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Evaluating the interaction of different parameters of the barrier on each other by Response Surface Methodology

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ABSTRACT For the last two decades, researchers have focused on vibration isolation since these vibrations have a major impact on the comfort of building occupants located near the source. A usual assumption for the study of ground-borne vibration is considering soil as homogeneous, which is not realistic. Therefore, it is necessary to find the effect of layering of the soil on the efficiency of the geofoam-filled trench. This study presents the performance of geofoam-filled trenches in mitigating ground vibration transmissions by the means of a comprehensive parametric study. Fully automated numerical models are applied to evaluate the screening effectiveness of the trenches in the near and far field schemes. The parametric study is based on complete automation of the model through coupling finite element analysis software (Plaxis) and Python programming language to control input, change the parameters, as well as to produce output and calculate the efficiency of the barrier. The result of interaction between all governing parameters demonstrated that the depth (D) and shear wave velocity of the soil (Vs) are the most important parameters.

Keywords: Vibration isolation, Layered soil, Geofoam-filled trench, Automated parametric study

1 INTRODUCTION

The vibration is transmitted through the ground surface to the foundation of the building and creates distress to the buildings and their inhabitants. There are some mitigation measures that can be applied to either the vibration source or at the receiver. The installation of a wave barrier between the vibration source and the building is an alternative method to mitigate ground vibration. This study deals with mitigation measures in the transmission path through installing a geofoam-filled barrier.

The trench is used to attenuate the incoming waves and through complex effects, considerable mitigation of ground-borne vibration beyond the trench is attained. The incident waves tend to bend around the edge of the trench. Therefore, the barrier must be constructed deep enough to attenuate the incoming waves. Open trenches are the most effective system in terms of mitigating the ground-borne vibration for relatively short wavelength [Toygar et al., 2021]. However, open trenches are not applicable in many cases for a longer time due to stability problems. In such case, in-filled trenches are more preferred [Jazebi et al., 2021, Naghizadehrokni et al., 2020].

A full-scale experimental investigation has been conducted by [Jauhari, N. 2023] under different frequencies of excitations to explore the possibilities of utilizing dual open and geofoam-filled trenches. The influence of three different vibration locations was analyzed under five combinations of single and dual trenches. The results showed that the use of dual trenches reducs the vibrations more effectively than single trenches. The dual open and geofoam-infilled barriers with normalized depth of 0.3 decreased the vertical vibrations by 76% and 65%, respectively, compared to no trench conditions.

Mahdavisefat et al. (2018) described the results of experimental studies to compute the screening efficiency of open and filled trenches in the case of active and passive schemes under a harmonic load with a frequency range of 10 – 400 Hz. The site soils were characterized as sand with density of 2 gr/cm^3. The observations illustrated that the most important parameters influencing the trench performance are impedance ratio and the trench depth. An increase in trench depth and a reduction in the impedance ratio lead to better performance of the trench. In addition, observation reveals that incoming waves are attenuated by 60-70% by increasing the depth of the trench until a normalized depth of 1.5 [Mahdavisefat et al., 2018].

Naghizadehrokni et al. (2020) described the results of experimental studies to compute the screening efficiency of geofoam-filled trench in the case of near and far field system under a harmonic load with a frequency range of 20-80 Hz. The site soils were characterized as sand with density of 2 g/cm^3. The observations illustrated that near field isolation can be a better solution to hinder incident waves in comparison with far field isolation based on the results of the field test. However, the results also showed that the first point after the trench had the highest amount of mitigation and a normalized depth of 0.6λr was enough to reach the highest value of efficiency for both near field and far field isolation systems [Naghizadehrokni et al., 2020].

A developed BEM model by [Gao et al., 2018] is used for studying the vibration mitigation of wave impeding block (WIB) in a layered soil under horizontal loads. Two types of layered half-space model under the horizontal-rocking excitations (site A: the stiff soil ground with relatively soft overlying soil layer, site B: the soft soil ground with relatively stiff overlying soil layer) were considered. The results proved that WIB has more effectiveness in the stiff soil than soft soil ground.

