2006
ULTRASONIC BENCHMARKS

Problems for 2006

This year the ultrasonic benchmark study involves scanning of rectangular defects on a variable slope bottom specimen. These experiments were proposed and conducted by CEA.

For this year the cases are different than those proposed in previous years. The main topic of this study is to check the different corner echoes provided from rectangular surface breaking defects, assuming a varying slope of the back-wall specimen.

Below are outlined the experimental studies performed with these samples.
2006 Benchmark Problems

The proposed experiment set-up has been made to measure pulse-echo response of two type of reference reflectors using either a 45° refracted P-wave or S-wave contact angle beam transducer.

The two reflector types were: a side-drilled hole and a rectangular defect.

The interest of this 2006 ultrasonic benchmark is to study a rectangular defect response with a varying slope of the back-wall.

In all these cases we obtained the pulse-echo B-scan response of the reflectors from the test block. More details of the actual cases considered are given bellow.

Rectangular defects (RD) on 0 to 20° slope bottom specimen

The set of experiments proposed by CEA for the 2006 Benchmark involve the examination of a stainless steel component (see table 1) containing 5 rectangular defects (RD) and one side drilled hole (SDH). The slope of the component bottom varies between 0° and 20° by 5° steps (see figures 1 to 5). The rectangular defects are 10mm height by 20mm length with 0.2mm width (for more precise definition of the defect widths see figure 6 and table 4) and the 2mm diameter side drilled hole is located at 37.5mm depth (the depth is measured to the center of the hole).

Planar contact transducers (Tables 1 to 3) were scanned parallel to the surface at using 45° refracted angles for P- and S-waves (see figures 1 to 4). A reference scattering experiment was performed by using the SDH for P- and S-waves (see figures 1 and 3).

For each probe a reference A-scan was obtained from the maximum amplitude of the SDH response (see figures 1 and 3). For each slope unrectified A-scans can be extracted from the B-scans corresponding to the line scanning over the middle of the defect.
### Table 1: Acoustical properties of materials used

<table>
<thead>
<tr>
<th>Material</th>
<th>Density</th>
<th>$c_L$</th>
<th>$c_T$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stainless steel</td>
<td>7.9 gm.cm$^{-3}$</td>
<td>0.5748 cm.ms$^{-1}$</td>
<td>0.3157 cm.ms$^{-1}$</td>
</tr>
<tr>
<td>Plexiglas Wedge</td>
<td>1.18 gm.cm$^{-3}$</td>
<td>0.268 cm.ms$^{-1}$</td>
<td>0.132 cm.ms$^{-1}$</td>
</tr>
</tbody>
</table>

### Table 2: Transducer characteristics

<table>
<thead>
<tr>
<th>Waves</th>
<th>Shape</th>
<th>Dimension</th>
<th>Central frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>P-waves</td>
<td>circular</td>
<td>12.7mm</td>
<td>2.25MHz</td>
</tr>
<tr>
<td>S-waves</td>
<td>rectangular</td>
<td>22×20mm</td>
<td>2MHz</td>
</tr>
</tbody>
</table>

### Table 3: Wedge dimensions

<table>
<thead>
<tr>
<th>Waves</th>
<th>Front length</th>
<th>Back length</th>
<th>Height</th>
<th>Width</th>
<th>Incidence angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>45° P-waves</td>
<td>9.5mm</td>
<td>11.5mm</td>
<td>9mm</td>
<td>18.2mm</td>
<td>19°</td>
</tr>
<tr>
<td>45° S-waves</td>
<td>20mm</td>
<td>20mm</td>
<td>17mm</td>
<td>25mm</td>
<td>36°</td>
</tr>
</tbody>
</table>
45° refracted P-waves inspection

Reference scattering experiment on SDH

Figure 1: 45° refracted P-wave contact probe setup for SDH inspection (Reference experiment)
45° refracted P-waves inspection

Scattering experiments on RD with 0 to 20° slope bottom specimen variation

Figure 2: 45° refracted P-wave contact probe setup for RD inspection
45° refracted S-waves inspection

Reference scattering experiment on SDH

Figure 3: 45° refracted S-wave contact probe setup for SDH inspection (Reference experiment)
45° refracted S-waves inspection

Scattering experiments on RD with 0 to 20° slope bottom specimen variation

Figure 4: 45° refracted S-wave contact probe setup for RD inspection
45° refracted P-waves and S-waves inspection

General dimensions of the specimen

Figure 5: Specimen dimensions from top view
45° refracted P-waves and S-waves inspection

Dimension plan of defects

The widths of the rectangular defects are approximately of 0.2mm. Table 4 gives the dimensions of the defects obtained by impression of the slots (Figure 6 presents the dimension plan of defects):

![Dimension plan of defects](image)

