ACOUSTIC PROPAGATION IN 1D AND 3D PERIODIC MEDIA UNDER CONSTRAINTS

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ABSTRACT

Acoustical propagation studies have been made by Daniel Royer (1988) and Michel De Billy (2000) respectively on steel beads and column of mono disperse beads of several materials, showing that the acoustical propagation is effective at the interface of the beads by the way of acoustical Rayleigh surface wave. More recent works of de Billy (2001) show the importance of the transducers polarization (longitudinal or transverse ones) on the detection of the type of surface waves (Rayleigh, torsional or spheroidal waves). These two works give a microscopic point of view of the acoustical propagation. The aim of this paper is to put into evidence the dimensionless problem by the way of preliminary experiments. Different granular medium are used like squared arrangement or hexagonal compact arrangement as well as random packing and we show the existence of chain modes in this structure bound with Hertz contact.

INTRODUCTION

Acoustic propagation in granular media under stress has led to a whole literature during the last decades. For example works by de Billy (2000) and Jia et al. (1998) have pointed out, both on periodic arrangement and random beads stacks, the importance of two different frequency regimes. The first one is typically a low frequency regime (LF). In that case, the acoustic signal is dependent of the Hertz contact. The Effective Medium Theory (EMT) suggests then a variation of K and µ (granular medium elastic constants) as $P^{1/3}$ (applied external pressure) by introducing the Hertz-Mindlin force law at each grain contact [Walton 1987]. These homogenised formulation can derive acoustic group velocity from the applied load as it has been done by Jia et al. [Jia 1998].
The second regime is a high frequency one (HF). In that frequency range, two main approaches have been pointed out.
First for a periodic one-dimensional granular medium of mono-disperse beads, de Billy has shown the predominance of the acoustic surface waves in the acoustic propagation process [de Billy 2000]. Rayleigh surface waves (SAWs) are present when beads columns are excited with longitudinal acoustic pulses. Other surface waves, torsional and spheroidal, are superimposed on a very low frequency wave, when the excitation is shear polarised. The Low frequency wave is then a signature of the Hertz contact.

Second for a random granular medium of glass beads of compacity 64 %, the high frequency component has been interpreted in term of multiple scattering [Jia 1998]. These different point of view should come from the modal behaviour of small container used by Jia et al. or from the beads dispersion. The aim of this paper is to show the predominance of the surface waves in the acoustic propagation processes for squared packing and hexagonal compact packing as another possible interpretation. Finally a brief comparison with signals obtained in random granular medium will be presented.

EXPERIMENTAL SET-UP

The experimental set-up we used is described below. Figure 1 gives a representation of a section of the experimental vessel. A Plexiglas vessel is filled with quasi mono-disperse steel beads of diameter 10 mm ± 5 µm. The spheres are arranged in a squared packing or a hexagonal compact packing. It is then possible to work respectively with a mono-dimensional configuration and a tri-dimensional configuration. The macro crystal of steel beads roughly represents a random network due to the quasi mono-dispersity of the beads, and to the non perfect parallelism of the vessel's walls. A constraint can be applied on the upper layer of the beads stack., where the excitation transducer is centred. It is, as the reception transducer, in contact with the upper and the lower layers of the macro crystal of the steel beads. These piezoelectric transducers (PANAMETRICS Videoscen v101 and v151) are respectively longitudinally and shear polarised. The number of beads in contact with the transducers is around 10. We suppose that the contact with the surface transducers and the beads, as the contact beads to beads, is not identical. This is due to the quasi mono dispersity of the beads.

