049 **ACCURACY OF SHEAR MODULUS RECONSTRUCTION DEPENDS ON IGNORING MEAN NORMAL STRESS DISTRIBUTION.**

Chikayoshi Sumi[1].*

[1]Dept of Info & Commun Sci, Sophia University, 7-1, Kioicho, Chiyodaku, Tokyo JAPAN.

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Summary: The effects of ignoring a mean normal stress distribution on a shear modulus reconstruction are investigated through simulations. As theoretically predicted, for stiff and soft inclusions, the shear moduli are estimated to be higher and lower than the originals, respectively.

1. Introduction

Mechanical properties such as viscoelasticities (e.g., [1]) are estimated using various mechanical sources such as a heart motion, a low frequency compression/stretching, an applied vibration, an acoustically radiated force etc. Such estimation is performed through measurements of deformations, shear wave propagations etc. The properties can also be reconstructed numerically or via signal processing. A stress tensor, internal mechanical sources and a mean normal stress can also be reconstructed simultaneously. However, various artifacts possibly occur under various assumptions such as an incompressibility, a low dimensionality of the mechanical property distributions (e.g., [2-4]), etc.

For the reconstruction of a shear modulus distribution, the distribution of a mean normal stress is often ignored. In this report, the effects of ignorance are investigated through simulations [5,6]. Theoretically, an assumption of a uniform mean normal stress distribution leads to reconstruction errors.

2. Theoretical prediction

The effect of ignorance the mean normal stress p can be theoretically predicted using a simple model having a stiff or soft inclusion (Fig. 1). By considering signs of the respective mechanical quantities for the inclusion cases, the effects can be predicted. For stiff and soft inclusion cases, the shear moduli will be estimated to be higher and lower than the originals, respectively. The same prediction can be obtained for stretching and compressional cases.

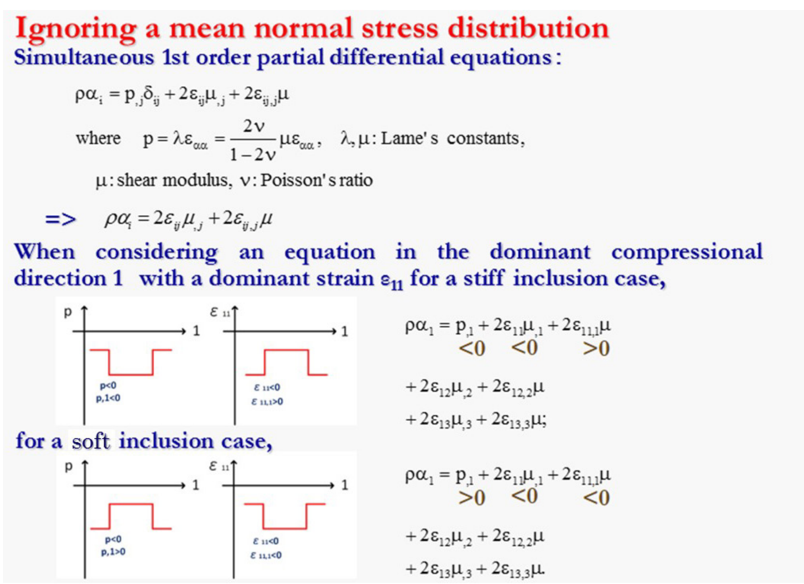

Fig. 1. Signs of respective quantities for stiff and soft inclusion cases.

3. Simulations

3.1 Methods

Various linear numerical cubic phantoms (50 mm sides) were dealt with. For instance, a Poisson's ratio was assumed to be uniform or nonuniform (~0.49). The phantoms had a stiff or soft spherical inclusion (10 mm dia.). The respective phantoms were compressed/stretched or vibrated (1 Hz, 10 Hz, 100

