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Reduction in ground vibrations by using shaped landscapes

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ABSTRACT

Reduction in traffic-induced ground vibrations by the use of shaped landscapes is investigated here by shaping the landscape surrounding a high-tech facility, using the landscape thus produced as a wave obstacle. The effects of the geometric parameters of a shaped landscape were examined in parametric studies. An architectural landscape design was also investigated in terms of its effectiveness in reducing traffic-induced ground vibrations. Finite element models, analysed in the frequency domain, were employed. The models involve a layer of soil and the underlying bedrock. It was found that anywhere from an appreciable reduction to an appreciable amplification of the vibrations produced can occur, depending upon the geometric parameters of the shaped landscape involved. The most effective shape was found for a topography that acted as a waveguide that reduced the level of vibration by approximately 35%.

1. Introduction

Occasionally, very strict vibrational requirements are specified for sensitive equipment used in high-tech facilities, such as radar towers and synchrotron facilities. Regardless of whether the sensitive equipment in itself is a significant source of vibration, or not, it is important to isolate it from external vibrations. High-tech facilities are often located in the vicinity of sources of vibrations of significant amplitude, radar towers often being found near rocket-launching facilities, for example, and synchrotrons near heavily trafficked roads, the latter for logistic reasons. The traffic-induced ground vibrations can propagate to facilities nearby and lead to the vibration requirements for sensitive equipment there being exceeded. It can be desirable under such conditions to reduce the ground vibrations by the use of wave obstacles. The traffic-induced vibrations can be reduced by various means, such as by shaping the landscape between the road and the facility.

It is known from the previous studies [1–3] concerning the synchrotron facility MAX IV in Lund, Sweden, that the material parameters of the soil there have a strong effect on the vibration levels that occur in sensitive parts of the facility, whereas structural modifications of the facility itself have only a negligible effect. Most of the vibration energy produced by vibrations induced on the ground surface is transmitted by Rayleigh surface waves that propagate close to the ground surface. Since Rayleigh waves attenuate with horizontal distance as well as with depth, the ground vibrations can be reduced by constructing a suitable wave obstacle in the ground between the wave source and the facility that is to be protected. Body waves propagate as a hemispherical wave front, whereas Rayleigh waves propagate radially as a cylindrical wave front [4]. The attenuation of the body waves is thus proportional to $1/r$, the attenuation of the Rayleigh waves, in contrast, being proportional to $\sqrt{1/r}$. Thus, at a relatively large distance from a vibration source the Rayleigh waves become the dominant wave form.

Constructing a shaped landscape as a wave obstacle between a vibration source and a facility creates a discontinuity for the propagating waves. Waves that are incident to the shaped landscape show different types of behaviours that are associated with changes in direction of the propagating waves. They are subjected to reflection as well as diffraction at the boundaries of the landscape. These two phenomena scatter the wave front and reduce the level of vibration at the facility.

At large construction sites, large amounts of soil are excavated in order to level the ground surface. This is necessary since, generally speaking, the surface needs to be horizontal before the construction of a building begins, the loose topsoil needing to be removed. The large amounts of excavated soil produced often need to be transported away from the construction site, which can be

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Fig. 1. The buildings of the MAX IV facility as they are expected to appear, as well as the nearby E22 motorway, as rendering in a drawing [5,6].

costly for the construction project. If instead, these soil masses can serve a useful purpose at the construction site, they can be retained and be used to construct a shaped landscape with hills and valleys, for example, see Fig. 1. The architect bureaus associated with the MAX IV project, *Fojab* and *Snøhetta* [5,6], developed an architect-designed geometry of a shaped landscape (cf. Fig. 1) surrounding the MAX IV facility, one based on ideas partly introduced by the Department of Construction Sciences at Lund University. This shaped landscape can serve to reduce traffic-induced ground vibrations incident to the facility and is regarded as representing an aesthetically desirable solution.

