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Measurement of Love wave propagation characteristics along elastic substrate and viscoelastic surface layer

粘弾性表面層を有する弾性体における Love 波伝搬特性の測定

Yusuke Chiba‡, Tadashi Ebihara*, Koichi Mizutani and Naoto Wakatsuki
(Univ. of Tsukuba)
千葉裕介 [1†]，海老原格 [2*]，水谷孝一 [2]，若槻尚斗 [2] ([1] 筑波大院・シス情工, [2] 筑波大・シス情系)

1. Introduction

Measurements of material properties using elastic waves have been widely used in various engineering fields.[1)] Elastic wave can be roughly classified mainly as bulk wave, surface acoustic wave (SAW) and guided wave, and are utilized as visualization of biomedical tissue or non-destructive evaluation to long distance structure.[2-3)] In particular, at viscoelastic evaluation field, Morita *et al.* have reported a method using shear-horizontal surface acoustic wave (SH-SAW).[4)] By using SH-SAW, which propagates along surface of piezoelectric substrate, shear modulus and viscosity can be measured from the propagation characteristics. It is one of the best solution to evaluate material viscoelasticity in small quantity. However, SH-SAW can propagate only surface of piezoelectric substrate. Moreover, viscoelastic evaluation area is limited within dimensions of the piezoelectric substrate. Therefore, viscoelastic evaluation using SH-SAW may not suitable for viscoelastic evaluation that distributed over wide area.

In this study, to evaluate material viscoelasticity in wide area, the author proposes viscoelastic evaluation method using Love wave Love wave is the shear horizontal wave propagating along substrate on surface layer[5)]. Love wave does not require piezoelectricity of substrate, therefore material viscoelasticity of surface layer on non-piezoelectric substrate can be evaluated. The authors have reported calculation method of propagation characteristic from displacement of Love wave and estimation method of viscoelastic constants from propagation characteristics of Love wave. [6)] In this paper, as pilot study, displacement of Love wave is measured using lase Doppler vibrometer, and phase velocity of Love wave is calculated by using measured displacement.

2. Experimental setup

Figure 1 shows an experimental system for measuring displacement on surface of layer-structured specimen. The specimen consists of acrylic resin and aluminium alloy as viscoelastic surface layer and elastic substrate, respectively. The surface layer and the substrate adhered each other by using epoxy resin adhesive. To excite Love wave, two piezoelectric vibrators (C-213, Fuji ceramics) having thickness shear mode were used. Electric field direction of the vibrator was the same, and poling direction of that was opposite as shown in Fig. 1. The vibrators were applied to sine-burst signal emitted from a function generator (FG; 33120A, Hewlett Packard). Frequency, amplitude and duration time of the signal were 150 kHz, 1.5 V and 26.67 μs, respectively. The voltage of signal was amplified 100 times by using a power amplifier (HSA4052, NF).

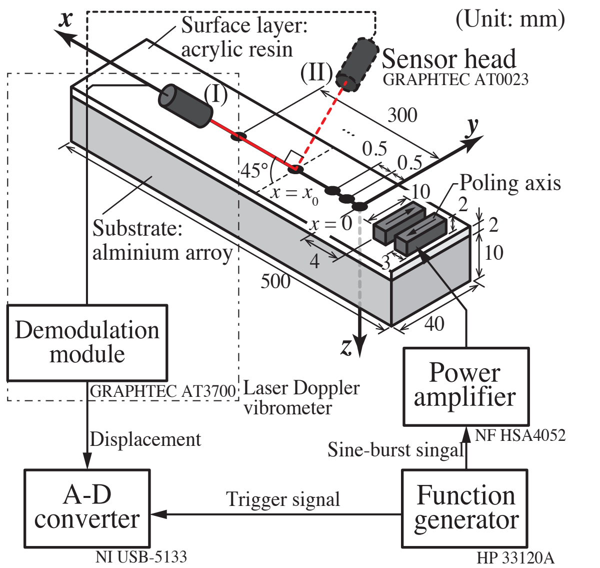

Fig. 1 Experimental system for measuring displacement of Love wave on surface of layer-structured specimen.

Displacement on surface of the specimen were measured by using laser Doppler vibrometer (LDV). The specimen was inclined that angle between the surface and axis of laser light radiated from a sensor head (AT0023, GRAPHTEC) of the LDV was 45 degrees. Displacement were measured by radiating laser light toward the inclined surface and converting scattering light using a demodulation module (AT3700, GRAPHTEC). When laser light was radiated toward the surface of the specimen, scattering light from the surface was converted to displacement. Displacement were recorded by using A-D converter (NI USB-5133, National Instruments) while syncing signal output of the FG. Sampling frequency and record time of the A-D converter is 2 MHz and 150 μs, respectively. When displacement was measured, a point to be 4 mm away from a vibrator toward *x*-axis was set as origin of coordinates. The specimen was moved by *x*-stage from the measurement start point to 30 mm at 0.5 mm intervals while measuring displacement.

