PERFORMANCE PREDICTION OF A TILE

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Introduction

For a variety of naval architectural applications elastomeric decoupling tiles have been designed. The behaviour of these tiles under practical conditions requires investigation. Prototype tile designs are expensive and it is difficult to reproduce all expected marine environments. It is necessary to resort to theoretical predictions of the tile behaviour to complement any experimental data [1].

A finite element analysis of the structural response is proposed. An important consideration lies in describing the hydrostatic deformation of the tile since its collapse under pressure changes its acoustic character. This non-linear static solution forms the basis of a prediction of the dynamic transmission loss. A similar investigation of the dynamics of decoupling tiles has been made [2] which is restricted to only very shallow depths as the effect of hydrostatic loading is ignored.

Construction

Consider a generic elastomeric tile designed to be an acoustic reflector. It is composed of a combination of natural and neoprene rubbers. The tile has a large number of identical cylindrical air filled voids arranged in a regular pattern.The regularity of the spacing allows for the simplification of the problem by considering only a section of a single void with appropriate boundary conditions (figure 1).

The rubbers used in the tile's fabrication are common materials. Nevertheless simple elastic moduli (which are frequency dependent) for such substances are difficult to obtain in practice [3]. These materials are almost completely incompressible and readily exhibit large strains. Special provision for their behaviour in both static and dynamic conditions must be made.

Theory

Two distinct aspects of this problem are identified; the hydrostatic deformation and the dynamic response. These are indicated by the tile's compressibility and transmission loss respectively. The static problem precedes the dynamic, only the stiffness matrix is modified by the hydrostatic forces. The loading is applied incrementally by the application of pressure as in the case of a bare tile or by a rigid boundary or anvil (figure 2.). The rigid anvil simulates the case where the tile is used as a mechanical isolator sandwiched by plates, for example. A converged solution is achieved iteratively and requires that the internal forces generated by the deformation be in equilibrium. As the anvil moves downwards onto the tile segment the reaction forces at the tile's surface give the equivalent depth pressure at a given deflection.

The possibility of large (i.e. finite) displacements is allowed for in this work. Geometric stiffening effects are included. The void walls may come into contact during the deformation process and their mutual interaction is incorporated. This is achieved by the introduction of slide-line elements. These are attached to the void walls and produce an increase in stiffness when surfaces coalesce. Sliding between interacting surfaces is unconstrained.

Interior void pressure may become significant as large volume changes arise. This is a possible mechanism contributing to structural hardening as depth is increased. The inclusion of a consistent interior void pressure is a difficult problem. No isothermal gaseous compression is permitted as the static finite element method forbids heat dissipation. However, an interior void pressure can be included assuming that the elastomeric material is truly incompressible and the gas ideal.

The dynamic behaviour is linear. Motion is limited to small (i.e. infinitesimal) harmonic fluctuations. The response is derived from a direct integration of the mass and stiffness matrices at a selected frequency. The effect of fluid loading is achieved by incorporating acoustic finite elements into the model or by the assumption that a simple acoustic plane wave is excited. The latter method imposes an appropriate boundary condition on the tile's normal velocity at its surface. The transmission loss is defined to be the ratio of pressure amplitudes at the fluid-structure boundary due to a harmonic excitation of the hull with and without the tile.

Material

In static investigations on rubber structures great success has been gained from using a hyperelastic material model rather than assuming linear elastic behaviour. A Mooney Rivlin or Ogden material model may be appropriate [3]. Here the material is assumed nearly incompressible and obeys a simple strain energy law. The deformation is not restricted to small strains: the pertinent variables being the principal stretches which are finite. The strain energy is taken to be a polynomial in the principal stretches with appropriate, and possibly temperature dependent, coefficients.

The simplest Mooney Rivlin model is adopted. Only two coefficients are required, values for which are known for natural rubber. Data for neoprene are derived from scaling the natural rubber data to the appropriate stiffness. Calculations simulating compressive tests on rubber samples confirm the model's validity. Owing to the model's simplicity, the coefficients are directly related to dynamic linear moduli based on a viscoelastic material. This gives an effective complex Young's modulus and a Possion's ratio of nearly one half.

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Models

Two models are adopted: a full three dimensional (3D) mesh based on a wedge section (figure 1.) and a simplified axisymmetric mesh with an effective outer radius.

The development of the axisymmetric model has advantages. Its ease of modification and fast computation compare favourably with the 3D case. The dominant mechanisms can be identified at different depths, thus reducing the much more significant computational effort required for the full 3D model. An effective radius was chosen to reprcduce the same linear deflection as the full 3D model. However, the axisymmetric model is still likely to be over stiff when including non-linear effects such as void wall contact. In addition the initial volume of the axisymmetric model is not that of true 3D section although its compressibility at depth must be similar.

