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REDUCING LOW FREQUENCY GROUND VIBRATION FROM TRAINS

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1. INTRODUCTION

The environmental effects of ground propagated vibration from trains can be divided into two areas[1]. Vibration generated by trains running in tunnels has frequency components in the range 30 to 200Hz. This may excite resonances in the floors and walls of nearby buildings which then re-radiate a characteristic rumbling noise into the rooms. There are established methods of control for this problem. These take the form of vibration isolation in the track and include:

1) resilient rail supports. These may be made to attenuate vibration in the range down to about 30Hz
2) tracks on resiliently mounted concrete slabs. The best cases of these isolate vibration down to about 20Hz.

Mainline trains running on the surface give rise to vibration between 2 and 20Hz and if the amplitude is great enough the vibration is felt. This problem is particularly associated with heavy freight trains but only occurs locally where there are certain ground conditions. In this frequency range a reduction of 6dB in the vibration level would be worthwhile and a reduction of 12dB would be regarded as substantial.

Mass-spring isolation for the low frequency range is impractical and for this kind of vibration problem there are no proven solutions. In this paper three possible solution techniques are explored using a three-dimensional layered ground model.

2. THREE-DIMENSIONAL LAYERED GROUND MODEL WITH TRACK

British Rail Research have developed a number of numerical models for the propagation of vibration from trains[2]. Here a model has been used which includes a two-dimensional representation of the track and a three-dimensional layered ground. The model is shown for the example of ballasted track in Figure 1. A vertical point load of unit amplitude is applied to the track top and the vertical and transverse horizontal components of the response are calculated at the ground surface a distance away. The track model includes the bending stiffnesses and mass of the rail, the vertical stiffness of the rail support, the sleeper mass and the vertical stiffness of the ballast layer with consistent mass. Each of the track components includes hysteretic damping; ie a loss factor associated with each stiffness property.

The ground is modelled using 'layer elements', which approximate the depth function of displacement using the finite element method with cubic polynomial shape functions. The layer elements allow travelling wave propagation to infinity in the horizontal directions. Below the layer elements a 'half-space' element is used to represent the substratum.

3. MODEL PARAMETERS AND VALIDATION

The Young's modulus, Poisson's ratio and an estimate of the density of each ground layer are obtained from measurements of the p-wave and s-wave speeds. The damping parameter is estimated by the comparison of measured and calculated transfer response functions from a small circular footing. In some soils the viscous damping model has been used while at others a hysteretic model shows better agreement.

Figure 2 shows the measured and calculated transfer response at an alluvial soil site. Here p- and s- wave speeds have been obtained from a survey at the site and viscous damping has been adjusted to give the best fit. In order to show the variability of the measured response functions, several measurements were made for several positions of the footing and the response within the area covered by the seismic survey and measurements were made on different days. The comparison has been made for a number of different distances for both vertical and horizontal responses and the agreement has been found to be good. Sets of parameters for a number of sites have been validated in this way.

4. MODAL PROPAGATION

The steep low-frequency cut-off shown in Figure 2 below 20Hz occurs because of the layer depth of the top weathered layer of the soil. Below a certain frequency no propagating mode shape can exist in this soil layer. This shows the importance of using a model which takes account of the layered structure of the soil when modelling surface propagation especially at low frequencies. The methods of vibration attenuation investigated are based on changing the modal propagation regime in the soil layers.

In order to compare the techniques in the study presented in Sections 5 to 7, the ground parameters for a reference site at which 3m of alluvial soil over-lie a foundation of compacted gravel, have been used in each case. A second case is also shown for each technique. The parameters representing a standard ballasted track have been kept constant.

5. SUPPORTING THE TRACK BELOW THE GROUND SURFACE

This situation is modelled by coupling the track model at a node in the FE ground model other than the surface node. This situation may be approximately achieved in practice using a piled foundation to transfer the track load to a lower point in the soil lithology.

The vertical and transverse horizontal components of the response for the reference ground at 8.7m are shown in Figure 3 for four cases of the depth at which the track model is coupled to the ground model. It can be seen that, below 10Hz, the horizontal component is reduced substantially. The vertical component, however, is increased. Since the horizontal component dominates in this frequency range the overall result is a reduction in the resultant level of about 12dB by coupling the track to the interface between the substratum and the layer.

