Ultrasonic Detection of Embedded and Surface Defects in Thin Plates Using Lamb Waves

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1 Introduction

Non-destructive Testing and Evaluation (NDT&E) is critical in the safety assurance of modern engineering structures. One of the most common techniques used in NDT&E is ultrasonic testing. Conventional ultrasonic NDT&E relies mainly on through thickness wave propagation. For plate-like sections, this is a very slow process. The present research is focused on exploring an alternative form of propagating waves. Lamb waves are waves that propagate longitudinally along a plate (as opposed to transversely through the plate thickness). At least two propagating (Lamb) modes can exist at any given frequency. These modes are classified as either symmetric or anti-symmetric. The lowest order symmetric mode is denoted S_0 and this is the mode which has been used in this work. The characteristic equation for symmetric Lamb waves in aluminium ($\nu = 1/3$) is given in (1).

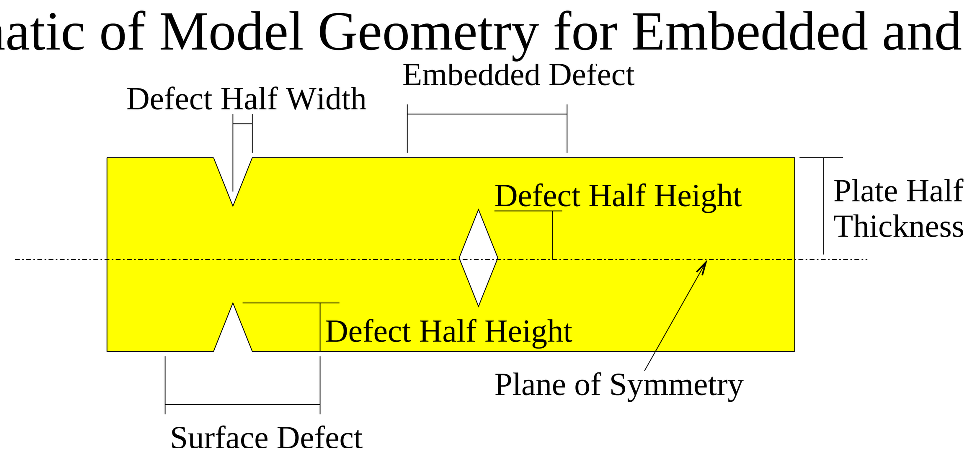
$$\frac{\tanh \bar{s}}{\tanh \bar{q}} = \frac{4F^2 \bar{q}\bar{s}}{\left(2F^2 - \Omega^2\right)^2} \qquad (1)$$

Here, Ω (or dimensionless frequency) is defined as $\omega d/c_t$, $\bar{q}$ as $\sqrt{F^2 - \Omega^2/4}$, and $\bar{s}$ as $\sqrt{F^2 - \Omega^2}$. ω is angular frequency, d is the plate half thickness, F is the dimensionless wavenumber, and c_t is the transverse wave speed of the plate material.

2 Finite Element Modelling

The models presented here were implemented in ABAQUS, using two dimensional plane strain, linear elastic elements. The material properties used for the plate are those of **aluminium**: Young's modulus ($E = 70.7\mathrm{GPa}$), Poisson's ratio ($\nu = 1/3$) and density ($\rho = 2700\ \mathrm{kg/m^3}$). A steady state dynamic analysis was performed. Frequencies in the range $\Omega < 2$ were used as this is safely below the cut off frequency of the S_1 mode. The results presented here relate to two classes of "lozenge" shaped symmetrical defects, studied separately in half plate models. Surface breaking and embedded defects have been studied. The defect geometries can be seen in fig. 1.

Figure 1: Schematic of Model Geometry for Embedded and Surface Defects



One height of defect will be presented here, which is 60% of plate thickness. This is a large defect, and has been chosen to emphasise some features of Lamb wave reflection. The defect width is varied from 0.0 to 0.6 of plate thickness. Reflection coefficient is plotted against defect width for embedded (fig. 2) and surface breaking (fig. 3) defects. The reflection coefficient is the ratio of the amplitude of the wave reflected from the defect to that of the incident wave.

