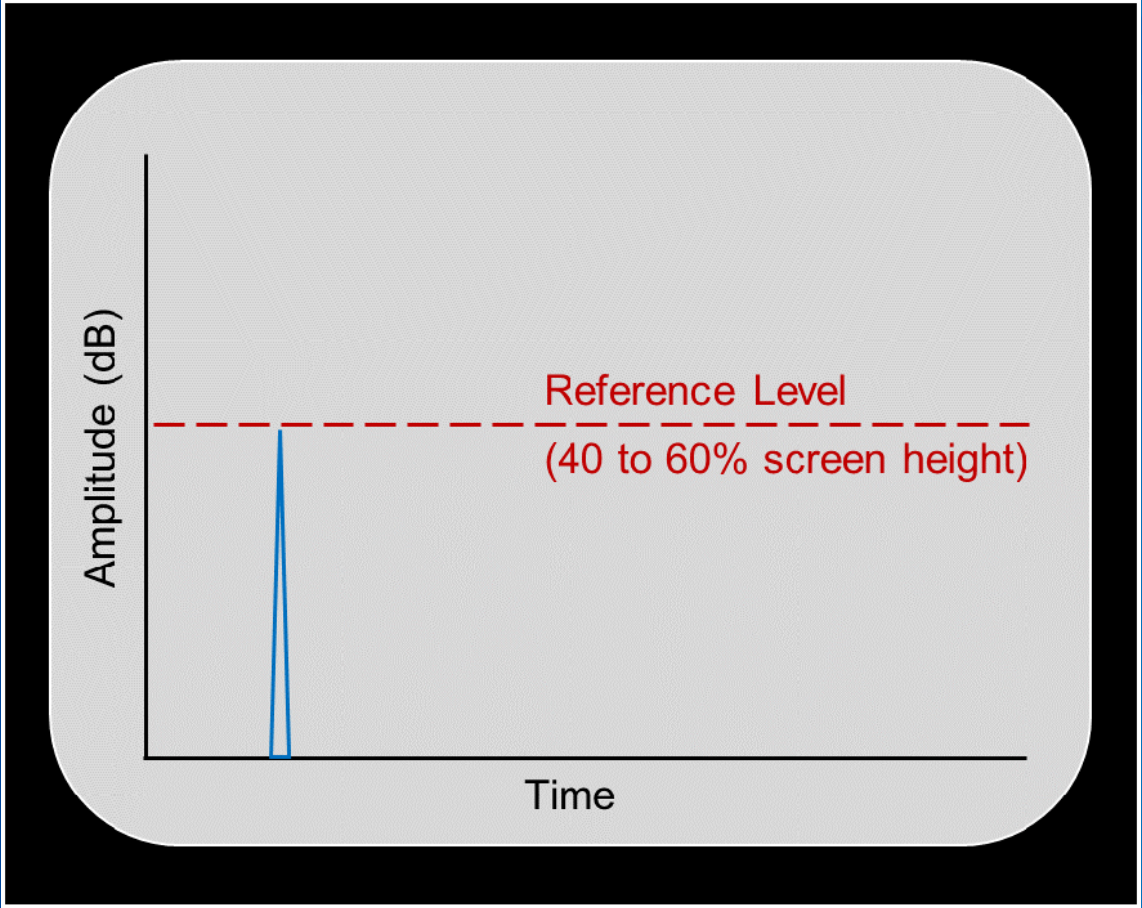
AASHTO/AWS D1.5M/D1.5[1] requires ultrasonic or radiographic testing, and sometimes both, of complete joint penetration welds.



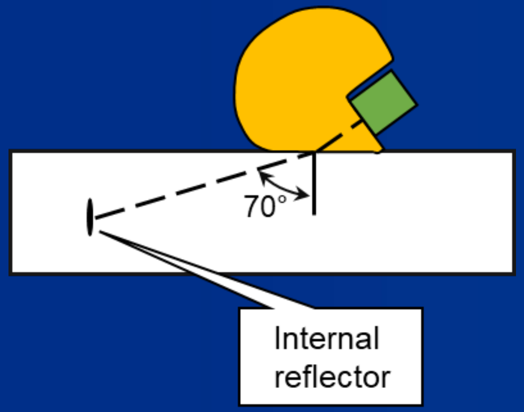
[1] AASHTO/AWS D1.5M/D1.5 is incorporated by reference at 23 CFR 625.4(d)(2)(iii)

