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Acceleration response of geocell barriers subjected to vibration loads

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ABSTRACT: Isolation of foundations and structures from the ground vibrations has been one of the prime interests of geotechnical engineers. Over the years, different methods have been used to isolate the geotechnical structures from ground vibrations. The latest trend is to use the barrier systems made from the geocells in such applications. In this regard, this study is intended to quantify the performance of the geocell barriers in mitigating the vibrations. For the study purpose, the geocell barrier was created in a test pit of size 3.6 m × 3.6 m × 1.2 m. To generate the ground-vibration, dynamic excitation of 1.5 kN was applied over the model block using a mechanical oscillator. In order to quantify the performance of the geocell barriers, the acceleration contours were measured within a radius of 2 m from the vibration source. On the basis of the acceleration measurement, the optimum recommendations for the width and depth of placement of geocell barriers were established. For the maximum isolation of induced vibration, the width and depth of the geocell barrier system were found to be $5B$ and $0.1B$ (B is the width of loading area) respectively. At the optimum parameters, a 41% reduction in the magnitude of acceleration was observed in the presence of geocells as compared to unreinforced bed. The measured acceleration contours revealed that the geocells barriers effectively reduce the lateral spreading of the induced vibrations. Isolation efficacy of geocell barriers was further increased by 20% with the provision of embedment to the vibration source.

RÉSUMÉ: L'isolement des fondations et des structures des vibrations du sol a été l'un des principaux intérêts des ingénieurs géotechniciens. Au fil des années, différentes méthodes ont été utilisées pour isoler les structures géotechniques des vibrations du sol. La dernière tendance est d'utiliser les systèmes de barrière fabriqués à partir des géocellules dans de telles applications. Une tentative a été faite dans cette étude pour quantifier la performance des barrières géocellulaires dans l'atténuation des vibrations. Aux fins de l'étude, la barrière géocellulaire a été créée dans une fosse d'essai de 3,6 m × 3,6 m × 1,2 m. Pour générer la vibration du sol, une excitation dynamique de 1,5 kN a été appliquée sur le bloc modèle à l'aide d'un oscillateur mécanique. Afin de quantifier les performances des barrières géocellulaires, les contours d'accélération ont été mesurés dans un rayon de 2 m de la source de vibration. Sur la base de la mesure de l'accélération, la largeur et la profondeur optimales de placement des barrières géocellulaires ont été déterminées. Pour l'isolation maximale des vibrations induites, la largeur et la profondeur du système de barrière géocellulaire se sont avérées être respectivement de $5B$ et $0,1B$ (B est la largeur de la zone de chargement). Aux paramètres optimaux, une réduction de 41% de l'amplitude de l'accélération a été observée en présence de géocellules par rapport au lit non renforcé. Les contours d'accélération mesurés ont révélé que les barrières géocellules réduisent efficacement la propagation latérale des vibrations induites. L'efficacité d'isolation des barrières géocellulaires a encore été augmentée de 20% grâce à la fourniture d'un encastrement à la source de vibration.

KEYWORDS: Geocell barrier, Field vibration test, Isolation, Vibration load, Acceleration contours

1 INTRODUCTION

The geotechnical structures such as the foundations supporting the industrial machines are often subjected to vibration loads. Owing to the rapid increase in the use of industrial machines, vibration response analysis of the foundation has become an influential research area in the recent past. Rotary machines, high-speed compressors, and turbo generators are the few practical examples to emphasize the machine-induced stipulations. The functioning of these machines could induce a substantial amount of vibration. Importantly, excess vibration results in numerous adverse effects. It includes jeopardizing the functioning of adjacent machines, sensitive instruments, and creating environmental problems. In some instances, it exhibits severe effects on the workers and the inhabitants living nearby. Thus, it is obligatory to give special attention to control the adverse effects of vibration emanated from the machine sources.

