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STUDY OF THE VIBRATIONAL POWER INJECTED TO A WALL EXCITED BY A GROUND SURFACE WAVE

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The physical understanding of ground/structure vibrational interaction is essential in order to relate ground vibration levels outside buildings to structural vibration levels in buildings. A 2-D FEM/BEM computer program has been developed and is used to study the simple problem of surface excitation of a single wall and its foundation. It gives some understanding for the case of buildings parallel to nearby surface railway tracks.

1. INTRODUCTION

The physical understanding of ground/structure vibrational interaction is essential in order to relate ground vibration levels outside buildings to structural vibration levels in buildings. In the case of ground surface excitation, ground-borne surface waves strike the building and transmit energy to the structure. However, vibration propagation in buildings involves different types of waves (bending and in plane waves for plates and bending longitudinal and torsional waves in beams and columns) with different attenuations at junctions. Therefore, and in order to estimate correctly vibration levels in buildings, the energy injected to the structure must be analyzed in terms of wave type.

In this paper, the simple problem of surface waves exciting a single partially buried vertical wall is considered, providing some answers for the case of buildings parallel to nearby surface railway tracks. The wall buried in an half-space homogeneous ground is excited by a surface line load located at a certain distance (Figure 1). Simple wave approaches [1] cannot be simply applied to a vertical wall excited by surface waves and a 2-D mixed finite element method (FEM)/boundary element method (BEM) is used instead. The computer program used (named MEFISSTO), has been recently developed at CSTB [2, 3] to study configurations including tunnels, obstacles (trenches) and building foundations usually too complex to be solved in 3-D (see section 2). Numerical applications are given (section 3) for three different types of ground and results, expressed in terms of vertical and horizontal velocity amplitude levels both on the wall and at the ground surface, are discussed.

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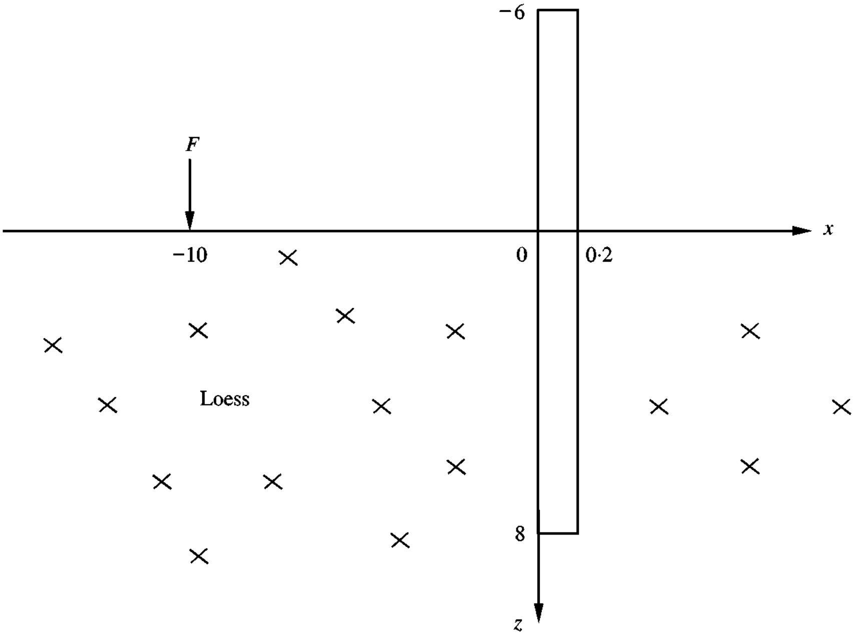

Figure 1. Geometry of foundation, wall and vertical force excitation.

2. THE NUMERICAL MODEL

FEM and BEM are well suited for complex geometries. In the MEFISSTO software used in this paper, both methods are mixed.

