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A spring model for perfect or imperfect contact interfaces

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ABSTRACT

A spring model for the simulation of the propagation of ultrasonic pulses through perfect or imperfect interfaces is proposed in the framework of the local interaction simulation approach (LISA). To demonstrate the applicability of the technique (which is particularly suitable for parallel processing) a few examples of numerical simulation of pulse propagation through interfaces with a delamination are presented and discussed.

INTRODUCTION

A local interaction simulation approach (LISA) for studying the propagation of ultrasonic pulses in inhomogeneous 1-D, 2-D and 3-D media has been recently proposed [1-4]. The method is designed to take full advantage of massively parallel computing, such as provided by the Connection Machine. The most important feature of parallel processing, with respect to applications to materials studies, is the mutual independence of the processors. By putting them into a one-to-one correspondence with the "cells" of the specimen (properly discretized), one can assume that each cell may have different physical properties, since the corresponding processors are mutually independent. All the material properties are assigned as initial data to each processor via a front-end computer. Thus (almost) arbitrarily complex media can be treated without increasing the computer time. Such a correspondence is at the basis of the LISA technique. The local interaction between cells may be transferred directly to the processors, bypassing the partial differential equation. Iteration equations may then be obtained directly from heuristic considerations (e.g. a spring model in the present paper).

In general, Finite Difference Equations (FDE) provide a very convenient tool for the solution of partial differential equations in media, in which the physical properties are homogeneous or vary continuously, such as in Epstein layers. However, when boundaries between different materials are present, the use of FDE's may be justified only as an approximation. In fact, for the conversion of derivatives into finite differences, a "smoothing" of the variables across the interfaces is required and, if the discontinuity is sharp, severe errors or ambiguities may result [2,5].

By contrast, a Sharp Interface Model (SIM), applied in conjunction with LISA, allows an exact treatment of any kind of heterogeneity. By assuming perfect contact, i.e., imposing the continuity of displacements and stresses at the interface between different media, iteration equations can be obtained directly for any kind of interface.

The purpose of the present contribution is to extend the LISA technique to the case of specimens having interfaces with imperfect contact between different materials. In fact the mechanical integrity of interfaces is of paramount importance in determining the serviceability of many structural components. As a consequence, a nondestructive characterization of interfaces, e.g. by ultrasonic techniques, is requisite for the prediction of the strength and life expectancy of a specimen (together, of course, with an analysis of the relation between interface flaws and mechanical properties

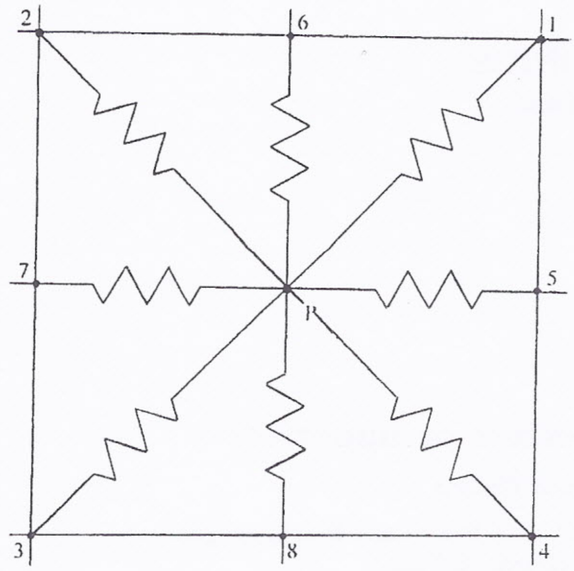

Figure 1: Spring Model for a generic gridpoint P.

