Investigation Effects of Trench Barrier on the Reducing Energy of Surface Waves in Soils

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SUMMARY:
One of the problems for buildings and structures is ground vibration, as waves propagate through the soil and interact with buildings, where they may cause damage to nearby structures or secondary ones. Horizontally propagating Rayleigh waves or any waves generated by dynamic loading are considered in this work. The soil medium is assumed to be linear elastic, homogeneous and isotropic. Most energy associated with any surface waves can be absorbed and damped by these barriers because of geometric damping and material damping. Isolation of structures and foundations from ground transmitted vibrations by installation of wave barriers has been tried many times and met with varying degrees of success. In this research various wave barriers filled with different material have been studied, and leads to the proficiency of wave barrier, response of the structure to the ground excitations and the ground response to a specific loading on the soil surface.

Keywords: Vibration Reduction; Wave Barrier; Soil Response; Wave Propagation.

1. INTRODUCTION

The ground born vibrations generated by machine foundation, traffic, dynamic compaction or blasting may cause distress to adjacent structures and annoyance to people. In most cases the major part of the vibration energy induced by dynamic sources transferred by the Rayleigh waves propagating in the region nearby soil surface may cause strong ground motions and stress levels that transmit the vibrations through the subsoil to the structures. Therefore, the permanent adversely affects of these excessive vibrations on the foundations, particularly supported on the soft soil deposits, cause structural damage to the adjacent structures. These vibrations give even disturbances to the nearby housing, sensitive electronic equipment, measuring installations and undesired actions on human comfort in the buildings.

For an effective protection of the buildings from structural damage due to dynamic loads generated by man-made activities, such as rock drilling and blasting in road construction, dynamic compaction in field construction, working engine foundations in industrial areas, heavy and dense transport traffics and any high frequency acoustics due to increasing interconnections of residential regions etc., there are many possibilities to be considered as vibration screening systems.

The reduction of the structural response may be accomplished as: a) by adjusting the frequency contents of the excitation, b) by changing the location and direction of the vibratory source, c) by modifying the wave dissipation characteristics of the soil deposit, and d) by partially interrupting the spreading of waves into the structure or by providing the structure more damping by means of installation certain devices such as additional dampers or other base isolation system.

Effective protection from harmful effects of Rayleigh waves may be obtained by using concepts of vibration screening which is made possible by proper interception, scattering and diffraction of surface waves with wave barriers. The wave barriers may consist of open trenches, trenches filled with bentonite slurry, sawdust, or sand, sheet piles, and piles. Open trench is often used as a wave barrier; however, there is an instability limitation in practice. In order to maintain an open trench at a considerable depth, in practice engineers need to use sheet piles or diaphragm walls on both sides of open trench to provide adequate stability of the open trench as a barrier.

A number of researches, both experimental and numerical, have been carried out in the last few decades to study the vibration-screening problem. In an experimental approach, Barkan and McNeill used sheet piles and open trenches to evaluate vibration isolation at selected locations from the source. Woods performed a series of field experiments on vibration screening by installing open trenches. He defined the amplitude reduction ratio and suggested that the average amplitude reduction ratio should be smaller or equal to 0.25 for efficiency of vibration reduction mechanism.

While full-scale model test results are often difficult to extrapolate to prototype situations, numerical technique can be an effective alternative for thoroughly investigating the vibration isolation phenomena. Starting from mid 1970s, various numerical methods emerged as an effective tool for solving wave propagation and vibration reduction problems. Vibration isolation problems can be solved efficiently by numerical methods, such as finite difference method (FDM), finite element method (FEM) and boundary element method (BEM). Aboudi and Fuyuki and Matsumoto adopted the FDM with a special treatment of external boundaries to calculate vibration response on the ground surface. In the last two decades, a great portion of the studies on wave propagation problems was performed by the boundary element method (BEM). This method is very well suited for wave propagation problems in soils because the radiation condition at the boundary is automatically accounted. Many authors adopted the BEM for the analysis of isolation effects of open and in-filled trenches in different types of soils and to present a simplified design method using empirical formulae. However, the boundary element method is not suitable for modeling of irregularities in geometry or material of the foundation and soils. To overcome this drawback, many coupling methods of finite boundary or infinite elements have been proposed following the pioneering works of Zienkiewicz and his co-workers. The finite difference technique was also used to study scattering of a Rayleigh wavelet by rectangular open trench. Some studies used finite element method to study the influence of barriers on vibration, such as Wass, Haupt, Segol and Mayand Bolt.

