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VIBRATION INFLUENCE ZONE CALCULATION USING MODIFIED MODAL IMPACT METHODS

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INTRODUCTION

The study of wave phenomenon produced by a sudden velocity 'jump', such as occurs during blasting, is identical to the study of wave motion produced by earthquakes and hence falls under the general classification of seismology. The general class of problems seeks to predict the vibratory response (at a point in space) due to some type of excitation. Past observational experience indicates that the constitutive (stress-strain) relationship of rocks and hard packed soils for infinitesimal strains and seismic frequencies is highly elastic so that Hooke's law is applicable for seismic propagation theory to a high degree of approximation.

Consider a large solid body made up of areas which are individually homogeneous and isotropic. Let each infinitesimal element of the body be in equilibrium. Applying Newton's second law to all forces applied to the element and noting that force equilibrium is maintained via Hooke's law leads one to the following vector equation of motion:

$$\rho \frac{\partial^2 \bar{s}}{\partial t} = (k + \frac{1}{3}\mu)\, grad\theta + \mu \nabla^2 \bar{s} \qquad (1)$$

In the above equation $\bar{s}$ is the particle displacement vector, $\theta = div\, s$ is the dilation of the element, ρ is the density of the element, μ is the element's rigidity, and k is the element's bulk modulus.

A direct closed-form solution of Equation 1 does not exist. A method known as *separation of variables* has traditionally been applied to this equation to uncouple the particle displacement vector $\bar{s}$ from the elements dilation $\theta = div\, s$ and treat each phenomenon separately.

The proposed methodology here will be to model the ground vibration propagation of a soil-structure system as a SDOF viscously damped harmonic oscillator subjected to an initial velocity input. The classification of dynamic soil behavior (especially damping) as a small-strain viscously damped medium is well documented [1]. Since we are only interested in the first vertical (shear or up-down) mode of the combined soil-structure system, the method of approximating the behavior due to blast excitation as a SDOF mechanical system is valid to within an acceptable engineering tolerances.

THEORY AND MODEL DEVELOPMENT

Consider now the modified solution to the underdamped free vibration of a system described with viscous damping and subjected to initial displacement and velocity u_o and $\dot{u}_o$.

$$u(t) = e^{-\varsigma(x)\,\omega_n t}\left(u_o \cos\overline{\omega_d}t + \frac{\dot{u}_o + \varsigma(x)\,\omega_n u_o}{\omega_d}\right)\sin\overline{\omega_d}t \qquad (2)$$

where,

$u(t)$ is the displacement of the system as a function of time,

$\varsigma(x)$ is the small-strain material damping coefficient as a function of distance,

ω_n is the undamped circular natural frequency of the soil-structure system, and,

$\overline{\omega_d}$ is the damped circular natural frequency of the system $= \omega_n\sqrt{1-\varsigma(x)}^{\,2}$

For this type of system, $\varsigma(x)$ is a continuous function of spatial position x, and is always less than 1.0. Taking the derivative of Equation 2 with respect to time t, and assuming no initial displacement u_o, gives the following simplified expression describing the motion of our system.

$$\dot{u}(x,t) = -\varsigma(x)\,\omega_n \dot{u}_o e^{-\varsigma(x)\,\omega_n t}\cos\overline{\omega_d}t \qquad (3)$$

Since the soil-structure system is assumed to be linearly elastic, general reciprocity rules apply. Equation 3 describes the spatial-time response of the soil-structure system when a velocity jump (blasting event) takes place at a measured distance x. The quantification of the soil-structure damping ratio $\varsigma(x)$, can be determined experimentally from the test specimen using common modal impact methods. An illustrative example of the method is shown below.

EXPERIMENTAL DETERMINATION OF DAMPING LEVELS

A future landfill site located in Southern California was chosen as the test location since it would require blasting for footprint excavation. The blasting would require a main service aqueduct to be relocated to a point outside the vibratory influence zone.

