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Building isolation using the transmitting behaviour of a soil layer

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ABSTRACT : We present an approach to isolate the foundation of a building from soil vibtations. It is based on the impeding behaviour of a soil layer over bedrock. This behaviour occurs as the frequency of the incoming waves is less than the lowest eigenfrequency of the soil layer. The building and the soil are described by means of the finite element and boundary element method, respectively. The calculations are performed in the frequency or Laplace domain.

1 INTRODUCTION

The dynamic response of buildings due to soil vibration can be reduced by a number of different methods: one can use friction elements at appropriate locations of a structure, to increase the structural damping through energy dissipation by friction at these locations (Dechent 1989); one can change the vibration behaviour of a building by exchanging the soil around the foundation; one can mount a device, e.g. rubber bearings (Kelly 1991), springs or a combination of springs and dampers (Makris, Constantinou & Hueffmann 1991) at the foundation of the building; or one can reduce the spreading waves by installing a wave barrier like a trench, a concrete wall (Haupt 1986) or a wall consisting of air cushions (Winkenholm & Agren 1986). The barrier disturbs the natural spreading of the waves and so screens the buildings at a certain region behind the barrier.

Our approach is based on the impeding behaviour of a soil layer over a bedrock. It occurs if the excitation frequency is below the lowest eigenfrequency of the layer. Field tests performed by Al-Hunaidi and Rainer 1991 confirmed this behaviour. Since in practice it is not always possible to find such a convenient real bedrock, we use a stiff obstacle as an artificial bedrock instead. The soil and the structure are described using the finite element and boundary elements (Chouw, Le & Schmid 1991a). It is assumed that the soil has no material damping. The calculations are performed in the frequency or the Laplace domain.

2 TRANSMITTING BEHAVIOUR OF A SOIL LAYER

2.1 Line wave source

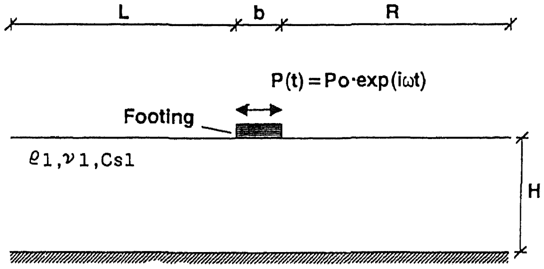

Figure 1. Surface foundation on a soil layer over a bedrock.

The soil considered has a density ϱ_1 of 1800 kg/m^3, a Poisson's ratio ν_1 of 0.33, and a shear wave velocity Cs_1 of 172 m/s. The wave source is a rigid and massless strip foundation with a width b of 3m. The foundation is excited by a horizontal, harmonic unit load p(t) with a frequency f of 16 Hz. The left and right side of the soil layer are discretized for a length L = R = 14 LR. The Rayleigh wave length LR is 10 m (Fig. 1).

The soil transmitting behaviour is represented by the dimensionless amplitude $A[-] = U.G_1$ of the steady-state vibration of the soil surface. U is the displacement related to a harmonic line-load and the shear modulus G_1 of the soil is 53 MPa.

The amplitude of the horizontal surface displacement in Figure 2 shows that no waves are transmitted when the excitation frequency is less than the lowest eigenfrequency of the layer or when the layer thickness is less than the corresponding critical thickness $H_{crit.} = Cs_1/4f = 0.268$ LR (see the case of H = 0.25 LR or H = 0.1 LR). Only when $H > H_{crit.}$, e.g. H = 0.3 LR or H = 1.0 LR, can the waves propagate laterally. H = 0.25 LR and H = 0.3 LR are slightly below and above the critical thickness. The displacement amplitude therefore has an amplification similar to the case of resonance. With increasing thickness the soil layer behaves more and more like a half-space (H = 1.0 LR). Chouw, Le &

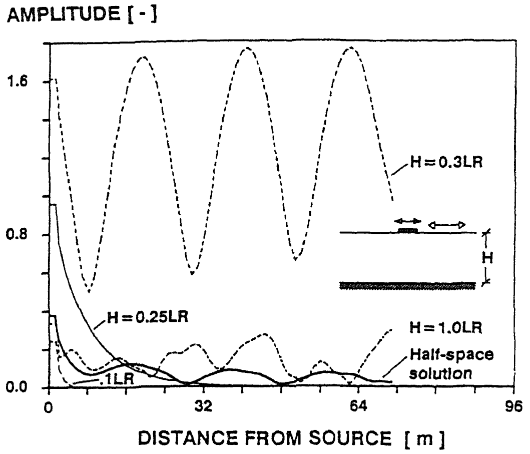

Figure 2. Influence of the layer thickness on the transmitting behaviour of the soil layer.