Table 4: Defect dimensions

<table>
<thead>
<tr>
<th>Slope</th>
<th>Surface slot width (mm)</th>
<th>Bottom slot width (mm)</th>
<th>Depth (mm)</th>
<th>Length (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0° slope</td>
<td>0.35</td>
<td>0.34</td>
<td>10.10</td>
<td>20.16</td>
</tr>
<tr>
<td>5° slope</td>
<td>0.29</td>
<td>0.24</td>
<td>10.03</td>
<td>20.16</td>
</tr>
<tr>
<td>10° slope</td>
<td>0.28</td>
<td>0.25</td>
<td>10.08</td>
<td>20.16</td>
</tr>
<tr>
<td>15° slope</td>
<td>0.32</td>
<td>0.32</td>
<td>10.09</td>
<td>20.05</td>
</tr>
<tr>
<td>20° slope</td>
<td>0.28</td>
<td>0.24</td>
<td>10.24</td>
<td>20.05</td>
</tr>
<tr>
<td>SDH</td>
<td>2.06</td>
<td>2.04</td>
<td>40.01</td>
<td></td>
</tr>
</tbody>
</table>
The B-scan and other data for these various cases are located according to the folder hierarchy shown in figure 7. The READ ME text file contains a copy of these notes. The results are separated into sub-folders according to the type of transducer (P or S-wave transducer).

In each of the final sub-folders a text file containing the reference A-scan results from the SDH reflection experiment, as described previously, is in the file name P_45_Ref.txt (or P_45_Ref.txt). The B-scan results contained in this sub-folder are text file containing all information needed to extract the defect responses.

Finally, in each final sub-folder the A-scan and all the B-scan results for the cases considered are contained in text files having a naming convention that will be described below. Please note that these text files also contain a header with information on the file contents followed by the data whose format is described next.

The format of the reference A-scan files is very simple. It is just a two column format, where the sampled time values (in μs) are given in the first column and the measured A-scan amplitudes (16 bits coded arbitrary unit) are given in the second column, separated by a tab, i.e.

\[
\begin{align*}
  t_1 & \quad A_1 \\
  t_2 & \quad A_2 \\
  t_3 & \quad A_3 \\
  \text{Etc…}
\end{align*}
\]

The format of the B-scan files is a three column format, where the scan positions values (mm) are given in the first column, the sampled time values (in μs) are given in the second column and the measured amplitudes (16 bits coded arbitrary unit) are given in the third column, separated by a tab, i.e. Information concerning the sampling of scan and time are given in these B-scan files, as the following description:

\[
\begin{align*}
  x_1 & \quad t_1 & \quad A_1 \\
  x_2 & \quad t_2 & \quad A_2 \\
  x_3 & \quad t_3 & \quad A_3 \\
  \text{Etc…}
  \end{align*}
\]

\[
\begin{align*}
  \text{…} \\
  x_n & \quad t_1 & \quad A_1 \\
  x_n & \quad t_2 & \quad A_2 \\
  x_n & \quad t_3 & \quad A_3 \\
  \text{Etc…}
\end{align*}
\]

Etc…
Figure 7: The file structure for the 2006 ultrasonic benchmark data
All the data files for the B-scan responses of the reflectors in the various cases considered follow the following format.

File name format for a “flaw” B-scan signal files

```
P_45_10_RD_Slope0_G50.txt
```

- Wave type incident on the reflector (P or S)
- Refracted angle (deg)
- Reflector size (Examples: 2 = 2mm diameter. 10 = 10mm height)
- Reflector type: Rectangular defect (RD). side-drilled hole (SDH)
- Slope of bottom specimen (deg)
- Experimental applied gain (dB)
The flaw data sets currently available are as follows:

Rectangular defects

- P_45_10_RD_Slope0_G50.txt
- P_45_10_RD_Slope5_G50.txt
- P_45_10_RD_Slope10_G50.txt
- P_45_10_RD_Slope15_G50.txt
- P_45_10_RD_Slope20_G50.txt

- S_45_10_RD_Slope0_G32.txt
- S_45_10_RD_Slope5_G32.txt
- S_45_10_RD_Slope10_G32.txt
- S_45_10_RD_Slope15_G48.txt
- S_45_10_RD_Slope20_G48.txt

Side-drilled hole

- P_45_2_SDH_G50.txt
- S_45_2_SDH_G48.txt

Reference A-scan signals

- P_45_Ref.txt
- S_45_Ref.txt

All the data for these experiments are available at ftp://cnde:Bruce@ftp.cnde.iastate.edu within the pub folder in a sub-folder named 2006_UT_benchmark
The 2006 Ultrasonic Benchmark Problem

1. Model the complete B-scan responses of the 12 cases listed on the previous page and compare to the measured B-scan results.
   
a. For the 45° refracted P-wave transducer study, try to define the different types of corner echoes present in the B-scan response. For help, see the following experimental analysis proposed in slides 16 to 21.

   b. The same analysis is required for the 45° refracted S-wave transducer. See slides 22 to 27.