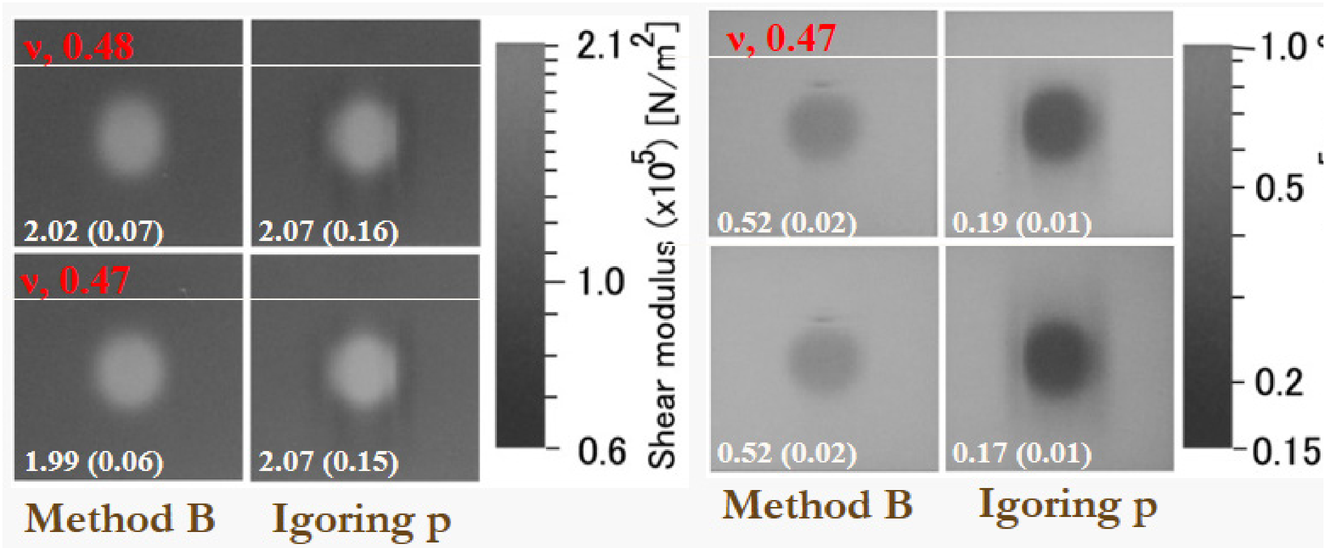

Fig. 1. For high and low shear modulus inclusions (2.00 and 0.50 vs 1.00 $\times 10^5$ N/m^2), log-gray-scaled images of shear modulus reconstructions using reconstruction methods (left) without and (right) with ignoring mean normal stress p for Poisson's ratios = 0.48 and 0.47 (for soft inclusion, only 0.47, however with using reference shear moduli far from inclusion, i.e., upper surface of ROI). Method without ignoring p is referred to as Method B in [3]. Means and SDs evaluated in inclusions are depicted.

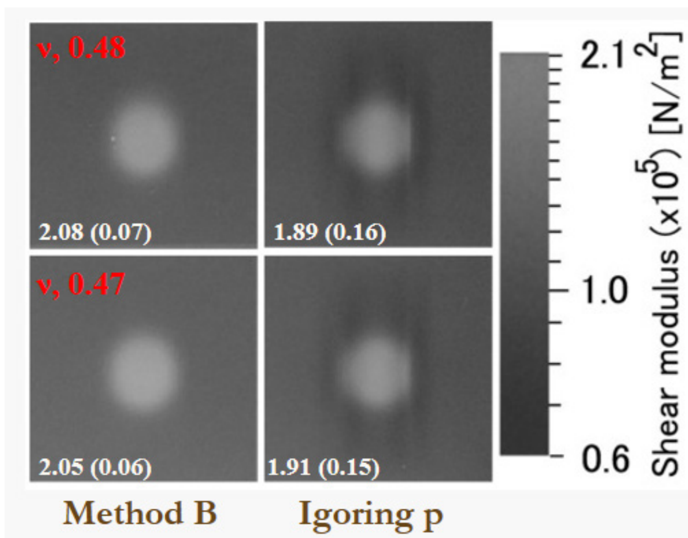

Fig. 2. For high shear modulus inclusion model (2.00 vs 1.00 $\times 10^5$ N/m^2) using reference shear moduli far from inclusion (upper surface of ROI), log-gray-scaled images of shear modulus reconstructions using reconstruction method (left) without and (right) with ignoring mean normal stress for Poisson's ratios = 0.48 and 0.47. Method B is referred to in [3]. Means and SDs evaluated in inclusions are depicted.

Hz) in a depth direction using large external sources generated at the top planes of the phantoms. The forward calculation was performed using the successive-over-relaxation (SOR) method. Using the reconstruction Method B described in [3], the shear modulus distribution was reconstructed together with the mean normal stress distribution (i.e., with Poisson's ratio distribution); and the shear modulus was also reconstructed using the method ignoring a mean normal stress distribution. Cubic ROIs with 30 mm sides were set on the center of the phantoms. The means and standard deviations (SDs) of reconstructed shear moduli were estimated in inclusions.

