Investigating on the performance of retrofitted trench with Leca in reducing ground vibrations

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ABSTRACT

Environmental vibrations can have a significant impact on noise pollution and the health of the residents of buildings adjacent the vibration sources. Therefore, the studies conducted in the last two decades on reducing vibrations have attracted a lot of attention from researchers. In this study, the effect of different types of improved trenches with Leca lightweight aggregate, including single and double-walled trenches in both active and passive modes, has been investigated, using the combination of Plexis3D finite element software and Python programming language, and the models with the results of other researches. It has been validated and also, a parametric study has been done to evaluate the effect of geometrical factors including depth, width and length for both systems. The obtained results indicate that in order to achieve an acceptable amount of trench efficiency, the depth of $0.8\lambda_r$ and $1\lambda_r$ is sufficient as the optimal depth for single and wall systems, respectively, and considering the effect of the width of the trench filled with Leca, a width equal to $0.2\lambda_r$ and $0.15\lambda_r$ are enough to reach the optimal width for single-wall and double-wall systems, respectively. Also, for passive design, the role of depth can be ignored for single and double-walled barriers, because trench width plays a more important role compared to trench depth. Moreover, to achieve an acceptable single-wall system, the normal width should be increased to about $0.2\lambda_r$.

Keywords: Retrofitted trench, Leca, Ground Vibration, Harmonic Load, Numerical Modeling.

INTRODUCTION

Most of the vibrational energy emitted near the surface of the earth spreads through Rayleigh waves [1]. Therefore, constructing a trench in the path of vibration is an appropriate solution, as it leads to the dispersion and reduction of wave vibrations [2]. This wall, through a complex interaction of waves including reflection, refraction, bending, and interference, cuts off, weakens, and disperses the emitted waves. The reduction and weakening of waves are classified into two general groups: an active design where the trench is installed near the vibration source, and a passive design where the trench is constructed away from the vibration source. Moreover, the practicality of wave barriers is also classified into two cases: open and filled trenches [3]. Woods was the first to conduct a full-scale experiment to assess the effectiveness of open trenches, suggesting that a trench is effective in reducing incoming waves if it blocks at least 75% of the waves [4]. However, due to construction and stability issues, open trenches are not practical in many cases over long periods, and filled trenches are usually used instead. Also, to understand the effectiveness of open and Leca-filled trenches, field studies have shown that the performance of open and Leca-filled trenches are 68% and 67% effective, respectively [5]. Selby and colleagues conducted various field experiments to calculate the reduction effect of open trenches filled with hard and soft materials in active and passive designs. The results show that active isolation is more effective than passive isolation, and soft fill materials are more effective than hard materials in damping incoming waves [6]. The effect of geometric factors of Leca-filled trenches in reducing incoming waves was conducted in a parametric study using a centrifuge device, and the results show that the wave reduction performance depends on the depth of the trench [7].

METHODOLOGY

In this article, a novel method for automating parametric studies using a combination of PLAXIS and Python has been investigated. This approach, developed using Python scripts to reduce time and increase accuracy in modelling ground vibrations, allows various finite element model settings to be applied quickly and precisely through these scripts, as indicated in Fig. 2. This enables extensive investigation of the impact of various geometric and physical factors on vibration reduction. The results from this automated study show high accuracy compared to existing data from similar studies. Automating modelling using PLAXIS in this research has led to significant benefits. This method enables faster and more precise execution of parametric studies, especially in projects with a wide range of variable conditions. In addition to field and laboratory tests, numerical methods such as the finite element method and the boundary element method are used as powerful tools for examining and evaluating the reduction performance of wave barriers.