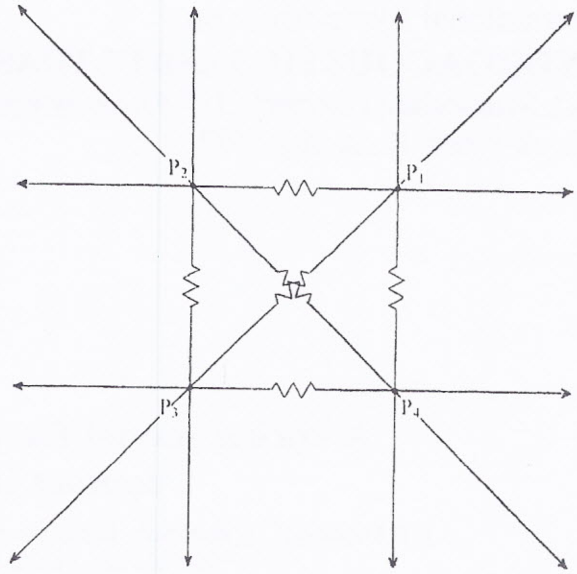

Figure 2: Splitting of the gridpoint P into four subnodes.

of the specimen).

A special issue of the Journal of Nondestructive Evaluation [6] has been recently devoted to theoretical and experimental models of ultrasonic wave interaction with imperfect interfaces. Therefore we refer to the many articles therein for a thorough review of the topic. We restrict ourselves here to a brief description (in Sec. 2) of the above mentioned spring model, which can be used to derive heuristically the iteration equations for the ultrasonic pulse propagation, and of its extension to the case of imperfect contact interfaces. Then in Sec. 3 we present and discuss a few examples of numerical simulations of pulse propagation through an interface with a delamination. The detailed formalism and more general examples of simulations will be included in a forthcoming article [7].

THE SPRING MODEL

An alternative procedure to the SIM treatment discussed in the Introduction is to model the local interaction among the discretization grid nodes by means of elastic forces. Fig.1 gives a pictorial representation of the spring model, by depicting the interaction of a generic grid point P with its nearest neighbours, labelled with integers from 1 to 8. If P happens to be an interface point between different materials at the right and left of the vertical through P, then the two vertical springs ($P-6$ and $P-8$) are each split into two separate springs, according to the physical properties of the corresponding materials.

Case	λ_1	λ_2	μ_1	μ_2	ρ_1	ρ_2
1	4.4	56	2.09	26	1.2	2.7
2	4.4	9.8	2.09	6	1.2	1.6
3	4.4	2.1	2.09	1.5	1.2	3

Table 1: Lamé constants and densities of the two materials for each of the three bilayers considered.

More generally, if P is a crosspoint at the intersection of two orthogonal interfaces separating four different materials, then all four horizontal and vertical springs ($P-5, P-6, P-7, P-8$) are split each into two springs, corresponding to the physical properties of the materials in the four quadrants. It is thus possible to obtain the iteration equations for the displacements of a pulse propagating into a discretized medium (which can be arbitrarily complex, since

each gridpoint may well be a crosspoint). The details of the derivations of the iteration equations are omitted here for brevity.

As a further step, one can also model the interface contact by means of additional springs: see Fig.2. The nodepoint P is split into four "subnodes" P_1, P_2, P_3 and P_4. Different kinds of imperfect contact can be modeled by assuming that the springs connecting the four subnodes are weakened or broken. As a first elementary application we consider in the next Section the case of an interface delamination, in which all the subnode springs are broken, except the vertical ones, for the entire