3.2 Results

For instance, for both phantoms having uniform Poisson's ratios 0.48 and 0.47 and an inclusion with a shear modulus higher than the surrounding region (2.0 vs 1.0$\times 10^5$ N/m^2), as theoretically predicted, the shear moduli of the inclusion was estimated to be larger than the original value, i.e., inaccurate [for respective Poisson's ratios 0.48 and 0.47, means (SDs) are 2.07 (0.16) vs 2.02 (0.07) and 2.07 (0.15) vs 1.99 (0.06)$\times 10^5$ N/m^2] (Fig. 2). The SDs also became larger (i.e., unstable). For soft inclusion phantoms, as

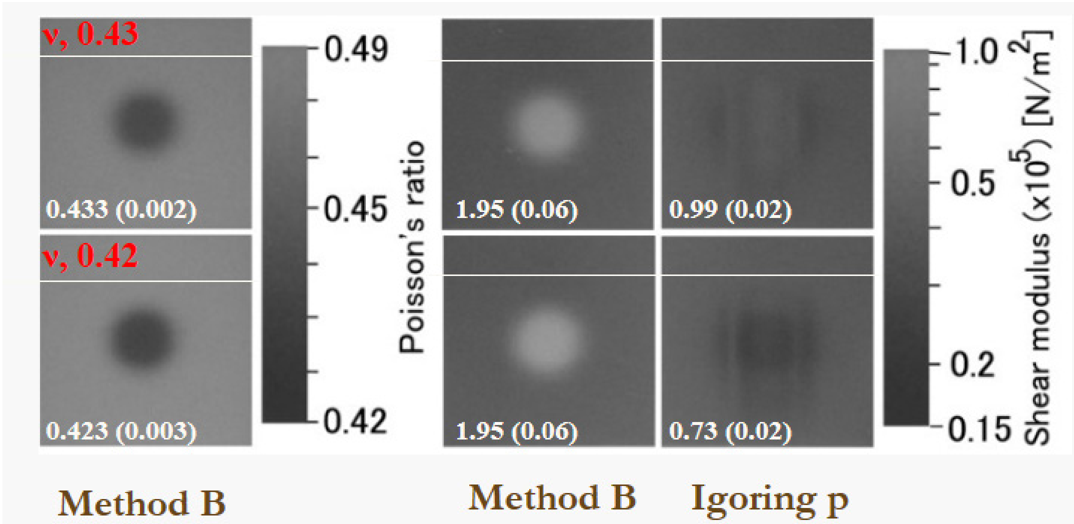

Fig. 4. For an inhomogeneous Poisson's ratio (Poisson's ratios = 0.43 and 0.42 in inclusion vs 0.47 in surrounding) and a high shear modulus inclusion (2.00 vs 1.00 $\times 10^5$ N/m^2), log-gray-scaled images of Poisson's ratio (left) and shear modulus (center) reconstructions using Method B [3] and shear moduli obtained with ignoring mean normal stress (right).

theoretically predicted, the shear modulus was estimated to be smaller than the original value (for instance, for a half shear modulus, 0.5×10^5 N/m^2 and Poisson's ratio, 0.47, means and SDs were respectively 0.19 (0.01) vs 0.52 (0.02)$\times 10^5$ N/m^2 (Fig. 2). At the surrounding regions of the inclusions, reconstruction errors were also detected rather for 0.48 than for 0.47. These results were obtained using reference shear moduli situated in a 5mm depth (depicted with white lines in Fig. 2). When performing the reconstruction ignoring the mean normal stress and using reference shear moduli far from an inclusion (upper surface of ROI), the reconstruction became inaccurate significantly (see a soft inclusion in Fig. 2 and stiff inclusions in Fig. 3). The high shear moduli were estimated to be smaller than the original; and the reconstruction errors at the surrounding region of the inclusion became intense.

When an inclusion had a smaller Poisson's ratio than that of the surrounding region (smaller than 0.43 vs 0.47), the twofold shear modulus was estimated to be smaller than that of the surrounding under the same assumption (for instance, when Poisson's ratio was 0.42, a mean was 0.73×10^5 N/m^2). See Fig. 4.

For the respective same phantoms, completely the same results were obtained in compression and stretching cases. For the dynamic deformation cases, results similar to the static deformation cases were also obtained (omitted).

4. Conclusions

The effects of ignoring a mean normal stress distribution were investigated. Theoretically predictable results were also numerically confirmed both for static and low frequency deformations. High and low shear modulus inclusions were respectively estimated to have higher and lower shear moduli than the originals. For imaging with a large dynamic range, the ignorance may be effective to increase the detectability of an inhomogeneous elasticity. However, inaccurate measurements were yielded. The ignorance also made the reconstruction sensitive to the position of the reference shear moduli. It was more sensitive for a high Poisson's ratio. Similar artifacts are generated when ignoring internal mechanical sources, viscosity, nonlinear properties, isotropic properties. Occasionally performed assumption of a local homogeneity also affects the reconstruction (i.e., decrease in a spatial resolution as well).

References

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