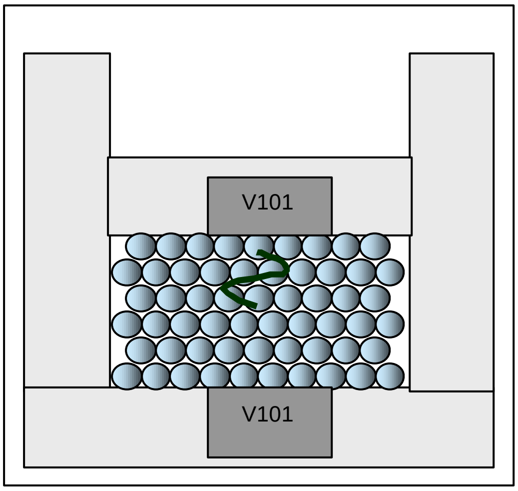

Figure 1. Experimental vessel section

Acoustic pulses are used to excite the medium. In this way, the excitation signal are broadband ones. We expect to have access to the two frequency regimes described below. A signal generator allows us to generate acoustic pulses with a central frequency between 5 kHz to 1 MHz. In our system the received acoustic wave, for an experimental realisation, might be averaged by all the acoustic path the wave incountered. We also realize averaging by the way of a digital oscilloscope to obtain a better signal to noise ratio.

QUASI MONO DIMENSIONAL MEDIUM

Our first experiment results are established for squared packing. Four layers of beads are placed between the two transducers. Two frequency regimes can be observed. The first one is a low frequency regime. This component then modulates the second and delayed high frequency regime (Figure 2 for longitudinal polarization, Figure 4 for shear polarization). The signals, obtained with a shear polarization, are comparable to those obtained by de Billy in the same polarization condition. Differences appear for longitudinal polarization. In this case the low frequency component is also present and still modulate the high frequency components. Both for longitudinal and shear polarization, the repetition time between two high frequency packet is roughly the same. It corresponds to the travel time of a Rayleigh surface wave on half a bead perimeter. It leads to a Rayleigh surface wave velocity value of 3150 $m.s^{-1}$. For an infinite steel plane (corresponding to an infinite radius for our case), the Rayleigh surface waves velocity is around 3005 $m.s^{-1}$, leading to an error less than 5 %.

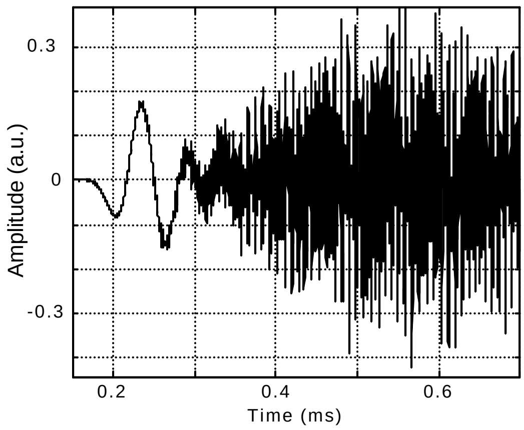

Figure 2. Time domain. Squared packing excited with a longitudinal impulsion. 60 kg applied load.

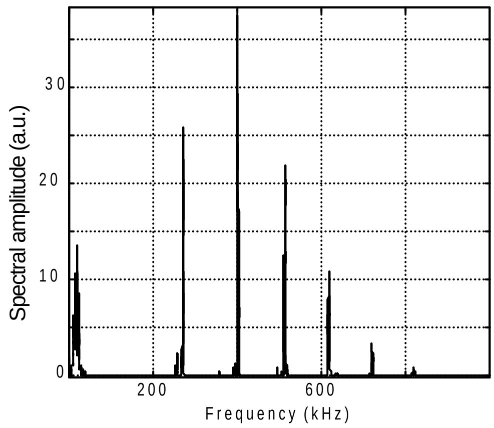

Figure 3. Frequency domain. Squared packing excited with a longitudinal impulsion. 60 kg applied load.

In the frequency domain, the two well separated frequency regimes (LF and HF) appear clearly (Figure 3 and Figure 5 respectively for the longitudinal polarization and the shear polarization). For the high frequency domain, Royer et al. (1988) have derived the SAWS group velocity from spectrum lines information :

$$V_g = 2\pi a \Delta f$$

where a and Δf are respectively the beads radius and two successive SAWS resonance modes. The same value of the SAWS group velocity is given by this formula.
Quite the same spectrum lines are found for the high frequency regime for the two polarization. For shear polarization other sphere's resonance can be present as torsional or spheroidal modes.

