1 Introduction

In order to evaluate the stability of a component, the shape of a defect inside it is discriminating for the evaluation and acceptance criteria which shall be adopted. (see window n°2). Defect shape is usually classified in two types: volumetric, for which the ratio between height and width is next to unity, and planar, whose width is, indeed, very small with respect to the height. In the reality, defects can have shapes which can range from the pure volumetric to the pure planar type. Thus, is of great interest to verify if exist, in principle, a value, for the ratio between defect height / defect width, below which the defect shall be considered as volumetric, applying to it the relevant criteria for the stability evaluation, and above which, indeed, the defect must be always considered as planar and, consequently, applying to it the relevant evaluation criteria which are very different from those for the volumetric type.

In this paper, the results of an experimental work, based on the ratio of diffracted echo amplitudes obtained with the pulse echo and phased array technique, are reported. This results are very promising and open to a more reliable distinction between planar and volumetric defects. The diagram of figure 1 is a synthetic representation of such results.

![Figure 1](image)

**Figure 1** Synthetic diagram showing the behavior of planar and volumetric defects defined on the base of diffracted echo amplitudes as indicated in table I and II.
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Indications characterized as cracks, lack of fusion, or incomplete penetration are unacceptable regardless of length. Other imperfections are unacceptable if the indications exceed the reference level amplitude and have lengths which exceed:

(1) \( \frac{1}{4} \text{ in. (6 mm)} \) for \( t \) up to \( \frac{3}{4} \text{ in. (19 mm)} \)
(2) \( \frac{1}{3} t \) for \( t \) from \( \frac{3}{4} \text{ in. to 2 1/4 in. (19 mm to 57 mm)} \)
(3) \( \frac{3}{4} \text{ in. (19 mm)} \) for \( t \) over \( 2 1/4 \text{ in. (57 mm)} \).

Where \( t \) is the thickness of the weld excluding any allowable reinforcement.

For a butt weld joining two members having different thickness at the weld, \( t \) is the thinner of these two thicknesses. If a full penetration weld includes a fillet weld, the thickness of the throat of the fillet shall be included in \( t \).

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The indications shall be evaluated as longitudinal or transversal according to their biggest size orientation. When this distinction cannot be done precisely, the indication shall be classified as transversal if the echo height, obtained during examination of transversal indications, is greater of 2 dB or more with respect to the echo eight obtained during examination of longitudinal indications. The indication evaluation can includes the discrimination among different types of defects, if this is included in the examination procedure. In such case, the characterization as planar indication can be used as primary discrimination for the acceptability or unacceptability. In such case all the indications which show an echo height greater than the evaluation level shall be characterized and all those which are characterized as planar must be considered not acceptable.

Window 2 Acceptance criteria of ASME and UNI EN code relevant to planar or volumetric defects.
2 Discrimination criteria between volumetric and planar defect based on diffracted echoes evaluation

The diffraction is a typical phenomena of planar defects, which, when an ultrasonic wave front is incident with a direction sufficiently inclined with respect to the normal to their surface, generate two cylindrical wave, and thus two echoes, in correspondence with their upper and lower tip. Also for the volumetric defects, such as a cylindrical hole, two echoes can be observed: the first is generated by geometrical reflection of the wave front incident on the defect; the second is generated by a complex series of steps involving wave mode conversion on the defect surface as depicted inside window 3; this second echo is still considered as diffracted echo even if its generation behavior is completely different.

A first consideration can be made: it is obvious that the ratio between the first and second echo is substantially different in the case of planar defect (smaller) with respect to the case of volumetric defect (bigger).

Now, if we consider a series of defect with the ratio height / width ranging from 1 (pure volumetric) to infinity (pure planar), we can ask if exist a value of such ratio below which a generic defect can be always considered volumetric and, over which, planar. The propose criteria is, thus, to evaluate carefully the value of the ratio between the first and the second echo (see figure 5) and, consequently, to evaluate, on the basis of this value, if the defect is planar or volumetric. Such transition value shall be necessarily determined by experiment using a specific test block containing a suitable series of defects with different values of their height/width ratio.

3 The test block for the experimentation

In order to implement the experimental work, a suitable test block was designed and manufactured. In such test block a series of five defects was inserted by spark erosion, each with a different value for the ratio height / width. Figure 2 report the sketch of the test block with the date relevant to each inserted defect.

**Figure 3** Sketch of the test block used for the experimental work; all the defects are been manufactured by means of spark erosion
4 Experimental results with a view angle of 45°

Using phased array technique, a set of two ultrasonic images was taken for each defect, trying to maximize, along an observation angle of 45°, at a first time, the amplitude of first diffracted echo from the upper part of the defect and, at a second time, the amplitude of the second diffracted echo from the lower part of the defect. The images so obtained are reported in figures 8-17, while Table I summarize the data of echo amplitudes and their ratio against height/width ratio of the defect, whose trend is shown in figure 7.

<table>
<thead>
<tr>
<th>defect</th>
<th>height H1 (first echo)</th>
<th>height H2 (second echo)</th>
<th>ratio of defect height/width</th>
<th>ratio H1/H2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>17,6</td>
<td>33,20</td>
<td>1</td>
<td>6,34</td>
</tr>
<tr>
<td>2</td>
<td>16,94</td>
<td>35,19</td>
<td>2,67</td>
<td>8,18</td>
</tr>
<tr>
<td>3</td>
<td>22,16</td>
<td>37,96</td>
<td>4</td>
<td>6,17</td>
</tr>
<tr>
<td>4</td>
<td>26,62</td>
<td>37,54</td>
<td>8</td>
<td>3,51</td>
</tr>
<tr>
<td>5</td>
<td>25,72</td>
<td>35,75</td>
<td>13,33</td>
<td>3,17</td>
</tr>
</tbody>
</table>
Figure 7: Graph of the ratio $H_1/H_2$ against the ratio of defect height/width: view angle 45°.