Figure 2: Reflection Coefficients for Central Embedded Defect (0.6)

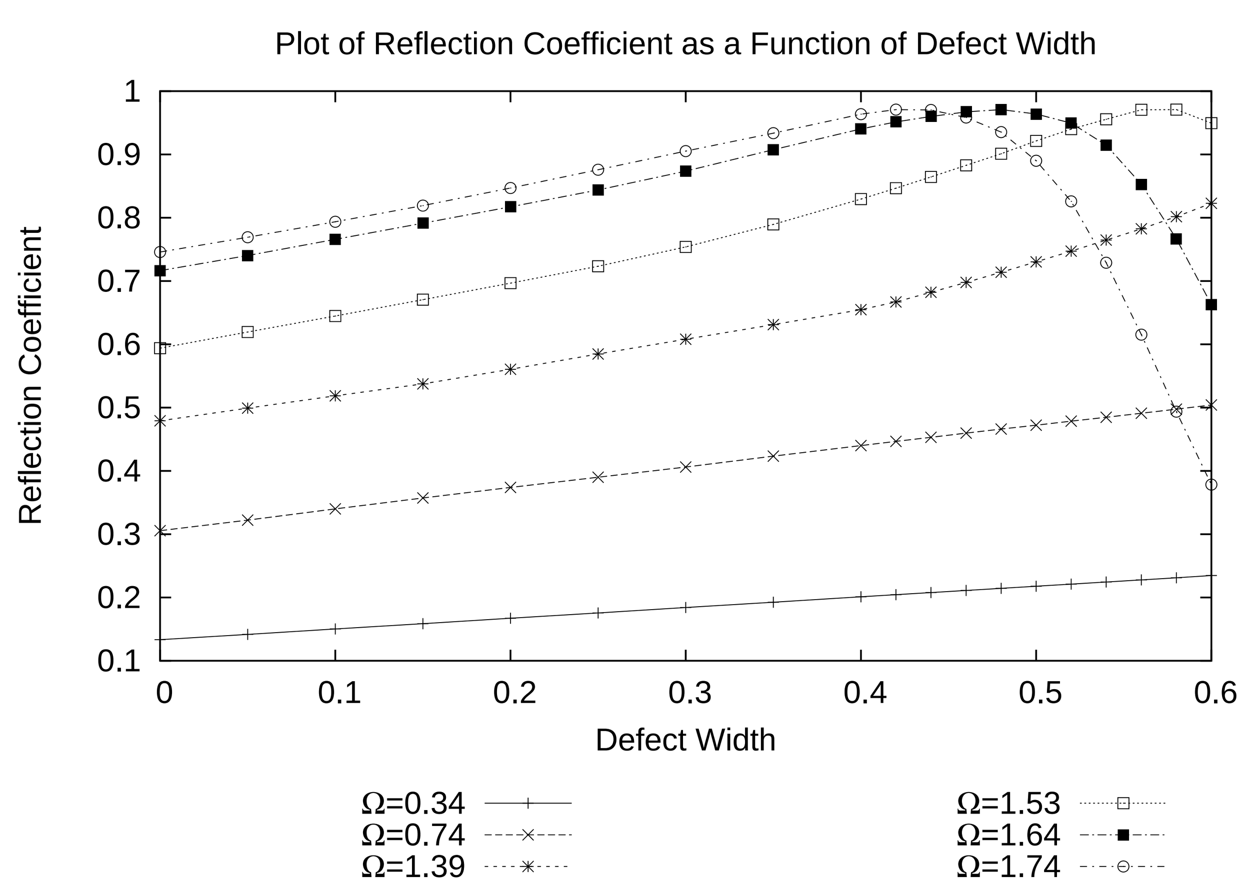


Figure 3: Reflection Coefficients for Symmetrical Surface Defect (0.6)