Notably, the foundation bed plays a prominent role in eliminating the adverse effects of ground vibration (Venkateswarlu and Hegde 2019). Numerous studies reported the potential benefits of strengthening approach of foundation bed in controlling the unwanted vibrations (Haldar and Sivakumar Babu 2009, Mandal et al. 2012). In this context, diverse materials like steel and planar polymeric products were used to strengthen the soil bed (Clement 2015, Sreedhar and Abhishek 2016, Ding et al. 2019). Nevertheless, limited studies have explored the efficacy of geocell barriers in isolation of machine-induced vibration. Geocell is a three-dimensional polymeric product used for enhancing the strength and stiffness of the foundation system. Geocells are also known for enhancing the elastic response of soil beds (Tafreshi et al. 2008, Hegde and Sitharam 2016). Such nature is an essential requirement to control the excessive limits of vibration. Considering this aspect, Venkateswarlu and Hegde (2020a) conducted a set of field vibration tests to highlight the isolation prospects of foundation beds reinforced with different geosynthetics. During the investigation, the foundation bed was reinforced with a single layer of geogrid, two layers of geogrid and the geocell reinforcement. Based on the results of field tests, the geocell reinforced bed found to exhibit the maximum screening effectiveness as compared to other reinforced beds. Also, the study recommended that the geocell could be used to safeguard the structures from the emanated vibration until the frequency of 50 Hz. In addition, the presence of a geocell found to enhance the damping behavior of a foundation bed (Venkateswarlu and Hegde 2020b). Hegde and Venkateswarlu (2020) described the geocell benefits in controlling the traffic-induced vibration. The study highlighted that the provision of geocell reinforcement not only mitigates the effect of traffic-induced vibration but also improves the dynamic behavior of the subgrade section.

It is clear from the literature that the existing studies highlighted the geocell efficacy in controlling the displacement amplitude. There is a lack of knowledge on the acceleration response of unreinforced and geocell barrier systems subjected to vibration loads. Thus, the major contribution of this investigation is to examine the variation in acceleration response of the unreinforced and geocell barrier systems at the footing and the surrounding area. In this regard, acceleration contours up to a distance of 2 m from the center of vibration source have been measured and compared. To study the acceleration response, rotating type dynamic excitation has been applied over the barrier systems. Further, numerous parameters, namely, width of the geocell barrier, depth of placement of geocell barrier beneath the footing and footing embedment have been varied in the experiments.

2 EXPERIMENTAL INVESTIGATION

Geocell mattress and two different types of soil namely, locally available sand, and river sand were used as test materials in the experimental investigation. Local sand is used to prepare the foundation bed and the other one is for filling the geocell pockets. The commercially available geocell made of novel polymeric alloy (NPA) was used in the study. Figure 1 shows the tensile load versus axial strain response of a geocell specimen confirming the standards of ISO 10319 (2015). As per the figure, the ultimate tensile load capacity of the geocell was noticed as 23.8 kN/m. The soil materials used in this study were classified as per the standards of the Unified Soil Classification System. Grain size distribution of these materials is shown in Figure 2. Local sand and river sand were meeting the classification requirements of silty sand (SM), and poorly graded sand (SP) respectively. Table 1 illustrates the additional properties of soil materials.

