# Numerical modelling and analysis of geogrid reinforced soil trench barrier-wall under combined static and dynamic loadings.

**I.Kafodya[1], F.N. Okonta[2]**

[1] Civil Engineering Science Department, University of Johannesburg, Johannesburg, Gauteng Province, ikafodya@poly.ac.mw
[2] Civil Engineering Science Department, University of Johannesburg, Johannesburg, Gauteng Province,fnokonta@uj.ac.za

## Abstract

The paper presents numerical investigation into the dynamic response of open trench barrier walls and the surrounded building to ground-acceleration, and the effects of geogrid reinforcements on the dynamic response. In this study, PLAXIS finite element code was used to simulate ground excitation. The soil medium was assumed to be stratified with elastic fill material, dense clay and decomposed rock. The responses of the building and barrier walls were studied at various trench depths (2m,4m and 8m) and number of geogrid layers. The results showed that the geogrid reinforcements reduced peak acceleration of both the trench barrier walls and the building. The acceleration damping efficiency of the geogrid layers was higher in the walls than the building .Inclusion of the geogrid layers increased peak acceleration frequency due to the enhanced system stiffness. Increasing depth of the trench produced undesirable effects due to the dominance of body waves.

***Keywords:*** *trench barrier, geogrid, soil wall, structural system.*

## 1. Introduction

Vibrations induced by heavy vehicles, blasts, railway, traffic, and other construction-related activities and earthquake tremors have become a major concern of cities in recent years, which, depending on their source and the distance to where they are originated can disturb both occupants and constructions containing sensitive equipment.(Hong, 2014).Therefore, vibration isolation requires considerable attention, especially when vibration source is in close proximity with sensitive constructions and establishments and, when it is inside or near densely populated urban cities.

Excessive vibration distorts sensitive instrument functions, distracts terrestrial constructions, and disturbs residents. Among isolation techniques applied to reduce undesirable effects of vibrations, active wave barriers (located close to the source of vibrations) and passive ones (more distant from the source of vibrations) have attracted a great deal of attention in recent years (Woods, 1968). These barriers include trenches (either open or infilled with special material such as bentonite, water, Geo-foam, or concrete), heavy mass technology, sheet piles, wave-impeding blocks, soil grouting, gas-filled cushion, groups of piles, or scrap-tire isolation walls. In respect of flexibility and economical aspects in construction procedure and good performance, trench barriers (open or infilled) are commonly applied. The influencing factors of wave-barrier performance, includes wave and soil characteristics, as well as geometrical parameters. Released energy from the vibration source propagates in forms of surface waves (Rayleigh waves) and body waves (including pressure (P) and shear (S) waves). Most of the energy (nearly two thirds) generated by vibrations is released in the form of Rayleigh waves (Miller G and Pursey H, 1955; Sánchez-Sesma et al, 2011)Therefore barrier effectiveness can be determined through the amount of Rayleigh waves reflected, diffracted, or scattered (Jain A and Soni D, 2007).Alterations in the amplitude of Rayleigh waves' components with depth are directly affected by the source of vibrations and dynamic properties of the soil medium.

Trench depth is the most fundamental factor affecting trench performance (Ahmad, 1991; Al-Hussaini TM and Ahmad S D, 1991; Bo Q, 2014; Saikia A 2014; Saikia A, 2014).Bo et al demonstrated that in not excessively thin trenches (with relatively small width to depth ratio), adding more depth to trenches strengthens vibration amplitude reduction; this proved to be right with vertical vibrations. On the other hand, wide shallow trenches magnify vibrations and exhibit undesirable results. Increasing the depth of trench in an average width improves its performance. Increasing the normalised depth however, slows vibrations down to steady value where the further addition to depth yields no considerable effect on amplitude reduction. This is attributed to the finite reduction effect resulted by deepening the trenches that in turn causes drastic decrease in Rayleigh wave amplitude. The trench depth can decrease both vertical and horizontal vibrations (Saikia A, 2014). A deeper trench reflects waves of greater depth, resulting in a better isolation. Regarding multiple trenches, (Saikia A 2014) demonstrated that deepening the trenches improves their performance against vibrations, especially vertical ones.