The relative amount of damping present at the blast site was determined using a modified modal impact methodology. A 5.4 kg (12 lb) calibrated modal sledge hammer impacted the upper exposed part of the aqueduct portal which in turn acted to transfer the energy into the ground. The accelerometer was positioned at a distance of 6.1 m (20 ft) from the edge of the portal housing and was affixed to a metal stake driven firmly into the ground. The results measured were therefore for the combined soil-aqueduct system. A total of 25 hammer blows averaging approximately 1,000 N of force each was applied to the portal during each data run to minimize sampling error and input variance. Coherence functions were examined though out the test trials and formed the basis for the rejection of poor quality data.

The solution strategy consisted of combining the force output from the hammer and acceleration output from the accelerometer to create a single vibratory measure called the transfer function (or frequency response function). This transfer function was saved for later recall during the post processing phase where the amount of modal damping (i.e., damping as a function of frequency) was determined using the Half Power Point Method [2]. Critical damping levels for this system were found to be 4.24 percent at a distance of 6.1 m (20 ft) [3]. This equates to a rigid-body aqueduct-soil interaction damping level $\varsigma(x)$ of 0.0069/m (0.0021/ft) within the experimental frequency range of zero to 154 Hz.

INFLUENCE ZONE CALCULATION

The determination of a vibratory influence zone is typically determined through a set of fixed impact criteria. For example, the U.S. Bureau of Mines in its report entitled, "Structure Response and Damage Produced by Ground Vibrations from Surface Blasting" (RI 8507) [4] has identified acceptable maximum transverse ground velocity levels. This criteria sets the maximum peak particle velocity as a function of frequency. The resultant values have been shown to produce negligible effects (displacement, fatigue, and damage) in conventionally constructed structures (i.e., structures built within the past 100 years). Comparable criteria can also be found in the ISO standards.

For our present example at the landfill site, we find that upon substitution of the experimentally derived aqueduct-soil damping level $\varsigma(x)$ into Equation 3 yields vibration influence distances as a function of blast decay rates and assumed frequency content. The graphical solution of this equation to the problem at hand is shown in Figure 1. As can be seen from this figure, the lower the blast frequency, the farther the distance required to decay to a specific level. For a maximum blast wave (recorded at a reference distance of 15.2 m or 50 ft) of 381 mm/sec (15 in/sec) at 20 Hz, the standards set by the Bureau of Mines would allow a maximum particle velocity of 25.4 mm/sec (1.0 in/sec). From the figure it can be seen that the minimum allowable blasting distance would be 32 m (105 ft).

CONCLUSIONS

The proposed method allows for the rapid determination of vibratory influence zones due to blasting based upon the solution of a SDOF viscously damped harmonic oscillator with linear-distance damping. The model has been shown to produce results which are conservative compared to those predicted by "blaster's equations" and has the distinct advantage of providing a solution which is frequency dependent. This frequency dependency is typically not found in most current modeling strategies and is often ignored. The limitations of the method are, of course, that the overall damping level $\varsigma(x)$ can not exceed 1.0 (requirements for an underdamped system) and that higher modes and in-plane activity can not be characterized. The first restriction sets an upper limit for which an influence zone can be determined, while the second is a physical limitation on the method.

REFERENCES

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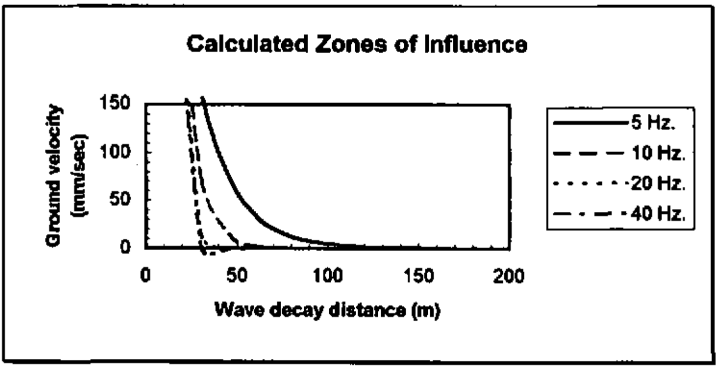

Figure 1: *Predicted Vibratory Zones of Influence for Test Site. $\varsigma(x)$ =0.0069/m, Blast decay rate of 0.25 sec.*