Ultrasonic Testing Calibration

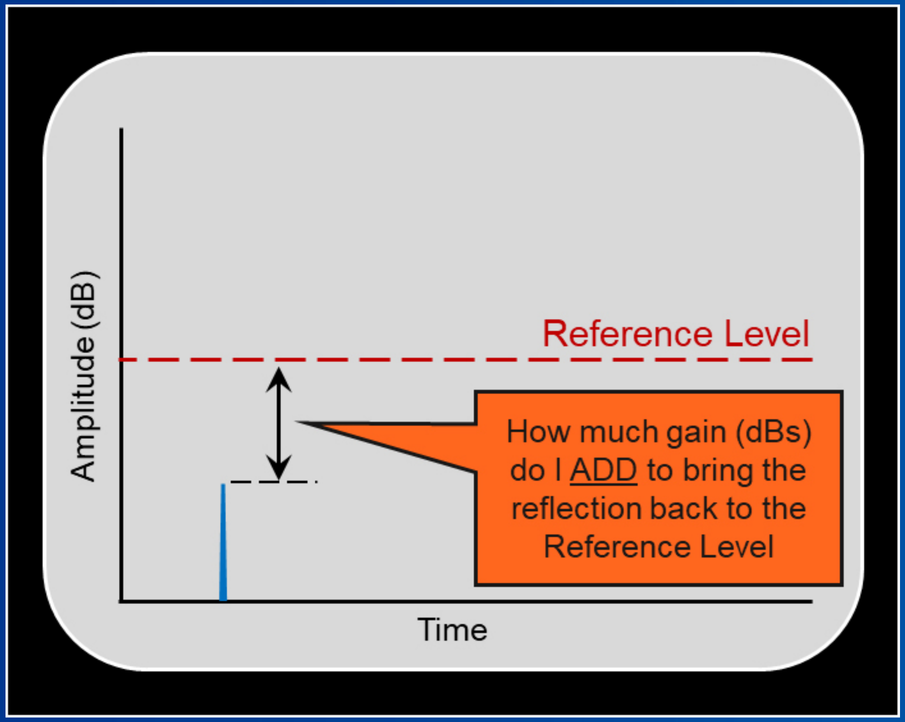




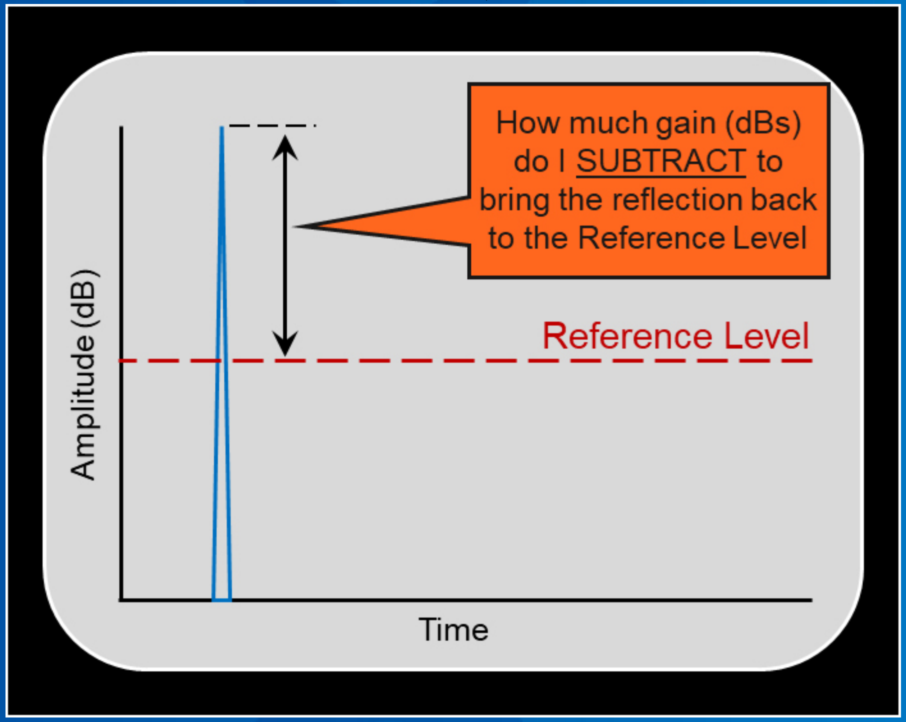
Ultrasonic Testing Acceptance Criteria



The reflector is less severe than $^{1}/_{16}$" side drilled hole (likely smaller)



The reflector is more severe than $^{1}/_{16}$" side drilled hole (larger or more crack-like)



This provides context for next slide regarding (+) and (-) dBs in acceptance criteria.

Ultrasonic Testing Acceptance Criteria

Severity Class	Weld Thickness (inch) and Search Angle							
	$^5/_{16} - {}^3/_4$	$>{}^3/_4 - 1^1/_2$	$>1^1/_2 - 2^1/_2$			$>2^1/_2 - 4$		
	70°	70°	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
Class B	+11	+9	+5 to +6	+8 to +9	+10 to +11	+2 to +3	+5 to +6	+7 to +8
Class C	+12	+10	+7 to +8	+10 to +11	+12 to +13	+4 to +5	+7 to +8	+9 to +10
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

Source: Adapted from AASHTO/AWS D1.5M/D1.5[1] Table 6.3

Class A → Rejected regardless of length

Class B → Rejected if length >¾ in.

Class C → See below

Class D → Accepted regardless of length

Class C rejected if:
- Length >2 in. in middle half, or
- >¾ in. in the top/bottom quarter of the weld thickness.

Note, at most, there is only 5 dB separation between automatic rejection and acceptance.

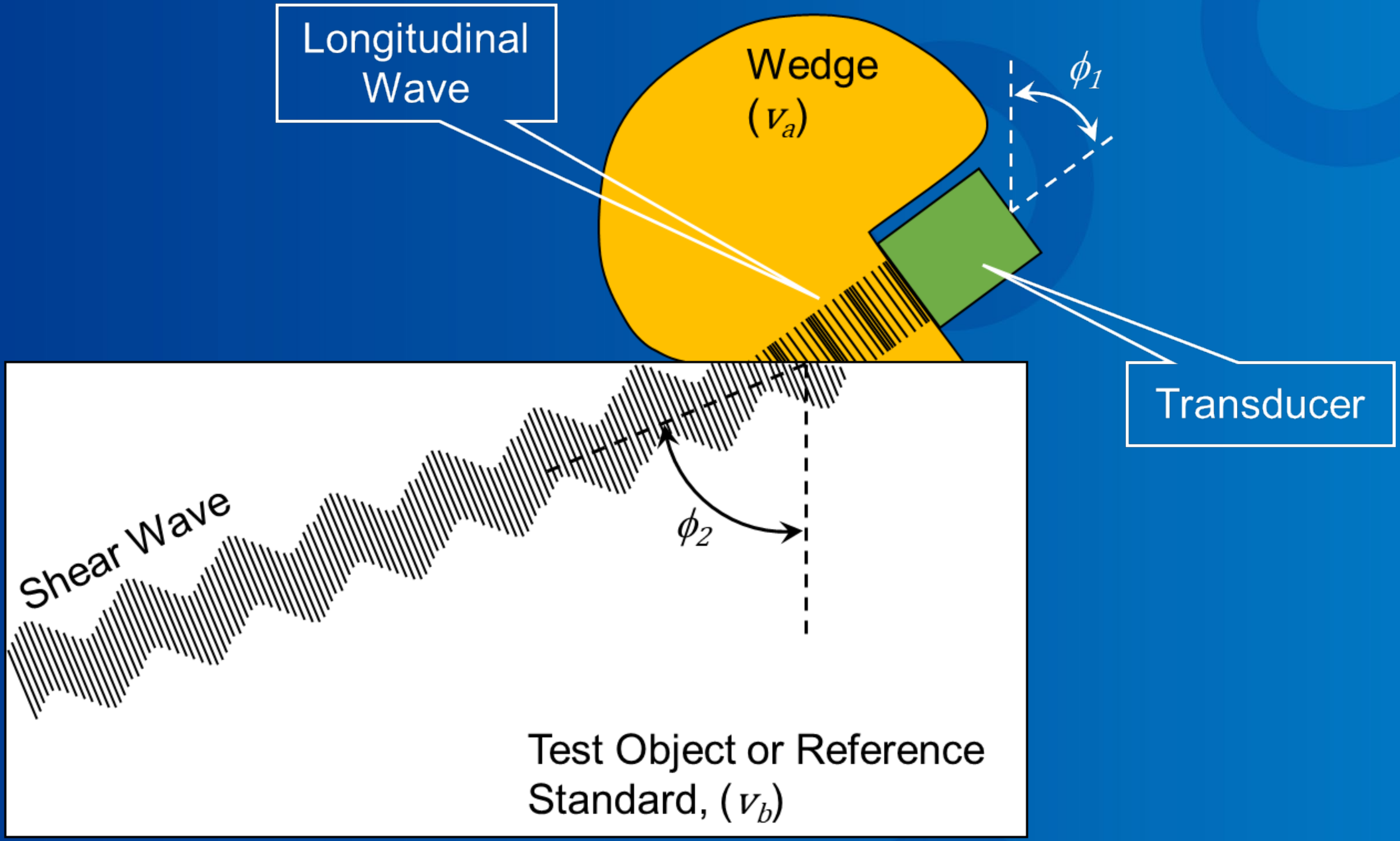
[1] AASHTO/AWS D1.5M/D1.5 is incorporated by reference at 23 CFR 625.4(d)(2)(iii)