The presence of the steel hull is included. It is taken to be fixed and rigid in the static case and described as an elastic plate during the dynamic analysis. For the frequency ranges considered the hull simply behaves as a mass loading.

Compressibility

The hydrostatic pressure is obtained from the computed reaction forces assuming perfect contact with the flat rigid anvil and that the surface area remains constant. Only a rigid-plate/tile/rigid-plate sandwich configuration is considered. This closely conforms to the experimental situation where the tile is sandwiched between plates of thick steel [1]. The free-surface case may be tackled but requires a different solution procedure.

Initial calculations based on a simple linear statics and material model indicate that the void walls begin to touch at moderate depths. This is inferred from an examination of the displacements near the void wall corners. Introducing slide-line elements to an axisymmetric model suggests a small increase in stiffness due to wall interaction. This is not surprising as the linear statics model predicts only very small relative motion between the walls. Calculations allowing for large displacements reveal that wall interaction ensues at slightly shallower depths but it is still not very strong (figure 3.).

When incorporating a hyperelastic material model the full consequences of the incompressible nature of the rubbers is apparent. The onset of wall interaction is almost immediate and rapidly increases. This is due to the rapid flow of material into the void cavity. The change in structural stiffness is marked as depth increases. Consideration of internal void pressure is only necessary at larger depths. Assuming incompressible material and an ideal isothermal gas, the void pressure is related to the current anvil displacement. The internal void walls experience a pressure which is deformation dependent. This non-linear effect tends to stiffen the structure but only when the void volume is very small compared to its original size.

Good accord with experiment [1] is seen even with the simple axisymmetric model (figure 3.). The agreement is improved when considering the full 3D case which is less stiff. It is interesting to note that the cylindrical shape of the void remains broadly intact (albeit smaller) even at very great pressures. Clearly the combination of incompressible material behaviour and void wall interaction is necessary to adequately describe the hydrostatic deformation. The predicted compressibilities are dependent on the Mooney Rivlin coefficients. This dependence is amplified when the wall interaction is strong. Thus to improve the calculations accurate material data is vital.

Transmission Loss

Here the tile is in direct contact with the water. Acoustic radiation normal to the top surface is assumed. Perfect contact between the hull, tile and water is enforced. The frequency dependent moduli, obtained from experiments on rubber samples are tabulated at specific frequencies. Linear interpolation is used to derive the complex Young's modulus at any general frequency value.

The water is described by acoustic fluid finite elements. These have a suitable damping term to reduce the effect of spurious reflections from the fluid mesh boundary. There is a simpler way of including effective fluid loading. Here the transmission loss can be viewed as the force at the hull's inside wall due an enforced motion at the fluid boundary. The displacement amplitude varies as the reciprocal of the frequency, characteristic of an acoustic plane wave. The two methods of incorporating fluid loading produce similar predictions for the transmission loss. At low frequencies the acoustic fluid mesh can become very large.

At very shallow depths the tile exhibits large transmission loss above a characteristic frequency (figure 4.). This is similar to the work in [2]. The characteristic frequency broadly corresponds to resonance behaviour of the tile hull plate system. The frequency of this resonance increases with depth as stress stiffening of the tile occurs. Overall, the transmission loss at a given frequency is gradually reduced when the tile goes deeper. This is in agreement with observation [1].

Conclusions

The dynamic performance of elastomeric decoupling tiles is affected by any large static loading that may be present. The compression of a tile under hydrostatic pressure significantly changes the tile's vibrational character. The hydrostatic compression is a complicated structural problem. It is a subtle combination of various mechanisms which requires a non-linear finite element approach to solve. The dynamic behaviour at a given depth can be predicted using matrices derived from the static calculation at the appropriate pressure.

Work is continuing to increase the utility of this procedure. Coatings fabricated from foam material also suffer from hydrostatic loading. Again large strains are present but here the bulk material has almost zero Possion's ratio. For oblique angles of incidence a more elaborate treatment of the fluid loading is required. A possible combination of the finite element method and the boundary element approach with periodic boundary conditions may prove useful [4].

References

[1] House J. "Some Practical Measurements on a Transmission Loss Coating", private communication (DRA, Holton Heath).

[2] Hibbert J.H. "Decoupling Performance of Viscoelastic Layers containing Cavities", Salford University Report N834-2 (for DRA, Holton Heath).

[3] Freakley P.K. and Pain A.R. "Theory and Practice of Engineering with Rubber", 1978 Pub. Applied Science Publishers Ltd. (Barking, Essex).

