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Experimental and Numerical Investigation on Vibration Screening by In-Filled Trenches

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SYNOPSIS: In-filled concrete and soil-bentonite trenches have been used in practice for many years as wave barriers to reduce transmission of moderate to high frequency ground vibrations generated by machine foundations or traffic. An experimental investigation on the influence of various geometrical and material parameters on vibration screening effectiveness of in-filled barriers has been conducted. The experimental data are compared with numerical (BEM) Solutions as well as with design formulas of Ahmad and Al-Hussaini (1991).

INTRODUCTION

Ground vibrations generated by machine foundations or traffic can have an adverse effect on nearby buildings, equipment, and people, ranging from annoyance or discomfort to structural damage to the facilities. Therefore, for prevention of damage to adjacent structures and equipments nearby, in many cases it is necessary to significantly reduce the transmission of such vibrations. For moderate to high frequency vibrations, this objective can be achieved by placing a wave barrier between the source of vibration and the area to be protected. In-filled concrete and soil-bentonite trenches have been used in practice for many years as wave barriers. An in-filled trench barrier reduces the ground-transmitted vibrations mainly by interception, scattering and diffraction of the surface waves.

In past few decades of research, both experimental and numerical approaches have been used to study the vibration screening effectiveness of open trenches.

Barkan (1962) and Doling (1965) were the first to present some field test results and suggest some guidelines for open (air) wave barrier design, which, however, were very limited in scope. Woods (1968) performed a series of field experiments (small scale model tests) on vibration screening by installing open trenches very close to the vibratory source (known a active isolation) as well as in the far field (known as passive isolaiton). Based on his experimental findings, Woods has presented some guidelines for the dimensions of an open trench to achieve a ground amplitude reduction of 75% or more.

The finite element method (FEM) with plane-strain idealization has been used by Lysmer & Waas (1972), Haupt (1977, 1978), Segol et al (1978), and May & bolt (1982) for analyzing a few open trench wave barrier problems. Boundary element method have been used by Dasgupta et al (1988), Banerjee et al (1988) and Ahmad & Al-Hussaini (1994) to study the screening effectiveness of open trenches in three dimensional space rather than the usual two dimensional analysis used by the earlier BEM and FEM researchers.

However, the problems of trench collapse and structural stability limit the use of open trenches in modern practice. Thus, in-filled trench barriers are more practical than open trench barriers. The vibration screening effectiveness of in-filled trenches has been investigated (numerically) by a limited number of researchers [Leung et al (1990), Ahmad & Al-Hussaini (1991,1994), Al-Hussaini (1992) and others]. Based on their numerical (BEM) results, Ahmad & Al-Hussaini (1991, 1994) have developed algebraic expressions for estimation of vibration screening effectiveness of open and in-filled trench barriers.

The primary objective of the completed work was to conduct an experimental investigation on the influence of various geometrical and material parameters on vibration screening effectiveness of in-filled trench barriers and then utilize the experimental data to verify and calibrate the analytical findings. To achieve this objective prototyped model tests were conducted in field in a remote area near the north campus of SUNY at Buffalo. Both near field (active) and far field (passive) vibration screening by concrete and soil-bentonite in-filled trenches were studied. Active isolation is modelled via an annular trench wall barrier around a vibratory source on the ground, with reduction of ground motions outside the barrier being focused upon. Passive isolation is modelled as a straight trench wall barrier located away form the source, with reduction of ground motions in a semicircular and rectangular region behind the barrier being focused upon. An electromagnetic vibratory oscillator was used as the vibration source to set out continuous wave trains at selected frequencies. Measurements of ground vibration at selected pickup points were made 'with' and without' the in-filled barrier in place. The effectiveness of the barriers were computed as the ratio of the ground motion 'with' and 'without' the barrier.

Recognizing the inherent difficulties in conducting a very extensive field investigation, a detailed companion numerical investigation of active and passive isolation by in-filled trenches utilizing a vigorous three-dimensional boundary element (BEM) computer code is also conducted. The field results are then compared with the BEM solution as well as with the simple design formulas presented by Ahmad and Al-Hussaini (1991, 1994).

DESCRIPTION OF THE FIELD STUDY

Test Site

The test site chosen was a level field remote form man-made vibrations situated about 1/2 mile south of the north campus of The State University of New York at Buffalo. Soil borings, test pit observations, and laboratory tests performed on the material indicated the soil profile shown in Fig. 1. A simplified soil profile at the site was considered to consist of topsoil and a 9 foot thick layer of over-consolidated clay of medium plasticity overlaying a dolomite half-space. An area of 450 ft. x 450 ft. was fenced and the ground was levelled after stripping the topsoil (see Fig. 2). The entire site was also followed with a dynamic roller to insure a smooth, firm surface.