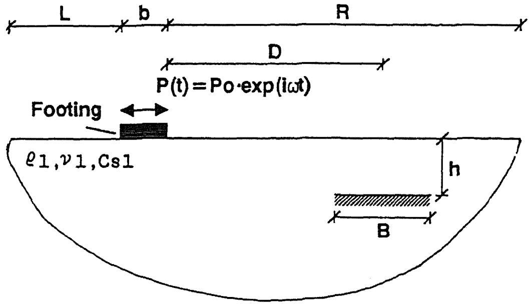

Figure 3. Surface foundation on a half–space with a finite bedrock.

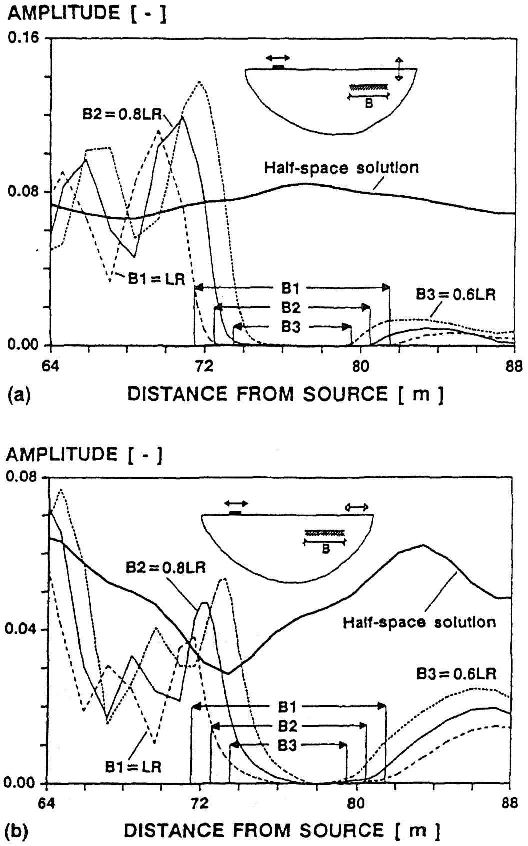

Figure 4. Influence of the extension B on the amplitude of (a) the vertical and (b) the horizontal surface dispalcement.

Schmid (1991b) show that if a bedrock of limited size exists and if the layer has an undercritical thickness, the wave spreading from the source into the surrounding soil would already be impeded. More details on vibration transmitting behaviour of a soil layer have been described by Chouw, Le & Schmid (1991a).

Figure 3 shows the case of incoming waves. The soil layer has an undercritical thickness h of 0.1 LR. The distance D between the excited foundation and the center of the bedrock extension B is 7.5 LR. The amplitude of the vertical and horizontal displacements at the soil surface (Fig. 4a and 4b) shows that although the waves will not be transmitted by the soil above the bedrock, they can pass underneath it because the bedrock is numerically described as a fixed interface. This results in soil vibration behind the screened area. The size of the screened area is determined by the extension of the bedrock.

2.2 Point wave source

The system is a half–space with two rigid and massless square foundations on the surface and a bedrock of limited size (Fig.5). The soil has a density ϱ of 2000 kg/ m^3 , a Poisson's ratio ν of 0.25 and a shear wave velocity Cs of 200 m/s. The footings have a size of 1 m∗1 m. The distance between the footing edges facing each other is 1.4 LR. The Rayleigh wave length LR is 10 m. The wave source is the first footing which is excited by a horizontal harmonic unit load P(t) with a frequency of 20 Hz. The bedrock is assumed centered below the unloaded footing at the undercritical depth of 0.1 LR and has a size of 1 LR ∗ 1 LR. The spreading waves are represented by the dimensionless amplitude $A_x[-] = U_x.G.b$ of the steady–state vibration of the soil surface. U_x is the horizontal displacement related to a harmonic point–load, the shear modulus G of the soil is 80 MPa and b is half of the width of the footing.