A substantial attenuation in both components of the response occurs in the frequency range from 10Hz to 50Hz. For the track acting half way down the layer the rise in response due to the onset of propagation occurs at a higher frequency. For the cases of the track acting on the substratum the effect of the onset of propagation in the layer is very much reduced.

In order to examine further the potential for transmitting the track loads to a depth within the ground, the analysis was repeated for a site at which 2m of weathered material overlies a stiff sandstone. The results are shown in Figure 4. At this site the vertical component of response is the greater below 10Hz and this component is unchanged with increasing depth of the track load in the ground. Although no benefit is obtained below 10Hz for the resultant amplitude at 8.7m, a possibly useful reduction is effected in the range 10Hz to 30Hz.

6. A STIFFENED TOP LAYER OF SOIL

Haupt[3] has shown, that a stiffer layer of material at the surface of a half-space of soil, can cause an increased attenuation vibration with distance. The possible benefit of using a stiffened layer of soil on a layered ground structure to attenuate low frequency vibration generated from trains has been investigated here.

The assumed method of stiffening the soil is lime stabilisation. In this process a soil with a high clay content is mixed with a small fraction of quick lime and is recompacted. Over a period of time the Young's modulus of the soil increases as pozzolanic (cementation) reactions take place between the clay and lime. Plant exists which treats the soil to a depth of approximately 0.4m.

The effect of lime stabilisation on vibration propagation parameters is not known. For the static elastic modulus a possible increase of 10 times is claimed and the Poisson's ratio is reduced significantly from its near 0.5, 'constant volume', value. It has been assumed here that a similar increase in the dynamic Young's modulus, could be achieved and that the reduction of the Poisson's ratio would also still apply.

The results of the analysis at the reference site are shown in Figure 5. This shows that both the components of the response at 8.7m have been reduced. The resultant amplitude below 10Hz has been reduced by 16dB.

The method of lime stabilisation is only applicable to sites with a sufficient component of clay in the upper soil layer. It has been 'applied' in the theoretical study to the case of the reference site regardless of this. The analysis has therefore been repeated for a London Clay site. The results for this are shown in Figure 6. Below 10Hz, the vertical component which dominates the resultant in this case, has not been reduced although the horizontal component has. The lime stabilisation of the top layer of soil at this particular site would therefore not be expected to have a beneficial effect on the resultant amplitude.

7. HIGH PRESSURE GROUTING

Schmid et al[4] investigated the use of a stiff layer within an elastic half-space to form an 'artificial bedrock' of finite extent to shield buildings from soil vibration. Here the prospect of vibration reduction within a layered soil is investigated. A sandy, or peaty soil may be stiffened by grouting. That is, the voids in the particulate material are filled with a concrete slurry by injection under high pressure. The soil adjacent to the surface cannot be treated as the grout would break out. As with the lime stabilisation technique, there are no available data on the effect on the wave propagation properties of the soil. It has been assumed that an increase in dynamic Young's modulus of the soil by a factor of 5 is achievable with an increase in density of the soil of 12%.

Figure 7 shows the results of an analysis at the reference site in which a layer 1m thick resting on the substratum has been grouted. A reduction in both components of the response occurs for frequencies between 2.5Hz and 17Hz although the horizontal response is only lowered by 1dB. As the technique effectively reduces the depth of the weathered layer of soil the low frequency cut-off of propagation in this layer is raised in frequency. For the frequency range from 10Hz to 17Hz, therefore, the attenuation is more substantial.

For the second case another alluvial soil on gravel site was chosen. The results for this are shown in Figure 8. As well as the rise in frequency of the cut-off the horizontal component of the response, which is the greater at this site, has been reduced by at least 8dB for frequencies below 10Hz. Below 5Hz the vertical component has been raised a little. The overall effect is a reduction due to grouting of about 3dB at 1Hz, 4dB at 5Hz and 15dB at 10Hz. A reduction occurs for frequencies up to 15Hz. The method of grouting a layer therefore shows promise at this site.

