# Condition monitoring of large oil and chemical storage tanks using guided waves

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**Abstract**

Large storage tanks containing hazardous liquids such as oil, oil derived products and food processing liquids are common throughout the world. Corrosion in the tank floor is a serious environmental and economic risk. In order to monitor the condition of the tanks and prevent leakage, the tanks must be inspected at regular intervals. Currently before an inspection can be carried out, the tank must be emptied and cleaned. This is an expensive and dangerous process due to weeks of lost production, transportation of liquids to temporary storage tanks and exposure of the workers to fumes during inspection and cleaning.

TWI is managing a European CRAFT project called TANKINSPECT to overcome the drawbacks of current inspection practices. By placing guided wave sensors outside the tank and using reconstructive tomographic techniques there is potential for carrying out an inspection of the whole tank instantly and without the requirement of emptying and cleaning the tank or operator entry inside the tank. TWI has been working with the University of Lithuania, using numerical modelling to study the potential of realizing such a technique. The effects of lap joints in the tank floors and attenuation into the liquid contents of the tank have been considered using both global matrix and finite element modelling methods.

## 1. Introduction

In producing a system for the inspection of tank floors there are many technical challenges to overcome. Guided waves, by nature, travel in prismatic structures and therefore any changes to the cross section such as a lap joint can cause undesirable reflections and noise, making the received signal difficult to interpret. In addition to this, the sound energy is attenuated by materials surrounding the tank such as the liquid contents, linings and sand or concrete underneath the tank. Modelling has been used in this work to study such effects in isolation and therefore gain a better understanding of these issues so that practical solutions can be found.

## 2. Global matrix model

An initial global matrix model(1) (a set of analytical formulae that describe lamb waves in a multi-layer structure) was set up to consider the effect of the varying connectivity possible at a lap joint. The bonding may vary in the region where the steel plates overlap and these variations have influence on the Lamb waves velocities and attenuation. The bond strength between the layers has been considered as three different states: “perfect”, “poor” and “slip”(2). The “Perfect” bond state means that all displacements are transferred through the interface. In this case, the bonding layer properties have been chosen to be the same as the steel plate properties and the bonding layer thickness is relatively small. The “poor” bond state means that displacements across the boundary are reduced compared with the “perfect” bonding case at the interface. This was achieved by reducing the longitudinal and shear wave velocities in the bonding layer by a factor of two. The “slip” bond state means that shear displacements are not transferred through the interface and this state was reached setting shear velocity to 0m/s. A schematic of the model is shown in Fig.1.

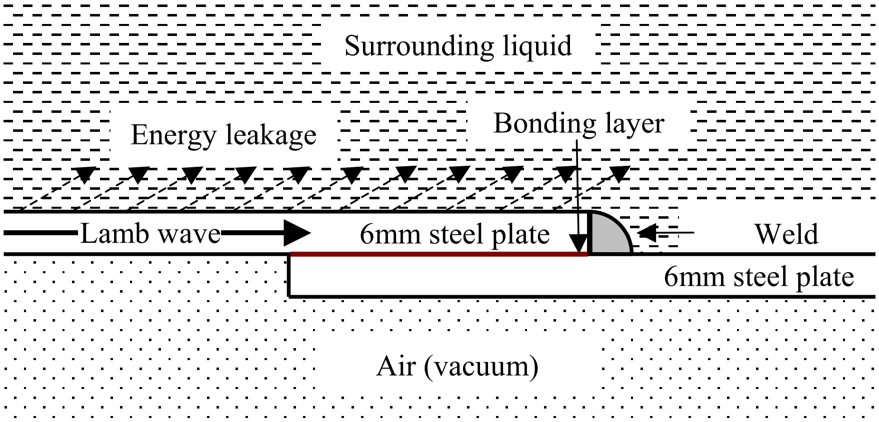

**Figure 1. Schematic of lap joint model**

The global matrix method has been used to predict the lamb wave phase velocity and attenuation due to energy leakage. The phase velocity dispersion curves for 6mm steel with diesel fuel oil on one side are shown in Fig.2. The attenuation curves due to energy leakage are shown in Fig.3. The lowest order symmetric and asymmetric ($S_0$ and $A_0$) modes can be generated at frequencies of less than 100kHz. The $S_0$ mode can be used for effective long range testing, because it has relatively low attenuation.