With the exception of few, most of the previous researches have mainly dealt with the development of different numerical methodologies as a tool for analyzing vibration isolation problems. Parametric studies have been rather very limited. In this work, the investigation is focused on the effects of trench barriers on the reduction of wave propagation with considering nearby building response on capability of barriers through a parametric study in direct time domain. The building is directly considered in the mathematical modeling and analysis. Therefore, different from others, the soil vibration and structure interaction effect is automatically taken into account and the effect of the barrier on the structure response is directly obtained. The building response is obtained in terms of acceleration and internal forces, which represent the most important design factors for the structural engineers.

2. FINITE DIFFERENCE ELEMENT MODELS

2D FDE models have been established by utilizing the finite difference element package in order to conduct an extensive parametric study. The process of the FDE models was performed using two well-documented reference studies. Given the fact that the 2D computational FDE model have been used in FLAC has much capability in modeling real soil behavior, such model would be more efficient in conducting an extensive parametric study to better understand the behavior of open or in-filled trench barrier with different dimensions, locations. The explicit dynamic analysis procedure has been adopted in performing the numerical modeling using direct integration solution. The soil, wave barriers and structure in the 2D model were modeled using 4-noded, plane-strain rectangular elements with relevant properties. A staged mesh refinement has been carried out to obtain an optimized meshing configuration.

To ensure complete energy dissipation, non-reflecting semi-infinite elements have been imposed at the artificial boundaries to simulate the far field conditions, wave reflections at model boundaries are minimized by specifying either quiet (viscous), free-field or three-dimensional radiation-damping boundary conditions, for this several formulations have been proposed. The viscous boundary developed by Lysmer and Kuhlemeyer (1969) is used in FLAC.

3. NUMERICAL MODEL AND CONSIDERED PARAMETERS

A parametric study was performed to examine the proposed isolation systems effectiveness by investigating the influences of the trench barrier geometric dimensions(depth and width), barrier-system type(its wall and in-filled materials), distance between the barrier and source of disturbance; distance between the barrier and structure, structure dimensions and load. The numerical model results are analyzed and interpreted to provide recommendations for design purposes. A typical schematic of the vibration isolation system and geometric parameters are shown in Figure 1.

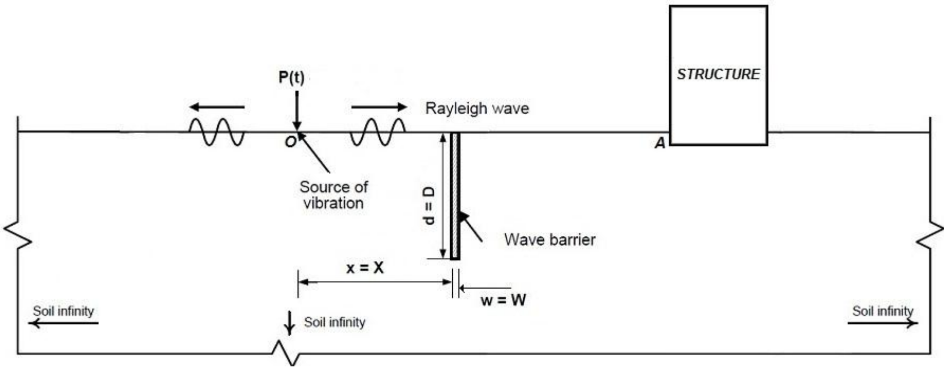


Figure 1. Typical schematic of the vibration isolation system (active or passive) and geometric parameters.

The main objective of this paper is to study screening effectiveness of the open and in-filled trench-wall barrier for isolating the vibration induced by applying vertical dynamic loading represented by a shock function, see fig. 2. This load was applied in 1.0 m width on surface.

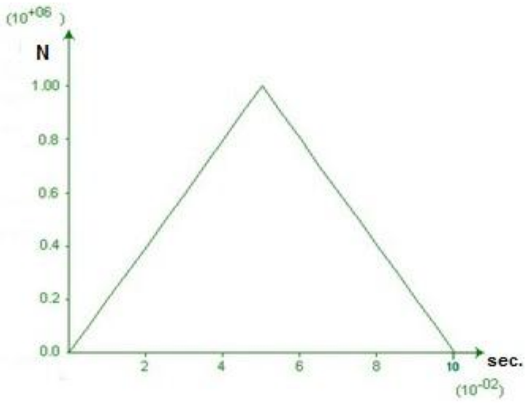


Figure 2. Source of disturbance, vertical impulse load (P=1000kN)