Figure 6a shows the spreading of the waves along the surface in case the bedrock underneath the second foundation does not exist. The amplitude of the displacement at the surface decreases with distance x from the source. The kinematic interaction between the second

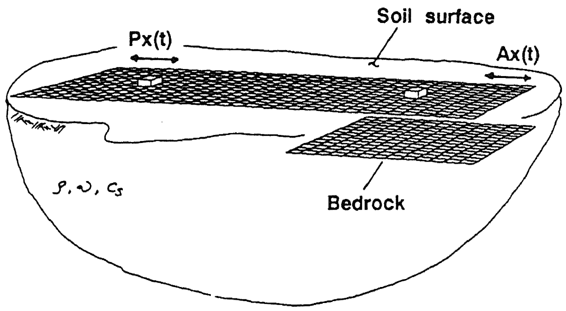

Figure 5. Discretization of the half-space surface and a finite bedrock below the unloaded footing.

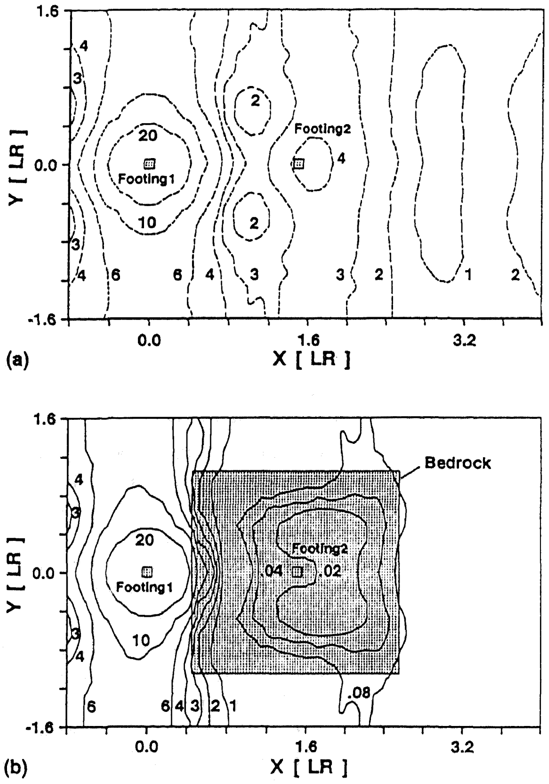

Figure 6. Lines of equal amplitude of the horizontal surface displacements Ax∗1000 (a) without and (b) with a bedrock.

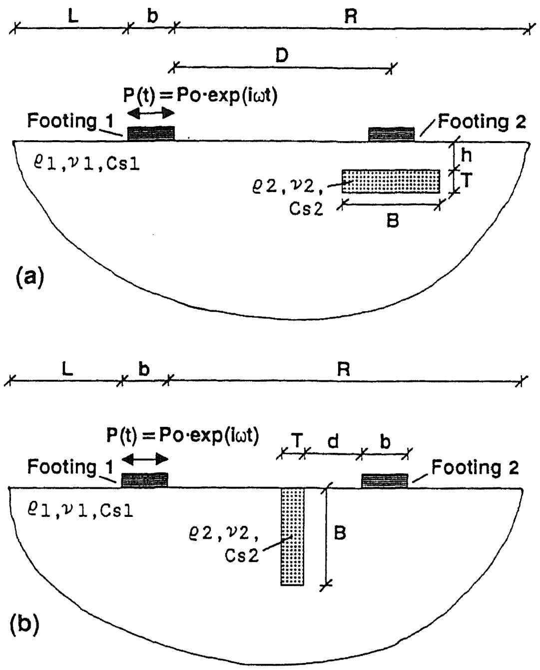

Figure 7. Two neighbouring footings on a half-space (a) with an artificial bedrock and (b) with a solid wall.