2. Taking as a reference the maximum amplitude of the SDH response (45° refracted P- and S-wave probes), compute the relative peak-to-peak amplitude responses for all corner echoes present on RD with slope bottom variation and compared to the experimentally observed ratios. For help see the experimental relative amplitude values of the different corner echoes presented in table 5 for the 45° refracted P-wave inspection and in table 6 for the 45° refracted S-wave inspection.

   \[ A_R = 20 \log_{10} \left( \frac{A_{\text{max}_{SDH}}}{A_{\text{max}_{RD}}} \right) - (G_{SDH} - G_{RD}) \]

   Relative amplitude (dB)  
   Gain (dB)

   The purpose of this study is to compare directly the model-based predictions (from different modelling approaches) of incident wave fields at the flaw which are a key aspect of modelling the flaw responses. This problem seems to be complicated but it is the second step to understand where modelling differences, if any, may occur.
45° refracted P-waves inspection

P_45_2_SDH_G50.txt

18.84 μs

60 mm

Direct P-wave: 0 dB

15.08 μs

33.92 μs

0 mm

60 mm
45° refracted **P-waves** inspection

P-wave corner echo: 2.1 dB

P- and S-wave corner echo: 4.9 dB

S-wave corner echo: 5.1 dB

P_45_10_RD_Slope0_G50.txt
45° refracted P-waves inspection

P-wave corner echo: -2.6 dB
P- and S-wave corner echo: -0.6 dB
S-wave corner echo: 3 dB
45° refracted **P-waves** inspection

P-wave corner echo: -6.2 dB

P- and S-wave corner echo: -6.6 dB

S-wave corner echo: 1.6 dB
45° refracted P-waves inspection

P-wave corner echo: -3.3 dB
P- and S-wave corner echo: 1.7 dB
S-wave corner echo: -3.1 dB

32.12 μs
79.8 mm
47.04 μs

14.92 μs
0 mm
79.8 mm
45° refracted P-waves inspection

P-wave corner echo: -5.3 dB

P- and S-wave corner echo: -13.1 dB

P_45_10_RD_Slope20_G50.txt
45° refracted S-waves inspection

S_45_2_SDH_G48.txt

Direct S-wave: 0 dB
45° refracted S-waves inspection

S-wave corner echo: 20 dB
45° refracted **S-waves** inspection

S-wave corner echo: 13.2 dB
45° refracted **S-waves** inspection

S_45_10_RD_Slope10_G32.txt

**S-wave corner echo: 12.1 dB**
45° refracted S-waves inspection

S_45_10_RD_Slope15_G48.txt

S-wave corner echo: 1.3 dB
45° refracted S-waves inspection

S-wave corner echo: 2.5 dB
### 45° refracted P-waves inspection

Relative amplitude in dB for each corner echo of RD

<table>
<thead>
<tr>
<th>slope (°)</th>
<th>P-wave corner echo</th>
<th>P and S-wave corner echo</th>
<th>S-wave corner echo</th>
</tr>
</thead>
<tbody>
<tr>
<td>SDH</td>
<td>P-wave direct echo is the reference amplitude</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0° Slope</td>
<td>2.1</td>
<td>4.9</td>
<td>5.1</td>
</tr>
<tr>
<td>5° Slope</td>
<td>-2.6</td>
<td>-0.6</td>
<td>3.0</td>
</tr>
<tr>
<td>10° Slope</td>
<td>-6.2</td>
<td>-6.6</td>
<td>1.6</td>
</tr>
<tr>
<td>15° Slope</td>
<td>-3.3</td>
<td>1.7</td>
<td>-3.1</td>
</tr>
<tr>
<td>20° Slope</td>
<td>-5.3</td>
<td>-13.1</td>
<td></td>
</tr>
</tbody>
</table>

Table 5: Relative amplitude of each corner echo of RD for 45° refracted P-waves inspection
### 45° refracted S-waves inspection

Relative amplitude in dB for each corner echo of RD

<table>
<thead>
<tr>
<th>slope (°)</th>
<th>S-wave corner echo</th>
<th>Relative amplitude (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SDH</td>
<td>S-wave direct Echo is the reference amplitude</td>
<td></td>
</tr>
<tr>
<td>0° Slope</td>
<td></td>
<td>20</td>
</tr>
<tr>
<td>5° Slope</td>
<td></td>
<td>13.2</td>
</tr>
<tr>
<td>10° Slope</td>
<td></td>
<td>12.1</td>
</tr>
<tr>
<td>15° Slope</td>
<td></td>
<td>1.3</td>
</tr>
<tr>
<td>20° Slope</td>
<td></td>
<td>2.5</td>
</tr>
</tbody>
</table>

Table 6: Relative amplitude of each corner echo of RD for 45° refracted S-waves inspection
PARTICIPATION IN THE STUDY

We have placed this data on the web at ftp://cnde:Bruce@ftp.cnde.iastate.edu. We would welcome you examining this data, comparing the data to model-based predictions, and sharing your results.

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May 19, 2006
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