3.1. Considered Parameters

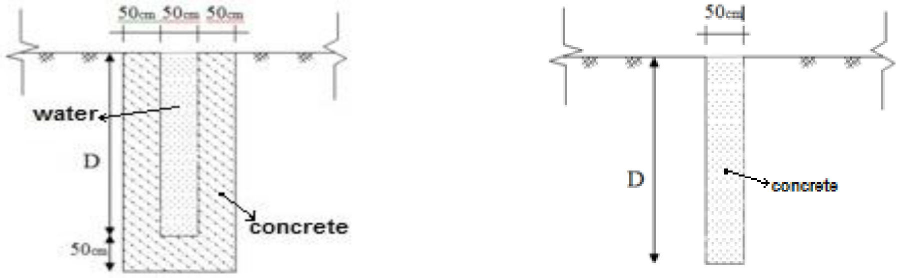
A trench barrier of width W and depth D is assumed to be located at a distance L measured from the trench to the building left side. The trench width W, depth D and the distance L are assumed to be variable parameters. Since most of the previous works have dealt with harmonic load of certain single frequency, it was common to relate each parameter to the Rayleigh wavelength L_r that depends on the applied frequency and the soil properties. For example, some researchers proposed the trench depth to lie between 0.6Lr and 1.33 L_r and the trench width to vary between 0.1L_r and 0.5L_r. However, the impulse load applied herein covers a wide frequency range. Therefore, the values of the studied parameters have been decided in average sense to cover the predominant frequency range as used.

3.1.1. Loading, structure and barrier configuration

The distance from the center loading source of wall was varied from 3 to 16m. The distance structure of wall ranged from 3 to 50 m. and the depth D ranged from 5 to 20m., for barrier width values W=50cm. The soil particle horizontal displacement was monitored along the path OA shown in Fig. 1.

One of the important parameters that could affect the system performance, is the distance of structure from trench, was investigated to understand the performance of material used as wave barriers. In this regard in some condition the distance from left-side of building to barrier right side was studied is 25m. A traditional building frame of 10 m width and 15 m height is located to the right side of a barrier as shown in Fig. 1. The building foundation level is located at depth of 1.0 m below the ground surface. The foundation type is assumed mat foundation with 1.0 m thickness.

As shown in Fig. 1, a trench of depth D and width W is located at a distance X from a load center. In this study the types of walls were chosen as diaphragm walls which were on both sides of open trench in order to stabilize the excavation surface. The material of diaphragm walls are concrete, and the thickness of walls were fixed at 0.5m, respectively. In order to have stability of walls, the walls can be extended below the bottom of the trench. The embedded wall length is assumed to be equal to open trench depth. For example see fig. 3a and b.



a) b)

Figure 3. Two typical schematic of geometric parameters isolation system (wave barriers)

A summary of the variable geometric parameters is given in Table 1.

Table 1. Geometric parameters of trench barrier

Parameter	Assumed values
Distance from building left side L (m)	3.0, 25.0, 50.0
Distance from load center to left side barrier X (m)	3.5, 8.0, 16.0
Depth of trench below ground surface D (m)	5.0, 10.0, 15.0, 20.0
Width of trench W (m)	0.5

3.1.2 Material characteristics of the barrier and wave propagation media

In order to understand the optimum configuration of the open trench-wall barrier, the parameters used in the study include soil property, types of wall and the distance between the source and the barrier. In the numerical analysis, the trench wall, structure and the soil were assumed to be isotropic, viscoelastic, and homogeneous. Moreover, the soil was modeled in half-space. That is, the authors assumed that all of the displacements are in elastic stage.

The values of the studied parameters have been decided in average sense to cover the predominant frequency range as given in Table 2. The Rayleigh damping is assumed 0.03(ξ=3%).

