FINAL PUBLISHABLE SUMMARY

The project aimed to establish the necessary scientific basis to pursue new methods to detect cardiovascular disease through the determination of material changes in arteries. The existing diagnostic methods are based mostly on detection of plaque when a disease has been getting progressively worse for decades. The changes in artery walls caused by cardiovascular decease development are very difficult to detect at an early stage. Clinical studies show that these changes usually occur at the inner layer of arteries. Therefore, this effect should be reflected in the long wave region of the dispersion spectrum of wave propagation through the artery walls. To investigate and describe this phenomena a special type of elastically restrained boundary conditions (ERBC) has been introduced and a series of long wave asymptotic models have been developed taking into account such key characteristics of human arteries as anisotropy, pre-stress and multi-layers.

The general approach is to introduce the most general linear combination of classical Neumann (stress free) and Dirichlet (fixed face) boundary conditions to model the influence of boundary changes by examining the behaviour of the fundamental modes and harmonics in the long wave region. Analysis of wave propagation in structures subject to elastically restrained boundary conditions has been performed starting from the simplest model (linear elastic isotropic plate) by increasing the complexity in turn to take into account all the essential characteristics of real human arteries like anisotropy, pre-stress and multi-layers. Generally, the analysis consists of several steps:

- derivation of the dispersion relation;
- numerical calculation and analysis of the dispersion relation;
- elucidating of modes transformation mechanism with respect to restraints degree at the boundaries;
- multi-parametric asymptotic analysis of the dispersion relation in the long wave region to obtain the approximate expansions in the vicinity of zero or cut-off frequencies;
- development of asymptotic models describing long wave motion to elucidate the mechanism of influencing of restraint parameters on the structure and type of the governing equations.

This plan has been sequentially applied to a series of problems with elastically restrained boundary conditions. As a result, the following progress has been achieved at the end of the reporting period:

1. Numerical and asymptotic analysis have been performed and long wave asymptotic models been developed for the following problems with ERBC:
   - pre-stressed incompressible plate;
   - transversely-isotropic plate;
   - linear isotropic, single cylindrical layer;
   - isotropic, anisotropic or pre-stressed multi-layered plate;
   - residually stressed cylindrical layer;
   - spirally wounded fibre-reinforced cylindrical layer;
   - multi-layered cylinder.
2. The software package DispRel has been developed for numerical solving of the dispersion relations including effects of anisotropy, pre-stress and multi-layers by using various root finding procedures.
3. Special types of asymptotics of the dispersion relation and approximate models uniformed in the area of close cut-off frequencies have been developed.

The main results achieved at the end of the reporting period:

1. A generalisation of the classical boundary conditions has been elaborated allowing the investigation of wave propagation in structures interacting with their surroundings (e.g. arteries, internals, etc.).

2. The mechanism of frequency gap formation on transition from free to fixed faces has been fully elucidated for different types of ERBC and materials.
3. A series of long wave asymptotic models have been developed in the case of ERBC for anisotropic, pre-stressed and multi-layered plates and cylinders.
4. Method of derivation of uniform asymptotics of the dispersion relation for the case of coalescing long wave limits of harmonics from various resonance families.
5. Special asymptotic integration method has been developed to derive uniform governing equations describing motion in the vicinity of coalescing long wave limits.
6. A software application *DispRel* has been developed to calculate numerically roots of the dispersion relations for various combinations of material parameters and geometry (anisotropy, pre-stress, multi-layered structures, cylindrical geometry). The interface of *DispRel* is shown below.

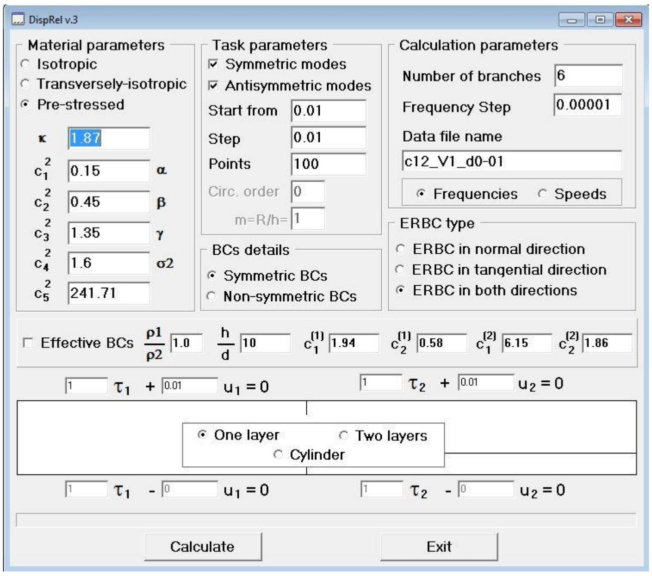

Fig. 1. DispRel software interface.

A novel technique has been developed which allows detection of the inner arterial wall mechanical changes through analysis of the fundamental mode. As a main result of the project the interaction between fundamental mode behaviour and boundary condition changes has been established which provides the scientific basis for much easier and more reliable methods for detection of cardiovascular disease at a much earlier stage. Upon elaborating a reliable non-invasive method of transmitted waves logging in arteries the models developed during the project can be used for the interpretation of the dispersion spectrum of the waves to identify changes at the inner boundary of the artery examined. This will give valuable information as a basis for new methods to detect cardiovascular disease in a novel and highly innovative way. The potential long-term socio-economic impact of new methods for early detection of cardiovascular disease is difficult to overestimate.

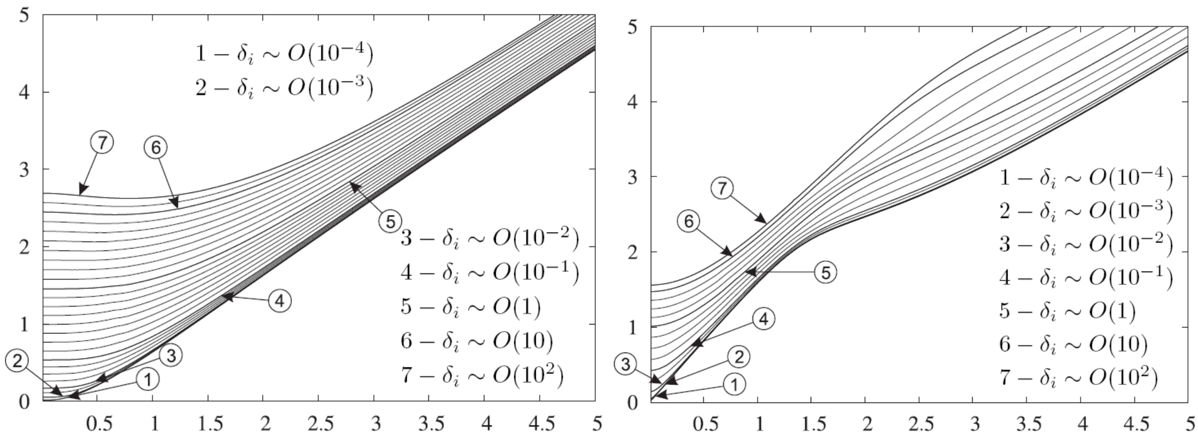

Fig. 2. Fundamental modes transition.