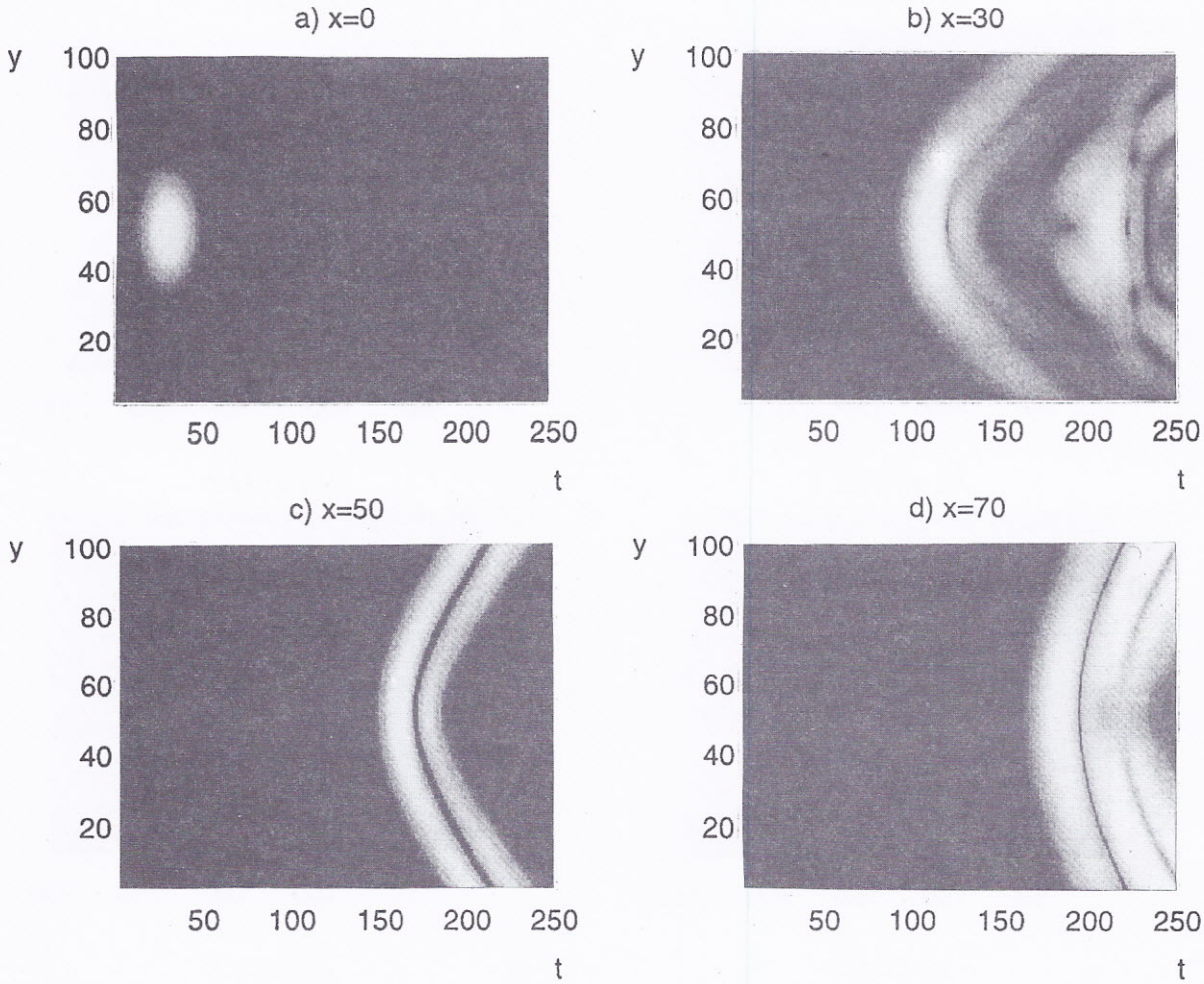

Figure 3: Time evolution plots of the pulse displacements at different sections of the specimen for a perfect interface a) input surface ($x = 0$), b) $x = 30$, c) at the interface ($x = 50$), d) at the exit surface ($x = 70$).

length of the delamination.

RESULT AND DISCUSSION

We consider a bilayered specimen with a vertical interface between two different materials. Three cases have been studied: they are summarized in Table 1.

Fig.3 represents the time evolution of a gaussian source pulse injected on the left surface of the bilayer (Fig.3a). In Fig.3b (before the interface) we begin to see the mode conversion of the source pulse. From the left we see first the longitudinal pulse front, then another l-pulse reconverted from the shear pulse (obtained by mode conversion from the original l-pulse), then the mode converted s-pulse in a complex pattern. In Fig.3c (at the interface) we only observe the original and reconverted l-pulses; shear pulses come at later times. The pattern becomes more complex at larger values of x (Fig.3d) and t.

Fig.4 (left plots) shows the time evolution plots of the pulse displacements at the exit surface for a specimen with an interface delamination in the three cases summarized in Table 1. For a better representation of the results the grayness scale is not kept constant in the various plots. The right plots of Fig.4 show the "signatures" of the interface delamination, i.e. the difference between the plots with and without defect. Interesting plots may be observed, which can be used for the purpose of interface characterization.

