IMPACT RESPONSE ANALYSIS OF THORAX BY THE THIN-LAYER METHOD

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INTRODUCTION

Development of lung injury criteria is essential to understand the damage incurred by automobile accidents or high velocity projectile impacts. While the car accidents are characterized by low velocity, high mass transferring energy to the thoracic tissues over a relatively long time period (~60 ms), the bullet impacts generate two waves arriving at around 100 µs and 1 ms. Thus, the thorax is subjected to a broad-band frequency loading throughout its life and it is essential to have a tool to characterize its behavior for both long and short duration loading.

A realistic Finite Element (FE) model of thorax with all its complexities is computationally very expensive especially for high frequency loading [1]. Following [1], it is assumed in this work that the thorax can be modeled as an assemblage of two-dimensional layered media. Among the existing methods, the Thin-Layer Method (TLM) is tailor-made for analyzing this kind of structure. The formulation is based on Fourier series representation of the unknown displacement components, which reduces the dimension of the problem and thus the cost of computation.

The method is employed to analyze thorax for several different stress pulses, which bring out the wave nature of the response (short duration load) and quasi-static behavior (large time load).

METHODS

The layered model is assumed finite in the Z direction only. The TLM starts by Fourier series representation of the displacement field in the X direction, which upon substitution in the elastodynamic equation generates a set of partial differential equations, where z and t are the only independent variables. This equation is supplemented by the displacement and stress boundary conditions. Discretizing this reduced set of equations by following the regular FE procedure, a set of ordinary differential equation (ODE) is obtained. Both implicit Newmark method and explicit central difference methods are adopted to solve the ODE. Thus, along with regular constrained structures, unconstrained media can also be analyzed using this method, which is instrumental in modeling the thorax. Further, sliding contact condition without friction is also incorporated in the formulation, which is useful in modeling the interface between the bone and the lung.

RESULTS AND DISCUSSION

The thorax is modeled by three layers of muscle, bone and lung, where the material properties and thickness of each layer are same as that given in Ref. [1]. Each layer is modeled with only 10 elements (system size 61×3). Three different unit stress pulses are applied on top of the layer, whose time dependency is given by Blackman window function; with duration of 50, 100 and 200 µs. The stresses are considered as point loading in space for simplification although any kind of variation can be taken. Figure 1 shows the displacement of the thorax at the loading surface and interfaces for the three different stress pulses. For 50 µs, considerable difference in displacement can be observed between the top layer and the interfaces, which suggests the predominant nature of the wave. However, for the longer duration loadings, all the three layers behave in the similar fashion, which signifies the quasi-static nature of the layers.

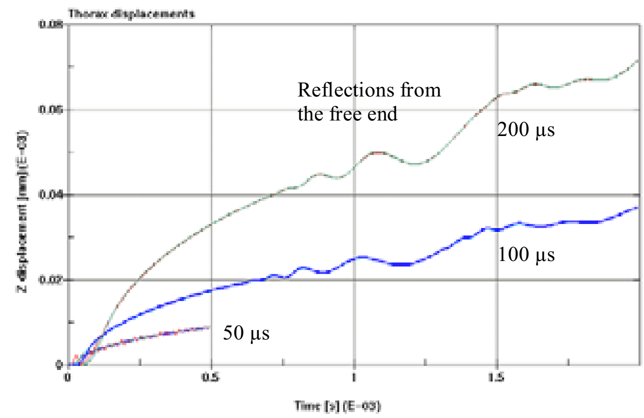

Figure 1: Displacement histories at the surface and interfaces

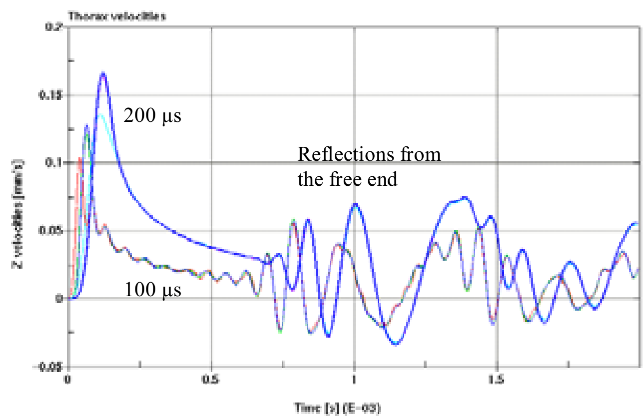

Figure 2: Velocity histories at the surface and interfaces

Figure 2 shows the velocity histories, where appreciable differences can be observed between surface and interface responses for 100 µs, which is missing for 200 µs loading. Further, the response is similar to that of a cantilever beam, whereas, for 50 µs loading the response is that of a rod (not shown here). These observations can be used to make one-dimensional model of the thorax, which will be helpful in establishing the injury criteria. Overall, the example shows the efficiency of the TLM as a tool for analyzing thorax.

REFERENCES

1. Grimal Q., et al. *Int. J. Impact Engineering,* **30**, 665-683, 2004.