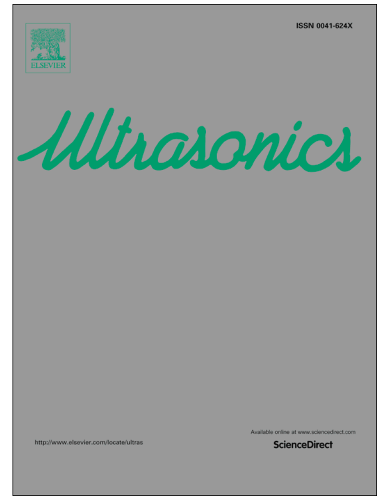
Accepted Manuscript



Comparison of Quasi-Rayleigh Waves and Rayleigh Waves, and Clarifying the Cut-Off Frequency of Quasi-Rayleigh Waves

Christopher Hakoda, Cliff J. Lissenden

PII: S0041-624X(18)30449-9
DOI: https://doi.org/10.1016/j.ultras.2018.08.021
Reference: ULTRAS 5819

To appear in: *Ultrasonics*

Received Date: 29 June 2018
Revised Date: 22 August 2018
Accepted Date: 31 August 2018

Please cite this article as: C. Hakoda, C.J. Lissenden, Comparison of Quasi-Rayleigh Waves and Rayleigh Waves, and Clarifying the Cut-Off Frequency of Quasi-Rayleigh Waves, *Ultrasonics* (2018), doi: https://doi.org/10.1016/j.ultras.2018.08.021

Comparison of Quasi-Rayleigh Waves and Rayleigh Waves, and Clarifying the Cut-Off Frequency of Quasi-Rayleigh Waves

Christopher Hakoda[a)] and Cliff J. Lissenden[b)]

Department of Engineering Science and Mechanics, Pennsylvania State University, University Park, PA 16802 USA

a) cnh137@psu.edu

b) Lissenden@psu.edu

Abstract. The Partial Wave Method is unique in that it establishes a foundation on which various elastodynamic guided waves can be compared. In this paper, the method is used to compare quasi-Rayleigh waves and Rayleigh waves, and investigate the eccentricities of the Partial Wave Method at phase velocities equal to the Rayleigh wave speed. The comparison results in the definition of two types of quasi-Rayleigh waves and an explanation for quasi-Rayleigh wave behavior reported in the literature at frequencies that do not satisfy Viktorov's quasi-Rayleigh wave condition. These conclusions are also verified by the superposition of A0 and S0 mode wave-structures calculated using the semi-analytical finite element method.

1. INTRODUCTION

To the best of the authors' knowledge, quasi-Rayleigh waves were first investigated in detail by Viktorov in [1], which was written in Russian and then translated into English and used as a subsection in Viktorov's book [2]. The contents of the book's subsection will be used primarily for this paper as opposed to the original paper. The quasi-Rayleigh wave is described as a superposition of A0 and S0 Lamb wave modes which interfere in such a way that the resulting wave-structure has an appearance similar to a Rayleigh wave. Michal et al. [3] contains a nice graphic showing the superposition and the resulting quasi-Rayleigh wave's wave-structure.

The quasi-Rayleigh wave will also exhibit a beat phenomenon in which the wave energy will appear to switch, back and forth, between the top and bottom surfaces of the plate. The effect of the beat phenomenon on wave-propagation can be seen in a waterfall plot shown by Masserey and Fromme [4]. Referred to as the beat length, L is the distance of propagation before the quasi-Rayleigh wave switches from one surface to the other and then back,

$$L = \frac{2\pi}{(k_{A0} - k_{S0})}. \tag{1}$$

The expression is intended to be a calculation at a single frequency where k_{A0} and k_{S0} are the wavenumbers of the A0 and S0 modes, respectively. The difference between wavenumbers yields a phase difference when multiplied by the propagation distance. When the phase difference is equal to π, the quasi-Rayleigh wave switches to the opposite surface. When the phase difference is equal to 2π, the quasi-Rayleigh wave switches back to its original surface [5]. Besides these characteristics, a general condition for the existence of a quasi-Rayleigh wave was approximated by Viktorov to be,

$$H \geq 2\lambda_R, \tag{2}$$

where H is the plate thickness and λ_R is the Rayleigh wave's wavelength [2]. Experimental evidence appears to be the origin of the condition, but the extent of the research is unknown from the literature available. For the purposes of this paper, henceforth, eq. 2 will be referred to as Viktorov's condition. The term "frequency-thickness product" will be used frequently throughout the paper to refer to an axis-specific convention common to the ultrasonic guided wave literature, see Figure 8-8 in Rose's book [6].

There are two objectives to this paper. The first objective is to briefly address the relationship between the quasi-Rayleigh wave and the Rayleigh wave by using the Partial Wave Method. The second objective is to develop an explanation for why quasi-Rayleigh wave behavior has been experimentally observed at frequencies that do not satisfy Viktorov's condition. To meet these objectives, two types of quasi-Rayleigh waves will be defined based on the criteria stated in the literature; a so-called "strict" definition and a "lenient" definition.

To summarize the contents of the paper by section, Section II develops the case that quasi-Rayleigh waves and Rayleigh waves are indeed separate modes of wave-propagation by analyzing their relationship through the perspective of the Partial Wave Method. Subsection 3.1 discusses a quirk of the Partial Wave Method when using the approach outlined by Hakoda and Lissenden [7]. Subsections 3.2 and 3.3 describe the strict and lenient definitions of a quasi-Rayleigh wave, respectively. The superposition of wave-structures calculated using the Semi-Analytical Finite Element (SAFE) method are provided to assist in verifying the results of the Partial Wave Method