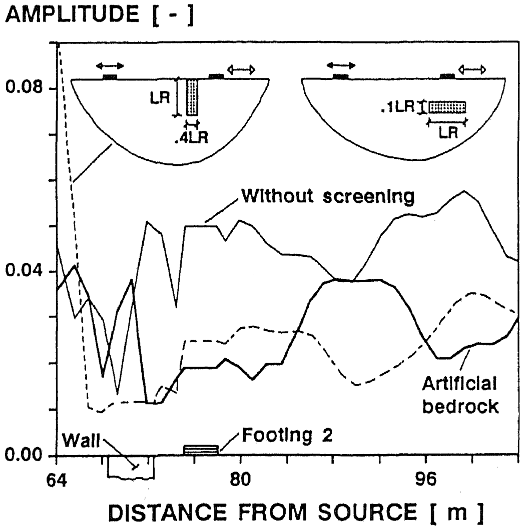

Figure 8. Screening effectiveness of an artificial bedrock and a solid wall in comparison.

footing (dotted area) and the soil only leads to a very local amplification of the displacement amplitude because the soil and the foundation considered here have a very small contact area. The existence of a bedrock (dotted area, see Fig.6b) considerably changes the transmitting behaviour of the soil above. The waves can only propagate up to a distance x of approximately 0.8 LR into the soil above the bedrock. The amplitude rapidly decreases after the waves enter the zone above the bedrock. The soil surface above the rest of this zone hardly vibrates at all. Neither does the area behind the bedrock vibrate, because the soil layer does not transmit waves.

In reality we do not always have a bedrock located at a certain depth and neither is it possible to create a real

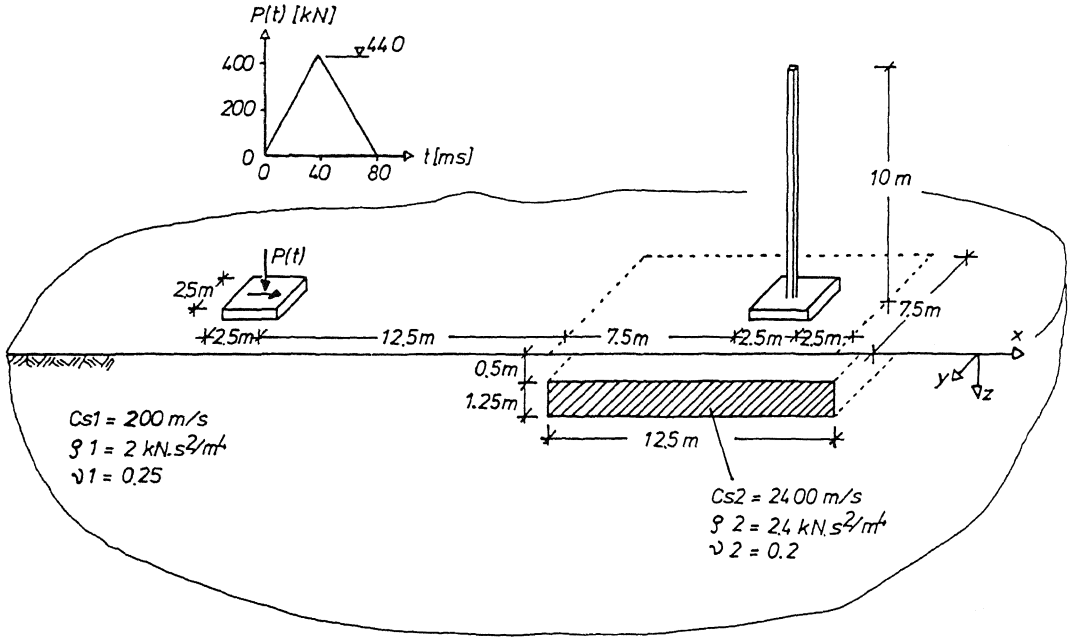

Figure 9. Foundation–soil–foundation–structure system with an artificial bedrock.

bedrock. But we can still enforce a similar soil transmitting behaviour by installing an obstacle made of some stiff material at a certain depth below the foundation. Thus we have created an artificial bedrock.