SA Hosseini et al. [Hosseini et al., 2019] used three methods of soft computing including genetic programming (GP), response surface methodology (RSM), and multivariate adaptive regression splines (MARS) to predict the peak particle velocity (PPV) value caused by the blast on the ground surface. The results showed that the coefficient of determination for the MARS model has the highest accuracy based on overall data results ($R^2 = 0.81$). This variation for the root mean of squared error (RMSE), mean of absolute deviation (MAD), and mean of absolute percent error (MAPE) values were equal to 0.85, 0.25, and 0.38, respectively.

Studying the conducted experimental and numerical investigations revealed that evaluating the influence of different parameters on each other in layered soil is required. This paper deals with filling this gap through a comprehensive parametric study.

The range of different parameters for the parametric study is presented in the numerical model section. The results of the detailed parametric investigation and the interaction of parameters on each other are presented in the discussion section and some applicable recommendations are provided for designing a practical wave barrier.

2 NUMERICAL MODEL

A time domain 2D numerical model using the finite element package, Plaxis was developed to examine the efficiency of geofoam-filled trench in layered soil.

Since the model is largely affected by the transmitted and reflected waves from the boundary, it is important to keep the region of interest far enough from the reflecting boundary. [Naghizadehrokni et al., 2020] stated that a zone extending to a minimum distance of (10λr) from the vibration source is sufficient for wave barrier analysis. With regard to the minimum distance and crucial zone behind the trench, which is (7λr), the dimensions of the model are selected as (70 ∗ 25 m) [Naghizadehrokni., 2023].

Viscous boundaries are applied to the bottom and right sides of the model. A viscous boundary condition, which is introduced by [Kuhlemeyer and Lysmer, 1973] consists of viscous dampers applied in X and Y axis in a Cartesian coordinates system along the boundary.

To maintain the independency of the analysis on the exciting frequency of the dynamic load, geometric parameters (distance between the trench and the vibration source) and dimensional factors (D, W), which are the governing factors in the wave attenuation, are normalized by R-wavelength equal to 4m. Furthermore, a simplification for the non-homogeneity of the soil is done by considering the layer interface parallel to the ground surface. The first layer is considered as a key layer for creating changes in the parameters.

The properties of the soil and geofoam obtained from a full experimental test by [Naghizadehrokni et al., 2020].

The ranges of governing parameters in the parametric study are presented in table 1.

Table 1. Ranges of different parameters in the parametric study

Parameters	**The selected value for the parametric study**				
Location (X)	3	6	9	12	15
Depth (D)	2	3	4	5	6
Width (W)	0.3	0.5	0.7	1	1.5
Thickness of the first layer (L)	2	4	6	8	10
Shear wave velocity (Vs) (m/s)	200	250	300	350	400

The vibration source in this study is modelled as a vertical harmonic load with the amplitude of 1 kN and frequency of 50Hz. The dynamic time interval is considered 0.5 S, which is enough to allow the passage of dynamic load [Naghizadehrokni et al., 2020]. The steel plate under the shaker is modelled as a plate and the shaker weight is considered a uniformly distributed load with a magnitude of 1 kN/m^2.

However, the weight of the steel plate and the shaker is kept constant during the parametric study since it does not play a significant role in the results and the difference for the efficiency of trench between zero and non-zero foundation weight is 1.5 %, which can be neglected [Alzawi & El Naggar, 2011; Naghizadehrokni, 2023]. The proposed FE model of the vibration isolation system and the defined parameters are presented in Fig. 1 [Naghizadehrokni et al., 2020].

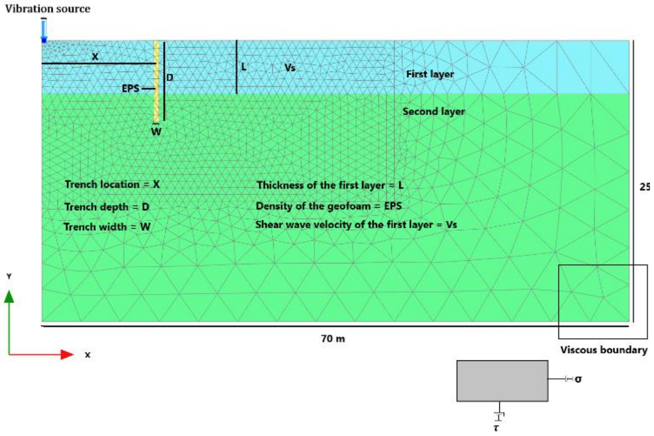

Figure 1. Schematic view of Plaxis model and selected parameters

In order to save calculation time, Plaxis remote scripting feature is used to couple the finite element model (Plaxis) with Python programming language. For this purpose, a script is developed to allow the user to control both the input and the output of the model through connecting Plaxis and Python. The main advantage of the automation is accelerating the pace of the parametric study.