Snell's Law

$$\frac{sin(\emptyset_1)}{v_a} = \frac{sin(\emptyset_2)}{v_b}$$

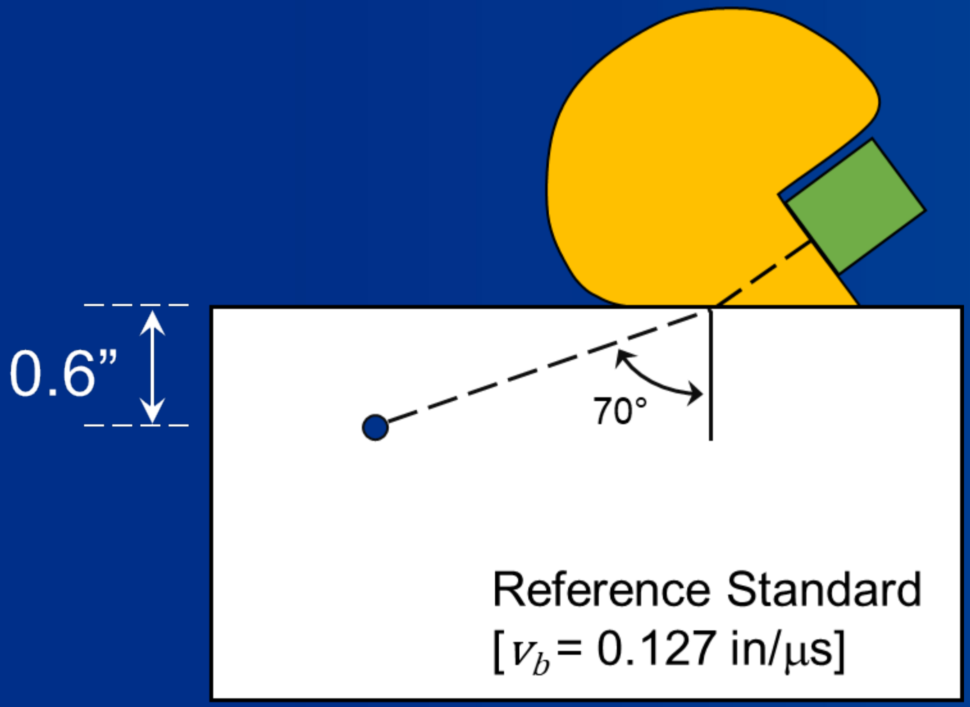
Wedge manufacturer:

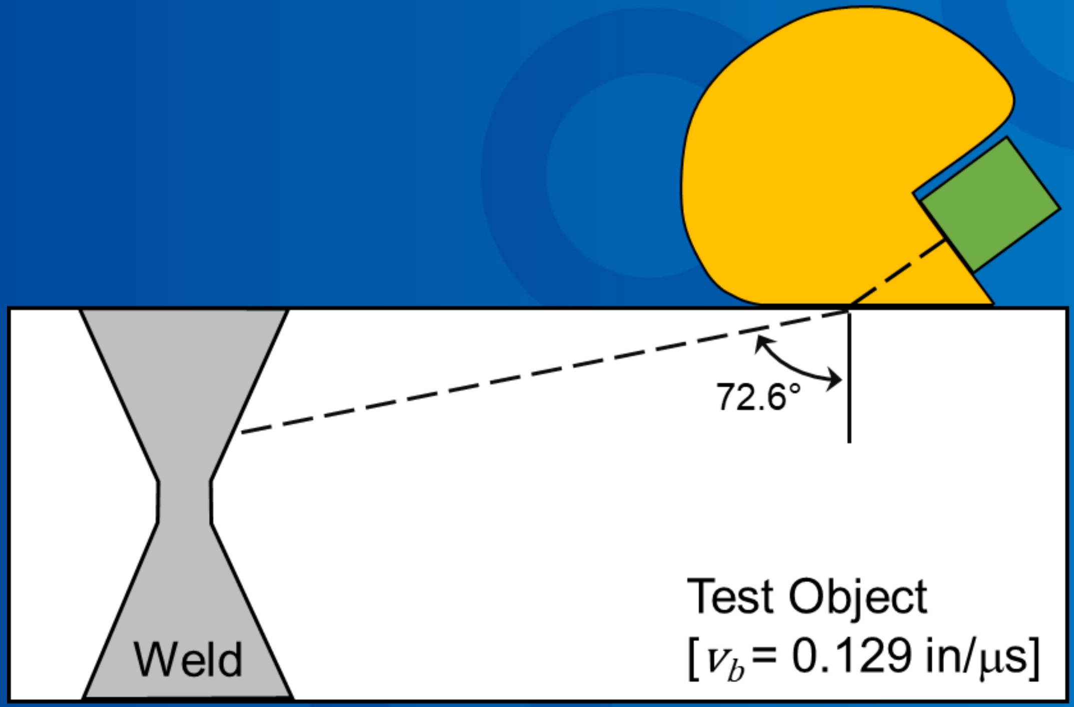
- Targets ϕ_2 from code,
- Knows v_a,
- Assumes v_b,
- Calculates ϕ_1 based on Snell's Law.



v_a = Velocity in wedge.
v_b = Velocity in test object or reference standard.
ϕ_1 = Angle of transducer relative to vertical.
ϕ_2 = Angle of wave relative to vertical.