3 ISOLATION OF BUILDING FOUNDATIONS

3.1 Line wave source

To compare the effectiveness of an artificial bedrock to that of a wave barrier, a wall consisting of the material of the artificial bedrock is chosen (ϱ_2 = 2400 kg/m^3, ν_2 = 0.2, Cs_2 = 12$*$$Cs_1$, see Fig. 7a and 7b). The material of the soil, the foundations and the load are the same as in section 2.1. The distance D between the wave source (footing 1) and the building foundation (footing 2) is 7.5 LR. The wall is built in at a distance d of 0.25 LR from the building foundation. Figure 8 displays the amplitude of the horizontal displacement of the footing 2 and its surrounding due to a horizontal excitation of foundation 1. The length B of the wall and of the artificial bedrock is 1.0 LR. Even though the width of the wall was chosen to be four times that of the thickness of the artificial bedrock, the bedrock (heavy dark line) reduces the vibration at footing 2 more effectively than the wall (dotted line). The influence of the material stiffness, the depth and the thickness of the artificial bedrock on its screening effect is presented by Chouw, Le & Schmid (1991c).

3.2 Point wave source

Results are presented that show the effectiveness of an artificial bedrock used to screen a building from transient soil vibrations. Figure 9 represents the system considered. Two surface foundations are located on a half-space. An artificial bedrock is located underneath the foundation with a structure. The soil is the same as in section 2.2. A mast with a mass of 10 kg/m and a flexural stiffness EI of 1.4$*$10^9 kNm^2 is chosen as a simplified structure. It has a material damping which is described by a Kelvin–chain with the parameters E1 = 10 and En = 10^{20} (Schmid & Hillmer 1990). Both foundations are assumed to be rigid. The soil vibrations are produced by a triangular load P(t) on the first massless foundation. The mast foundation has a thickness of 1.4 m and a density of 2500 kg/m^3. The mast is modelled by a beam element with continuously distributed mass. The coupling of the mast and the soil is achieved by fulfilling the compatibility conditions of the displacements at the mast's foundation and the equilibrium conditions of the interacting forces at the soil–foundation interface. The calculations are performed in the Lapalce domain.

Figures 10a and b display respectively the time–history of the vertical displacement of the mast due to the vertical and horizontal loading of the neighbouring foundation. Figures 11 and 12 show the time–history of the horizontal displacement of the mast's top and base due to the vertical and horizontal loading of the neighbouring foundation. The results indicate that an artificial bedrock can reduce the structural response. The load considered

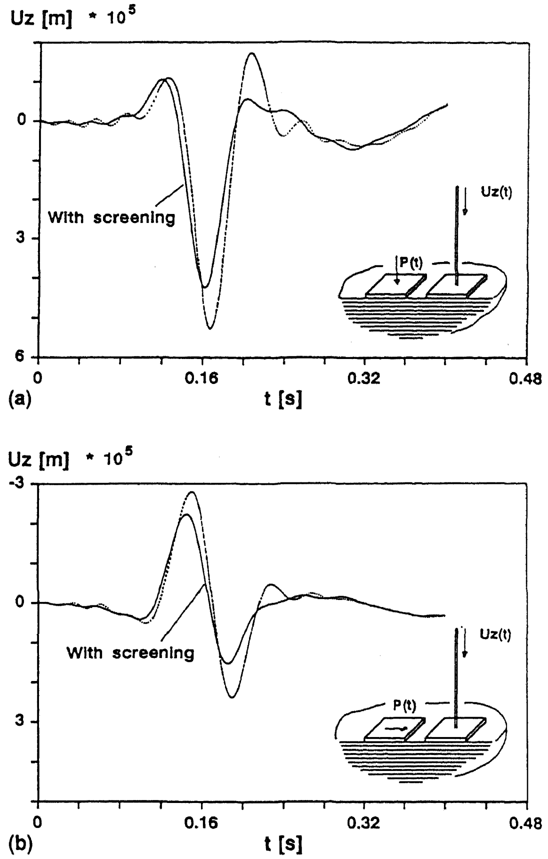

Figure 10. The vertical displacement of the structure due to (a) a vertical load and (b) a horizontal load.

