# The role of bedding on the pulse shape change: Numerical modeling calibration with a physical experiment

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## Abstract

The rocks in a sedimentary basin are made of several layers, as shown in well-logs, that go from some meters to millimeters in width, and maybe thinner. So, one could imagine that the seismic pulse is supposed to be reflected and refracted through hundreds to thousands of layers, most of them bellow the seismic resolution. These layers create a train of multiples that follows the main pulse with a very short time-lag among themselves. The summation of this train with the original pulse generates a new pulse shape which resembles the original pulse under the effect of absorption. This phenomenon was described in O'Doherty and Anstey (1971). The purpose of this work is to evaluate this effect through a numerical modeling calibrated with a physical experiment of ultrasonic-frequency wave propagation in samples composed of discs of aluminum and glass using a Finite Difference modeling of elastic wave equation.


## The Physical Experiment

The physical experiment can be divided into 3 parts:
i) The generation and recording device (fig.1) ;
ii) The pressure vessels (fig.2);
iii) The transducers and sample itself (fig.3).

Fig. 1 – The generation and record devices

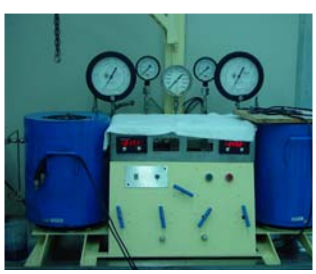


Fig. 2 – The Pressure vessels

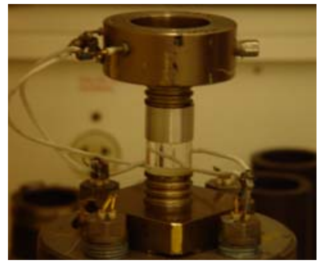


Fig. 3a – The piezoelectric transducers and a sample compound of glass and aluminum.

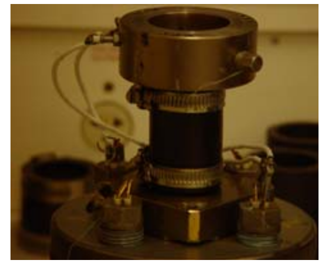


Fig. 3b – The sample inside the rubber jacket, ready to go to the pressure vessel.

The sample is placed between the transducer caps (figure 3a) and a rubber jacket is adjusted around the sample and the set is all immersed in a pressure vessel (the blue cylinders in figure 2) filled with oil. The pressure of 5,000 psi was used to guarantee a good coupling of all parts. The mounted device is shown in figure 3c.

Fig. 3c – The physical experiment

Four cylindrical samples were built as follows:

- All of them have the same diameter (1 inch) and about the same height,
- One of them was made of aluminum,
- The others ones were composed respectively of two, four and eight layers of aluminum and glass, the same amount being used for each sample. The samples are shown in the figures 4 to 7.

## Mathematical Formulation

Due to the axis-symmetry of the model, the elastic wave equation in cylindrical coordinates was adopted. The system to be solved became as follows:

$$\rho \frac{\partial v_r}{\partial t} = \frac{\partial \tau_{rr}}{\partial r} + \frac{\partial \tau_{rr}}{\partial r} + \frac{\partial \tau_{rz}}{\partial z}$$

$$\rho \frac{\partial v_z}{\partial t} = \frac{\partial \tau_{zz}}{\partial r} + \frac{\partial \tau_{rz}}{\partial r} + \frac{\partial \tau_{rz}}{r}$$

$$\frac{\partial \tau_{rr}}{\partial t} = (\lambda + 2\mu)\frac{\partial v_r}{\partial r} + \frac{\lambda}{r} v_r + \frac{\partial v_z}{\partial z}\lambda$$

$$\frac{\partial \tau_{zz}}{\partial t} = \lambda \frac{\partial v_r}{\partial r} + \frac{\lambda}{r} v_r + (\lambda + 2\mu)\frac{\partial v_z}{\partial z}$$

$$\frac{\partial \tau_{rz}}{\partial t} = \mu \frac{\partial v_r}{\partial z} + \mu \frac{\partial v_z}{\partial r}$$

The Finite Differences scheme used was that proposed by Levander (1986), using a fourth order operator for space derivatives and a second order one for time derivatives on a staggered grid scheme. The fourth order operator and stability criteria followed Graves(1996):

$\frac{\partial}{\partial r} v_r \approx D_r v_r \mid_P$; let $D_r$ be the discrete representation of the operator $\frac{\partial}{\partial r}$ on the variable $v_r$ at point $P$, with coordinates $(r = i\Delta r, z = j\Delta z)$. So the fourth order operator for spatial derivative is described as follow:

$$D_r v_r \mid_P = \frac{1}{h}\begin{Bmatrix} c_o\left[v_r(i+\frac{1}{2},z) - v_r(i-\frac{1}{2},z)\right] - \\ c_1\left[v_r(i+\frac{3}{2},z) - v_r(i-\frac{3}{2},z)\right] \end{Bmatrix},$$

with $c_o = \frac{9}{8}$, and $c_1 = \frac{1}{24}$, and with the stability criteria described by $\Delta t < 0.495 \frac{h}{v_{máx}}$, $h$ is the grid spacing, $\Delta t$, the time-step and $v_{máx}$, the maximum velocity of the model.