Shear Wave Velocity in Calibration





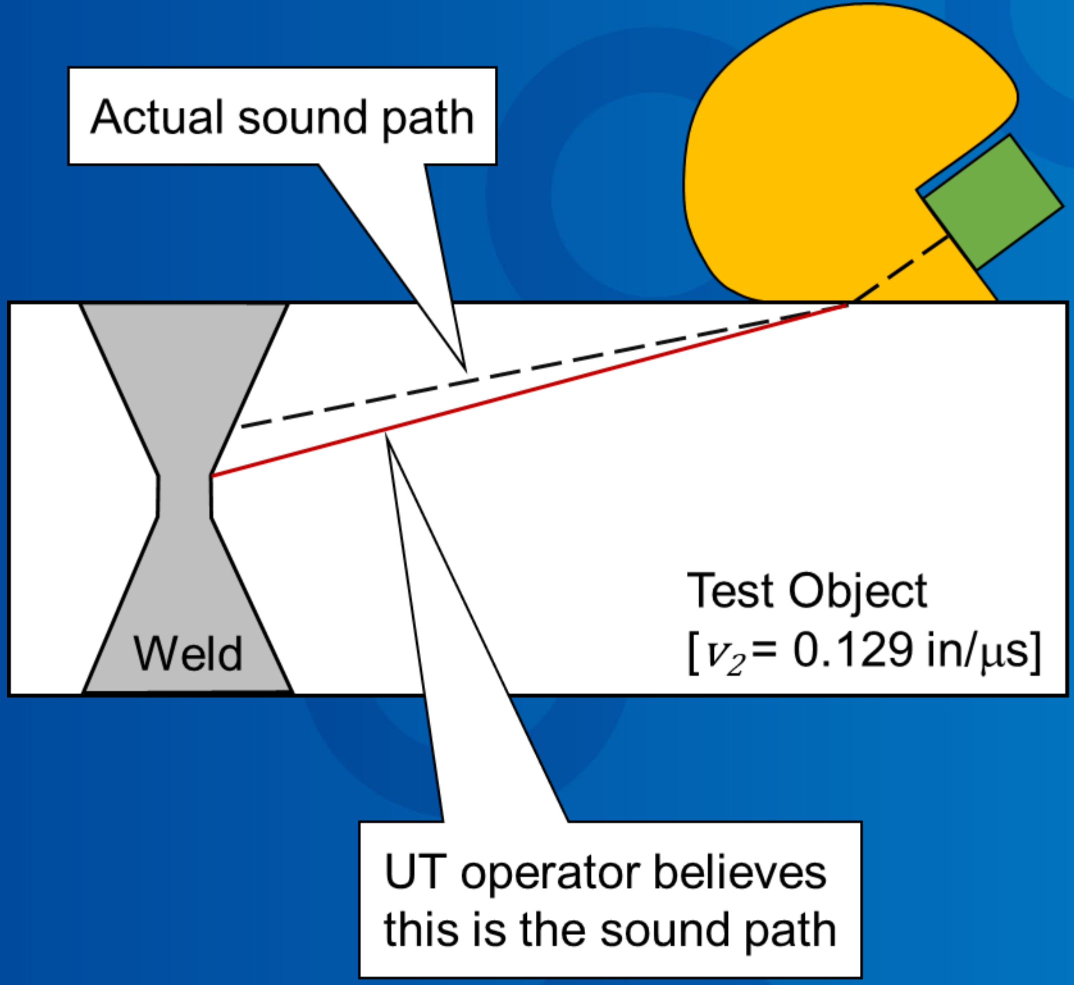
- Reference standards generally made from 1018 cold-rolled steel.
- Wedge manufacturer cuts angle generally assuming wave velocity of 0.127 in/μs.

- If test object has different shear wave velocity than reference standard, the angle in the test object is now different.

Shear Wave Velocity in Calibration

<u>Issue #1</u>[1]

- Inaccurate location of discontinuities, particularly in height direction.
- Could improperly characterize Class C defects as Class D.
- Not a huge problem considering the size of gouge removal.

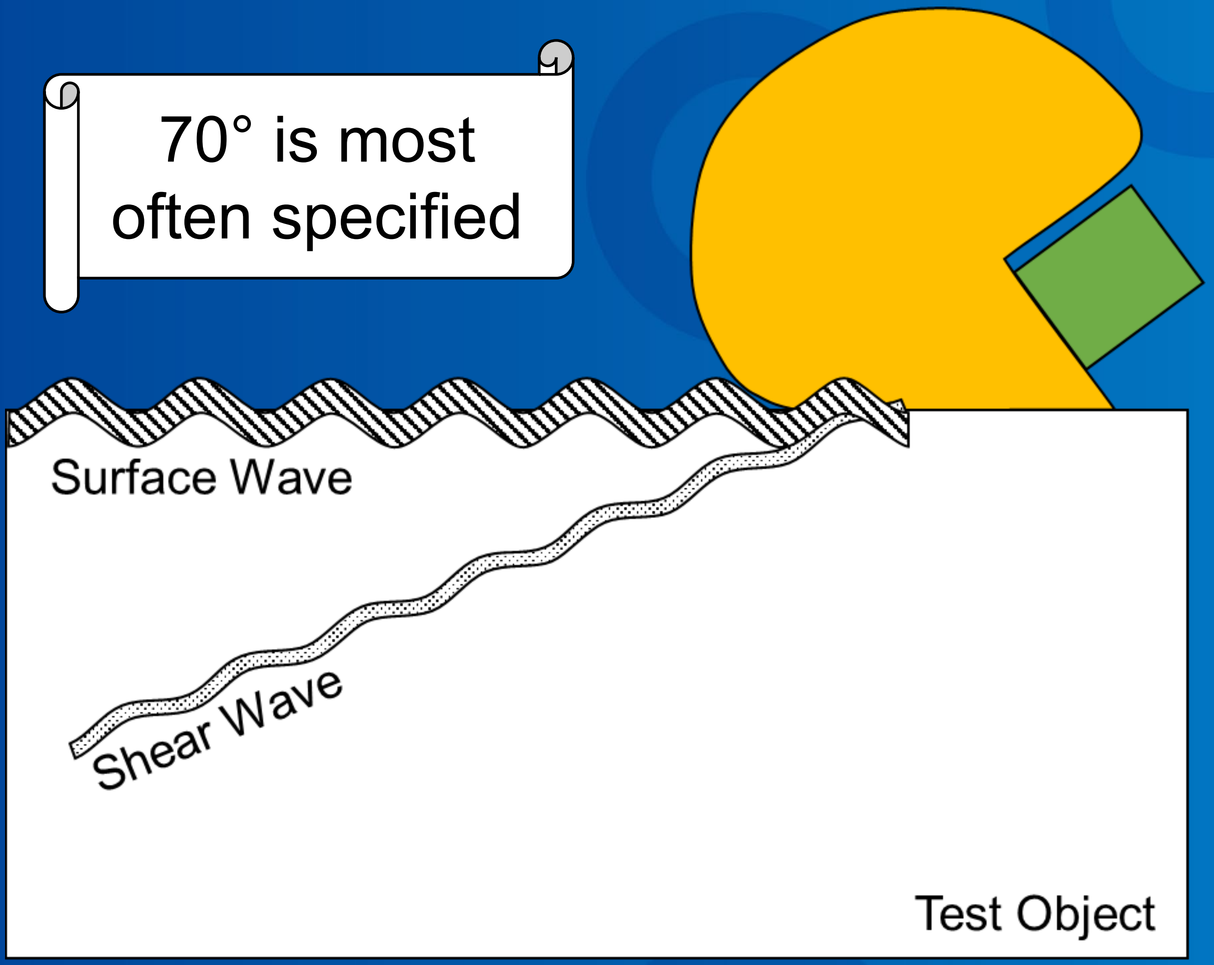


[1] NCHRP Report 908.

Shear Wave Velocity in Calibration

Issue #2[1]

- At high inspection angles, shear wave mode converges towards a surface wave.
    - 70° inspection angle most susceptible, particularly when test object has higher velocity than reference standard.
- If this happens, a volumetric inspection of the piece is NOT occurring.