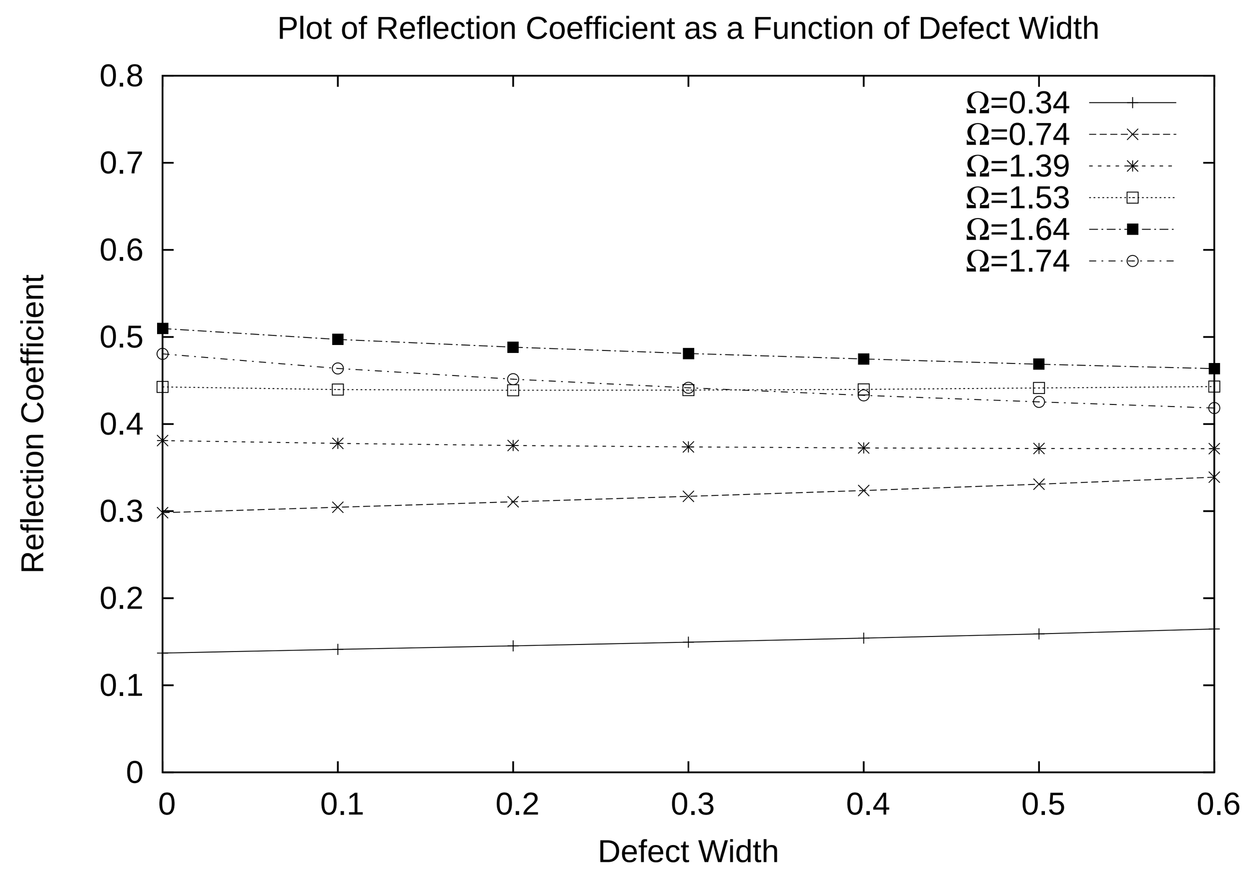
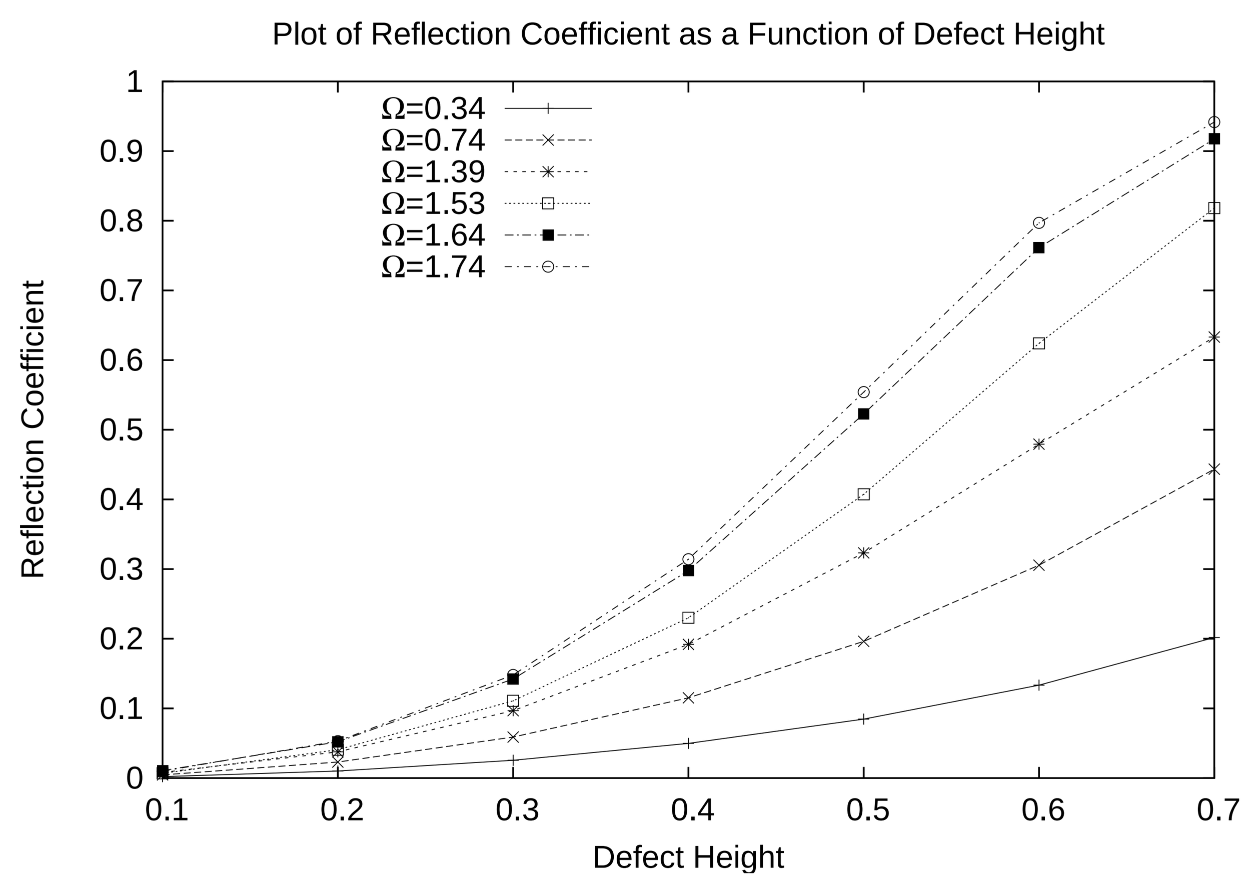