Table 2. Material properties of the building-soil-trench-building system

Material	Mass density ρ (kg/m3)	Shear wave speed V (m/s)	Poisson's ratio ν (--)
Half space	1865	120	0.36
Concrete	2400	2100	0.2
Water	1000		

3.2 Finite Element Models Verification

The system effectiveness can be evaluated based on the observed displacement, velocity or acceleration with and without the vibration barrier. The displacement reduction factor, A_r, at a node on the assigned monitoring path can be obtained by normalizing the post-trench installation maximum horizontal displacement component amplitude, $(A_h)_{After}$, by the maximum horizontal displacement component amplitude before trench installation, $(A_h)_{Before}$, measured on the ground surface (Eqn. 3.1). The maximum horizontal displacement component amplitudes are obtained at monitoring nodes from their time history. Woods (1968) considered the averaged vertical response amplitude reduction ratio to be smaller or equal to 0.25 for an effective isolation system.

$$A_r = \frac{(A_h)\ After}{(A_h)\ Before} \tag{3.1}$$

4. PARAMETRIC STUDY AND RESULTS

An extensive parametric study has been carried out to study the influence of various key parameters such as the trench dimensions, in-filled materials, type, location, and the structure on the screening effectiveness of an in-filled trench barrier. The results of the parametric study will be presented in the form of averaged amplitude reduction ratio. As described in the previous section, the amplitude reduction ratio, Ar. along the monitoring path is evaluated first using Equation 3.1.

4.1. Influence of Barrier Dimensions, In-filled Material and Location from the Source of Disturbance and Building

In this section, the depth of open and in-filled trenches varied from 5 to 10m., and with constant width w=0.5 m located at a distances X=3.5, 8, 16m from the source vibration in an elastic half-space soil was considered. And also structure in analysis located at different distances that as mentioned above. The vibration is modeled as a vertical impulse load triangular shape of magnitude 1.0 MN, see fig.2.

Figures 4 to 6 summarize all computed results for some types of barrier when the distance structure of the wall (L) is 25 m and the distance trench from load center(X) is 8m. By changing the distance in the right side of barrier for the same depth D, it is observed that in most condition the measured normalized soil particle displacement declined for increased distances from the barrier. The sharp and sudden changes are seen in figures took place under building foundation. But the effectiveness and capability of depth barrier depends on type and its in-filled material. As shown in figures 4 and 5 in two types of barriers, with increasing distance from trench effectiveness of barrier are reduced and normalized soil particle displacement decreased. But this behavior is not being seen in open trench as a wave barrier, see fig.6.

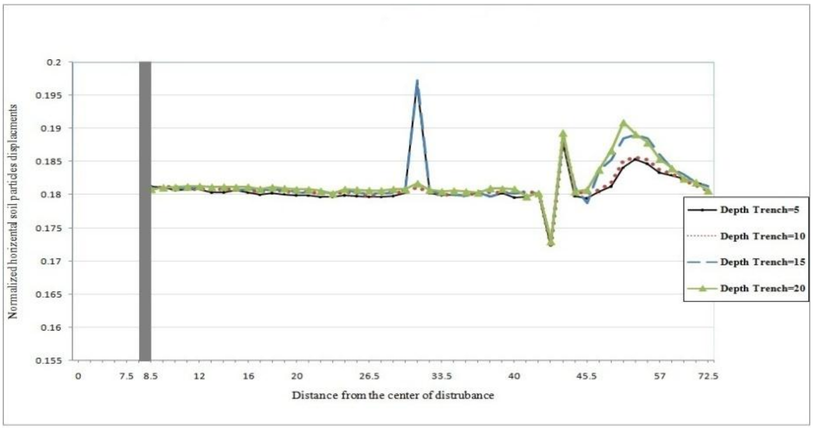


Figure 4. Influence of wall dimensions and its location on the single-wall, in-filled trench(Trench filled with concrete), L= 25m X=8m.

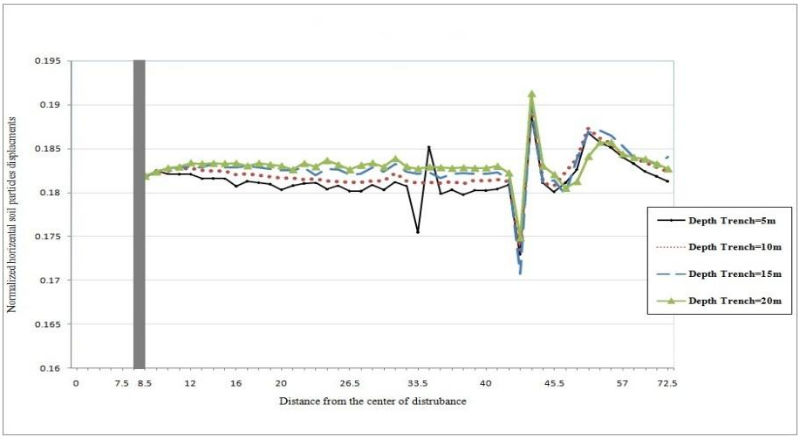


Figure 5. Influence of wall dimensions and location on the single-wall, in-filled barrier (Trench filled with water and with concrete walls), L= 25m X=8m.