8. FURTHER WORK

It has been found that each method will work at some sites and not others. Additionally each of the ground stiffening methods is only applicable to some soil types. However, the analysis shows that there are possible methods of significantly reducing the vibration levels in the low frequency range.

In the analysis, to date, it has only been possible to change the properties of whole infinite layers. It is not known to what distance the ground layer must be stiffened to obtain the attenuation at distances typical of houses at the line side. For this, further analysis with a different kind of model is required. A cross-sectional model, similar to that of Waas[5], of the track and ground is being used for this further investigation. The idea is to use this as a complimentary model to the three-dimensional one. Near the track the ground is modelled using conventional finite elements - farther from the track special semi-infinite wave-propagating elements are used. For this work high order semi-infinite elements have been developed[2].

The model can also be used to look at the effects of other things such as ditches and buried walls, track on an embankment or in a cutting. It has also been used to incorporate a tunnel structure and to model the propagation of vibration in the re-radiated noise frequency regime.

9. ACKNOWLEDGEMENT

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10. REFERENCES

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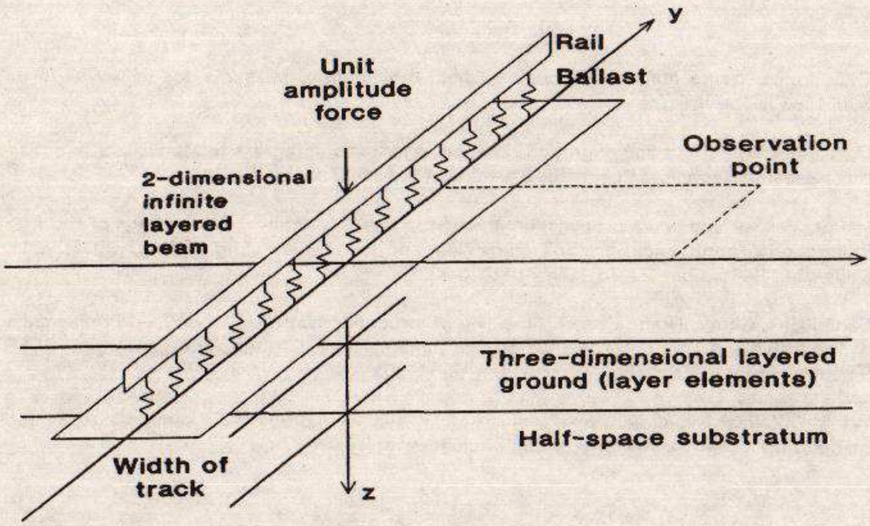


Figure 1 Model of track on layered ground

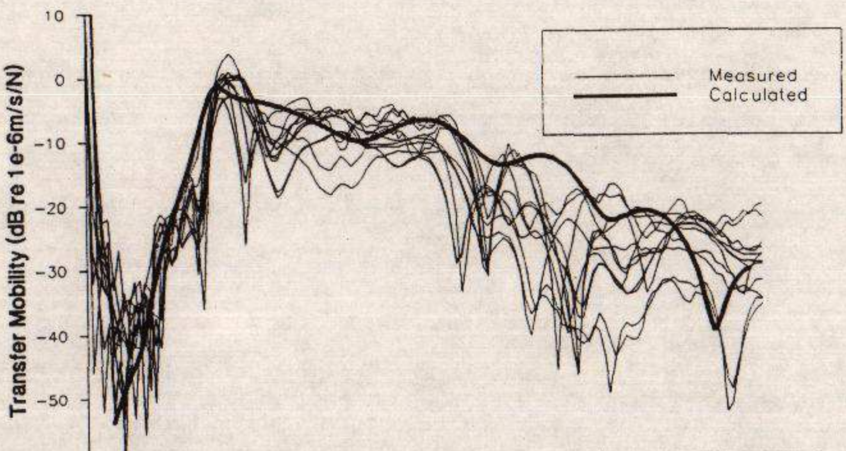
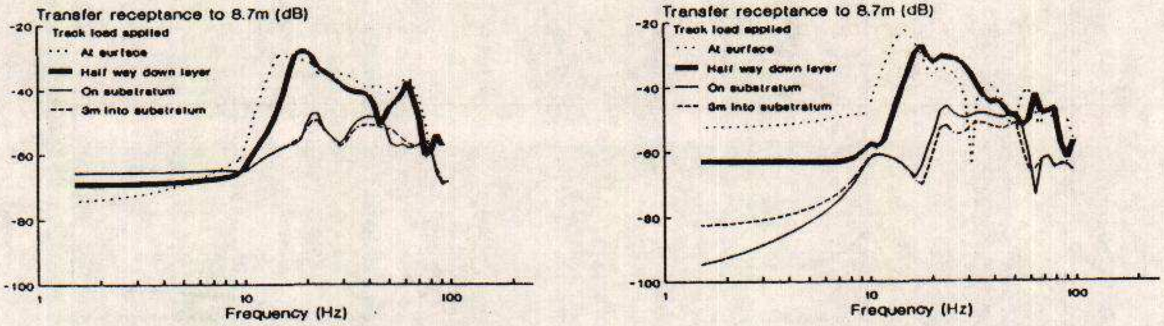