Figure 8: difetto 1, ottimizzazione del primo eco; angolo di vista 45°

Figure 9: difetto 1 con ottimizzazione del secondo eco; angolo di vista 45°

Figure 10: difetto 2 con ottimizzazione del primo eco; angolo di vista 45°

Figure 11: difetto 2 con ottimizzazione del secondo eco; angolo di vista 45°
Figure 12: difetto 3 con ottimizzazione del primo eco; angolo di vista 45°

Figure 13: difetto 3 con ottimizzazione del secondo eco; angolo di vista 45°

Figure 14: difetto 4 con ottimizzazione del primo eco; angolo di vista 45°

Figure 15: difetto 4 con ottimizzazione del secondo eco; angolo di vista 45°

Figure 16: difetto 5 con ottimizzazione del primo eco; angolo di vista 45°

Figure 17: difetto 5 con ottimizzazione del secondo eco; angolo di vista 45°
5 Experimental results with a view angle of 50°

The same series of tests is been repeated with an observation angle of 50°. The reason for such repetition is due to the consideration that the diffracted echo amplitude depends in general from the incidence angle of the wave front on the defect and, thus, we can suppose that also the ratio of echo amplitudes can depends from the incidence angle. The obtained images are reported in figures 19-28, while the results summary is illustrated in Table II. Finally, figure 18 shows the graphical trend of the ratio amplitude of first echo / amplitude of second echo against the ratio between defect height and defect width.

Table II Experimental results with a view angle of 50°

<table>
<thead>
<tr>
<th>defect</th>
<th>height H1 first echo</th>
<th>height H2 second echo</th>
<th>ratio of defect height/width</th>
<th>ratio H1/H2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>18,11</td>
<td>34,19</td>
<td>1</td>
<td>6,37</td>
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<tr>
<td>2</td>
<td>18,11</td>
<td>33,15</td>
<td>2,67</td>
<td>5,65</td>
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<tr>
<td>3</td>
<td>22,72</td>
<td>38,85</td>
<td>4</td>
<td>6,40</td>
</tr>
<tr>
<td>4</td>
<td>28,62</td>
<td>38,85</td>
<td>8</td>
<td>3,25</td>
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<tr>
<td>5</td>
<td>26,41</td>
<td>37,33</td>
<td>13,33</td>
<td>3,68</td>
</tr>
</tbody>
</table>

Figure 18 Graph of the ratio H1/H2 against the ratio of defect height / width: view angle 50°.
Figure 19: difetto 1 con ottimizzazione del primo eco; angolo di vista 50°

Figure 20: difetto 1 con ottimizzazione del secondo eco; angolo di vista 50°

Figure 21: difetto 2 con ottimizzazione del primo eco; angolo di vista 50°

Figure 22: difetto 2 con ottimizzazione del secondo eco; angolo di vista 50°

Figure 23: difetto 3 con ottimizzazione del primo eco; angolo di vista 50°

Figure 24: difetto 3 con ottimizzazione del secondo eco; angolo di vista 50°
Figure 25: difetto 4 con ottimizzazione del primo eco; angolo di vista 50°

Figure 26: difetto 4 con ottimizzazione del secondo eco; angolo di vista 50°

Figure 27: difetto 5 con ottimizzazione del primo eco; angolo di vista 50°

Figure 28: difetto 5 con ottimizzazione del secondo eco; angolo di vista 50°
6 Result evaluation
Comparing the graphs of figure 7 and figure 18, we observe a substantially constancy of the ratio $H_1/H_2$ trend; small differences are present due, surely, to oscillation of the single measures. Thus, we can assume the average of the two graphs, obtained at 45° and 50°, as representative of the $H_1/H_2$ trend against defect height/width ratio; this average trend is illustrated in figure 29.

The characteristic S-shape of the graph indicate a clear clustering of the behavior of $H_1/H_2$ ratio into two class. Defects which have an height/width ratio lower than a certain transition value show a $H_1/H_2$ ratio quite constant in the range 6-7; while defect with a value of their height/width ratio higher than the transition value shows values of $H_1/H_2$ ratio in the range 3-3.5. Hence, the ultrasonic transition value is about 4.5: for $H_1/H_2$ ratio lower than this value, the ultrasound consider the defect as volumetric, otherwise planar. This ultrasonic transition value corresponds to a geometrical transition value of about 6; that is, for the ultrasounds, defects with an height less than 6 time the width are to be considered as volumetric. If this conclusion could be considered as true is a matter of a suitable evaluation with fracture mechanics criteria.

![Figure 29 Average trend of the ratios H1/H2 shown in the figures 12 and 23](image)

7 Conclusion
The ultrasonic method is thus able to produce a precise criteria for which defects can be classified as planar or volumetric, where, obviously, volumetric or planar are to be intended “according ultrasound”. Consequently, it could be of great interest to verify, by means of fracture mechanics criteria, if the transition value posed by ultrasonic is also coherent with the correspondent evaluations of fracture mechanics; that is, if for the defects classified as volumetric or planar by ultrasounds, the component stability condition can be evaluated using the relevant criteria, respectively, for volumetric or planar defects.
**Window 3** Diffraction phenomena representation with computer simulation and experimental results

**BIBLIOGRAPHY:**
R. S. Sharpe “Research Techniques in Nondestructive Testing Vol. IV