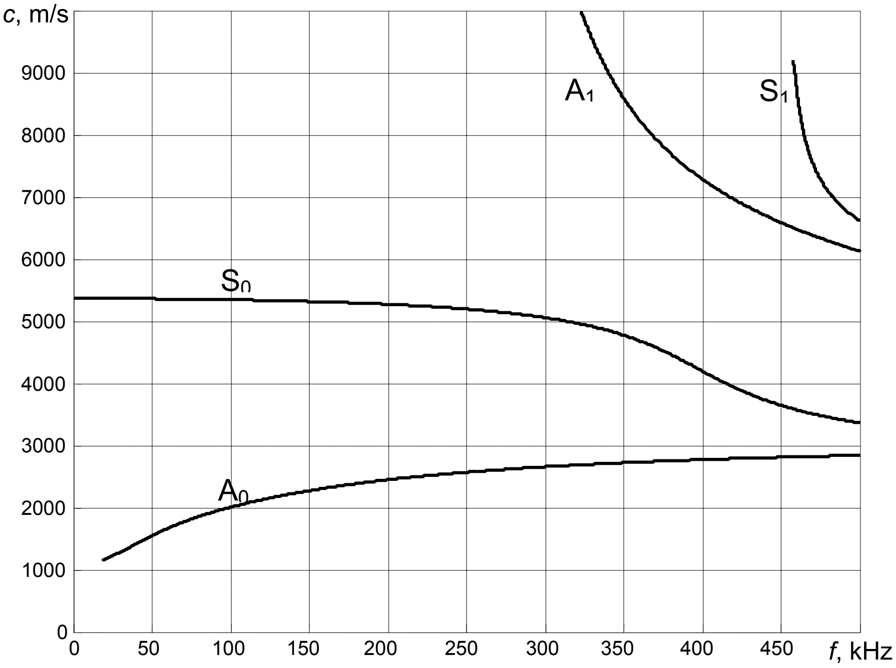

Figure 2 Phase velocity dispersion curves for 6mm steel plate

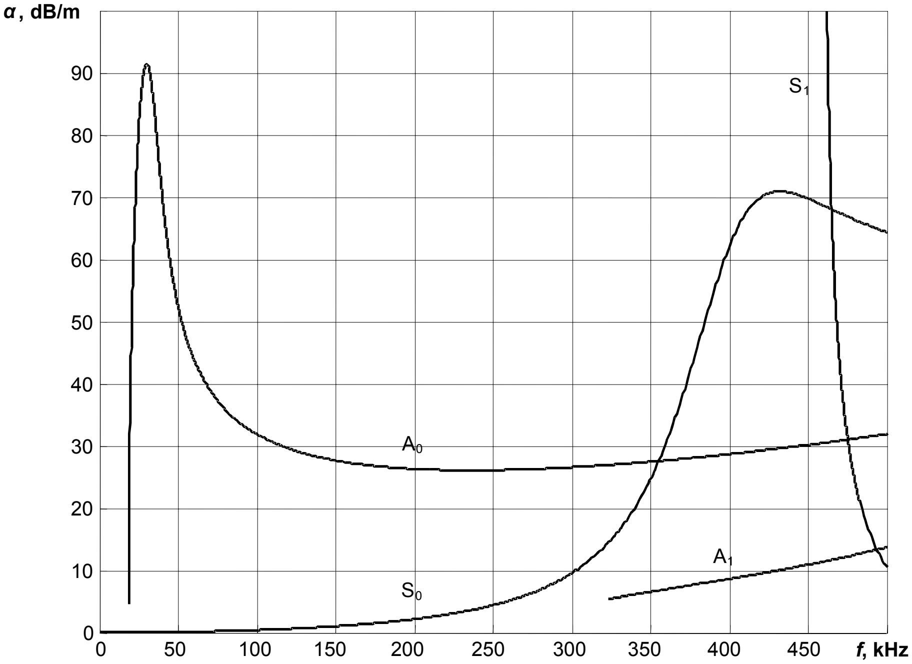

Figure 3. Attenuation curves for 6mm steel plate with diesel on one side

The phase velocity dispersion curves for a multi-layered zone with diesel on one side are shown in Fig.4. There is little difference between the three bond states considered. However, in the “slip” case, it was found that a wave can be generated that propagates in the bond interface with zero attenuation, called a Stoneley wave.