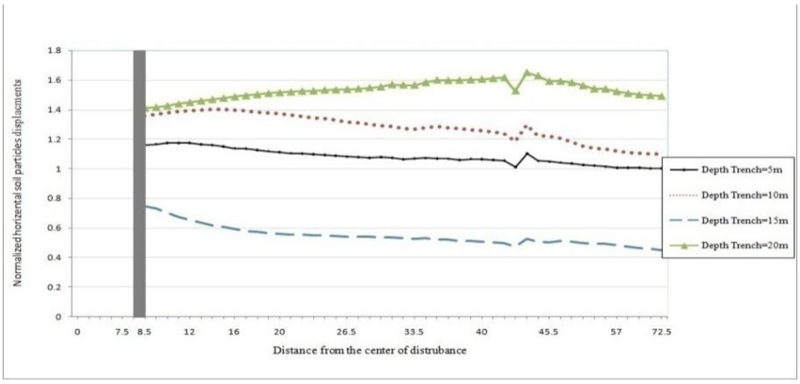


Figure 6. Effect of wall dimensions and location on the single-wall, open trench, L= 25m X=8m.

4.2. Attenuation Due to the Presence of Barriers and Structure-the Depth of Barrier is Constant

Figures 7 and 8 show the measured soil particle displacement ratio on the ground surface (i.e. attenuation curves for horizontal soil particles displacements) for the cases of open, in-filled and without barrier for various distances structure of barrier location. The recorded measurements follow the expected trends in terms of amplitude versus distance for all distances when the distance of source disturbance is 3m or 16m except when this distance is 8m.This decrease means that the ground motion is damped both geometrically and materially. It is worth mentioning that as the distances of the barrier increases, the geometric damping increases as well, which results in further attenuation of the generated surface waves. But in some distances of wall be viewing local increasing, this may be attributed to two reasons: first, the structure vibration under dynamic loading also can affect the vibration of particle soils on earth surface. The waves produced of structure at the soil, which pass from soil-structure interfaces are in-phase or out-of-phase; second, the vibration amplitudes are very negligible even without the barrier, and any variation in the response represents a large change in the ratio.