A 2-D approach has been chosen initially, since it greatly reduces computation time and permits the study of rather large geometries over the full frequency range of interest (from 20 up to 100 Hz and even higher). 3-D models may seem more realistic but they would limit the study to reduced geometries or frequency ranges. It should be noted that railway excitations are long-line sources that can be realistically assumed infinite, at least in near field (10–20 m); however, in a 2-D approach, these infinite sources are assumed to be coherent [4] which is a major drawback.

The FEM permits the introduction of spatially varying properties of the media. However, the FEM implies a full discretization of these media up to a certain distance and the introduction of boundary effects at the outer nodes.

The BEM [2, 3, 5–7] can be considered as a more sophisticated approach since, by using integral representations of the displacement fields, it leads to a discretization of only the media boundaries. In the case of 2-D ground-borne propagation, the boundaries will be lines for layer interfaces and the profile of the structures, obstacles or trenches. The layer interfaces are still infinite, but the solution converges rapidly for a finite length of discretization. An alternative also programmed consists in using Green functions established for layered media [1, 7]. The elementary Green functions are rather long to compute but the length of discretization is greatly reduced, since only finite structures are discretized.

It is advantageous to use simultaneously FEM for structures and BEM for semi-infinite media. The coupling of both methods can be obtained [5] by condensing each part modelled by FEM to its boundaries which are coupled to the parts modelled by BEM, by equating displacements at the coupled boundaries and by considering the BEM stresses as external forces on the FEM domains. MEFISSTO has been developed to meet these requirements. It defines a list of domains; each domain is either an homogeneous domain modelled by BEM or a domain, eventually comprising several sub-domains of different characteristics, modelled by FEM. Open domains are always modelled by BEM and stratified media Green functions can be used. The BEM elements are either constant or linear elements (one central or two extreme nodes) and for FEM, several rectangular 2-D standard FEM elements are available (4, 6, 8 or 9 node isoparametric elements). Automatic meshing varying with frequency is possible, allowing infinite BEM meshing of layer interfaces to be prolonged at lengths defined as a function of the Rayleigh wave numbers.

3. NUMERICAL APPLICATIONS

In this section, a 20 cm thick concrete wall is considered with 8 m buried in the ground (foundation), and 6 m extending above the ground (wall). The soil, made of loess, has a Young's Modulus of 26·9 MN/m^2, a density of 1550 kg/m^3. The Poisson's coefficient is 0·257 and the internal loss is 10%. The concrete structure has an internal loss of 1%. The behaviour of the foundation, the wall and the ground is analyzed for frequencies below 200 Hz, which is the frequency range of interest for ground-borne vibration from railways. Both horizontal and vertical components of the velocity level are given.

Figure 1 shows the reference situation, where a vertical unit force is applied at $x = -10$ m and the structure is positioned at $x = 0$ m.

3.1. EFFECT OF FOUNDATION

The foundation is placed at $x = 0$ m and is eventually prolonged by an upper wall. Figure 2 shows the third octave velocity level along the ground surface at 40 Hz. Due to the foundation, stationary waves are created between the excitation and the foundation; they are little affected by the presence of the upper wall. The ground surface field would be very similar for an incoming Rayleigh wave.

The type of ground is also an important factor since it will affect both the propagation in the ground and the coupling with the foundation. In Figure 3, results for three types of soil are presented. The Young's modulus of the reference loess is either divided by 5 (softer soil) or multiplied by 5 (harder soil). The velocity level spectra at the upper part of the foundation ($x = z = 0$ m), without the upper wall, are represented and referenced to the level without the foundation. The thick line, for the hardest soil, shows that the levels are little affected by the presence of the foundation since the impedance mismatch between soil and foundation is not sufficient to modify significantly the velocity levels. For loess and for the point