**Numerical Modeling**

For the numerical modeling some assumptions must be considered:

a) Although the excitation of the piezoelectric transducer (figure 3d) is not, in fact, axis-symmetric but considering that the polarization velocity of the transducer is much higher than the wave propagation velocity in steel, aluminum or glass, it was assumed that the excitation of the transducer is also axis-symmetric;

b) The source curve, Sc (figure 3e) adopted was an attenuated version of the curve recorded when no samples were within the device, if the physical source was an impulse Sc could be called "the impulse response of the system";
REMARK: *After many tries with different curves, the best result was achieved using Sc* ;

c) Considering the same assumption of item a, the record of the transmitted pulse is supposed to be axis-symmetric;

d) It was used a paste between the discs in order to improve coupling. Due to the difficult in defining the mechanical properties of the paste, these interfaces were modeled assuming Shear modulus of about $10^{-6}$ Ga, where Ga is the shear modulus of Aluminun. These interfaces were considered to have the same thickness of $\Delta z (= \Delta x)$ of the model, $10^{-4} m$.

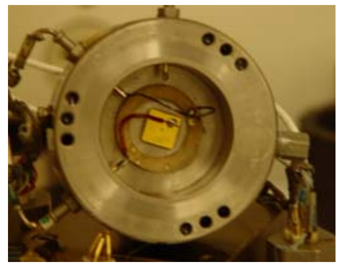


Fig. 3d – A top view of the ring transducer


Fig 3e – The source curve for the modeling.

**Numerical model Calibration**

After generating the code and using all the assumptions listed above, four numerical models based on the real samples were generated:

i) One cylinder (length =L) of aluminum;

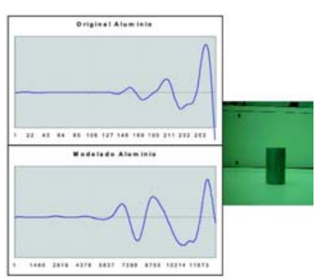
ii) One cylinder (length=L) made up of two cylinders (length=L/2) of aluminum and glass;

iii) One cylinder (length=L) made up of two aluminum cylinders(length=L/4) and two glass cylinders(length=L/4);

iv) One cylinder (length=L) made up of four aluminum cylinders (length=L/8) and four glass cylinders (length=L/8).

Numerical curves were generated and then each one of them was compared with the corresponding real sample.

The comparison (calibration) is shown in figures from 4 to 7.



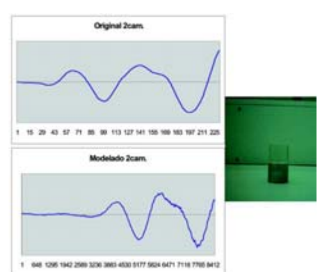



Fig.4-Aluminum cylinder Fig.5 Two layers cylinder

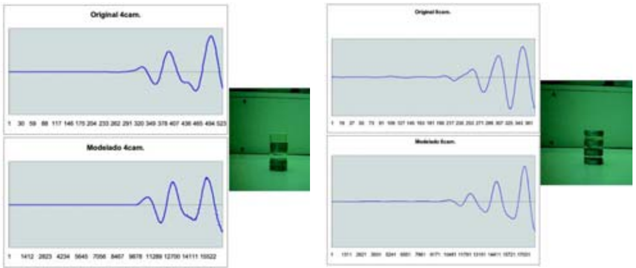


Fig.6- Four layers cylinder Fig.7- Eight layers cylinder

The numerical curves fitted the original ones quite well. So the next step was to analyze a more complex model, that couldn't be built in the lab.

### A More Complex model

A 32 layers model was created in order to analyze the behavior of the transmitted pulse through a pack of layers. The curve generated was plotted together with the some previous ones. Figure 8 shows the result:.

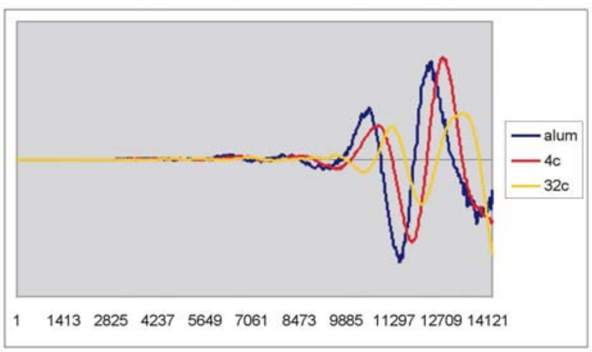



Fig.8 – The effect of layers on the shape of the pulse

The numerical curves displayed in figure 8 shows the effect of the layers on the shape of the pulse. The effect is supposed to be the same for the real sample if the 32 layer cylinder had been built, since it was possible to reproduce numerically the real curves in the figures 4 to 7. The yellow curve shows a loss of amplitude and a greater delay when compared to the other curves. It is important to highlight that models proposed by other authors (Trorey,1962) to simulate the effect of absorption, were not used in the present numerical modeling. So the effect that resembles the absorption was created exclusively by the multilayer media.

### Conclusions

Based on the very good fit attained in our numerical modeling it is possible to infer that:

1. Since electrical events were not considered, e.g. cross-feed, and possible coupling problems, it is possible to conclude that the equipment as a whole can generate a very good and a clean signal;
2. The assumption of the axis-symmetry of the source was correct;
3. The use of a staggered grid scheme dealt very well with the high impedance contrasts, e.g. rubber-steel, of the model;
4. The modeling of the interfaces between the cylinders of aluminum and glass was very important, since otherwise it would not be possible to reproduce the real curves without the interfaces;
5. In fact, the effect of layers resembles that of absorption, due the so-called "stratigraphic-filtering", even when dealing with a completely elastic medium like the one used in this work. The challenge from now on is to quantify the role of layers in the change of the pulse when compared to absorption from the visco-elastic behavior of the rocks in subsurface.

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