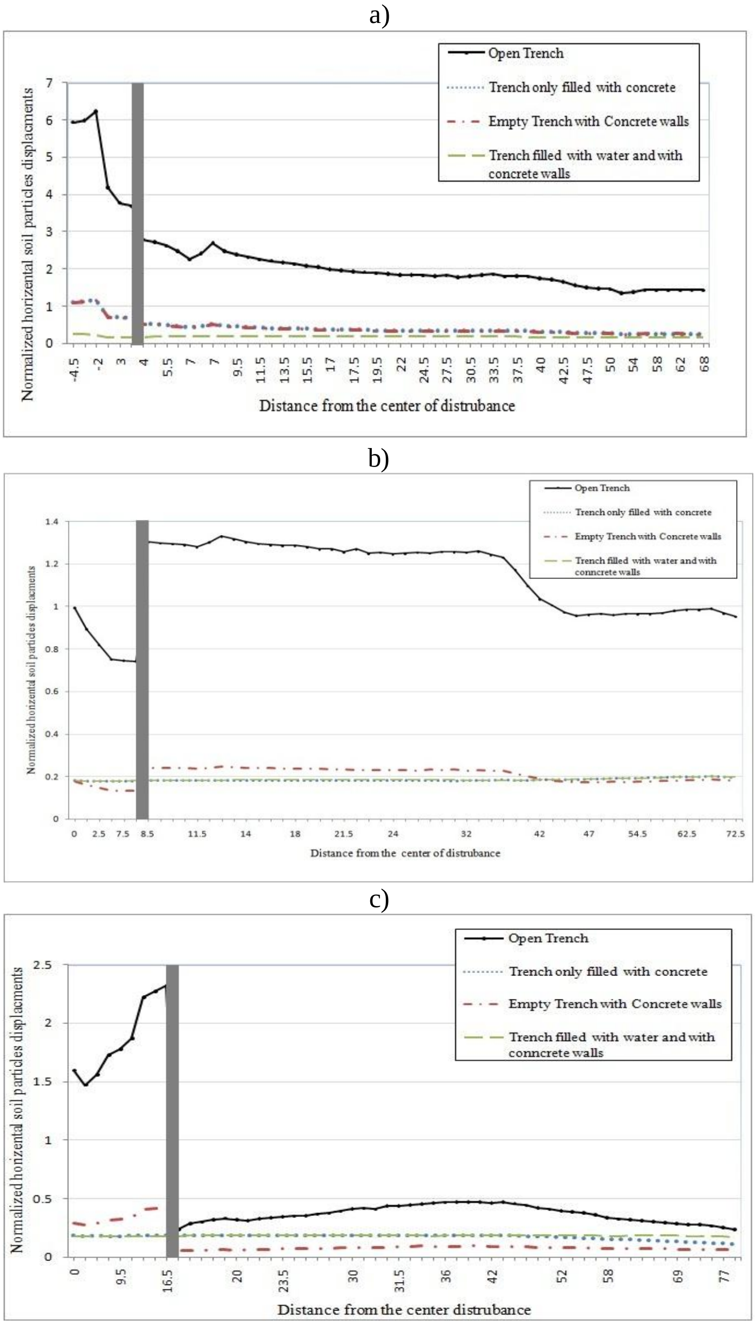


Figure 7. Normalized ground motion for distance structure of trench, L=3m., (a) trench at first location, 3.0m, (b) trench at second location, 8.0m, (c) trench at third location, 16.0m

As be pointed out, in open and some other in-filled trenches when the distance of source disturbance of barrier is 8m., barrier act reversely and the normalized particle displacements after barrier increased (figures 7b and 8b). To studying this behavior other analysis have been done, the results show that this matter can be explained because of the structure affects on barrier capability since the results obtained from analyzing barrier without structure show that the normalized particle displacements after barrier decreased (figure 9). Also the obtained results show that with mentioned dynamic conditions for open trenches, if the depth of trenches is smaller than 15m and source of disturbance is located in 8 m of trench, after barrier(trench) the normalized displacement of soil particles (i.e comparing without trench) will be decreased (figure 10).

It is noted from Figures 7 and 8 that at the measuring point located 70.0 m from source of disturbance, the attenuated displacement amplitude is less than 5% of that at the source for the ground conditions at this site. Therefore, the analysis of A_r and barrier effectiveness will be limited to a distance 70.0 m from the source, as the amplitudes at larger distances are negligible, even without any wave barrier. Hence, the measured responses will not allow reliable and meaningful evaluation of the barrier effectiveness at distant points.