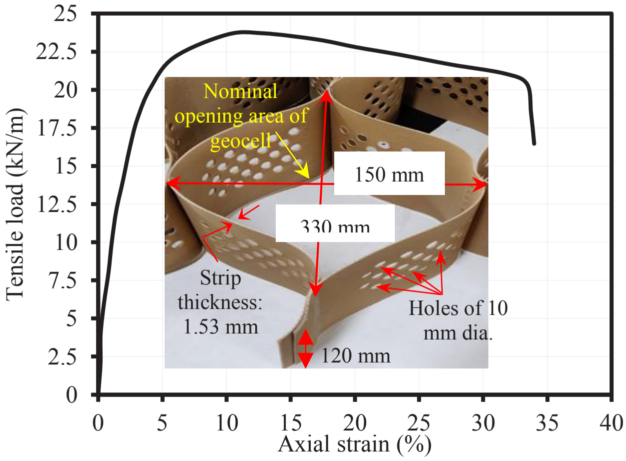

Figure 1. Tensile load versus strain variation of geocell material

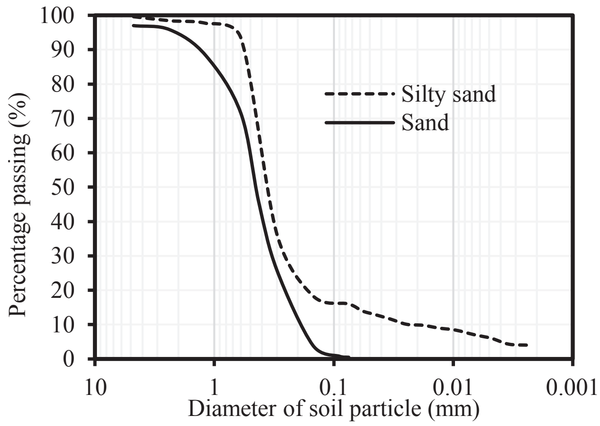

Figure 2. Grain size distribution of soil materials

Table 1. Geotechnical characteristics of soil materials

Parameter	Soil type	
	Locally available	River sand
Uniformity coefficient	22.22	2.63
Curvature coefficient	10.12	1.28
Fines content (%)	16	2
USCS classification	SM	SP
Cohesion (kN/m^2)	2	0
Friction angle (°)	32	36
Maximum dry density (kN/m^3)	17.9	18.6

The arrangement of the field vibration test is shown schematically in Figure 3. The prominent component of the test setup is the mechanical oscillator. It induces periodic vertical mode dynamic force by the counter clockwise movement of rotating elements. To vary the operating frequency of an oscillator, it was connected to a DC motor of 6HP capacity using a flexible shaft. The frequency ranges of DC motor employed for the present study is 0 Hz - 50 Hz. The running frequency of a motor was assessed using a speed control device (SCD) by the assistance of a speed measuring sensor. Table 2 illustrates the details of the testing program. The acceleration variation corresponding to change in footing embedment, and reinforcement parameters was studied.

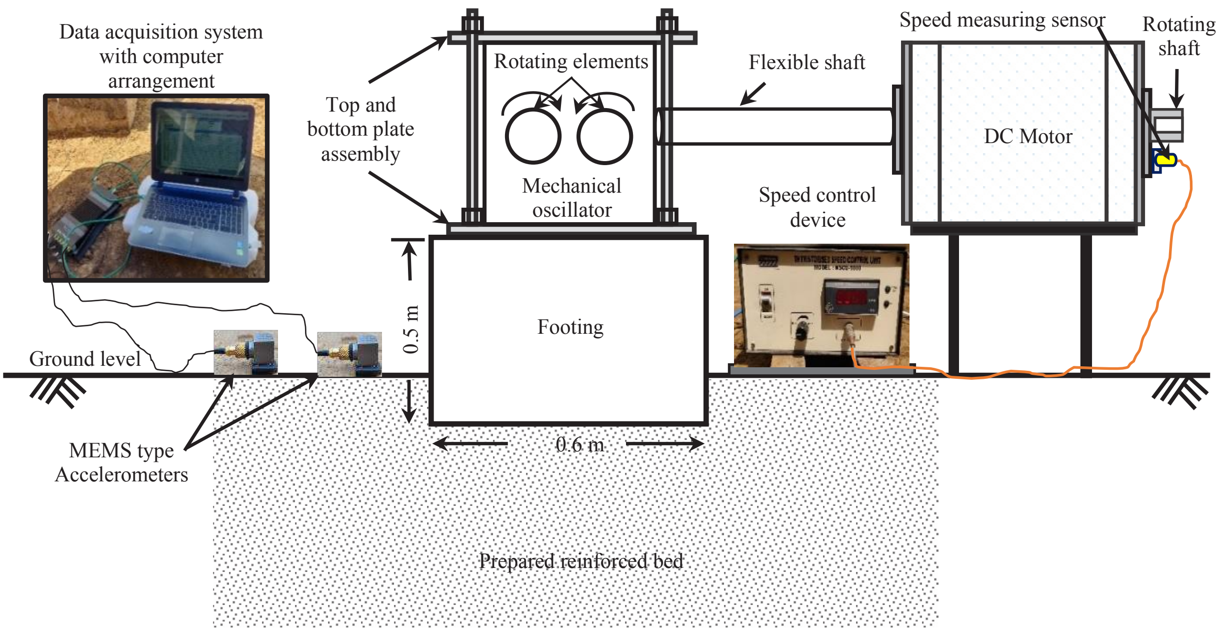

Figure 3. Schematic outlook of the arrangement of filed vibration test

During the variation of width of the geocell barrier, 0.1*B* was maintained as the depth of placement of geocell (*U*) beneath the footing. Similarly, width of geocell (*b*) was maintained as 5*B*, while changing the depth of placement of geocell reinforcement. The pluviation method was adopted to fill the sand within the geocell pockets in the aforementioned experiments. Overall, 12 numbers of field vibration tests were performed over the unreinforced and geocell barrier systems. The difference between both beds is shown schematically in Figure 4. The compacted foundation bed in both the cases was prepared using silty sand material. The dry unit weight and moisture content of the bed were maintained as 17.25±(7%) kN/m^3 and 12.2±(0.12)% respectively. Similarly, the achieved average dry unit weight of the infill was noted as 17.3 kN/m^3.