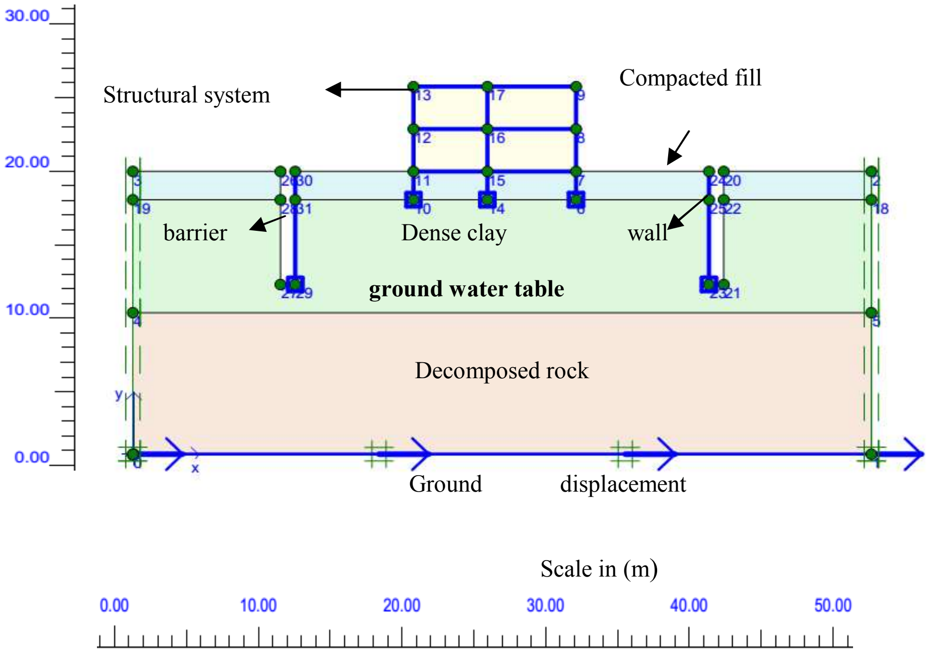
The majority of investigations indicate little effect of trench width on the amplitude reduction. Undesirable effects are exhibited with wider trenches however, adding depth and distance from the source can diminish these effects. This is attributed to the fact that when a trench is located near the source of vibration, body waves play a more dominant role with respect to surface waves, and thus a shallow trench would allow greater amounts of body waves to underpass the trench. A wider trench provides a greater free surface that converts body waves to surface ones, yielding undesirable effects. When the distance is increased further away from the source of vibration, surface waves gain dominance over body ones. When the trench is deep enough, most surface waves are reflected by the trench and effect of width becomes minor. The source-barrier distance has a low effect on barrier's performance (Saikia A 2014; Yang YB and Hung HH, 1997)

The geosynthetic inclusion in the earth retaining structure has shown to improve response of the wall to vibrations (Hadi Khabbaz, 2013; Magdy M. EL-EMAM, 2004)

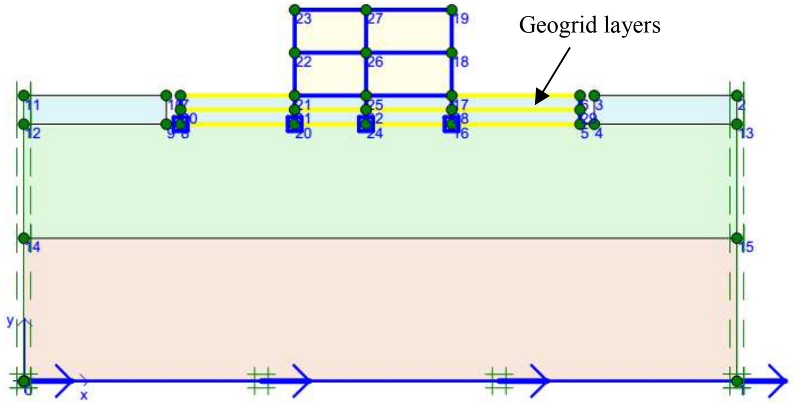
In this study, a numerical model was employed to investigate the wall and structural responses to ground-borne vibration. Of interest were the effects of geogrid reinforcement on the acceleration response of the walls and the building in a plane strain context. The behaviour was numerically studied using a finite element code, PLAXIS. The wall and structural systems were assumed to be elastic, exerting dead load on the soil medium.. The structure and wall responses were studied at various trench depths (2m, 4m and 8m) and number of geogrid layers (0, 2, 3 and 4).