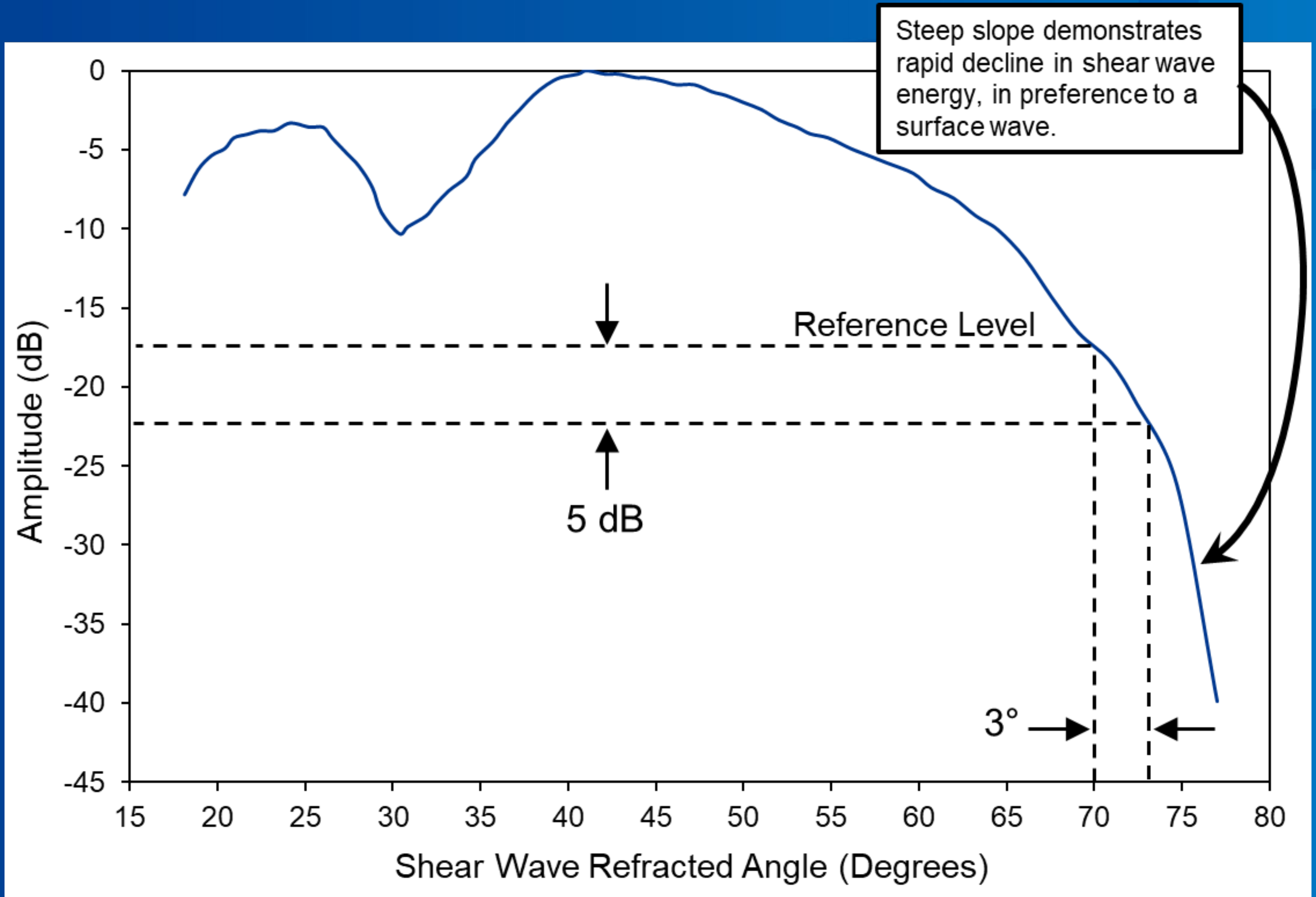


[1] NCHRP Report 908.

Shear Wave Velocity in Calibration

Issue #2 (continued)[1]

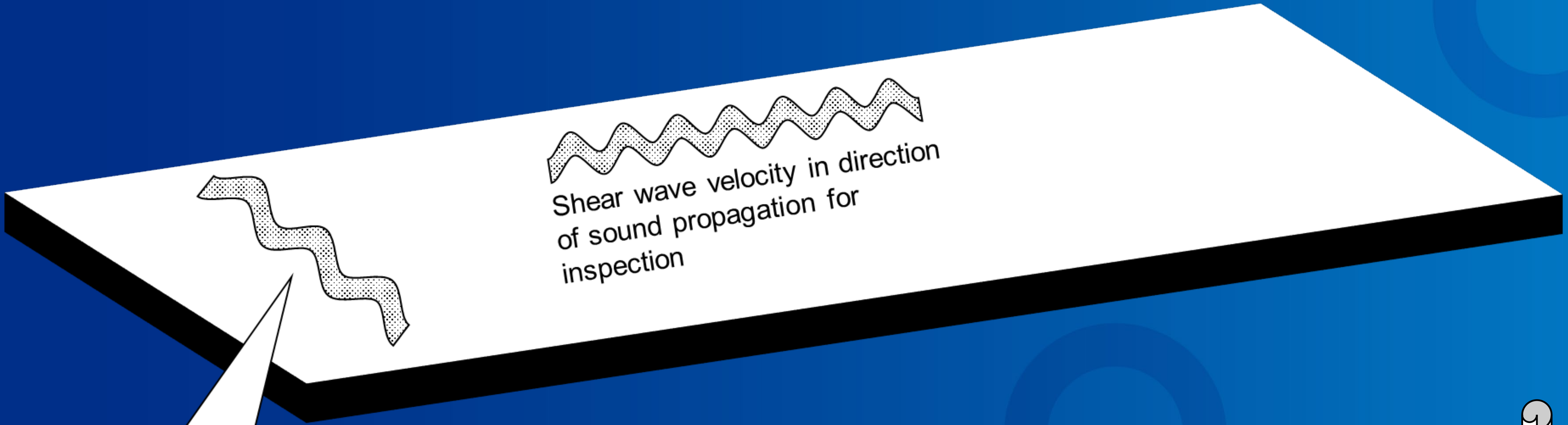
- Only a 3° change in angle results in 5 dB drop in reference signal.
  - Can make a Class A discontinuity appear like a Class D.



Source: Washer, Agbede, Yadav, Connor, and Turnbull (2024)

[1] NCHRP Report 908.