3. Measurement of Love wave displacement using laser Doppler vibrometer

In general, laser light of LDV is radiated toward vibrating plane orthogonal to the laser light axis, and normal direction vibration of the plane can be detected as Doppler shift of the laser light. On the other hand, Love wave is in-plane vibration, therefore displacement of Love wave cannot be measured by using single laser light of LDV. To solve this problem, displacement was measured at the same point by using different optical path of the laser light (I) and (II). Difference and sum of displacements measured by path (I) and (II) were calculated, displacements by in-plane vibration ((I)-(II)) and out-of-plane vibration ((I)+(II)) can be measured.

Figure 2 shows displacements of (a) in-plane vibration and (b) out-of-plane displacement at surface of the specimen. Horizontal and vertical axes indicate elapsed time of signal output from FG and distance from origin of coordinates, respectively. Color bar denotes amplitude of displacement. In the Fig. 3(a), displacement by in-plane vibration caused by sine-burst signal is observed. In addition, number of waves increases according to get longer distance from origin of coordinates because of dispersity of elastic wave. In the meanwhile, in Fig. 3(b), displacement by out-of-plane vibration is hardly detected. The observation results indicate that longitudinal or shear vertical wave does not propagate in the specimen. Therefore, it appears that an elastic wave shown in Fig. 3(a) is Love wave.

Next, phase velocity of Love wave was calculated from Fig. 3(a). Time difference of first wave front in Fig. 3(a) at x = 0 mm and x = 30 mm was calculated. Fig. 2 shows theoretical and experimental phases velocity of Love wave. Theoretical phase velocity was calculated by characteristic equation analyzed by Sezawa *et al.*[7] Material properties (μ: shear modulus, η: viscosity, ρ: density and h: surface layer thickness) of the surface layer and the substrate were below: surface layer were μ_1 = 1.19 GPa, η_1 = 0 Pa s, ρ_1 = 1,190 kg/m^3, h = 2 mm, and substrate were μ_2 = 25.5 GPa, η_2 = 0 Pa s, ρ_2 = 2,690 kg/m^3. In the Fig. 2, theoretical phase velocity at 150 kHz is 1,648 m/s, however, experimental phase velocities is 2,400 m/s. Although the experimental phase velocity is smaller than shear wave velocity of the substrate (3,078 m/s), theoretical and experimental phase velocity is different. The reasons may be presented as follows: existence of adhesive layer between the surface layer and the substrate or interference caused by reflected wave.

4. Conclusions

In this paper, as pilot study, displacement of Love wave propagating viscoelastic surface layer on elastic substrate was measured by using LDV, and phase velocity of Love wave is calculated. As a results, it appeared that displacement obtained from LDV is Love wave. In the meanwhile, experimental phase velocity was larger than theoretical one. In the future works, the authors examine factors of error between experimental and theoretical phase velocity. Moreover, the authors also measure attenuation of Love wave.

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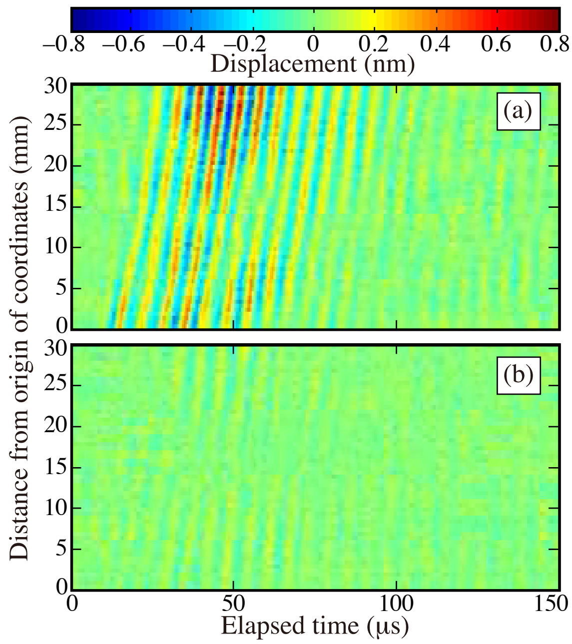

Fig. 3 Displacements on surface of specimen with changing measurement point using laser Doppler vibrometer. Plots (a) and (b) denote in-plane and out-of-plane vibration, respectively.

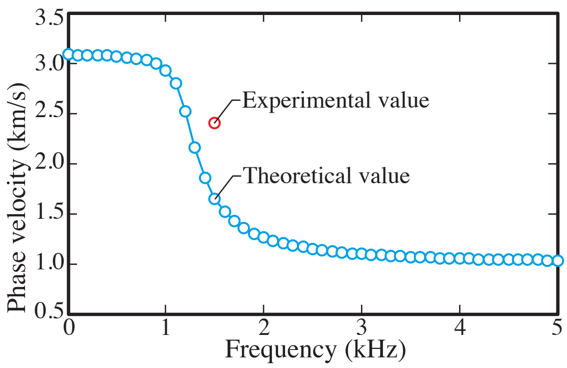

Fig. 2 Theoretical and experimental phase velocity of Love wave.