## 2. Problem definition

2-D finite element model was used to conduct an extensive analysis to determine the effect of trench depth and geogrid reinforcements on the response of the structural system to underground-borne vibrations. The typical variables in the analysis were trench depths and geogrid layers. The model comprised of a 2 storey composite structure (average floor height of 3m) supported by the strata of soil media of 20m x50m in dimension. The first stratum (2m deep) composed of compacted fill material, second stratum (8m deep) composed of dense clay and last stratum (10m deep) composed of decomposed rock. The ground water table was located at 10m depth. The ground citation was located at 20m depth below foundation level. The idealised problem definitions are shown in Fig 1a and b.



(a)



(b)

Fig 1.Idealised problem definitions (a) structural system and soil strata (b) geogrid reinforcement layers

The structural system was assumed to have beams and columns of the same size (230mm x450mm). The height of the beam was assumed to be monolithic with the slab. The behaviour of the structural system was taken as linear elastic. The Mohr-Coloumb failure criterion for soil was adapted with drained condition. The soil wall was assumed to be comprised of high strength concrete (50MPa) of 450mm thickness and 1000mm width. The trench width of 1m was kept constant for all numerical analysis scenarios. The ground displacement of 0.2m was prescribed. The magnitude of ground acceleration was kept unity. The default number of calculation steps (250) was adopted and dynamic analysis period of 0.5seconds was employed. The summaries of the material properties and analysis parameters are shown in Table 1 and Table 2.

Table 1.Material properties

| Property | Unit | Compacted fill | Dense clay | Decomposed rock |
|---|---|---|---|---|
| Unit weight γ | (kN/m$^3$) | 18 | 18 | 25 |
| Lateral Permeability | m/day | 1 | 1 | 0.001 |
| Vertical Permeability | m/day | 1 | 1 | 0.001 |
| Elastic modulus | kPa | 3x10$^3$ | 8x10$^3$ | 3x 10$^7$ |
| Poison ratio | | 0.25 | 0.3 | 0.3 |
| cohesion | kPa | 1 | 4 | 1 |
| Angle of friction φ | | 30 | 25 | 40 |
| Shear wave velocity Vs | m/s | 25 | 45 | 173 |
| Shear wave velocity Vp | m/s | 47 | 90 | 325 |
| Shear modulus G | kPa | 1154 | 3007 | 1.1x10$^7$ |
| Interface interaction factor | | 0.7 | 0.7 | 1 |

Ref(Tanchaisawat T, 2008)

Table 2.Structural material properties

| Property | Unit | Structural Members | Wall | Geogrid |
|---|---|---|---|---|
| Flexure rigidity EI | kNm$^2$/m | 87 | 380 | |
| Stiffness EA | kN/m | 5175 | 2.x10$^4$ | 5x 10$^3$ |
| Poison ratio | | 0.3 | 0.3 | |
| Weight | kN/m$^2$ | 7.5 | 7.5 | |
| Young modulus E | MPa | 50 | 50 | |
| Damping ratio | % | 5.0 | 5.0 | |

Ref(Hadi Khabbaz, 2013)
The flexural rigidity and stiffness were calculated using Eq 1 and Eq 2 respectively

$$\gamma = \frac{Ebh^3}{12} \qquad (1)$$

$$\kappa = Ebh \qquad (2)$$

where b and h are width and thickness of the member and E is the elastic modulus.

## 3. Finite element model and validation

The problem was simulated in PLAXIS using a 2-D.A plane strain model with 15 nodded triangular mesh elements. The model dimension for the structure was kept as 6 m x 10 m while the soil medium was kept as 20mx50m.The special boundary conditions were defined to account for the reflection of waves that could cause perturbations. To avoid reflections, absorbent boundary conditions were specified at the bottom, right and left side boundaries. In Plaxis code, the wave absorption on the absorbent boundaries is improved by introducing wave relaxation coefficients $C_1$ and $C_2$. In this study default values of $C_1 = 1$ and $C_2 = 0.25$ were used. A typical finite element model and discretisation are shown in Fig. 2. The validation was done by comparing the results with previous studies.