In this method, Plaxis connects to Python, and the scripts are imported to Plaxis as a text file. Thereafter, Python reads the code and evaluates the dimensions and the position of the trench based on the input data, and creates a new FE model.The script starts by creating a borehole and sbsequently installs the trench, defines different phases, runs the model, and calculates the efficiency of the trench. The entire process is executed automatically as shown in Fig. 2.

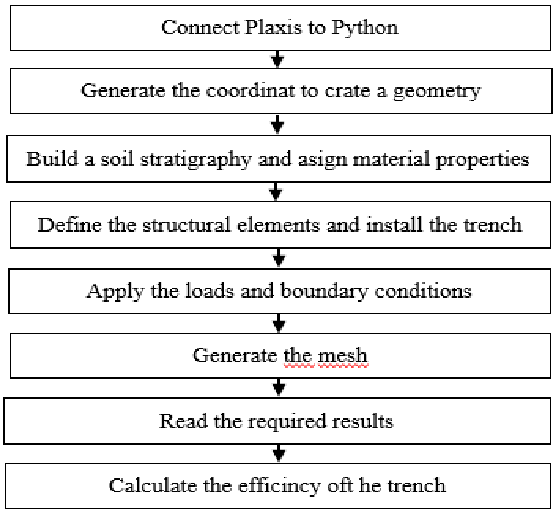

Figure 2. Automation process of FE model by connecting Plaxis with Python

2.1 Response Surface Methodology (RSM)

Response Surface Methodology (RSM) is a statistical method for investigating the interaction and relationship between the independent variables with different responses. RSM uses quantitative data from appropriate experiments to determine regression model equations and operating conditions [Naghizadehrokni, 2023]. RSM is a collection of mathematical and statistical techniques to model and analyse problems in which a response of interest is influenced by several variables.

The advantages offered by RSM can be summarized as determining the interaction between independent variables, modelling the system mathematically, and saving time and cost by reducing the number of trials.

3 DISCUSSION

3.1 Interaction of D and Vs

Fig. 3 illustrates the interaction of depth of the barrier (D) and shear wave velocity of the soil (Vs) on the efficiency of the geofoam-filled trench. Increasing D and Vs result in attenuating more incoming waves in parallel. The contour diagram at the bottom, which is the reflection of the interaction of two parameters on the screening effectiveness shows that efficiency of the trench follows the same pattern for different D and Vs.

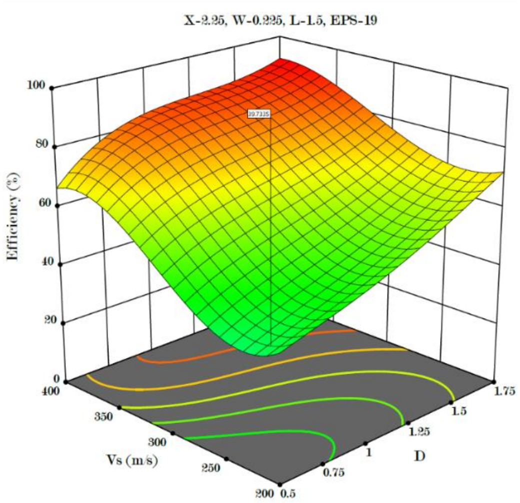

Figure 3. Interaction of D and Vs on the response of the trench (X = 2.25)

Fig. 4 is depicted for interaction of D and Vs at the location of X=3.5. The results illustrated that the effect of these parameters on the efficiency of the geofoam-filled trench follow the same pattern as for X=2.25. The difference is the value of efficiency, which is considerably decreased for all value of D and Vs in comparison with X = 2.25. For instance, there is 50% reduction in the efficiency of the trench for the lowest value of efficiency when increasing the distance from X = 2.25 with efficiency of 39.7% to furtherer the location of X = 3.5 with the efficiency of 19.2%. This issue proves that an near field trench has more capability in screening of incoming waves in comparison with a far field trench although having the same value for D and Vs.