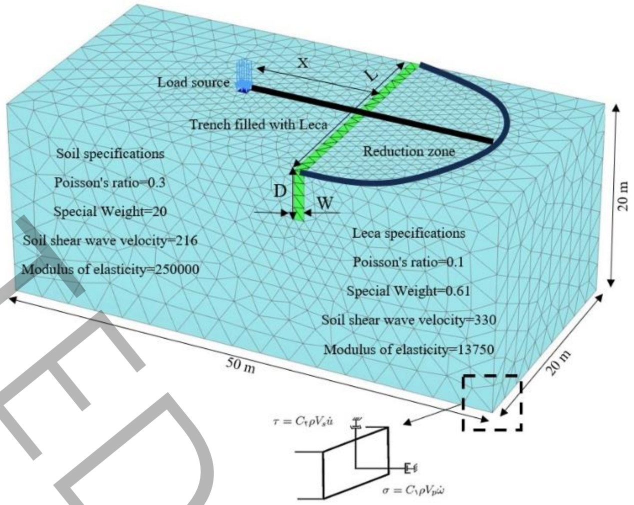

Figure 2: Geometry of the model in this study

RESULTS AND DISCUSSION

The normalized speed of soil particles was compared in scenarios with and without a trench implementation. A trench filled with Leca was strategically placed at 0.5 meters, and its normalized depth was set at 1 meter. The findings revealed that the normalized speed of soil particles on the ground surface, beyond the reduction zone, exhibits no significant differences between the scenarios with and without the trench for a single-wall system. Further analysis demonstrated that with an increase in the normalized length of the trench from 0.5 to 2 meters, there is a notable increase in trench efficiency. The efficiency improves by approximately 40% for narrow trenches and about 30% for wide trenches, highlighting that trench length plays a more significant role in vibration reduction for narrower trenches compared to wider ones. Moreover, the effectiveness of the trench in reducing surface vibrations does not change for lengths greater than 2 meters, suggesting that this length can conservatively be considered optimal for use across various systems. In cases where the implementation of a single-wall system is challenging due to excessive depth, the effectiveness of wave damping with a double-wall system becomes significant. This is because using a double-wall system filled with Leca may require less depth compared to a single-wall system.

In this study, the distance between the trench filled with Leca and the vibration source was set at 3 meters. A significant reduction in vertical ground displacement was observed both before and after the installation of the trench, which was placed at a normalized distance of 10 meters from the source. This normalized distance was chosen to calculate the average reduction amplitude. The results indicate that there is no fundamental relationship between the calculated and the normalized depth since the differences between the curves drawn for various depths are minimal and negligible. This slight variation suggests that increasing the depth of the trench does not significantly change its efficiency. Conversely, increasing the thickness of the trench walls leads to greater dispersion of ground vibrations from the vibration source. As the width (W) of the trench increases from 0.05 meters to 0.2 meters, there is a 30% improvement in trench efficiency across all depths, indicating that a width of 0.2 meters is considered optimal for achieving a reasonable level of damping.

For systems with double walls, changes in trench depth do not affect the average reduction amplitude, and increasing the width (W) does not alter how depth (D) influences. A comparison of the efficiency of the trench in double-wall systems shows even less impact of depth compared to single-wall systems because the lines representing different depths are very close together. Some of the Rayleigh waves, after hitting the edge of the first wall, are reflected downwards and to the left towards the trench, while others are transmitted to the right of the trench. Subsequently, the transmitted waves are reflected again at the discontinuity between the two walls.

CONCLUSION

In this article, a parametric study to evaluate the effect of important factors such as the depth, width, and length of the improved trench with Leca lightweight aggregate in active and passive mode was carried out and the results were compared and two different systems including single and double-layer wall It has been chosen to evaluate the effect of the trench shape on the reduction of incoming seismic waves on the ground surface. Also, to increase the speed of analysis, the numerical model automation process has been done by coupling PLAXIS and Python.

In general, the conclusions obtained from these analyses show that the location of the trench does not play a role as an effective factor in the efficiency of the trenches filled with Leca. In other words, changes in trench location (X) did not significantly affect the amount of vibration reduction. These findings show that in the design of improved trenches with Leica to reduce vibration, the location of the trench is less important than the source of vibration, and it is possible to focus more on other effective parameters such as depth, width, and characteristics of filling materials.

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