Table 2. Details of the experimental investigation

Type of test bed	Parameter varied	Range	Increment
Unreinforced	Footing embedment	----	----
Geocell	Width of geocell	3*B*-6*B*	1*B*
Geocell	Placement of geocell	0.1*B*-0.5*B*	0.2*B*
Geocell	Footing embedment	0*B*-0.5*B*	0.25*B*

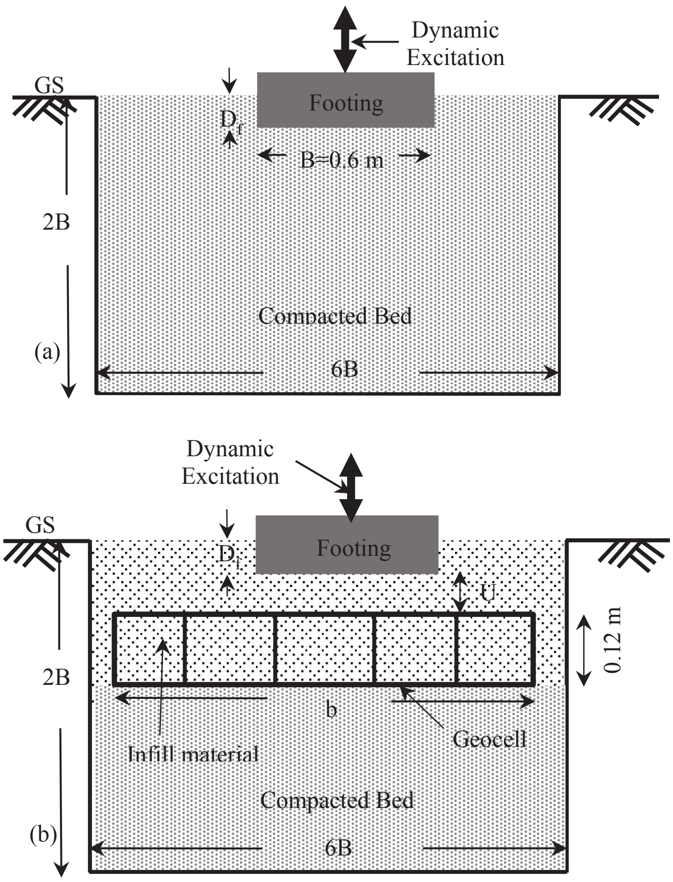

Figure 4. Schematic view of barrier conditions: (a) unreinforced; and (b) geocell reinforced

To quantify the acceleration response of induced vibration, a micro-electrical mechanical system (MEMS) based accelerometers were utilized. These accelerometers were selected based on their practical adaptability and high precision in quantifying the acceleration with regards to a specific axis. Total, 17 numbers of accelerometers were used to cover the surrounding distance of 2 m from the footing. Four accelerometers were placed in a radial direction at every 0.5 m from the center of footing. One is placed at the center of the vibration source. The layout highlighting the positioning of accelerometers is shown in Figure 5.

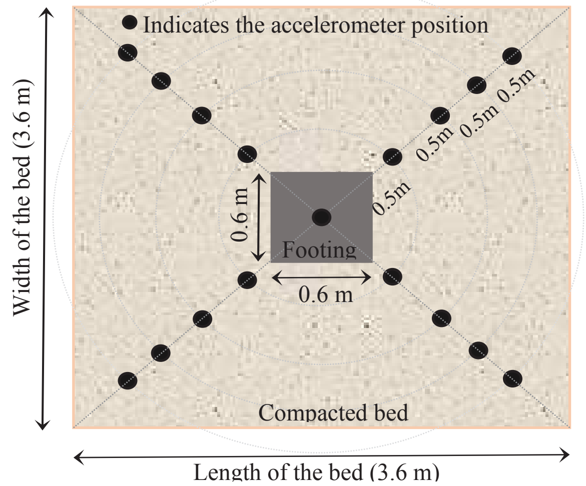

Figure 5. Layout of an arrangement of accelerometers over the foundation bed (not to scale)

To acquire the data of all the accelerometers, a data acquisition system (DAS) with frequency measuring capacity ranging from 1 Hz to 25.6 kHz was used. DAS was further connected with the computer having LABVIEW software to control and monitor the data of accelerometers. In all the cases, a dynamic force of 1.5 kN was applied over the footing. The dynamic force is varied by changing the eccentric setting and frequency of the oscillator (Venkateswarlu et al. 2018). Operating frequency and eccentric setting were maintained as 30 Hz and 50^0 respectively to generate 1.5 kN dynamic excitation. At an applied dynamic excitation, the response of each accelerometer was recorded for 150 sec.