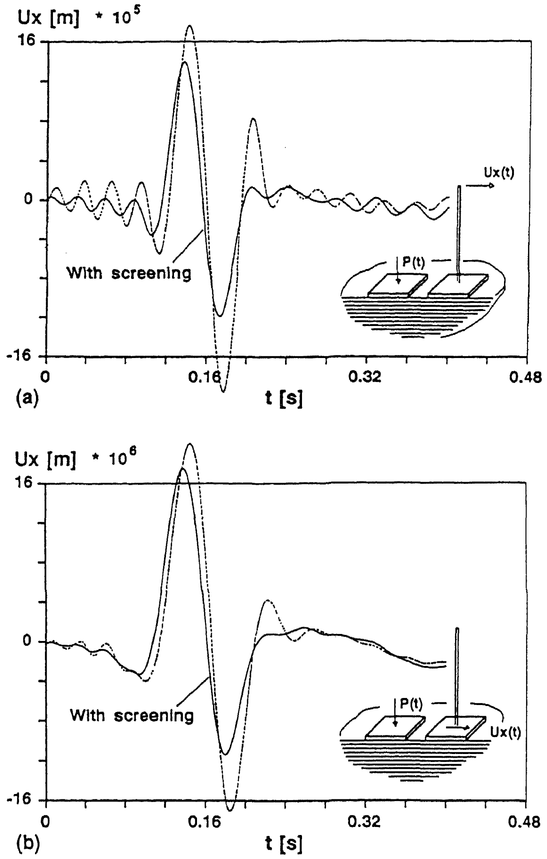

Figure 11. The horizontal dispalcement (a) at the top and (b) at the base of the mast due to a vertical load.

here has a dominant frequency content of 5–24 Hz. To further impede the low frequency part of the soil vibrations the artificial bedrock has probably to be extended into the direction of the incoming waves.

4 CONCLUSIONS

An approach is presented to isolate foundations of buildings from steady–state or transient soil vibrations. The impeding behaviour of a soil layer is created by a stiff obstacle (an artificial bedrock) under the building's foundation. If the excitation frequency is less than the lowest eigenfrequency of the layer, the waves spreading into the layer will be impeded. The excitation of the building's foundation and so the structural response of the building are therefore reduced.

At the moment we are conducting laboratory experiments and field tests on the effectiveness of an artificial bedrock to impede the spreading of waves.

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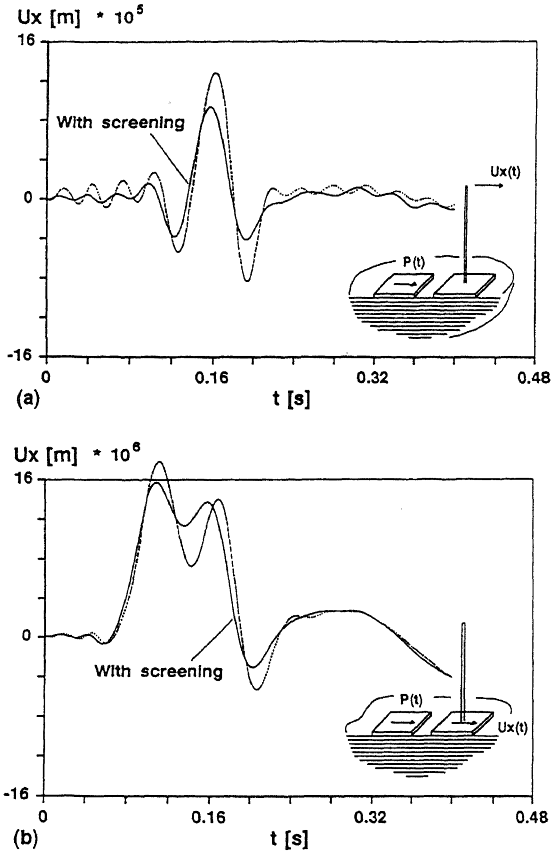

Figure 12. The horizontal displacement (a) at the top and (b) the base of the mast due to a horizontal load.

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