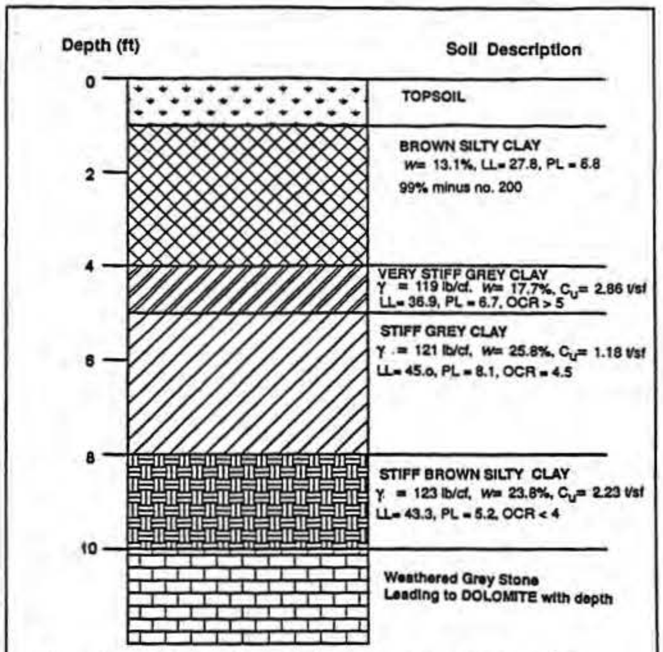


Fig. 1 - Soil Profile at the test site

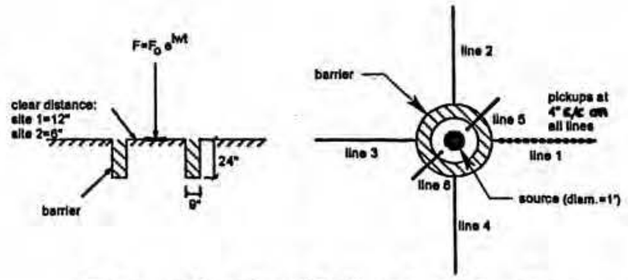
Instrumentation and Test Layout

The main equipment used in the field study consisted of an electromagnetic oscillator attached to a 1 foot diameter steel base plate, (circular foundation), a function generator, 16 accelerometers, a 32 channel amplifier, a computer with DaDisp data acquisition system, and a power generator. The computer along with the function generator and the amplifier were always kept inside a rented van (see Fig. 3).

Fig. 2 - Picture of the Test Site Located near the North Campus of SUNY at Buffalo

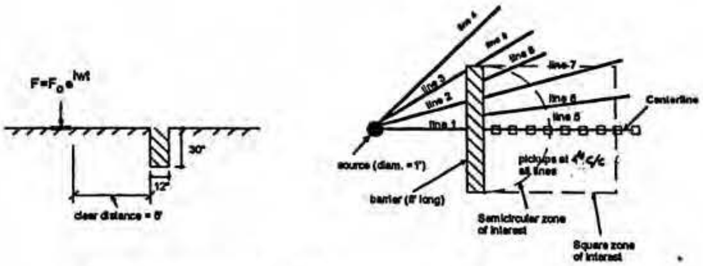
Fig. 3 - Data Acquisiiton and Vibration Generation Equipment.

The electromagnetic vibrator along with the function generator was used to generate harmonic vertical ground motion (at specific frequencies) at four selected site'. These four sites were set up so that two active and two passive barrier cases could be studied. Of each set of two barriers, one was constructed of concrete ('stiff barrier') and the other was constructed of a soil-bentonite mixture ('soft barrier'). Schematic of active and passive isolation test layouts are shown in Fig.s 4 and 5, respectively. Photographs of actual test layouts for site 1 (active isolation by soil-bentonite trench) and Site 3 (passive isolation by concrete trench) are shown in Fig. 6 and 7, respectively.