3 RESULTS AND DISCUSSION

Variation in acceleration contours of the unreinforced bed with the distance is shown in Figure 6. The contours reported in the figure are corresponding to the footing resting on the surface. The maximum acceleration of 8.4 m/sce^2 was noticed at the vibration source. As the increase in distance from the source of vibration, the attenuation of acceleration was observed. The material damping of soil was the reason for this attenuation.

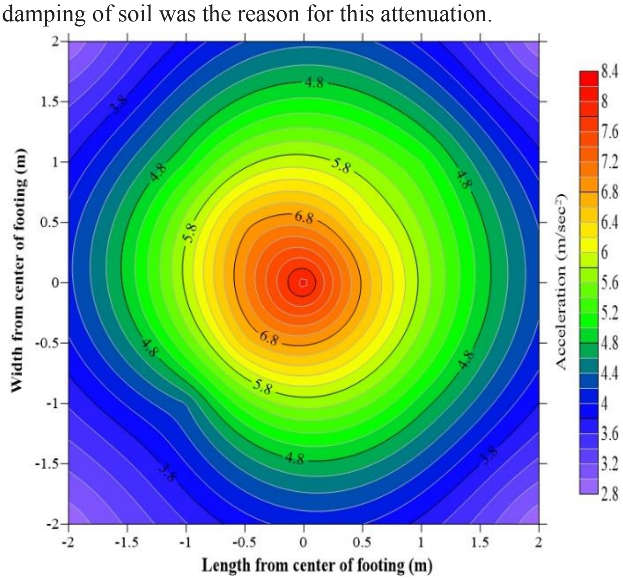

Figure 6. Acceleration contour variation of unreinforced bed

Acceleration contours of geocell reinforced bed for different width of the geocell barrier is shown in Figure 7. Regardless of distance, the gradual attenuation of acceleration was observed with the increase in barrier width. Moreover, the geocell barrier width of 5*B* was found sufficient to attain the maximum isolation efficacy. At this width of a barrier, more than 41% reduction in acceleration was observed as compared to unreinforced case irrespective of the distance from a vibration source. Beyond this width, a very marginal decrease in acceleration was noticed.

The confinement area within the foundation bed increases with the increase in geocell width. As a result, the shear resistance offered from the bed increases by enhancing the integrity between the soil particles and eventually dissipates the significant amount of vibration energy. Consequently, more reduction in vibration acceleration was noticed. On the other side, integrity between the soil particles is reduced due to the cyclic nature of the induced vibration in the presence of unreinforced system. It results in less dissipation of energy causing higher acceleration as compared to the geocell reinforced bed.