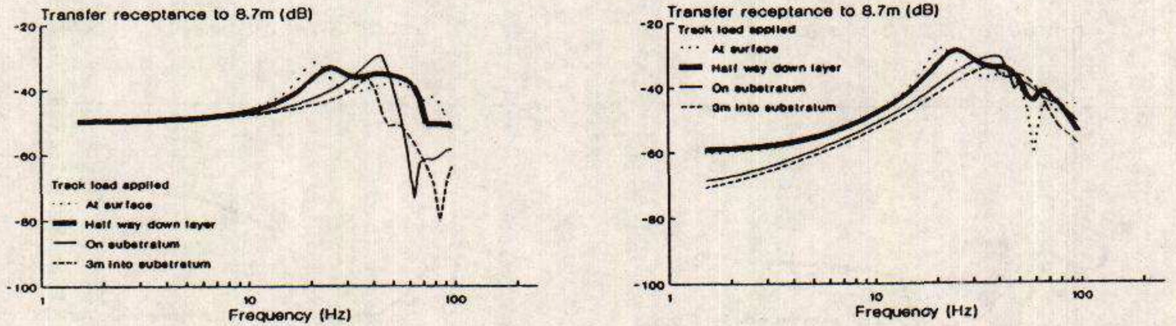
Figure 2 Comparison of measured and calculated vertical response at 6m from a small circular footing



(a) vertical response

(b) horizontal response

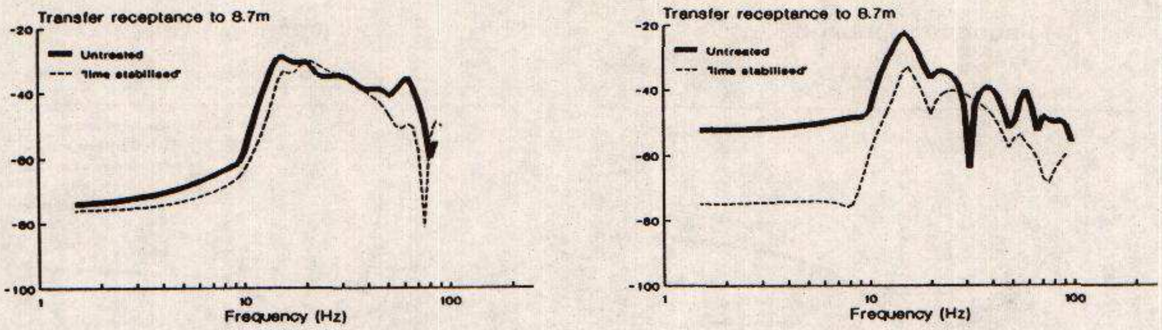
Figure 3 Response at reference site for load applied at various depths