Shear Wave Velocity Differential in Test Object



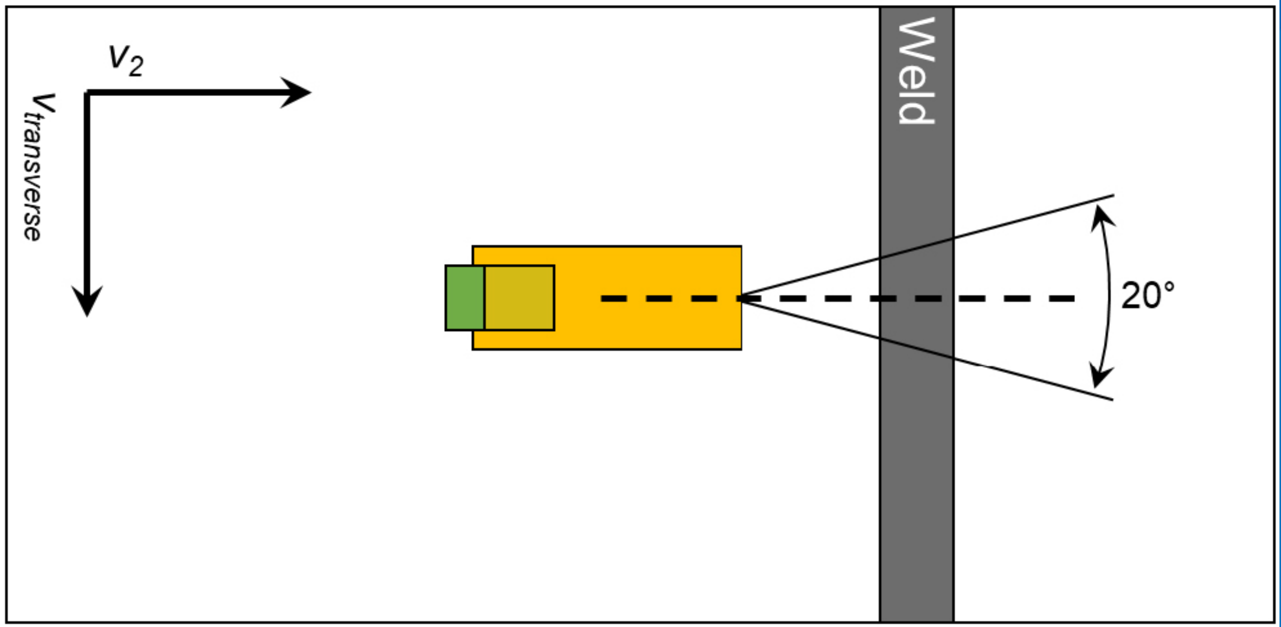
Shear wave velocity transverse to direction of sound propagation for inspection

Shear wave velocities differ in the two directions - this is called acoustic anisotropy

Shear Wave Velocity Differential in Test Object

<u>Issue #3[1]</u>

- Acoustic anisotropy causes the beam energy to split when probe is rotated.
    - Reduces the energy reflected off discontinuities and can lead to missing defects, or not properly classifying them.



AASHTO/AWS D1.5/D1.5M[2] requires probe rotation of ±10° during scanning.

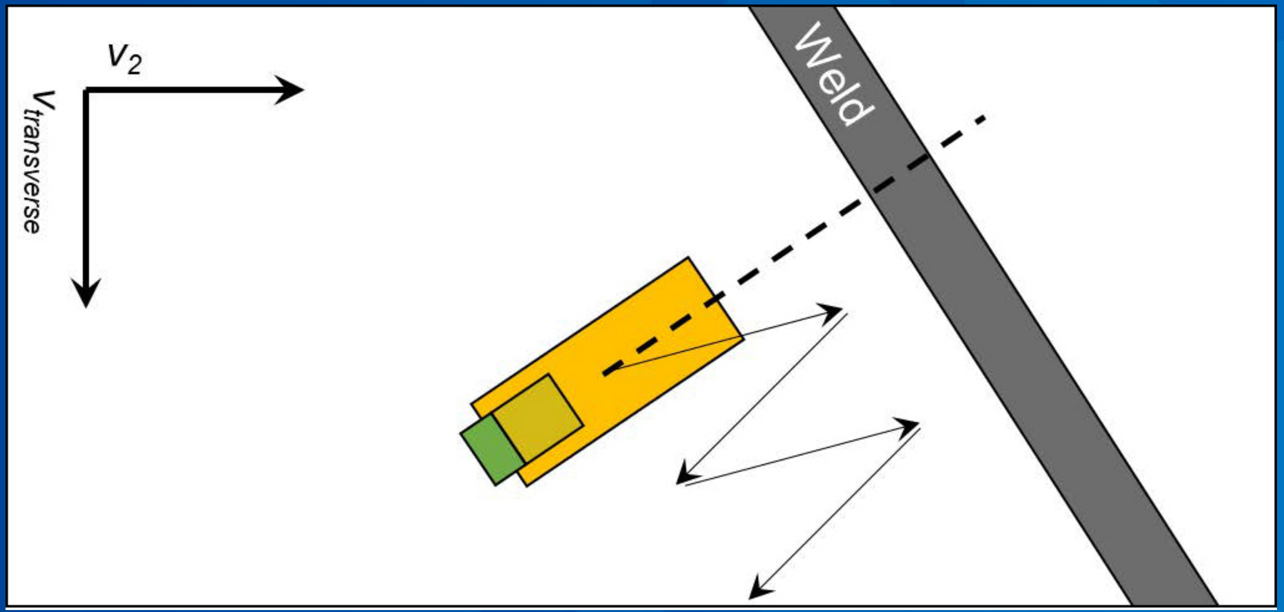
[1] NCHRP Report 908.
[2] AASHTO/AWS D1.5M/D1.5 is incorporated by reference at 23 CFR 625.4(d)(2)(iii).

v_2 = acoustic shear wave velocity in direction of sound propagation of test object
$v_{trtansverse}$ = acoustic shear wave velocity transverse to direction of sound propagation in test object

Shear Wave Velocity Differential in Test Object

<u>Issue #3 (continued)[1]</u>

- Same issue can arise during probe rastering if weld is off-axis to plate roll direction.
    - Weld not normally off-axis to one of rolling directions, but it further illustrates the effect of anisotropy.



AASHTO/AWS D1.5M/D1.5[2] requires probe movement towards and away from weld while rastering length of weld.

[1] NCHRP Report 908.
[2] AASHTO/AWS D1.5M/D1.5 is incorporated by reference at 23 CFR 625.4(d)(2)(iii).

v_2 = acoustic shear wave velocity in direction of sound propagation of test object
$v_{trtansverse}$ = acoustic shear wave velocity transverse to direction of sound propagation in test object

What is FHWA Memo Recommending?

- Bridge owners should develop supplementary contract provisions to work within the authority of the *Bridge Welding Code*[1] when performing ultrasonic inspections to ensure that proper calibrations are being performed, that procedures can properly account for acoustic dissimilarities between the reference standard and test object, and that acoustic anisotropy effects are properly considered in materials acceptance.
  - Memo provides recommended special provision language.
  - Owners will need to decide which steel bridge members to apply it to.