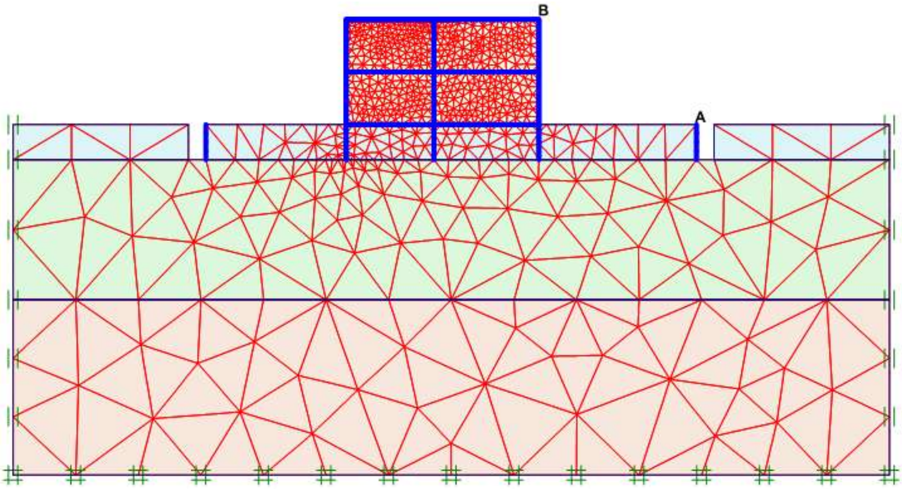
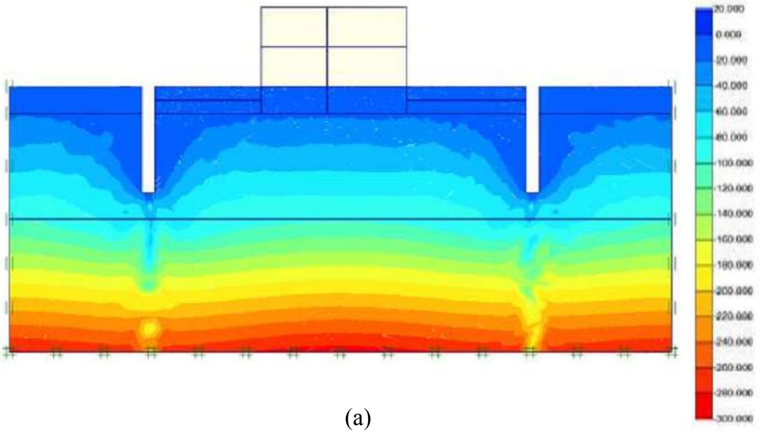
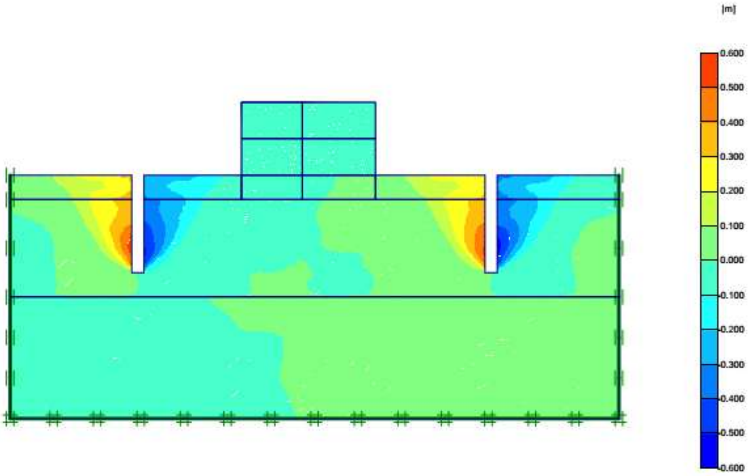


Fig 2 Finite element model discretisation.

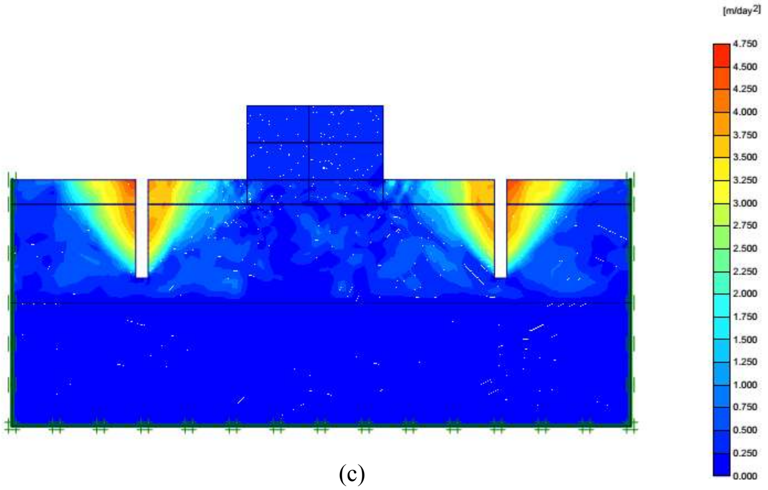
A linear elastic material model was used in the analysis with the parameters as shown in Table 1. The material type was considered as drained with material damping of 5%.The assumed Rayleigh parameters were α=0.9 and β=0.000488. The mesh discretisation was done with medium elements size. The time interval for dynamic analysis was taken as 0.5 s. The system effectiveness was evaluated based on the observed acceleration response with and without the vibration barrier and geogrid layers. The effectiveness of reinforcement inclusions was determined by normilising acceleration at the monitoring nodes (A and B see Fig 2) with reinforcements by the other without reinforcements at a given trench depth. Typical displacement and acceleration intensity distributions are shown in Fig 3a and b respectively.