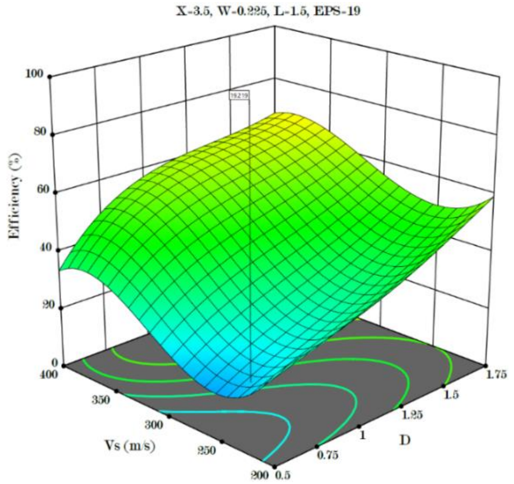

Figure 4. Interaction of D and Vs on the response of the trench (X = 3.5)

Another remarkable point of the results is that there is not any local maximum in the figure and the efficiency of the barrier increases continuously with increasing both parameters.

3.2 Interaction of Vs and L

The influence of shear wave velocity (Vs) and thickness of the first layer (L) of the soil at the location of X = 0.75 on the attenuating of incoming waves is presented in Fig 5. The screening effectiveness of the trench increases with increasing the thickness of the first layer for lower value of Vs (200 < Vs < 300). However, for stiffer soil (Vs > 300), increasing L does not have any effect on the efficiency of the trench and the efficiency is almost constant for all values of L. Making the soil stiffer results in increasing the homogeneity of the soil, therefore changing the value of L will be meaningless because the soil is already nearly homogeneous.

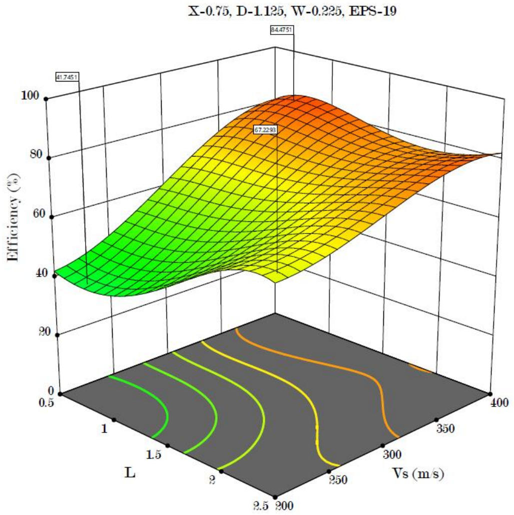

Figure 5. Interaction of Vs and L on the response of the trench (X = 0.75)

3.3 Interaction of X and Vs

One of the most complicated interaction is related to the iteraction of location of the barrier (X) and shear wave vlocity of the soil (Vs), which is depicted in Fig. 6. The location of the barrier seems to affect the efficiency in such a complex way that the results of wave propagation in layered media are unpredictable. The trench response in terms of location is including several peaks and valleys. These fluctuations result in distinct feature of wave attenuation in layered soil. The superposition of reflected and passed waves from and underneath the trench and new generated waves from the effect of layering results in constructive or destructive interference, depending on the phase of the wave. The constructive feature creates a peak and the destructive feature creates a valley.