[4] Hardie D.J.W. "An Introduction to Finite Elements", in "Finite Elements Applied to Sonar Transducers". Proc. Inst. of Acoustics, 10(2), Birmingham, December 1988. pg. 1-15.

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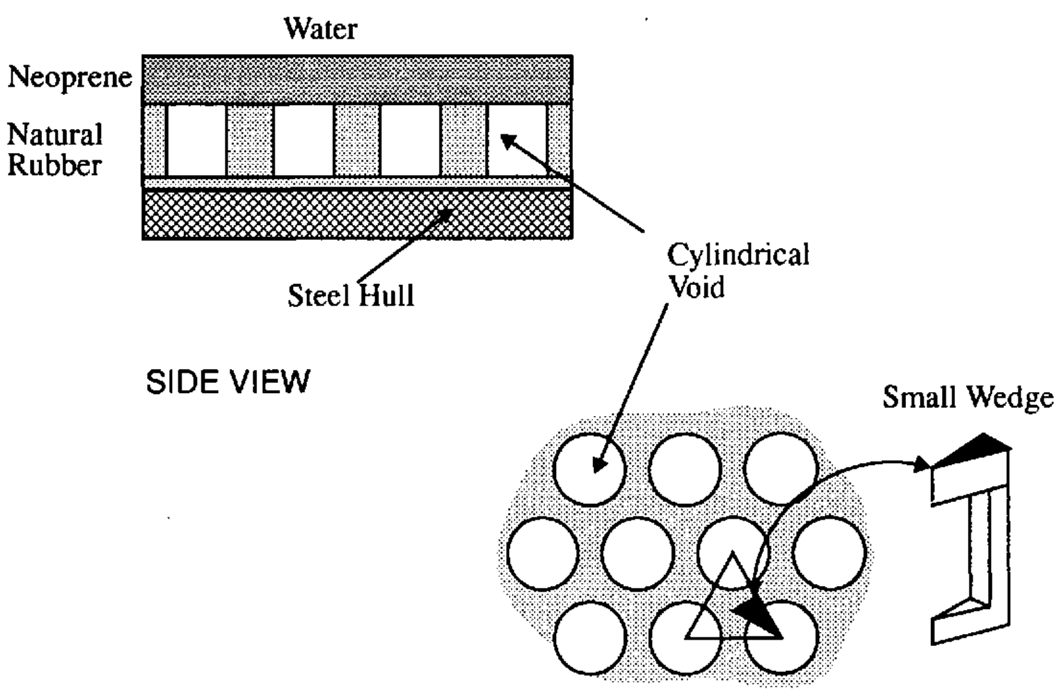

