1. Introduction

This technical note is Part 12 of a series in NDT.net. Description of the associated video is provided in this technical note and remarks are made on some of the features seen. In Part 12 we examine the effects of a compression pulse from an immersion probe as it enters a cylinder wall.

This demonstration was made using an immersion probe 19mm (3/4 inch) diameter 2.25MHz and equipped with a waterproof UHF connector. The probe was mounted in a manipulator that allowed angulation of the beam in the X and Y planes.

Pulsing of the probe was provided using the USBox (by Lecoeur) with the pulser tuned to provide the optimum output at in a single cycle pulse at 250 V with pulse-duration tuned to 2.25MHz.

The cylinder model is made of soda-lime float glass (compression mode velocity 5850m/s, transverse velocity 3450m/s, density 2.5g/cm$^3$). The model was cut so as to simulate a 3 inch schedule 80 pipe. Nominal dimensions for the pipe are 89mm diameter OD 7.6mm wall thickness. The glass model is 89mm outside diameter with a 7.5mm wall thickness. Through-thickness of the model, parallel to the light path, is 25mm so the beam from the 19mm diameter probe does not pass through water on either side of the model.

A machinist’s-style V-block was used to support the cylinder and the probe was offset from normal incidence so produce a nominal 43° refracted shear wave. Figure 1 illustrates the test setup.
Offsetting the probe relative to the normal incidence allows an approximation of the angle of the refracted transverse mode. For tubular products the 45° refracted angle is estimated by using and offset of one sixth of the diameter (one sixth of the outside diameter if testing from the outside surface and one sixth of the inside diameter if testing from the inside surface).

In our setup for this demonstration 14mm offset was used. Assuming the acoustic velocity of water to be 1490m/s and the transverse velocity of the glass as 3450m/s this offset results in an incident angle of approximately 17°. The resultant refracted transverse mode is therefore 43°. The centre ray path of the transverse mode for the 17° incident beam is illustrated in Figure 2.
Although Snell’s Law indicates a nominal 43° refracted angle, the actual beam that results has little resemblance to the simple centre ray shown in Figure 2. In fact, the beam model seen in Figure 3 (Civa beam modelling) for the pulse in the cylinder seems to have no particular refracted angle. This is due to the many entry angles of the plane wave as it is incident along the curved surface. In Figure 3, the points to the left of the centreline produce incident angles of increasing value over the nominal 17° whereas points to the right of the centre ray in Figure 3 produce decreasing values of incident angles.
The portions of the beam at the higher angles to the left in Figure 3 are soon making incidences near the second critical angle and the transverse mode is seen to arc up to the outside surface and form a near-vertical wavefront. Ray paths for seven rays have been added to the image in Figure 3. The black rays from the probe to the surface are the compression mode paths in water. At the water/glass boundary the compression mode rays are changed to green and the transverse ray paths are indicated as red. Note that at the far left there are no associated rays entering the glass.

2. Comments on the Video

The video begins with a pulse formed in the water just prior to the entry into the cylinder.

Upon entry we see the small incident angle portion of the pulse on the right side of the image making a weak compression mode in the glass and at the same time it mode converts to transverse. The incident plane wave is seen to reflect as an arc from the curved surface. These features are seen in Figure 4.

![Figure 4](image_url)  
Figure 4 Initial interaction with cylinder

A very rapid transition occurs as the plane wave begins to interact at points farther to the left. The compression mode that is transmitted into the glass arcs up to become glancing at the cylinder surface and at about the same time the weak portion of the transmitted compression mode that entered at a smaller angle reflects off the cylinder inside surface.
Figure 5 illustrates the variety of modes and angles that form as the effects of boundary interaction along the curved surfaces provide opportunity for mode conversions. The initial compression mode that was transmitted into the glass has a portion of the pressure re-transmit into the water at the inside surface of the cylinder.
By the time the last edge of the incident pulse has reflected from the outside surface of the cylinder, the portion of the beam that was seen as a transmitted compression mode is seen to have a near-vertical wavefront that effectively covers the entire wall thickness. (This compression mode that connects the ID and OD surfaces at nearly a parallel to the radius is also seen in the Civa mode in Figure 3 at the lower left side of the cylinder). By glancing along the outside surface this compression mode is seen to be generating a shear headwave. The same process is occurring at the inside surface and the glancing incidence with the inside surface of the cylinder is seen to form a strong shear headwave that is moving ahead of the intended 43° transverse wave predicted by Snell’s Law. These features are illustrated in Figure 6.

Figure 6  Transmitted L-mode generates shear headwaves
By the time the nominal 43° shear mode is reflecting off the inside surface its shape has altered so that it too makes a glancing incidence with the outside surface. As with the compression mode, the shear mode, calculated by Snell’s Law to be at 43°, is now seen to be a nearly parallel to the cylinder radius as a wavefront straddling the outside and inside surfaces. In Figure 7 we see that multiple re-transmissions are visible in the water as the process moves around the cylinder wall.

Figure 7  Reflecting shear mode from refracted nominal 43° shear wave

The video to this article can be seen here:
www.ndt.net/search/docs.php3?id=14630&content=1

For more information about the photoelastic system see www.eclipsescientific.com.