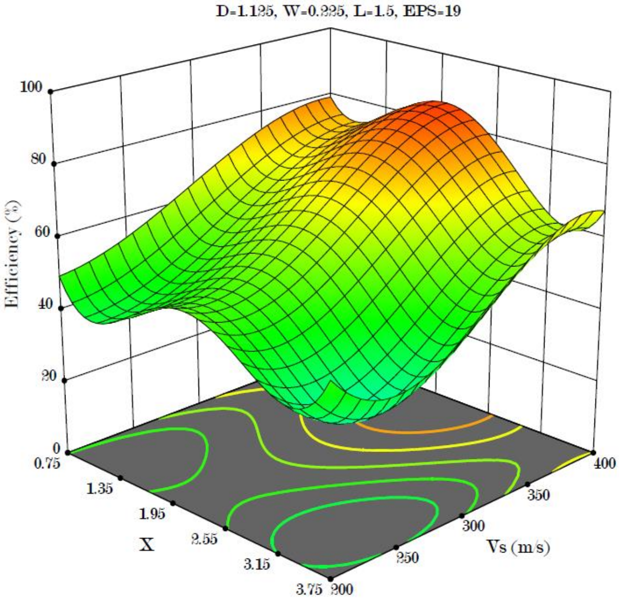

Figure 6. Interaction of Vs and X on the response of the trench (D = 1.125, L = 1:5)

The interaction of X - Vs is also analysed for the deepest barrier and lowest thickness of the first layer (D = 1.75 and L = 0.5). The results, which are presented in Fig. 7 showed that increasing D and decreasing L cannot detach the influence of layering of the soil, in terms of several maximums and minimums in the efficiency of the trench. The difference is the value of efficiency, which is considerably increased for all value of X and Vs by installing a deeper geofoam-filled trench (D = 1.75), which represent the influence of the depth of the barrier.

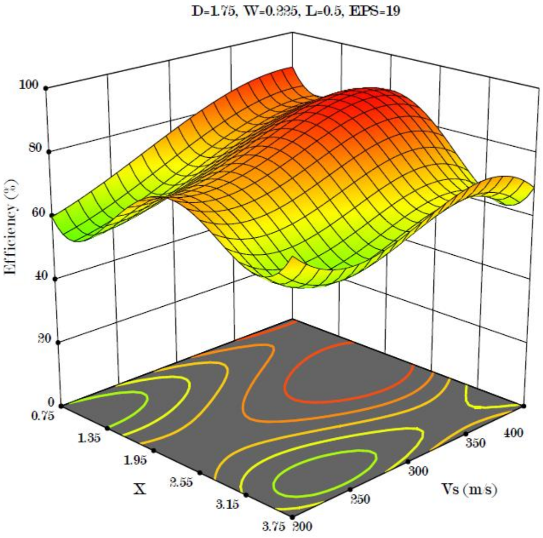

Figure 7. Interaction of Vs and X on the response of the trench (D = 1.75, L = 1.5)

3.4 Interaction of X and D

Fig. 8 shows several peaks and valleys, which results in changing the location of the trench for each value of D. However, efficiency remains approximately unchanged with respect to the location. A remarkable reduction in the vertical displacement of ground surface is visible, when increasing the value of D and this issue proves that D can be recognized as the governing parameter to reduce ground born vibration.

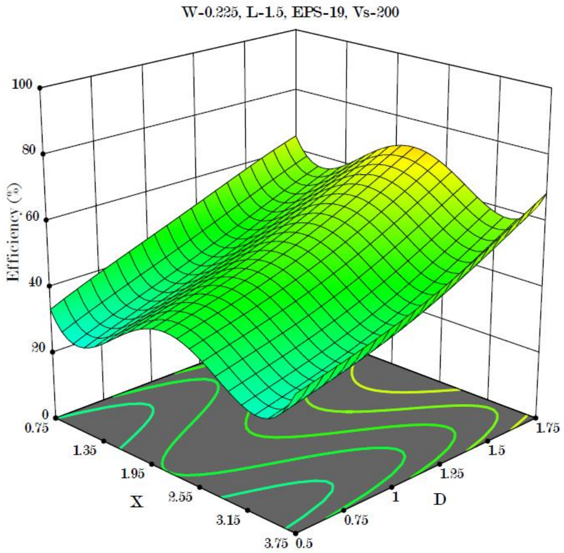

Figure 8. Interaction of X and D on the response of the trench (Vs = 200m/s)

The same pattern for the trench's response is obtained for the result of Vs = 350 m/s, which is presented in Fig. 9. There is not a considerable difference in the behaviour of the trench in terms of changing the location and the depth. However, increasing Vs leads to shifting the whole diagram approximately 20% upwards of the vertical axis.