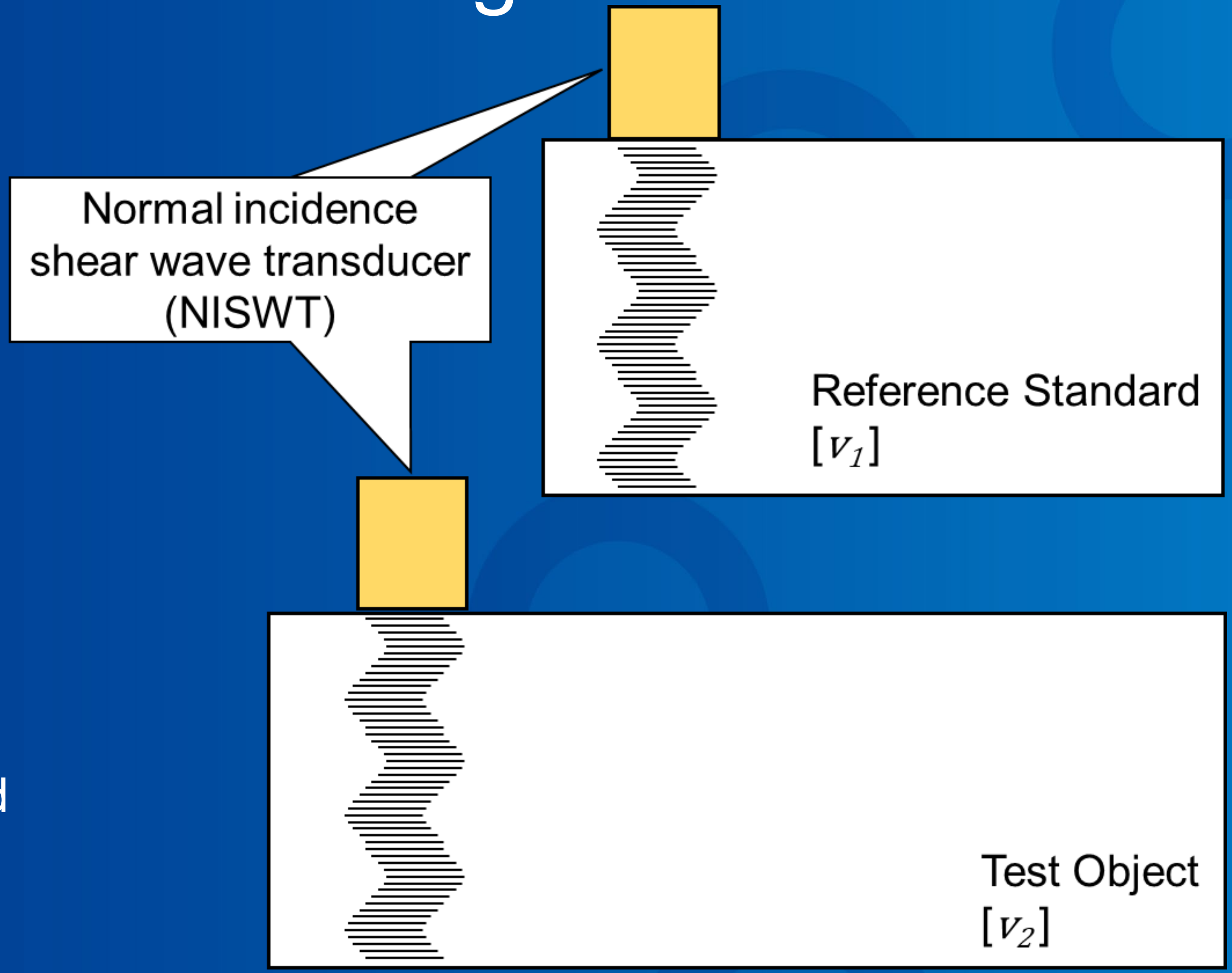
[1] AASHTO/AWS D1.5M/D1.5 is incorporated by reference at 23 CFR 625.4(d)(2)(iii)

What is FHWA Memo Recommending?

- Measure shear wave velocity in both reference standard and test object. Calculate shear wave velocity ratio as:

$$\left|\frac{v_2}{v_1} - 1\right| * 100\ (\%)$$

- If shear wave velocity ratio is:
  - ≤1.0%, no action.
  - >1% but ≤2.5%, restrict inspection angles to ≤60°.
  - >2.5%, a new calibration block, and likely a new wedge too.



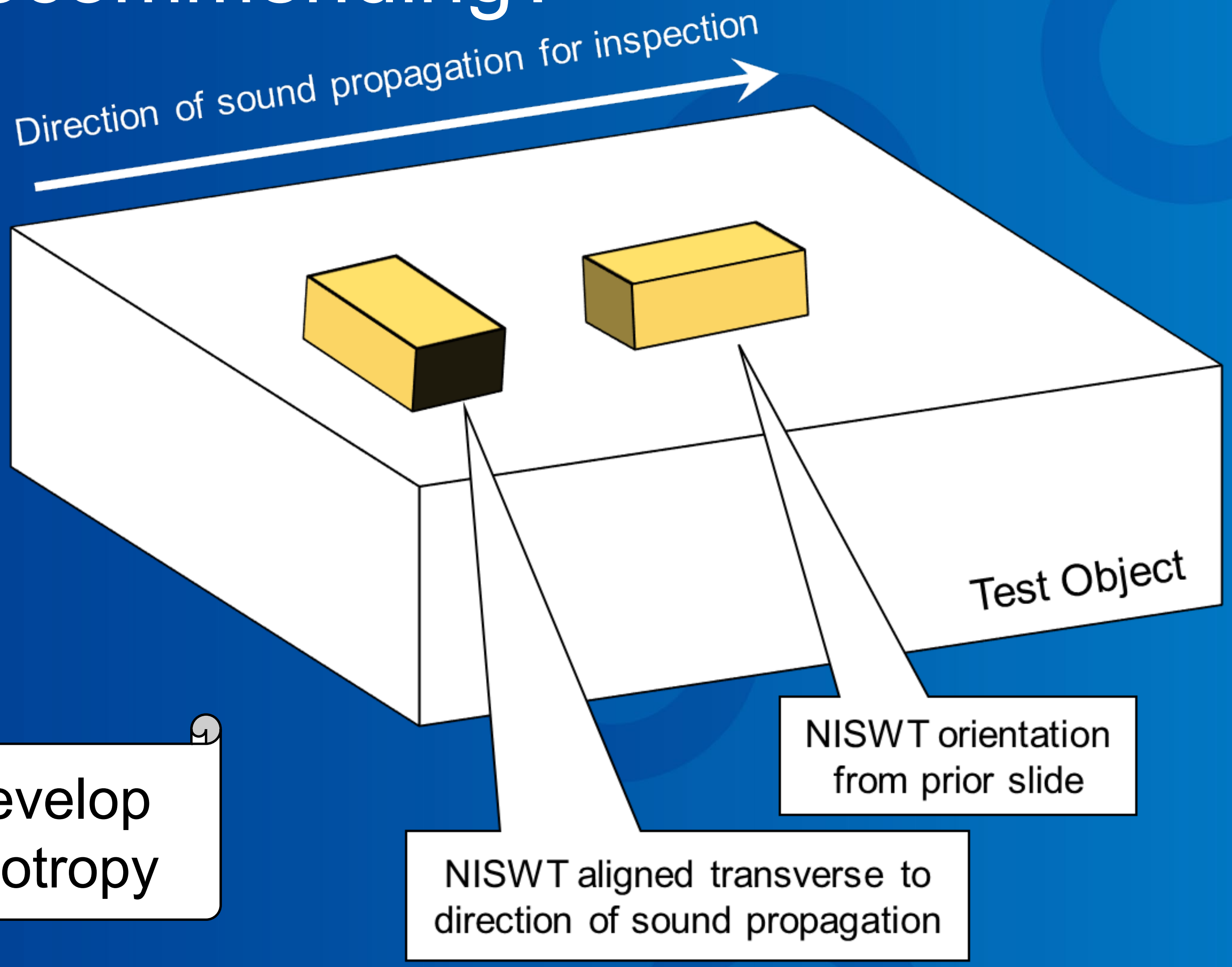
v_1 = acoustic shear wave velocity in direction of sound propagation of reference standard
v_2 = acoustic shear wave velocity in direction of sound propagation of test object

What is FHWA Memo Recommending?