Figure 4: Reflection Coefficients for Vertical embedded Crack



3 Discussion

From the results of the analyses presented in § 2, it is clear that the reflection coefficient from embedded defects depends strongly on the defect width. This dependence is very weak for surface defects. Koshiba has observed a similar distinction in the behaviour of surface breaking versus embedded defects [Koshiba et al., 1984].

Also clearly apparent is that for particular combinations of defect width and frequency, the reflection coefficient peaks at near unity, and then falls rapidly as defect width increases further. Higher frequencies peak for narrower defects. Indeed the wavelength and peak reflection defect-width are roughly proportional. The overall frequency/reflection relation: that defects reflect better at higher frequencies (at least until resonant behaviour occurs) is also apparent. This relationship is also true for simple vertical defects, as can be seen in fig. 4.

Assuming the resolution of a signal processing system can distinguish reflection coefficients greater than 10% from background noise, it is clear that all widths of defect studied could be potentially detected. The difficulty that a given reflection coefficient for a particular frequency input could correspond to one of two defect widths (or, in general, to a different height width combination) could possibly be to overcome by evaluating the behaviour of a range of frequencies. The combined behaviour of the components could give a signature for the defect. For surface defects, it would be more straightforward to determine defect depth, though there would be very little information on defect width.

4 Acknowledgements

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References

[Koshiba et al., 1984] Koshiba, M., Karakida, S., and Suzuki, M. (1984). Finite-element analysis of Lamb wave scattering in an elastic plate waveguide. *IEEE Transactions on Ultrasonics, Ferroelectrics and Frequency Control*, 31:18–24.