(a)



(b)



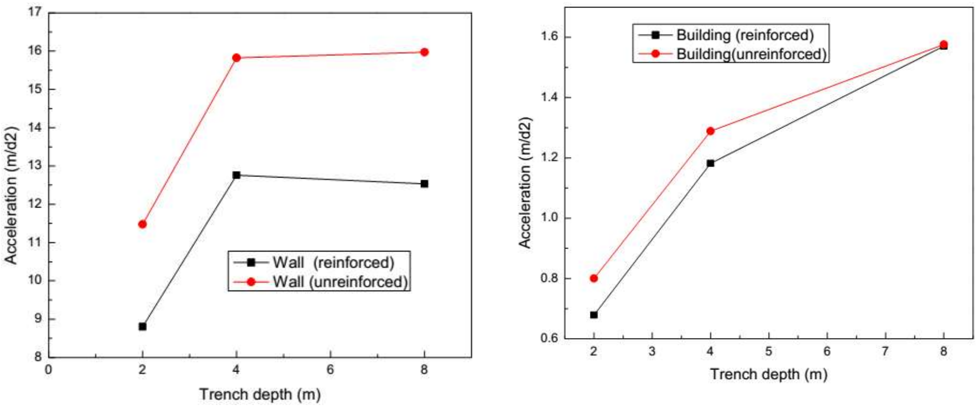
(c)

Fig 3.Response of the structure and the trench barrier (a) stresses (b) displacements (c) acceleration

## 4. Parametric study and results

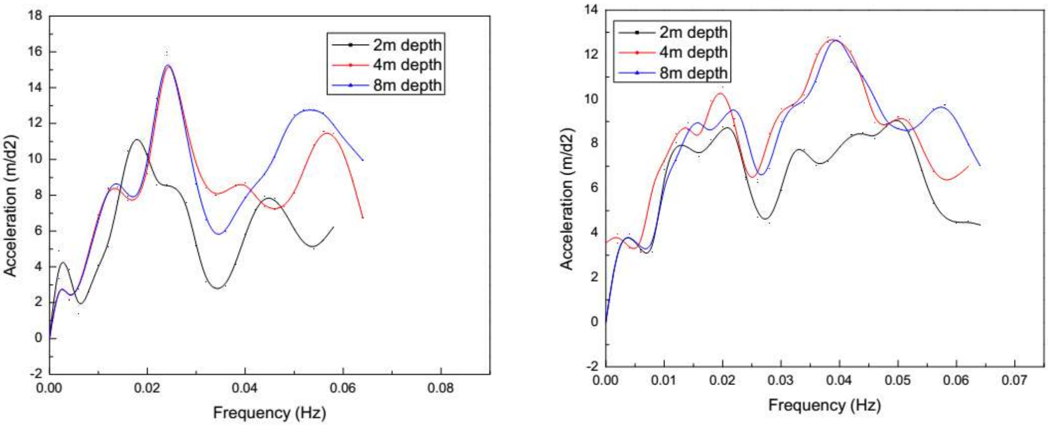
### 4.1. Responses of the wall and building with trench depths

The acceleration responses of the walls and the building are shown Fig 4a and b for wall and building respectively. It can be noted that increase in trench depth causes an increase in peak acceleration of walls and the building. In comparison, barrier walls exhibit more pronounced effects than the building. Geogrid reinforcements reduce the undesired effects of the ground excitation. The increase in peak acceleration was due to the dominance of body waves under passing the trench. The trench barrier isolation system is normally effective when the surface waves are dominant (Jain A and Soni D, 2007). It can be noted in Fig 4c and d that geogrid inclusions increase peak acceleration frequency. This was attributed to the stiffness of the geogrid members. The high resistance of the building was due to the high global stiffness of the structural system contributed the individual members



(a)

(b)



(c) (d)

Fig 4.Acceleration responses and spectral curves for wall (a) wall (b) building (c) response of unreinforced wall (d) response of reinforced wall

The efficiency of the geogrid reinforcement is shown in Table 3 for both the wall and the building.