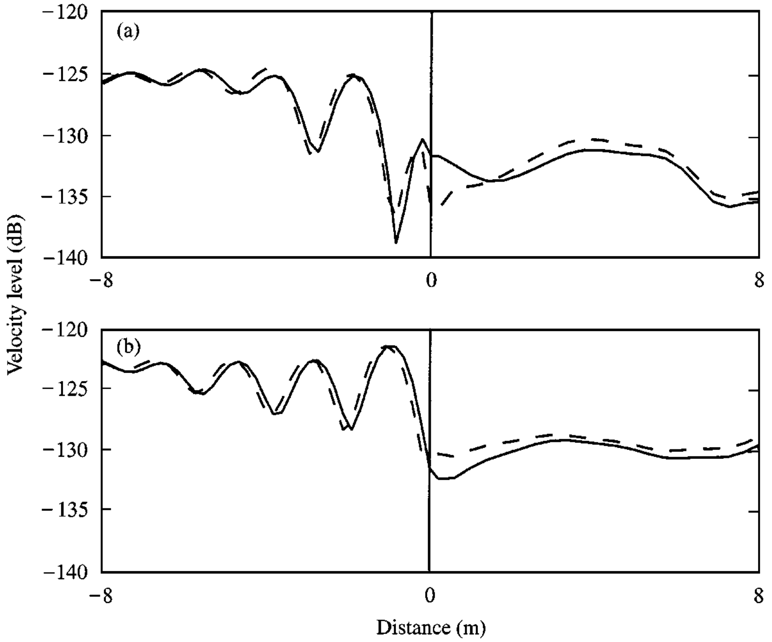

Figure 2. Effect of top structure on ground surface velocity at 40 Hz. (a) Horizontal component; (b) vertical component. —, foundation; - - -, foundation + wall.

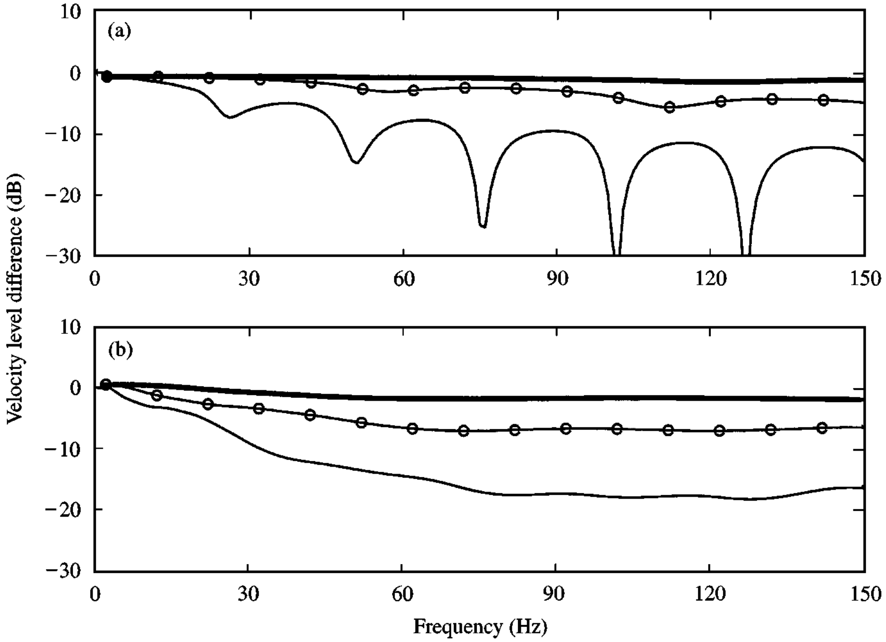

Figure 3. Effect of ground on velocity at ground surface, referenced to the case without structure. (a) Horizontal component; (b) vertical component. ——, $E/5$; —o—o—, Loess; ——, $E*5$.

chosen, the presence of the foundation reduces the velocity levels by a few dB and slightly more for the vertical component. Finally, the softer soil shows reductions reaching 15 dB. This obviously points at the important action of the type of ground on foundation behaviour.

3.2. EFFECT OF UPPER WALL

It is interesting to consider how the upper structure affects the behaviour of the foundation. The spatially average velocity levels in the foundation (curves A and B in Figure 4) and in the upper wall (curve C) are represented. First, plots A and B for the foundation without and with the upper-wall look, at first sight, similar. However, at 42 Hz the upper wall influences the foundation horizontal velocity due to a resonant bending behaviour. Above 90 Hz the vertical level of the foundation is reduced due to the presence of the upper wall. Below 150 Hz the upper wall presents several flexural modes resulting in maximum levels of the horizontal component of C. The levels in the upper wall are much higher than the levels in the foundation.