Figures 5 and 6 display a different representation of the pulse propagation in the cases 1 and 2, respectively. Instead of time evolution plots at the exit surface, they show "snapshots" at fixed times

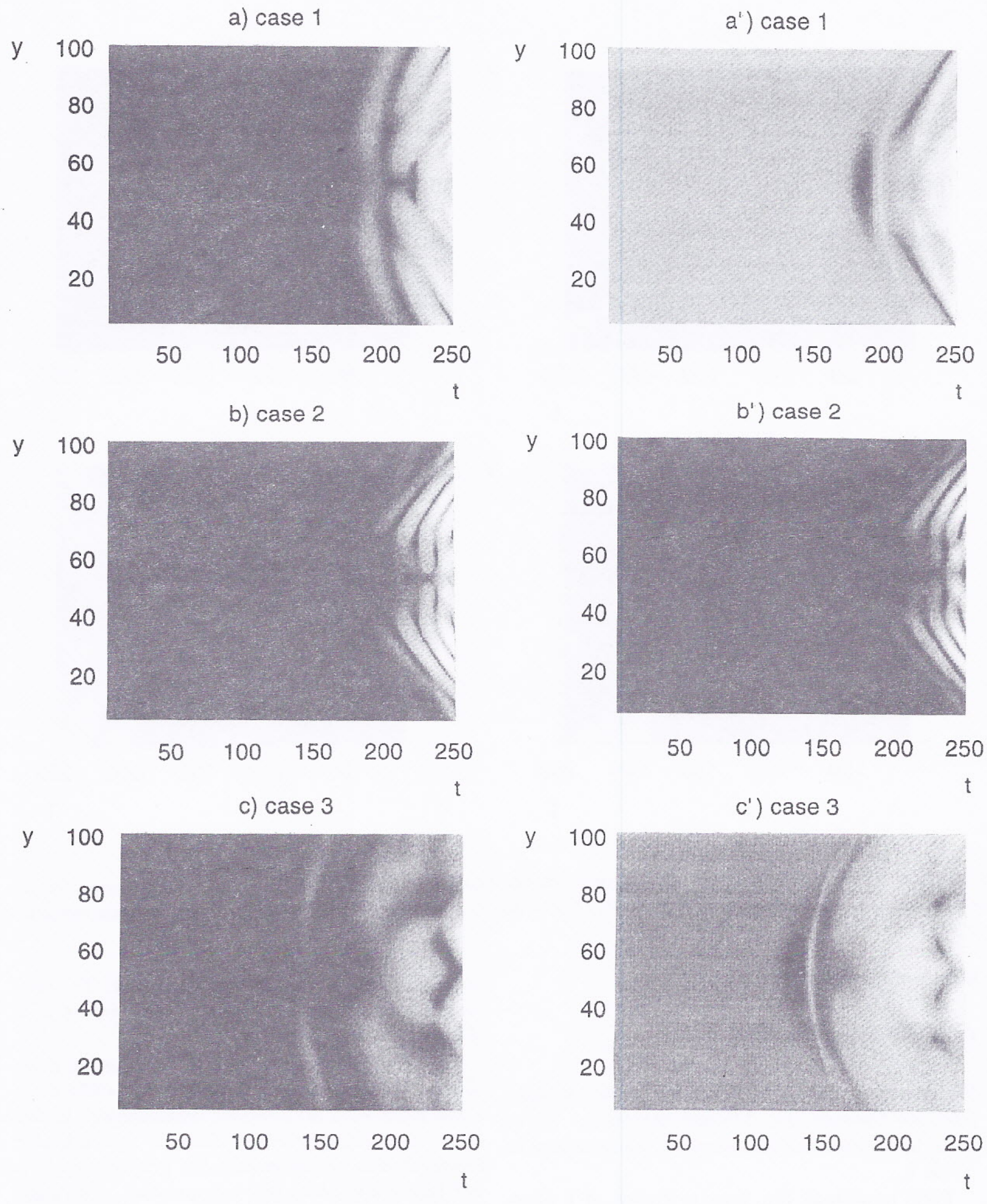

Figure 4: Time evolution plots at the exit surface for a specimen with an interface delamination of length $l = 21\epsilon$ for three different cases (a,b,c). The plots a', b', c' represent the differences between the plots a, b, c and the corresponding plots for perfect interfaces.