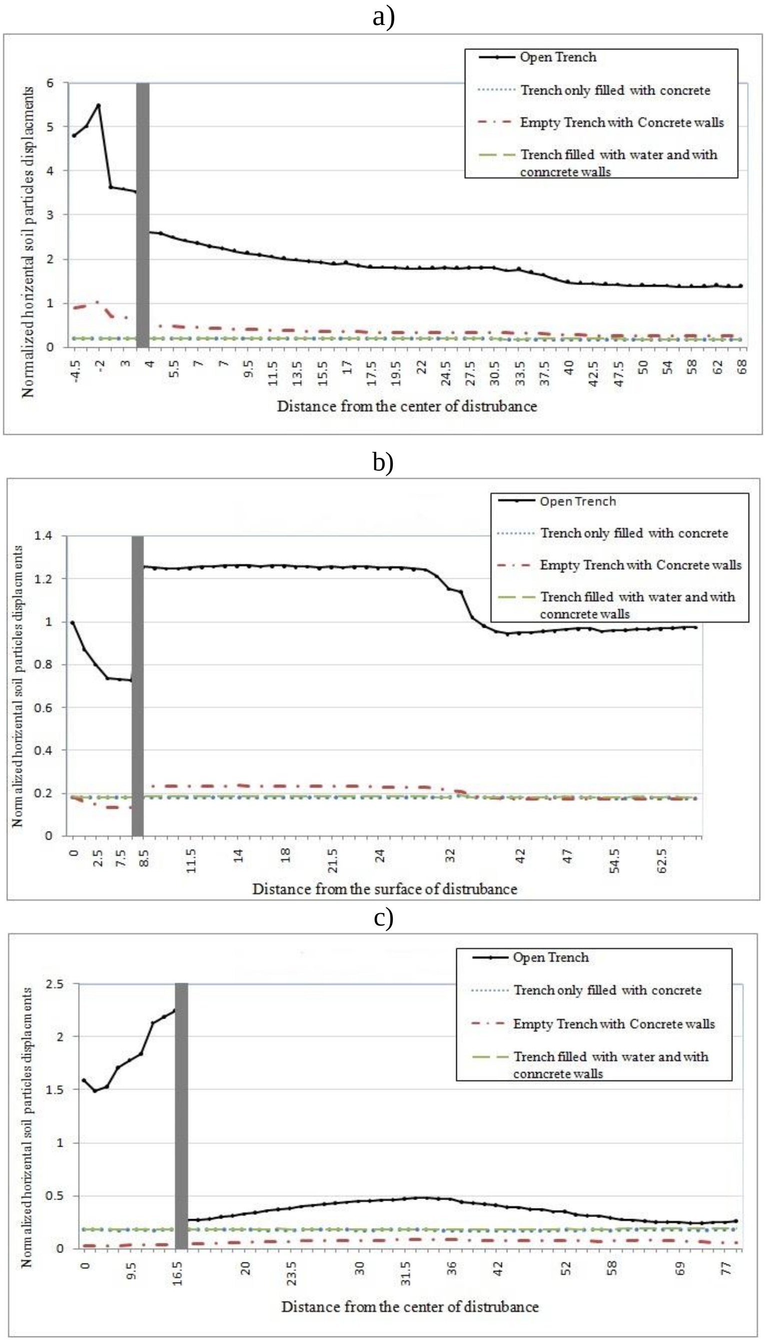


Figure 8. Normalized ground motion for distance structure of trench, *L*=50., (a) trench at first location, 3.5m, (b) trench at second location, 8.0m, (c) trench at third location, 16.0m

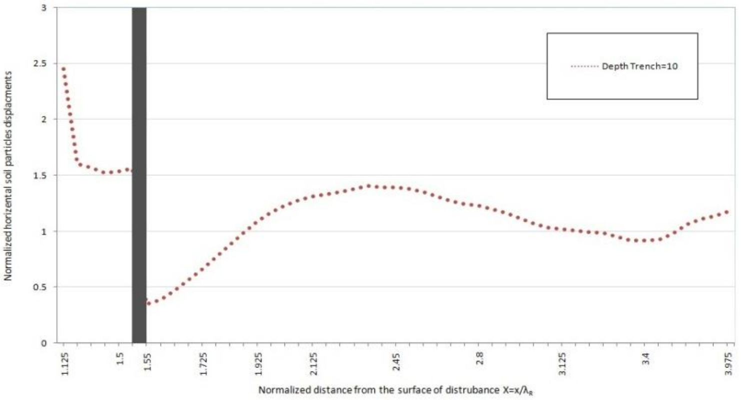


Figure 9. Normalized ground motion without structure, source of distribution location of trench, 8.0m

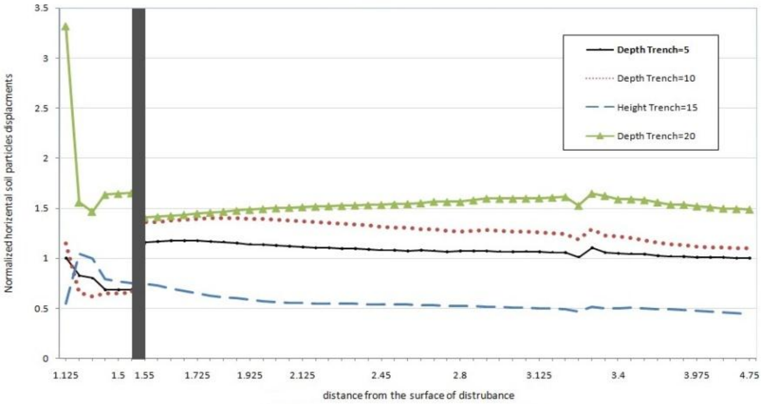


Figure 10. Normalized ground motion with structure, source of distribution location of trench, 8.0m

5. SUMMARY AND CONCLUDING REMARKS

The analysis of active and passive vibration isolation problems was carried out to investigate the protective effectiveness of different configurations of in-filled trench barriers systems. The proposed systems were evaluated and compared based on the gained reduction in the soil particle displacements through an intensive parametric study. From the previous discussions and analyses of the results, the following understandings and conclusions can be made;
All the proposed in-filled barrier systems perform well in reducing the surface waves and the screening effectiveness. Furthermore, in most times the in-filled barriers are of variable protection performances in presences of structure. The single-continuous wall system is an economic solution as a passive isolation system since less material will be used.