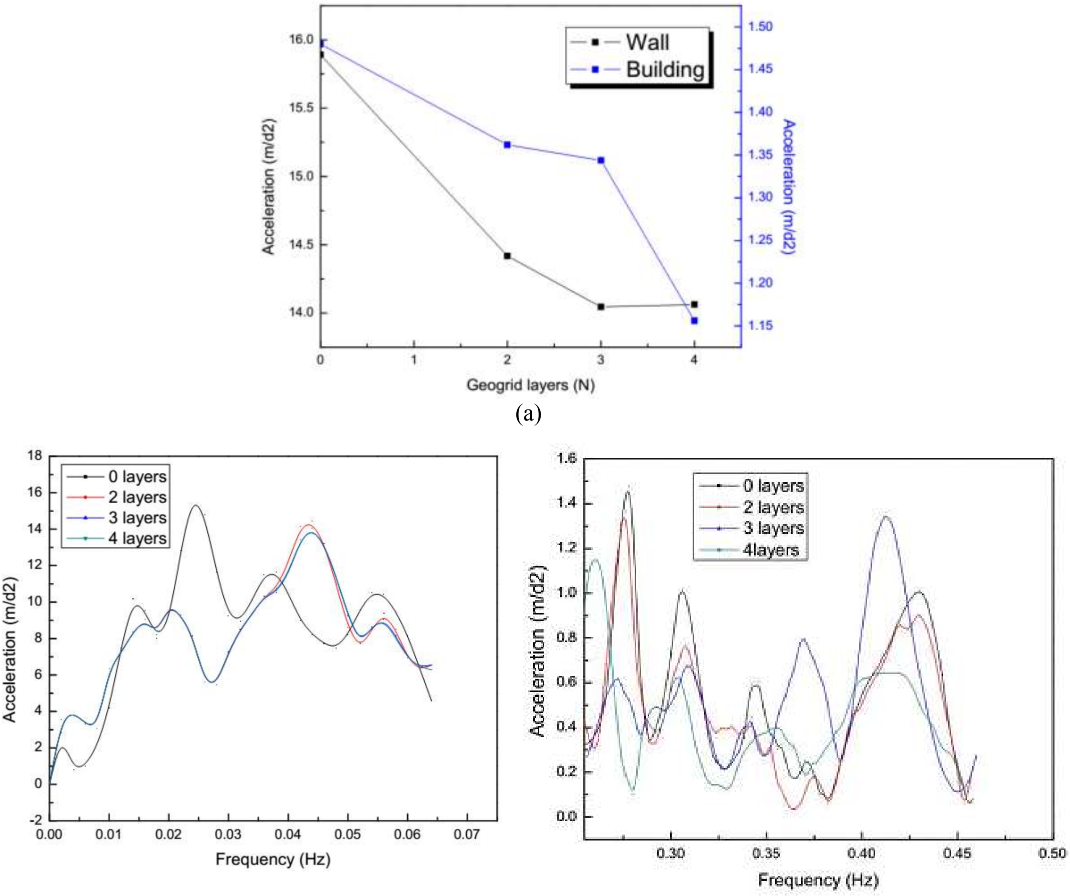
Table 3.Geogrid reinforcing efficiency

| Trench depth | Reinforcement efficiency (%) | |
|---|---|---|
| | Wall | Building |
| 2 | 23 | 15 |
| 4 | 20 | 9 |
| 8 | 22 | <1 |

It can be noted that geogrid layers are more effective in enhancing response of the wall to acceleration than the building. This was attributed to the direct interaction of the geogrids with barrier wall that endowed the wall with enhanced stiffness. The model behaviour is in agreement with one obtained by (Hadi Khabbaz, 2013; Li-yan Wang 2014; Tanchaisawat T, 2008)

### 4.2. Effects of geogrid inclusions

The effects of geogrid inclusions for the barrier wall and the building are shown in Fig 5a. It can be seen that increasing number of geogrid layers causes reduction in the wall and building peak acceleration. In comparison, barrier walls exhibit higher rate of reduction than the building. The difference in rate of reduction was attributed to the mechanical interactions of the wall and building with geogrids .The walls in the model were directly supported by the geogrid layers and this endowed the walls with considerable stiffness. The resistance by the building was mainly contributed by the column stabs below foundation level which was dependent on the member stiffness. The acceleration spectral curves in Fig 5b and c. show that increasing geogrid layers causes an increase in the peak frequency as a result of increased global system stiffness.