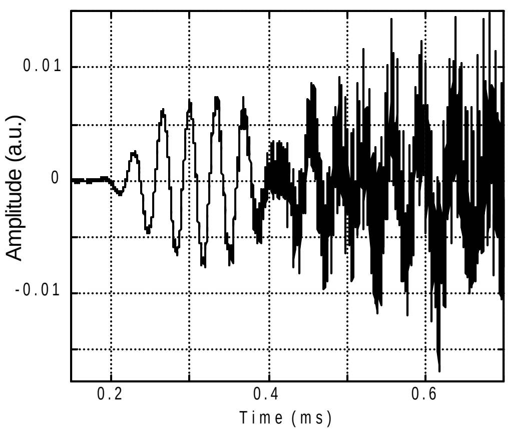

Figure 4. Time domain. Squared packing excited with a shear impulsion. 20 kg applied load.

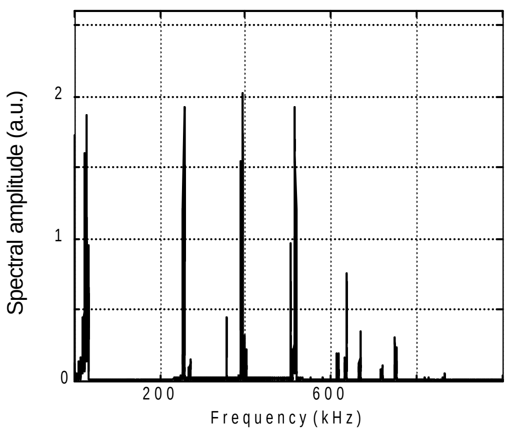

Figure 5. Frequency domain. Squared packing excited with a shear impulsion. 20 kg applied load.

The results obtained are comparable to those of by de Billy [de Billy, 2000]. It is not surprising as working with a squared packing configuration is similar to work with a mono-dimensional medium. We extend de Billy's results finding the presence of the LF even in longitudinal polarization. As for de Billy, the presence of this LF in transverse polarization is the characteristic of a chain mode bounded with Hertz contact. Finding this LF in longitudinal polarizatioin is not in contradiction with this assertion.

TRI-DIMENSIONAL MEDIUM

These results presented here have been obtained for a hexagonal compact configuration. Four layers of steel beads are placed between the two transducers. The signals, for longitudinal polarization and shear polarization, are similar to those obtained for squared packing (Figure 6 for longitudinal plarization and Figure 7 for shear polarization). Two frequency regime can be observed as in the former cases. The LF component first arrived followed by the high frequency packet, modulated by this LF. Same value of the SAWs group velocity than for squared packing are found both in time domain and in frequency domain

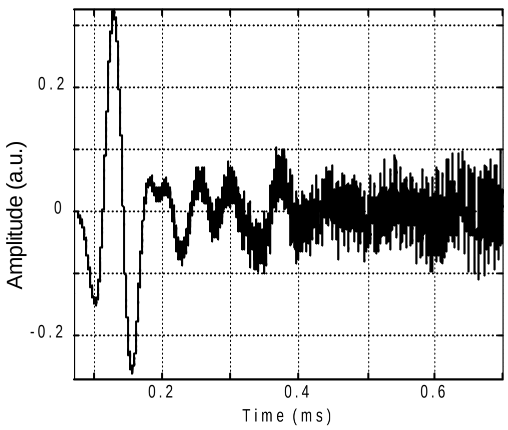

Figure 6. Time domain. Hexagonal compact packing excited with a longitudinal impulsion. 69 kg applied load.