Schematic of the Active Isolation Tests Sites 1 and 2

Fig. 4



Schematic of the Passive Isolation Tests Sites 3 and 4

Fig. 5

Fig. 6 - Test Layout for Acitve Isolation by Soil-Bentonite Trench (Site 1)

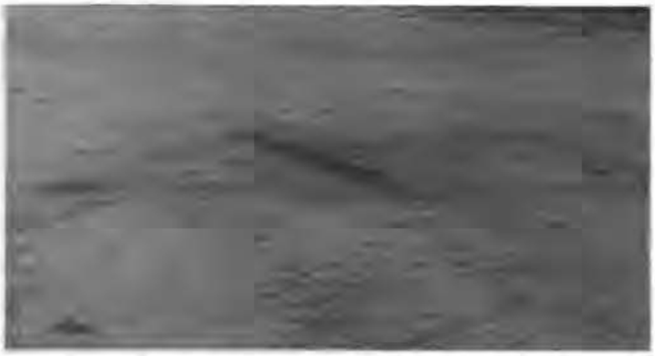


Fig. 7 - Test Layout for Passive Isolation by Concrete Trench (Site 3)

Barrier Materials

The concrete used to fill the trenches at Sites 2 and 3 was a quick setting 5000 psi plain concrete. It was placed at approximately a one inch slump and mechanically vibrated in place. The concrete's compressive strength was found to be around 5000 psi at 7 days and 6000 psi at 28 days. The measurements of ground accelerations with the barriers in place were done between 10 and 29 days after placement of the concrete.

The soil-bentonite slurry used to fill the trenches at sites 1 and 4 was mixed on site with a rotary mixer. A mixture of 2.5% by weight bentonite and native clay was mixed at a moisture content of 50 to 55% and mechanically vibrated in place in both the active and passive trenches. After the completion of field testing, undisturbed samples of the soil-bentonite mixture were taken for further laboratory testing. The samples were found to have an average dry unit weight of 61.3 lb/cf, Liquid limit = 49.4, Plastic limit = 26.6, and natural moisture content = 43.7. This yields a void ratio of approximately 1.3 . Consequently, tested Cu values of 100 to 175 lb/sf were observed. The in-situ Rayleigh wave velocity of the soil-bentonite material was measured as 100 ft./sec.

Data Acquisition

For each test layout, measurements of ground acceleration were made at specific locations (pick up points) as the ground was vibrated (at selected frequencies) by the oscillator placed at the source location. The pickup accelerometers mounted on 2" x 2" steel places were placed at 4 inches center to center in neat 2" x 2" x 1/4" deep cuts along a marked radial line on the ground surface (Figs. 4 & 5) and sealed in place by wetting the native clayey soil. After the full range of frequencies was run through, all pickup plates (a total of 15) were moved to the next radial line location. The ground accelerations on various lines were measured from furthest away from the source to closest to it. Measurements of background noise acceleration at each pickup point were also taken to correct the measured data.

After the installation of the barriers, the ground at each site was vibrated again at the same frequencies as done earlier for the 'without barrier' case (see (Figs. 8-11). The ground acceleration was again measured at the selected pickup points. These accelerations were then corrected for the change in transmissibility ratio of the soil-foundation system resulting from the installation of the concrete or soil-bentonite barrier. The reduction in the ground displacement amplitude at every pickup point resulting from the installation of the barrier was calculated in the form Amplitude Reduction Ratio, A_{rr}, as defined as:

$$A_{rr} = \frac{\text{Displacement Amplitude with the barrier}}{\text{Displacement Amplitude without the barrier}} \quad (1)$$

Thus, an $A_{rr} = 0.3$ indicates a 70% reduction in displacement amplitude.

Fig. 8 - Test Setup of Active Isolation by a Soil-Bentonite Trench (Site 1 with barrier)

Fig. 9 - Test Setup of Active Isolaiton by a Concrete Trench (Site 2 with barrier)

Fig. 10 - Test Setup of Passive Isolation by a Concrete Trench (Site 3 with barrier)

Fig. 11 - Test Setup of Passive Isolation by a Soil-Bentonite Trench (Site 4 with barrier)

TEST RESULTS AND DISCUSSION

The ground displacements (average of all radial lines) with and without the barrier at site 2 (active isolation) for a frequency of 300 Hz is shown in Fig. 12. The ground displacements for 'without barrier' condition is decaying with distance from the source due to both geometrical and material damping.

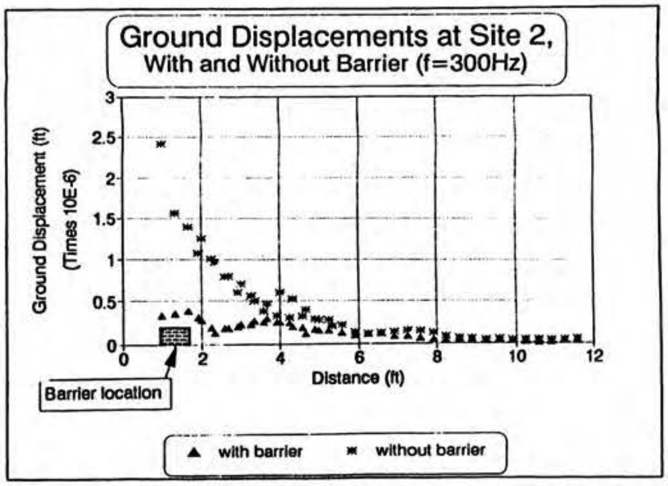


Fig. 12 - Variation of Vertical Ground Displacements with Distance form the Vibration Source, at Site 2.