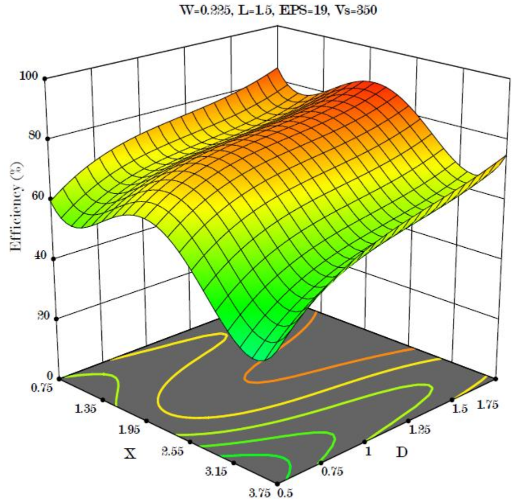

Figure 9. Interaction of X and D on the response of the trench (Vs = 350 m/s)

3.5 Interaction of X and L

Fig. 10 is depicted for better understanding of the effect of layering for soft soil. The complexity of the result with changing L shows the unpredicted influence of L. However, varying the value of L and X cannot create considerable change in the efficiency of the trench and the screening performance of the trench for all values of X − L is approximately between 40 − 60%. Increasing stiffness of the first layer is an effective factor that can diminish the influence of layering. However, the result of stiff soil is not presented here because L does not play any role in changing the efficiency of the trench. The reason is that increasing Vs means increasing the homogeneity of the soil and this issue result in diminishing the influence of L on efficiency.

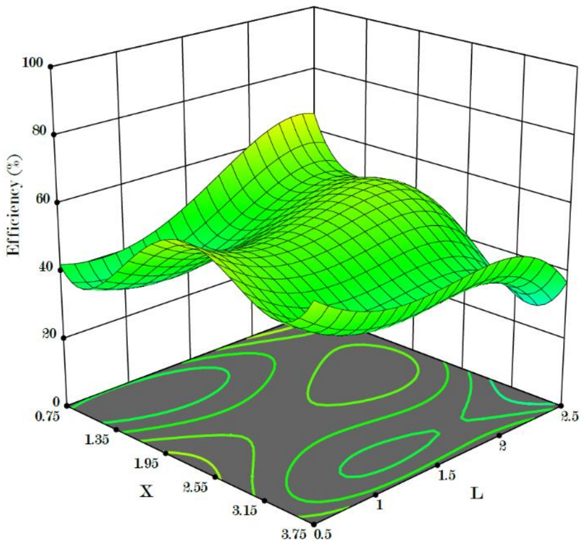

Figure 10. Interaction of X and L on the response of the trench (Vs = 200 m/s)

4 CONCLUSION

A comprehensive parametric study has been performed for evaluating the efficiency of the geofoam-filled trench in layered soil using a combination of Plaxis and Python program. A statistical model in terms of Response Surface Methodology (RSM) has been developed for finding the interaction between the governing parameters. The conclusions drawn from the results of the parametric study can be summarized as follows:

- The result of interaction between all governing parameters demonstrated that D − Vs, L – Vs and X −D have the highest influence on the efficiency of the trench. of These interaction show that the vibration isolation topic is a non-linear problem and single parametric study of the trench is not sufficient for finding the impact of different factors.
- Analysing the influence of D on the screening effectiveness showed that D = 1 is enough to have an optimum depth for X = 0.75. Increasing the distance X = 1.5 results in increasing the optimum depth to D = 1.25. For far field system, the results are irregular, especially for softer soil (Vs = 200 and 250 m/s).
- The shear wave velocity of the first layer plays a significant role in mitigating of incoming waves since increasing the value of Vs leads to improved efficiency of the system in various situations. This means that stiffer soils have more resistance to the incident waves from the vibration source in comparison with the softer soil. In addition, Vs = 250 m/s can be recognized as the critical value of the near field system.
- Concerning the location, the highest attenuation of incoming waves for stiff soil (Vs = 350 and 400 m/s) is recorded when installing the barrier near to the vibration source (X = 0.75 − 2.25) regardless of the thickness of the first layer and normalized depth.

5 ACKNOWLEDGEMENTS

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