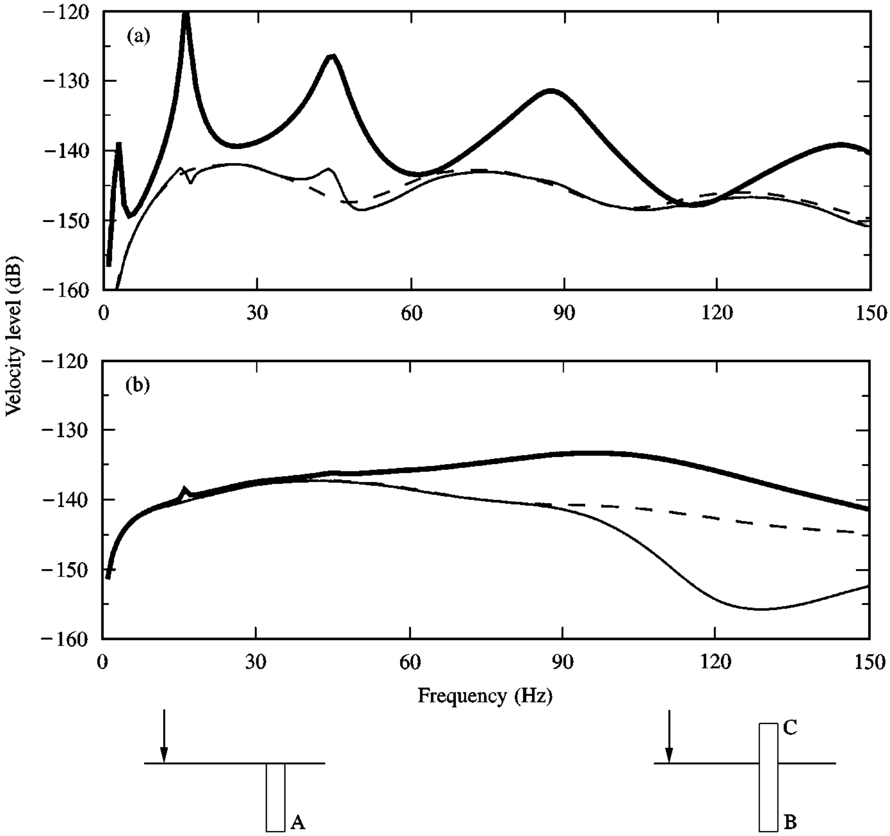

Figure 4. Effect of upper structure. (a) Horizontal component; (b) vertical component. ——, part A; ---, part B; ——, part C.

More complex upper structures [3] have been studied and it appears that the third octave velocity levels of the simple upper-wall are little affected when connected to a larger structure. Longitudinal velocities were nearly unchanged, whereas the flexural levels only showed a shifted modal behaviour of little consequence on the mean levels. Consequently, the simple case presented hereby gives significant and realistic results.

4. CONCLUSION

The simple problem of ground surface waves exciting a single partially buried wall has been considered in terms of velocity field both at the ground surface and along the wall. Further calculations have shown that, without wall, the ground surface velocity field depends on the type of excitation (Rayleigh waves or line load), pointing to the importance of modelling correctly the excitation for near-field prediction. With the wall, the same ground-surface stationary waves appear in front of the wall, whatever the type of excitation. The presence of the foundation affects the ground velocity profile at the wall position more or less, depending on the type of ground; the upper-part of the wall was found to have an influence on this profile only in case of strong structural modes. At very low frequencies (below 50 Hz), a significant amount of energy is injected as flexural modes and at above 50 Hz, most of the energy is injected as longitudinal waves. The results show the complexity of relating ground vibration levels to structural vibration in buildings; however, even the simple case studied can provide some significant answers.

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