In the paper, the reduction in vibrations that shaped landscapes are expected to bring about were investigated, the MAX IV synchrotron facility serving as an example case here. Fig. 1 presents an architectural sketch of the facility as planned. MAX IV is to be built approximately 100 m from the motorway E22. In the MAX IV facility, a beam of electrons is to be controlled by a large number of magnets that are distributed along the ring-shaped structure and along beam lines that lead beams of electrons to measurement stations. Since the quality of the measurements obtained is dependent upon the levels of vibration of the magnets, very strict requirements regarding the vibration levels have been specified. The vibration requirements for MAX IV regarding vertical displacements of the magnets are especially strict, its being required that these be less than 20–30 nm in RMS per second within a frequency span of 5–100 Hz.

1.1. Literature review

Several investigations of the effects of irregular topography on ground vibrations have been carried out.

Lee and Wu [7,8] presented a numerical solution for the two-dimensional (2D) scattering and diffraction of plane P, SV and SH waves by canyons of arbitrary shape in an elastic half space. The displacements were computed numerically using the method of weighted residuals (moment method). It was concluded that the ground vibrations were frequency dependent and were also dependent upon the orientation of the incident waves. It was found that the shape of the canyon had an effect on the displacement amplitudes at the surface of the canyon and in the nearby half-space [8]. Zhou and Chen [9] investigated the effect of topography on Rayleigh waves excited by an explosive source near the surface, their employing the local indirect wave-number method. The energy and the frequency content of waves before and after passing through the topography involved were compared in order to evaluate the effect of the steepness of the topography. Reduction in the energy of the waves and loss of their high frequency content were found to occur. The authors concluded that these effects were more obvious where the topography was steeper.

Mossessian and Dravinski [10] investigated the diffraction of plane harmonic waves by three-dimensional (3D) surface irregularities by the use of an indirect boundary integral method. The irregular shapes were arbitrary and were embedded in the half-space. It was found to be important to use 3D numerical models when investigating the scattering of elastic waves by surface topographies of arbitrary shape. Sánchez-Sesma and Campillo [11] investigated the topographical effects for P, SV and Rayleigh waves in an elastic half-space, through the use of the indirect boundary element (BE) method, their finding that the topography can have an appreciable effect on both the amplification and the reduction in the level of vibration at or nearby the topographic features in question. Reinoso et al. [12] investigated through the use of a direct BE method the 3D scattering of seismic waves from irregular topographies, due to the presence of incident P-, S- and Rayleigh waves in the time domain. The irregular shapes were those of both mountains and valleys. It was found that an irregularity affects by way of its geometry the level of amplification achieved. It was concluded that mountains with vertical walls generate higher amplification levels than walls of mountains with a smooth slope. Nguyen and Gatmiri [13] used a 2D direct BE method for examining the scattering of seismic waves by topographic features of different types. They found that a topographic feature modifies the seismic waves at and near to the topographic feature in question. Zhenning and Jianwen [14] investigated the scattering of incident SV waves by a canyon in a layered half-space through use of an indirect BE method. They found that the presence of a layered half-space affects both the displacement amplitudes on the ground surface and the frequency content of the displacements. They observed that the displacements obtained depended upon the type of excitation.

Bouckovalas and Papadimitriou [15] employed the finite difference (FD) method to study the effects of the topography and of vertically propagating SV waves on seismic ground vibration in step-like ground slopes. It was found that the topography involved can lead to either an amplification or a reduction in the level of vibration at the crest of the slope or nearby. Amplification generally occurs near the crest of the slope and reduction at the toe of the slope. Ducellier and Aochi [16] developed an FD-FE method for modelling seismic wave propagation in a 2D elastic medium having an irregular surface topography. To study amplification effects there, numerical simulations of seismic wave propagation in a series of hills were carried out and were compared with a single-hill case. The authors found that the presence of several hills, as opposed to a single hill, can increase the amplification effects produced by the topography of the ground surface. They concluded that in evaluating topographic site effects the