- Measure shear wave velocity transverse to direction of sound propagation, $v_{transverse}$.
- Calculate anisotropic ratio as:

$$\left|\frac{V_2}{V_{transverse}} - 1\right| * 100\ (\%)$$

- Do not allow steel with anisotropic ratio >1.0% for CJP groove welds.



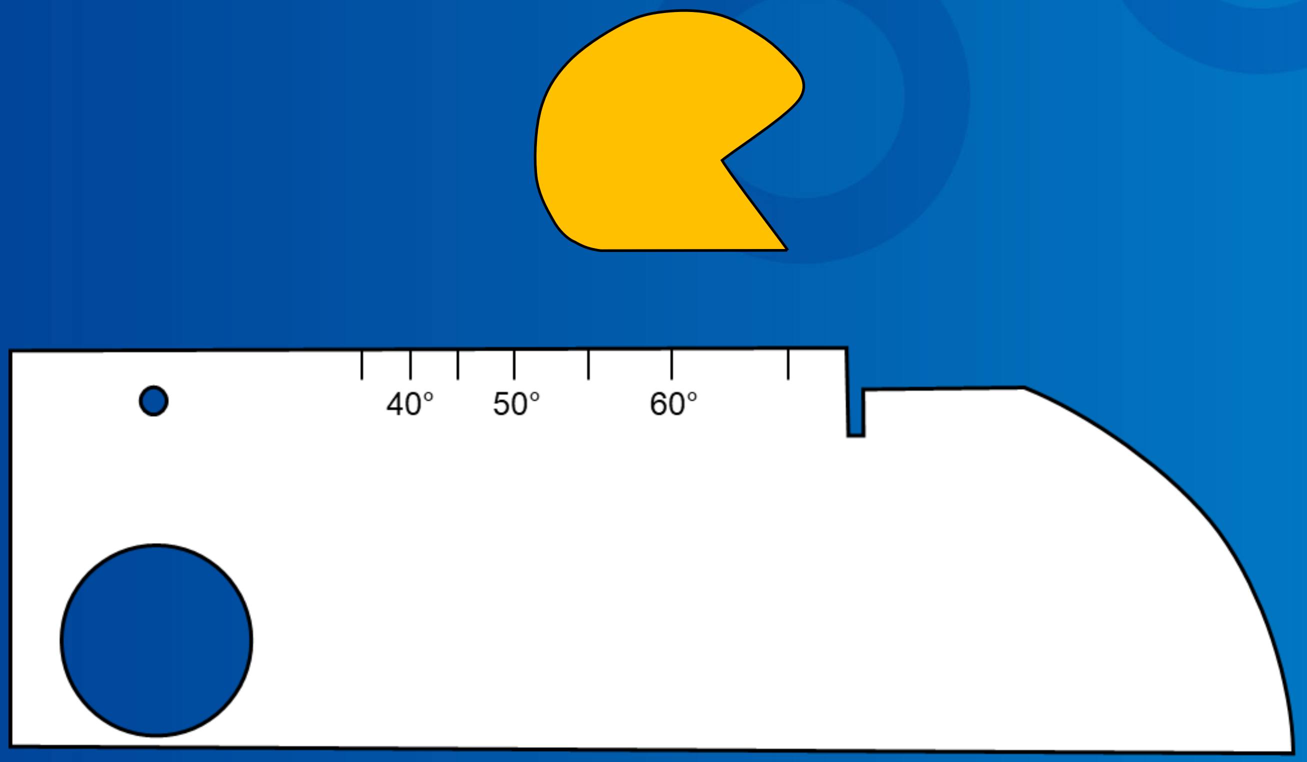
Further research needed to develop means to compensate for anisotropy

v_2 = acoustic shear wave velocity in direction of sound propagation of test object
$v_{trtansverse}$ = acoustic shear wave velocity transverse to direction of sound propagation in test object

Implementation Considerations

<u>IIW reference blocks are not sold with a defined shear wave velocity.</u>

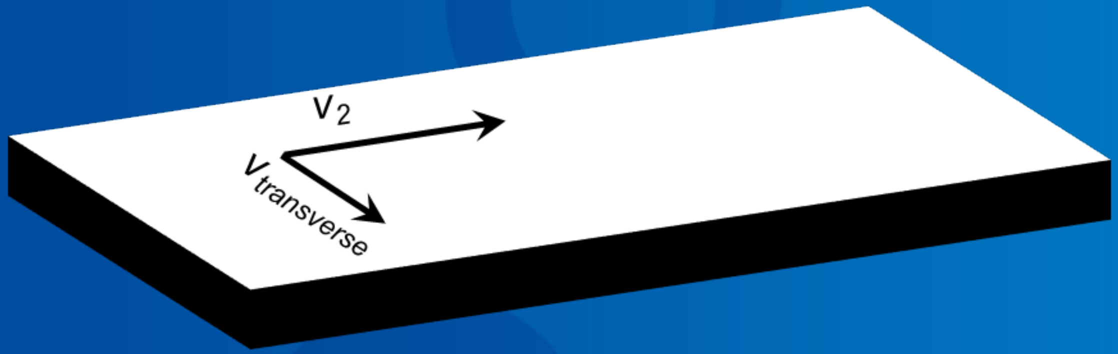
- Inspectors may have to make new reference block(s) as need arises from test object steel.
- New wedges may also be needed to match new reference block to meet 2° beam angle tolerance.
- With time, it is expected that fabricators will eventually acquire 3 to 4 block/wedge sets to cover the typical shear wave velocities.



Implementation Considerations

<u>What is the basis for screening out steel with anisotropic ratios >1.0%</u>

- 1% limit was a recommendation from NCHRP Report 908[1].
- No action is not acceptable, must ensure fabricated steel is properly inspected.
- Industry will have to find a solution to ensure proper inspection of anisotropic steel.
- Bridge owners will need to decide how far to extend the recommendation.



[1] NCHRP Report 908.

?? Questions ??

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