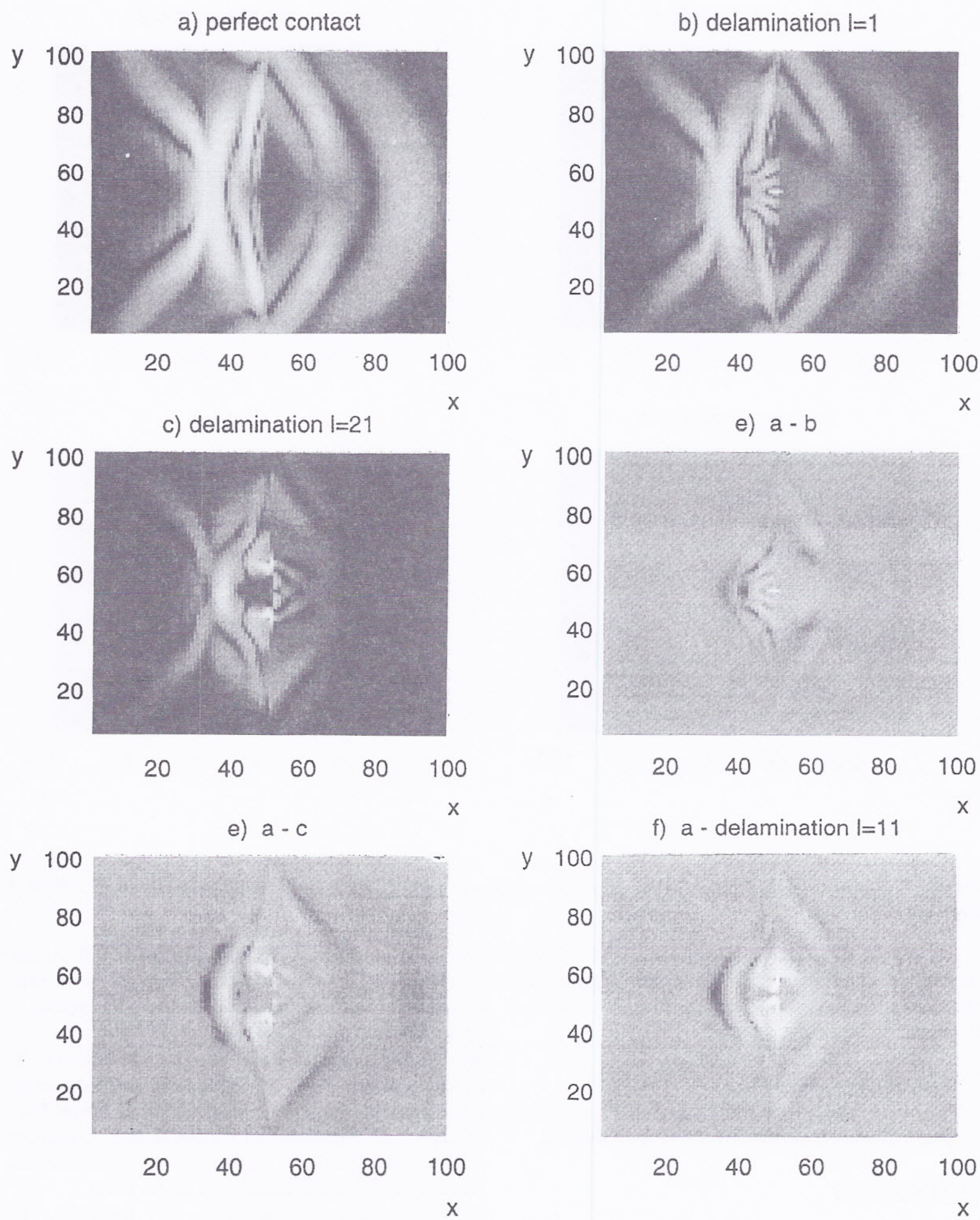

Figure 5: Snapshots of a pulse propagating in a Al-plexiglass bilayer (case1) for interface delaminations of different length l.