figure 1: Schematic Diagram of Tile Construction

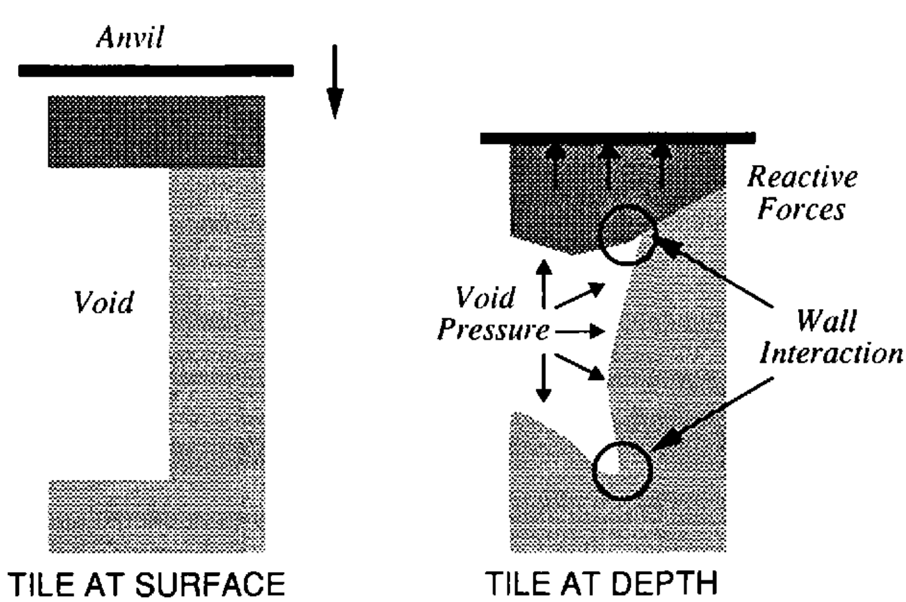

figure 2: Static Deformation of Tile

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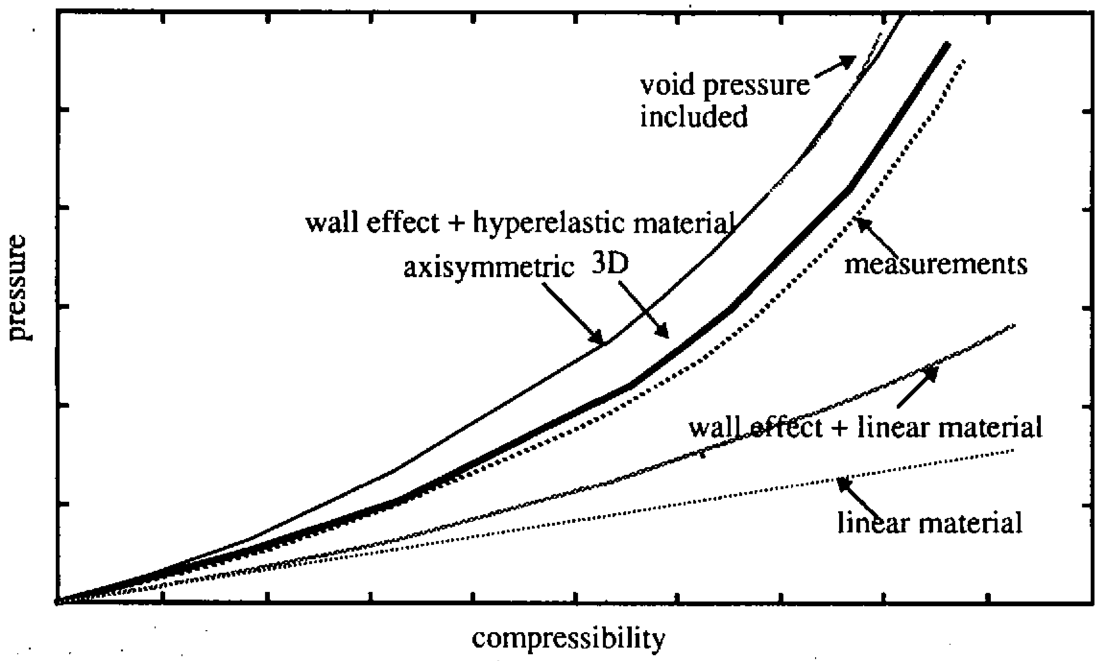

figure 3: Compressibility of Tile

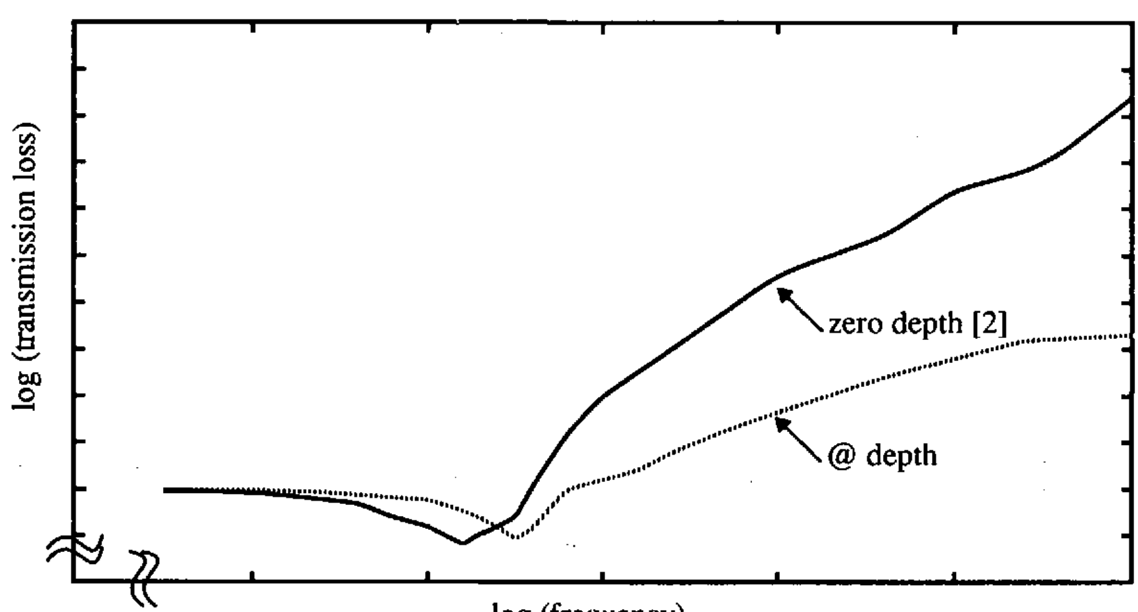

figure 4: Transmission Loss as Depth