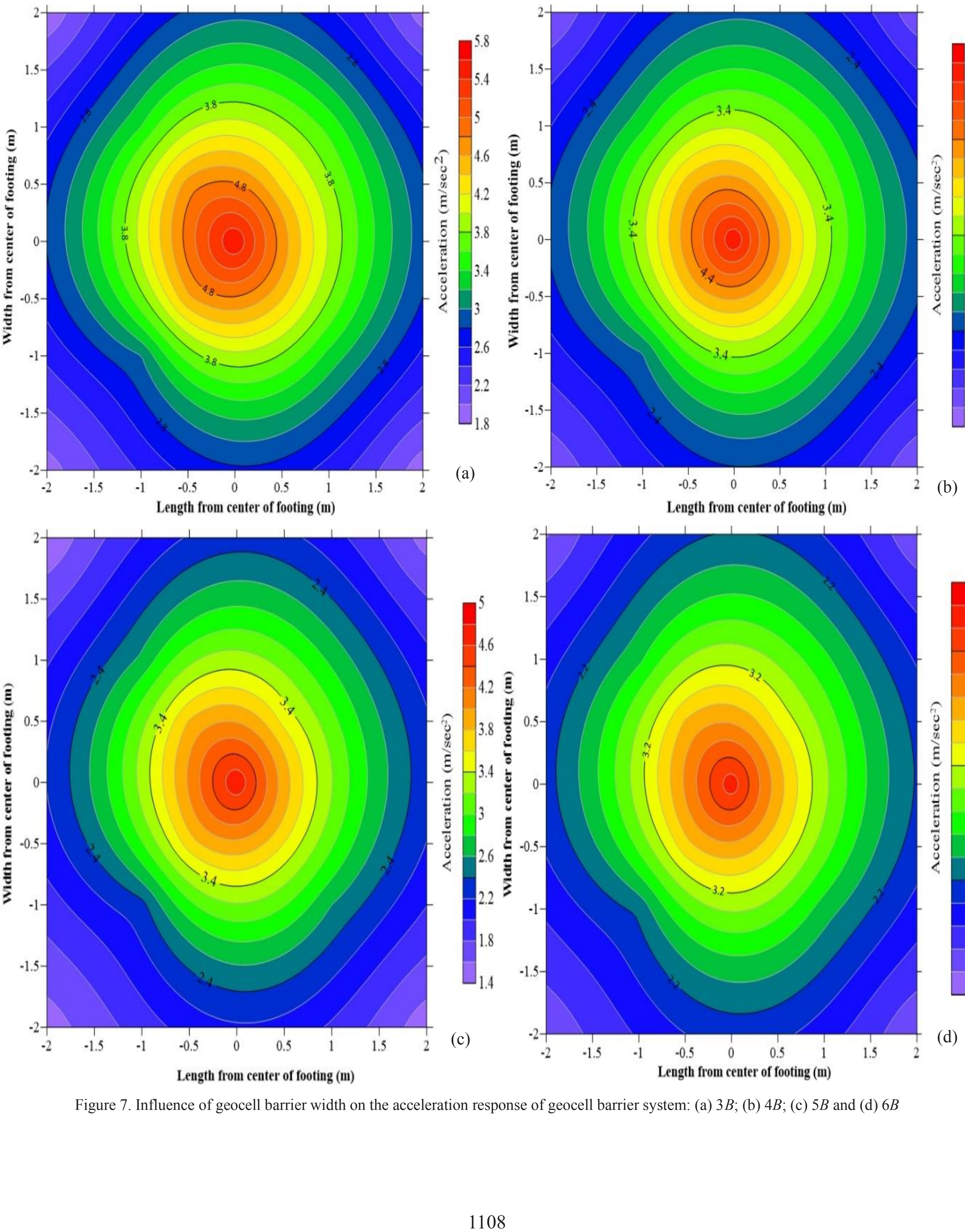

Figure 7. Influence of geocell barrier width on the acceleration response of geocell barrier system: (a) 3*B*; (b) 4*B*; (c) 5*B* and (d) 6*B*

Figure 8 shows the acceleration response of the geocell reinforced foundation bed for different depth of placement of the geocell barrier. Three different depths namely, 0.1, 0.3, and 0.5 times the footing width were considered. Among the considered locations, 0.1*B* depth was found optimum for the mitigation of vibration. With the increase in depth of placement of the barrier, amplification in the acceleration response was observed. Thus, it is suggested to place the geocell barrier at the depth of 0.1*B* below the source of vibration for effective vibration isolation. As the vibration travel along the ground, it is important to place the geocell at a shallow depth.

Influence of footing embedment on the acceleration contours of geocell barrier systems is shown in Figure 9. The footing embedment was found to play a significant role in mitigating the acceleration of vibration. With the increase in depth of embedment, the attenuation in the magnitude of acceleration was observed. From the test results, a marginal reduction in acceleration was observed between 0.25*B* and 0.5*B* cases. As reported by Mbawala et al. (2017), the increase in the depth of embedment footing increases the radiation damping of the foundation bed.

4 CONCLUSIONS

The variation in acceleration response of foundation bed due to the inclusion of the geocell barrier was broadly examined in this investigation. The numerous parameters were varied in the field tests to find the best combination to maximize the isolation efficacy of the geocell barrier system. Acceleration was recorded up to a vicinity of 2 m from the center of source of vibration. The following are the noteworthy observations found from the experimental analysis.