The relatively constant vertical ground motions observed between one and two feet from the source of vibration are the ground motions recorded by the accelerometers placed directly on the barrier. Given the stiff nature of the concrete barrier, this behavior is expected.

The difference between the without and with barrier ground motions are due to the installation of the barrier as a physical obstacle to the transmission of ground waves and the change in the effective spring and dashpot constants of the soil-founation system with the installation of the barrier.

Fig. 13 shows ground displacements along the central radial line of site 4 for with and without the barrier conditions. It can be seen that significant decrease in displacement amplitudes was achieved due to the installation of concrete barrier.

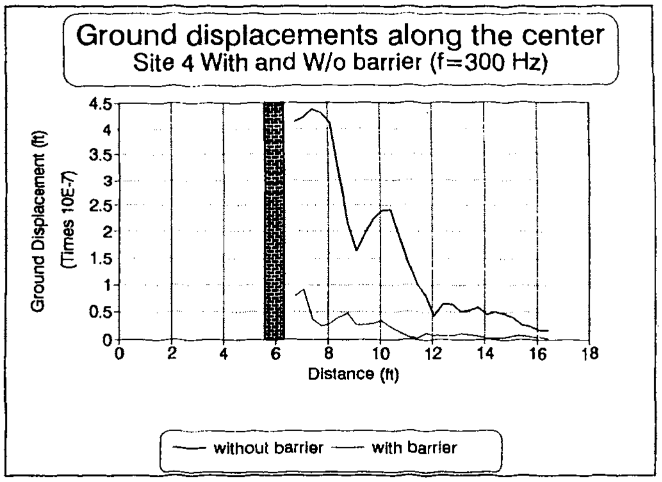


Fig. 13 - Variation of Vertical Ground Displacements Along the Centerline with Distance from the Source, at Site 4.

Two contour diagrams of amplitude reduction ratio, A_{rr}, for site 3 and site 4 are shown in Fig. 14 and 15, respectively. It can be seen that the amplitude reductions of 75% or better was achieved in the semi-circular zones behind the barriers.

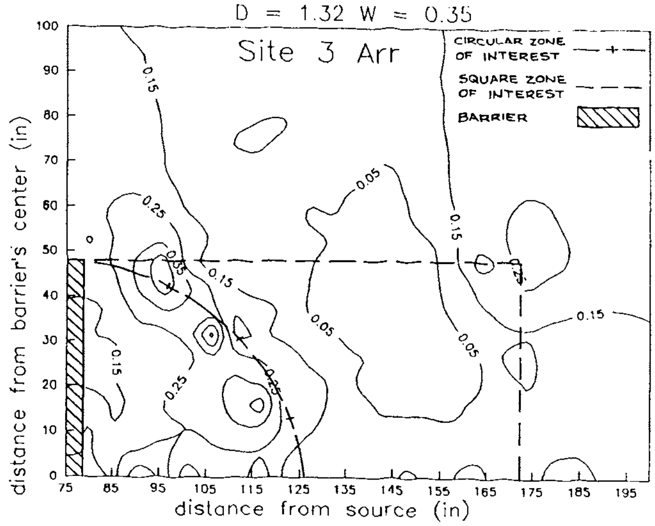


Fig. 14 - Contours of Amplitude reduction ratio for Site 3 (f = 200 Hz, D = depth of trench wall/L_r, W = width of trench/L_r).

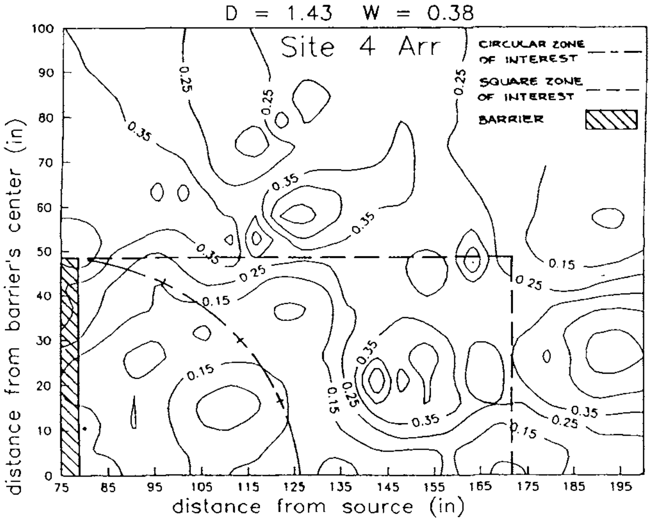


Fig. 15 - Contours of Amplitude reduction ratio for Site 4 (f = 300 Hz, D = depth of trench walls/L_r, W = width of trench/L_r).