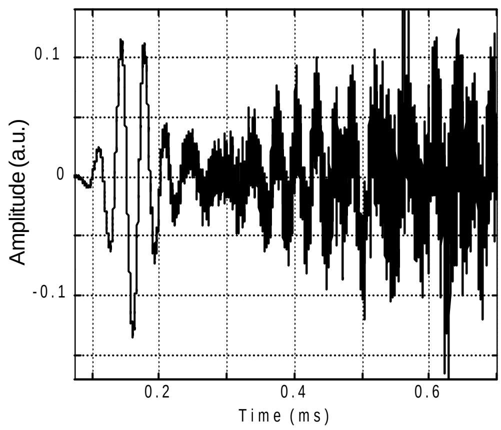

Figure 7. Time domain. Hexagonal compact packing excited with a shear impulsion. 69 kg applied load.

These results demonstrate that the acoustical process is not dimensional dependent. Changing the position between the beads in the macro crystal can change the average force applied on each contact beads. but it does not change basically the propagation behaviour : a LF regime that propagate faster than a HF regimeessentially made of surface waves. The beads are not yet connected by their opposite pole, which is the preferential crossing point for the HF energy. The HF energy upon LF energy ratio thus decreases in such configuration.

ARRANGED BEADS STACKS VS RANDOM BEADS STACKS

These last results ask for a comparison with a purely random experiment comparable to Jia's work. We compared here two configurations. First we use an hexagonal compact arrangement of steel beads of diameter 10 mm as previously studied. Second we use a polydisperse granular medium of glass beads of diameter between 0.8 mm to 1.2 mm. Two components (or more) are present. The first arrival LF component is well defined and modulates the HF delayed component (Figure 8). We typically find the signals obtained for periodically arranged medium. These signals are comparable to those obtained by Jia et all. (1998). It is not very surprising because our experimental condition, except the inner spatial dimension of the container (50 * 70 * 20 mm), is near the one he used. They present two well separated regimes. A LF ones, that appears more complicated than for the macro crystal studied before, is contrarly not mono chromatic. This LF regime is followed by a HF regime that may be compared of a complex interference of surface waves.

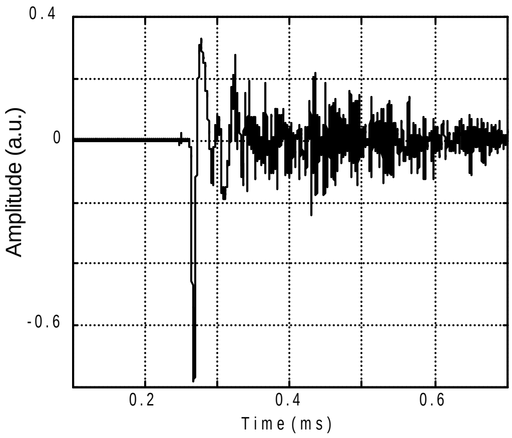

Figure 8. Time domain. Glass beads granular medium.

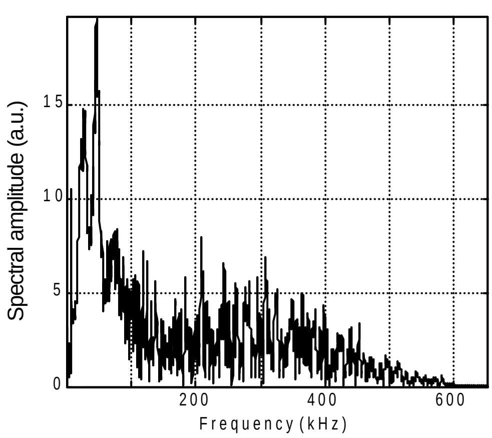

Figure 9. Frequency domain. Glass beads granular medium.

CONCLUSION

This paper presents new results for propagation in periodic granular media. In such medium, two ways of acoustic propagation can be seen. The first and very low frequency component can be interpreted as a crystal resonance mode. The second and high frequency component corresponds to an acoustic surface propagation. The identity of the SAWs depends on the polarization of the transducers. It gives also a comparison between this macro crystal and random arrangement where the same kind of behaviour may be also identified.

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