(a)

(b) (c)

Fig 5.Effects of geogrid reinforcement and spectral curves (a) variation of acceleration response (b) spectral acceleration curve for the wall (c) spectral acceleration curve for the building

## 5. Conclusions

In this study, numerical modelling and analysis of the building and geogrid reinforced trench barrier walls under dynamic loading were conducted using PLAXIS 2 D finite element code. The parametric study of the building and the wall peak acceleration responses were investigated with various numbers of geogrid layers and trench depths. The geogrid reinforcing efficiency was also evaluated. Based on the results, the following conclusions are made;

a. The geogrid reinforcement reduces peak acceleration of both the trench barrier walls and the building due to the enhanced stiffness of the system
b. The acceleration damping efficiency is more pronounced in the wall than the building due to the direct mechanical interaction between geogrids and walls
c. Inclusion of the geogrids in the system increases peak acceleration frequency due to the enhanced stiffness.

## References

Ahmad, S. Al-Hussaini, T 1991. Simplified design for vibration screening by open and in-filled trenches. J Geotech Eng, 117, 67–88.

Al-Hussaini TM and Ahmad S D. 1991. Design of wave barriers for reduction of horizontal ground vibration. J Geotech Eng 117, 616–636.

Bo Q, Ali L, Irini D-M. 2014. Numerical study of wave barrier and its optimization design. Finite Elem Anal Des, 84, 1–13.

Hadi Khabbaz, Biood Shrestha and Behzad Fatahi. 2013. Parametric study on behaviour of reinforced soil walls with combined horizontal and vertical geosynthetics Paper presented at the Australian Geomechanics Society Sydney Chapter Symposium,, Sydney.

Hong, T., Ji, C., Park, J., Leigh, S.-B. & Seo, D.-Y. 2014. Prediction of environmental costs of construction noise and vibration at the preconstruction phase. J Manag Eng, 31.

Jain A and Soni D. 2007. Foundation vibration isolation methods. Paper presented at the 3rd WSEAS International Conference on Applied and Theoretical Mechanics.

Li-yan Wang , Peng Gao and Susumu Iai .2014. Numerical Study on Seismic Performances of Geogrid Reinforced Soil Retaining Walls in Liquefiable Backfill Sand. J Engi Sci Techn Rev 7 (1), 109 - 115.

Magdy M. El Emam, Richard J. Bathurst and Kianoosh Hatami 2004. Numerical modeling of reinforced soil retaining walls subjected to base acceleration Paper presented at the 13th World Conference on Earthquake Engineering, Vancouver, B.C., Canada.

Miller G and Pursey H. 1955. On the partition of energy between elastic waves in a semi-infinite solid.Proceedings of the Royal Society of London A: Mathematical,Physical and Engineering Sciences, London.

Saikia A .2014. Numerical study on screening of surface waves using a pair of softer backfilled trenches. Soil Dyn Earthq Eng, 65, 206–213.

Saikia A and Das UK..2014. Analysis and design of open trench barriers in steady-state surface vibrations. Earthq Eng Eng Vib 13, 545–554.

Sánchez-Sesma et al. 2011. Energy partitions among elastic waves for dynamic surface loads in a semi-infinite solid. . Bull Seismol Soc Am, 101, 1704–1709.

Tanchaisawat T, Bergado D. T., Lai Y. P., Piyaboon S and Anujorn P. 2008. Numerical simulation of geogrid reinforced light geomaterilas on soft ground area Paper presented at the 4th Asian Regional Conference on Geosynthetics, Shanghai, China.

Woods, R. 1968. Screening of surface waves in soils. Am Soc Civil. Eng J Soil Mech.

Yang YB and Hung HH. 1997. A parametric study of wave barriers for reduction of train-induced vibrations. Int J Numer Methods Eng, 40, 3729–3747.