(a) vertical response

(b) horizontal response

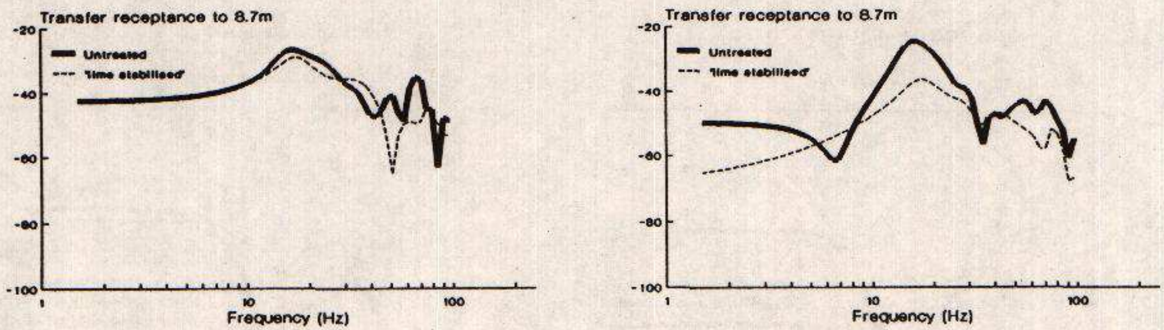
Figure 4 Response at sandstone site for load applied at various depths



(a) vertical response

(b) horizontal response

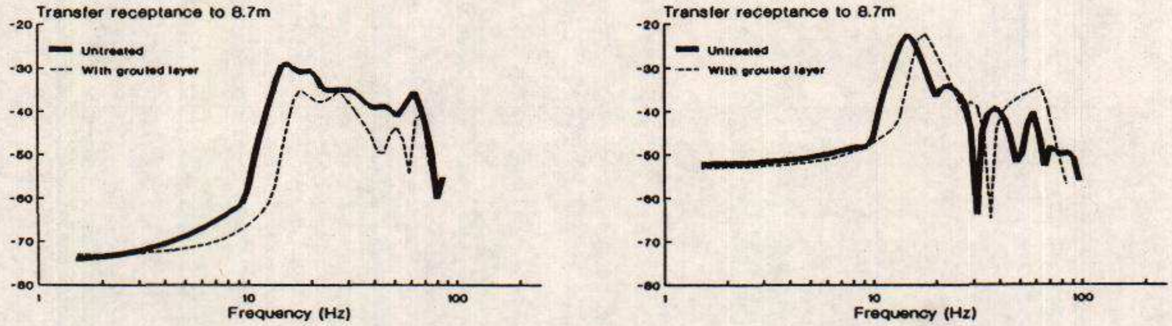
Figure 5 Response at reference site with a *lime stabilised layer*



(a) vertical response

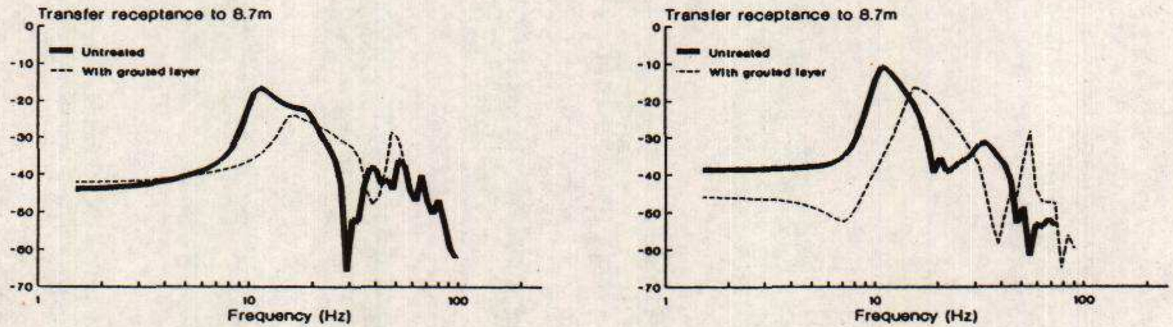
(b) horizontal response

Figure 6 Response at London clay site with a lime stabilised layer



(a) vertical response (b) horizontal response

Figure 7 Response at reference site with a grouted layer



(a) vertical response (b) horizontal response

Figure 8 Response at alluvial soil/gravel bed site with a grouted layer