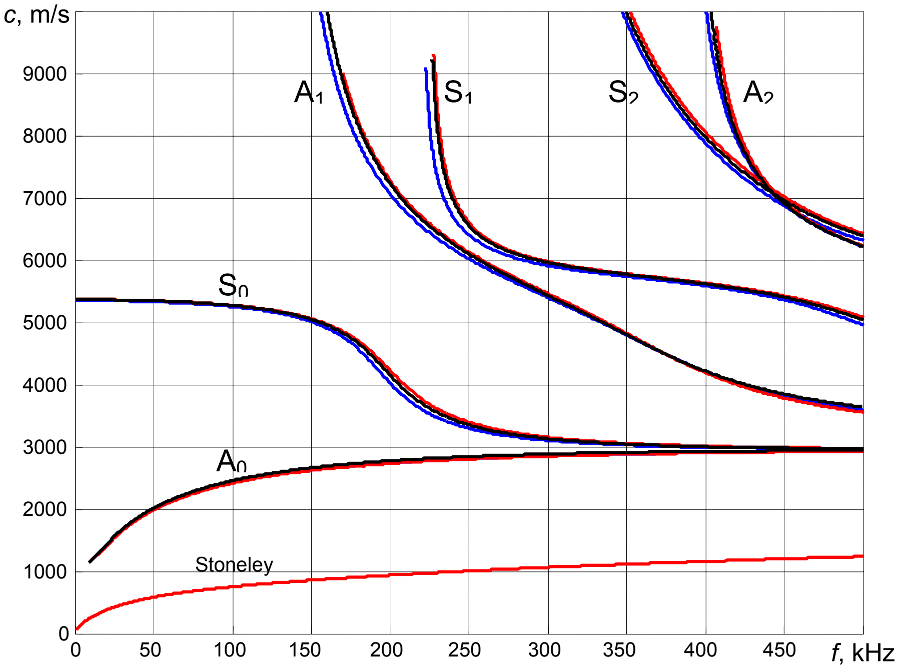

**Figure 4 Phase velocity dispersion curves for steel lap joint with different bonding layer conditions**

## 3. Finite element model

A finite element model was used to analyse the propagation of lamb waves in a lap joint with diesel on one side and a vacuum on the other. A gap of 0.5mm was assumed to exist between the two plates. The plates were assumed to be joined by a 45° fillet weld. Figure 5 shows the propagation of the lamb wave at different moments in time. The first two figures in Fig.5 shows the lamb waves in the upper plate and the attenuation into the liquid before the waves reach the weld. The lower figures in Fig.5 shows the interaction of the waves with the joint. This is shown in more detail in Fig.6. A lot of attenuation into the liquid is observed, induced by the fillet weld geometry. Figure 7 shows the energy still existing in the lower steel plate after passing through the lap joint.