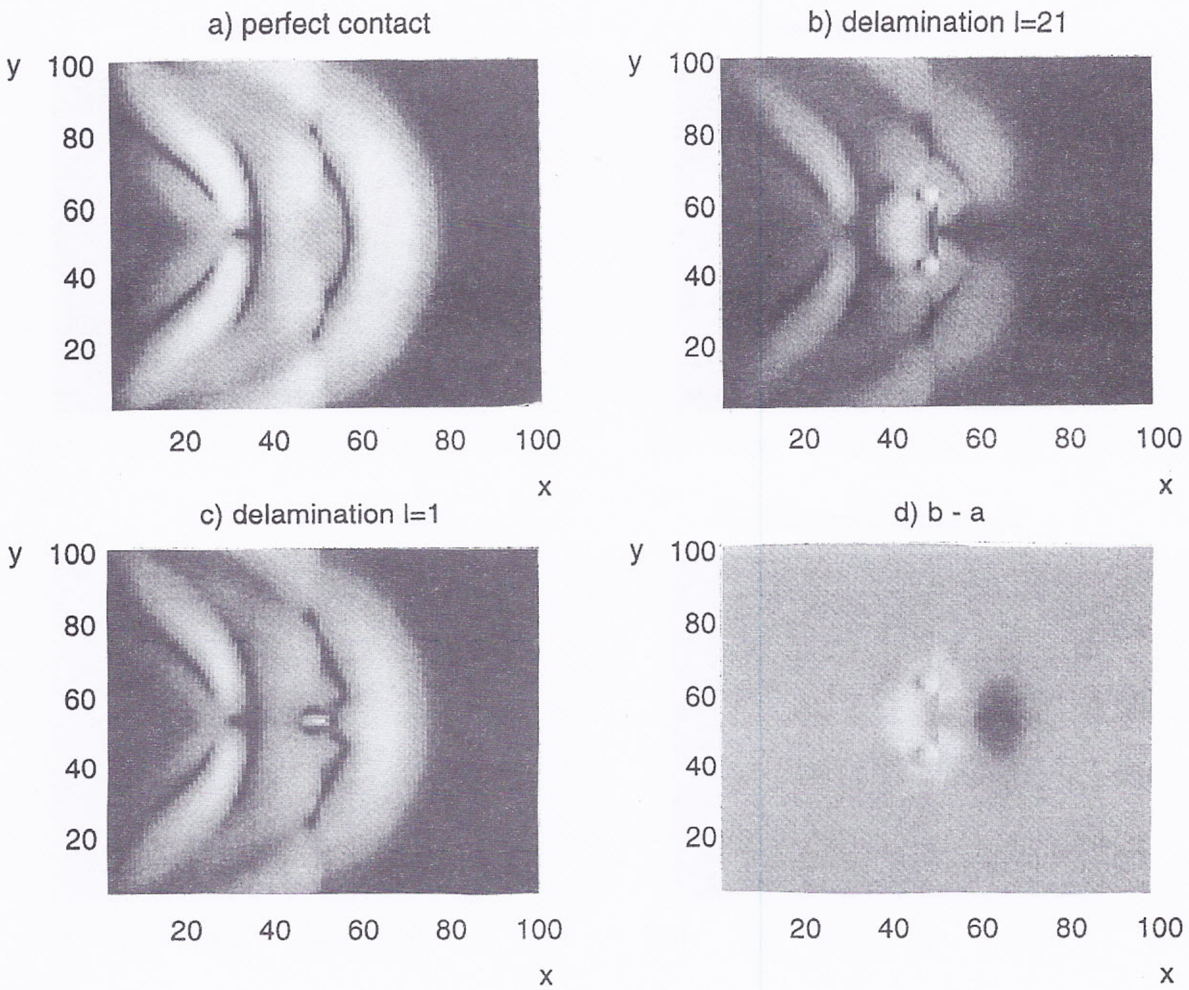

Figure 6: Snapshots of a pulse propagating in a bilayer (case2) for interface delaminations of different length l.

of the whole displacemets amplitude field. Both the actual snapshots and the pulse "signatures" are shown. Again some very interesting patterns develop.

ACKNOWLEDGMENTS

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