To obtain an average amplitude reduction ratio ($\overline{A}_{rr}$), zone of interests similar to Woods (1968) and Al-Hussaini (1992) were selected. For active isolation, this zone was an area behind the barrier extending a distance 5 L_r (where, L_r = Raleigh wave length). Whereas, for passive isolation two zones of interest, a semicircular zone and a square zone, were selected (see Figs. 14 and 15). The average amplitude reduction ratios for the selected zone of interests were computed using Gaussian integration along with eight noded surface element interpolation. The $\overline{A}_{rr}$ values obtained for various depth of trench wall are shown in Fig. 16 and 17 for sites 2 and 3, respectively. Also shown on these plots are the BEM solution and the results obtained from the design formulas developed by Ahmad & Al-Hussaini (1991, 1994) and Al-Hussaini (1992).

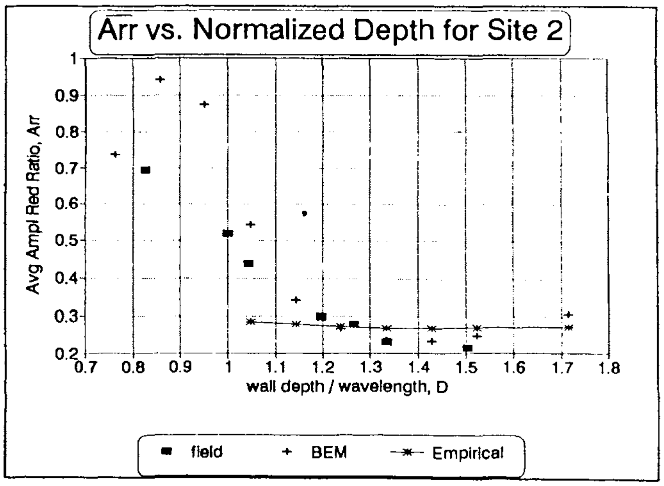


Fig. 16 - Comparison of Filed Data with Analytical Results for Site 2.

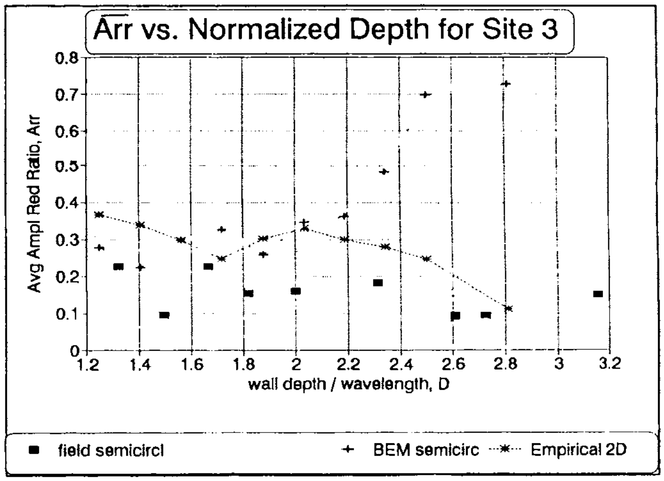


Fig. 17 - Comparison of Field Data with Analytical Results for Site 3.

CONCLUSIONS

Based on the field testing some conclusions can be drawn about concrete trench wall barriers. A concrete trench wall (both in active and passive isolation) with dimensions of D as low as 1.2, and W = 0.35 (with B = 0.5 to 1.0, and L_{active} = 0.21 to 0.38 or $L_{passive}$ = 2.7 to 6.3) will result in an $\overline{A_{rr}}$ value of 0.3 or lower. That is an average amplitude reduction of 70% or more will be achieved. The above conclusion is also true for passive isolation by soil-bentonite barrier.

In summary, the findings of this research can be applied to a variety of physical sites and loading conditions. The key parameters needed by a design engineer will be material properties of soil and trench wall, operating frequency of the machine and amplitude of load transmitted to the ground.

ACKNOWLEDGEMENT

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