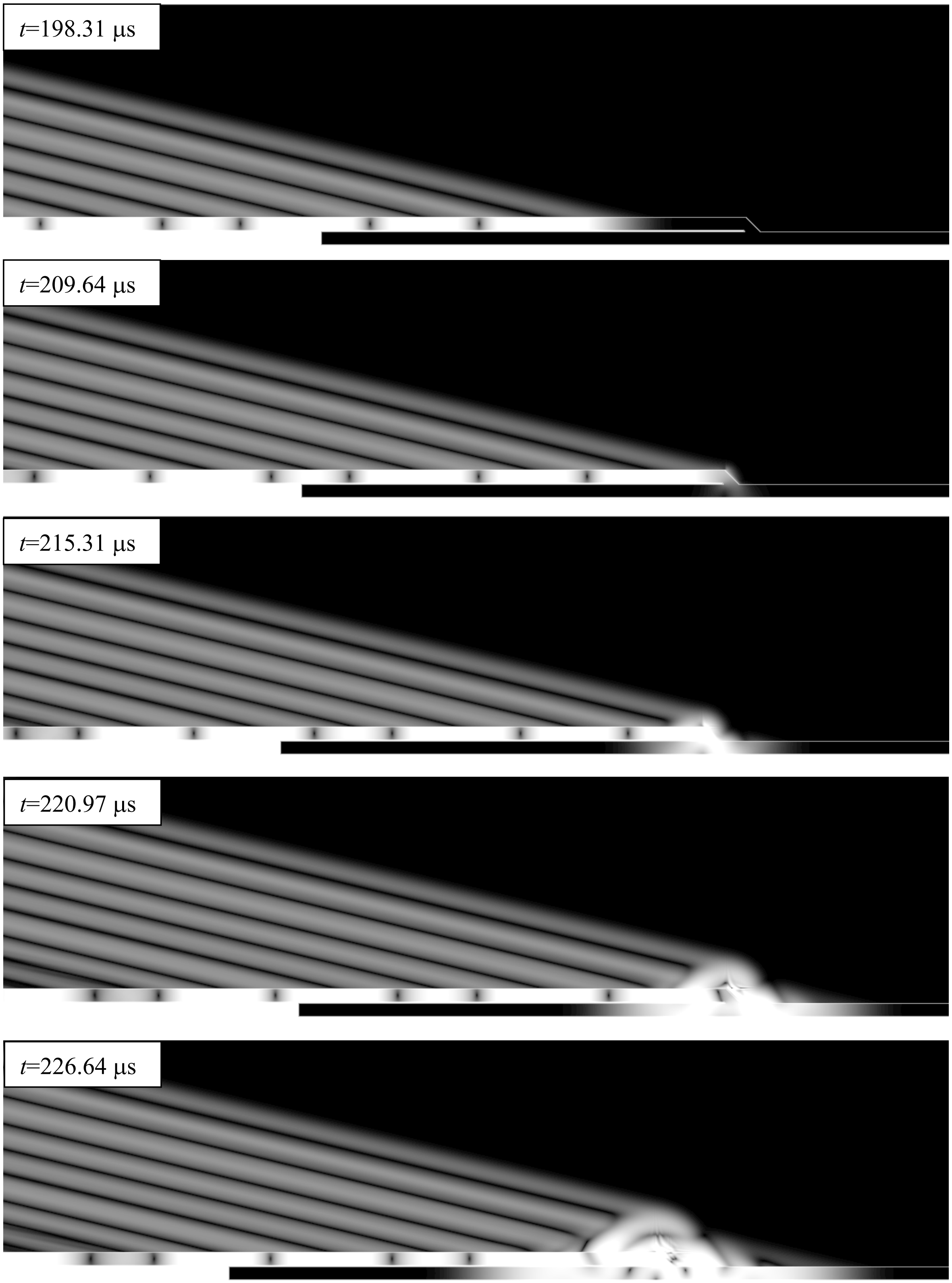

**Figure 5 Lamb wave propagating in steel lap joint at different moments in time**

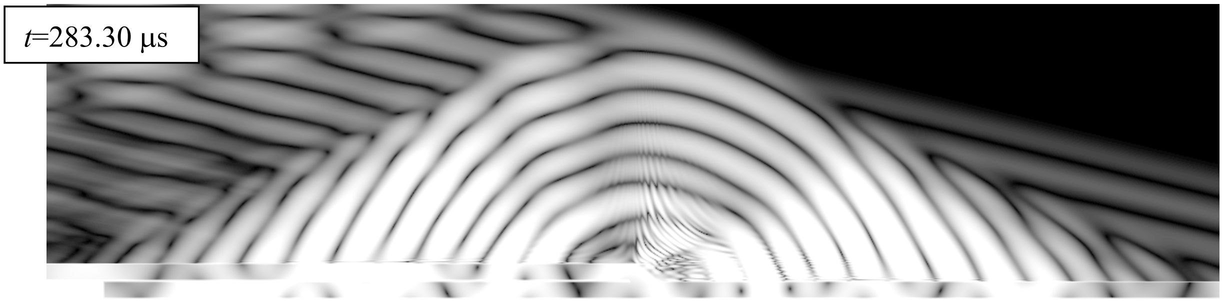

**Figure 6 Finite element modelling results around lap joint**

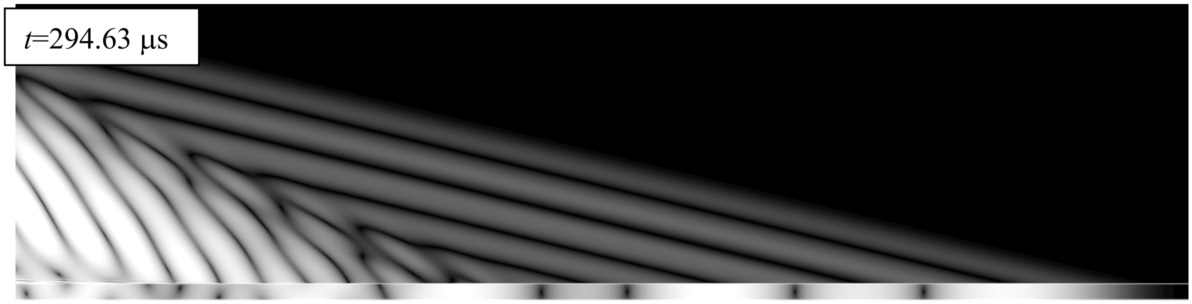

**Figure 7 Finite element modelling results after lamb wave has passed through fillet weld**

## 5. Conclusions

There is great potential for the use of guided waves to inspect tank floors in-service. The work has shown that modelling can be used to select wave modes to optimise the minimisation of attenuation losses into the liquid contents of the tank. The modelling has also shown that lamb waves can propagate past fillet welds and therefore there is potential for detecting corrosion anywhere on a typical tank floor with lap joints.

## 5 Acknowledgement

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