Because of presences structure, in open and some other in-filled trenches, for example when the distance of source disturbance of barrier is 8m and the depth of trench is lower than 15m., barrier act reversely and the normalized particle displacements after barrier increased but without structure be shown that the recorded measurements follow the expected trends in terms of amplitude versus distance for all distances. his may be attributed to two reasons: first, the structure vibration under dynamic loading also can affect the vibration of particle soils on earth surface. The waves produced of structure at the soil, which pass from soil-structure interfaces are in-phase or out-of-phase; second, the vibration amplitudes are very negligible even without the barrier, and any variation in the response represents a large change in the ratio.

REFERENCES

Aboudi, J. (1973). Elastic Waves in Half-Space with Thin Barrier. Jour. of Engng. Mech. (ASCE).99(1):69-83.

Woods, RD., Barnett, NE. and Sagesser R. (1974). Holography, a New Tool for Soil Dynamics. Journal of Geotec. Engineering (ASCE); 100(11):1231-1247.

Ahmad, S. and Al-Hussaini, T.M. (1991). "Simplified Design for Vibration Screening by Open and In-filled Ttrenches," J. Geotech. Engng., ASCE., No. 117(1), pp 67-88.

Ahmad, S., Al-Hussaini, T.M. and Fishman, K. L. (1996). An Investigation on Active Isolation of Machine Foundation by Open Trenches. Journal Geot. Engng., ASCE., No. 122, pp 454- 464.

Al-Hussaini, T.M. and Ahmad, S. (1991). "Design of Wave Barriers for Reduction of Horizontal Ground Vibration," J. Geotech. Engng., ASCE., No. 117, pp 616-636.

Al-Hussaini, T.M. and Ahmad, S. (2000). Numerical and Experimental Studies on Vibration Screening by Open and In-filled Trench Barrier. In Chouw, N and Schmid, G. (Editors). (2000). International Workshop on Wave Propagation, Moving Load and Vibration Reduction. Brookfield. pp 241-250.

Barkan, DD. (1962). Dynamics of Bases and Foundations.Translated from Russian by Drashevska L and translation edited by Tschebotarioff, GP. New York: McGraw-Hill.

Beskos, D., Dasgupta G. and Vardoulakis, I. (1986). Vibration Isolation Using Open or Filled Trenches, Part1: 2-D Homogeneous Soil. Computer Mechanic. No. 1, pp 43-63.

Emad, K. and Manolis, G.D. (1985). Shallow Trenches and Propagation of Surface Waves. Journal Engng. Mechanic ASCE, No. 111, pp 279-282.

Fuyski, M. and Matsumoto, Y. (1980). Finite Difference Analysis of Rayleigh Wave Scattering at a Trench.Bulletin of the Seismological Society of America. 70: 2051-2069.

Haupt, WA. (1981). Model Test on Screening of Surface Waves. In:Proceedings of the 10th Int. Conf. Soil Mech. and Found. Engineering. 3:215-222.

Krylov, V.V. (1996). Vibration impact of high-speed trains effects of track dynamics. Jou. Acous. Soceity Amer.

Leung, K., Beskos, D. and Vardoulakis, I. (1990). Vibration Isolation Using Open or Filled Trenches, Part 3: 2-D Nonhomogeneous Soil. Computer Mech., No. 7, pp 137-148,

Leung, K.L., Vardoulakis, I.G., Beskos, D.E. and Tassoulas, J.L. (1991). Vibration Isolation by Trenches in Continuously Nonhomogeneous Soil by the BEM. Soil Dynamic Earthquake Engng., No.10(3), pp172-179.

Liao, S. and Sangrey, DA. (1978). Use of Piles as Isolation Barriers.Journal of Geotechnical Engineering (ASCE). 104(9):1139-1152.

Massarsch, K.R.. (2000). Settlements and damage caused by construction-induced vibration. In: Proceedings of International Workshop Wave 2000. Chouw and Schmid (eds), Bochum, Roterdam: Balkema.

McNeill, RL., Margason, BE. and Babcock FM. (1965) The Role of Soil Dynamics in the Design of Stable Test Pads. Proceedingsof Guidance and Control Conference. 366-375.

Öztürk, T. and Öztürk, Z. (2008).Vibration absorption and isolation in dynamically loaded foundations. The 14th World Conference on Earthquake Engineering.

Woods, RD. (1968). Screening of Surface Waves in Soil. Journal of Soil Mechanicsand Foundation Engineering(ASCE). 94(SM4):951-979.

Zienkiewicz, O.C., Kelly D.M. and Bettess, P. (1977). The Coupling of the Finite Element Method and the Boundary Solution Procedures. Int. J. Numer. Meth. Engng., No. 11, pp 355-376.