- Increasing the width of the geocell barrier caused the increase in isolation efficacy. Due to the change in barrier width from 3*B* to 6*B*, acceleration was found reduced from 30% to 43% in comparison to unreinforced case. Notably, the percentage reduction in acceleration was found insignificant beyond the barrier width of 5*B*.
- The depth of placement of the geocell barrier had a great influence on attenuating the acceleration of vibration. From the results, 0.1*B* was found to be the optimum location for achieving maximum isolation.

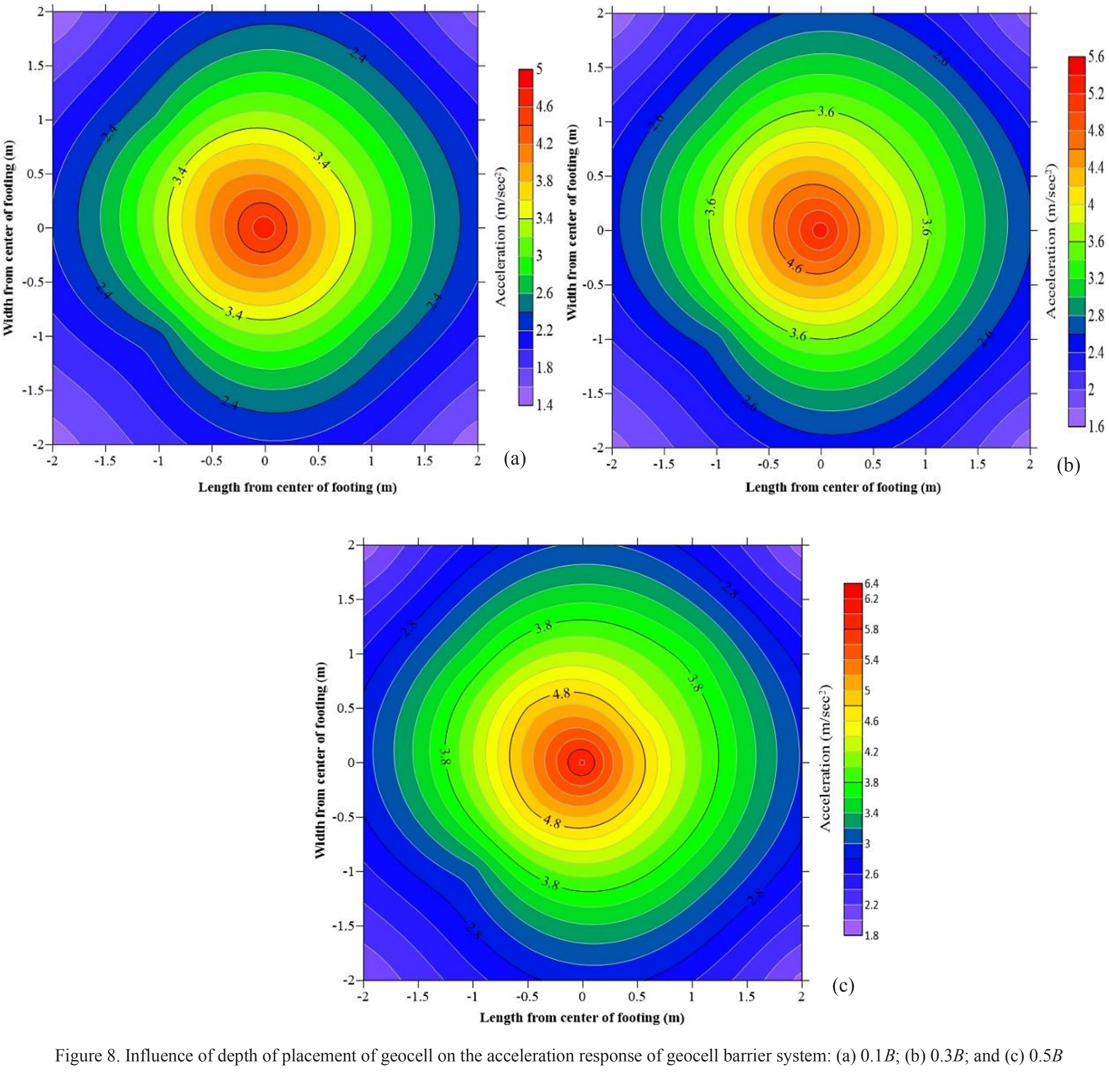

Figure 8. Influence of depth of placement of geocell on the acceleration response of geocell barrier system: (a) 0.1*B*; (b) 0.3*B*; and (c) 0.5*B*

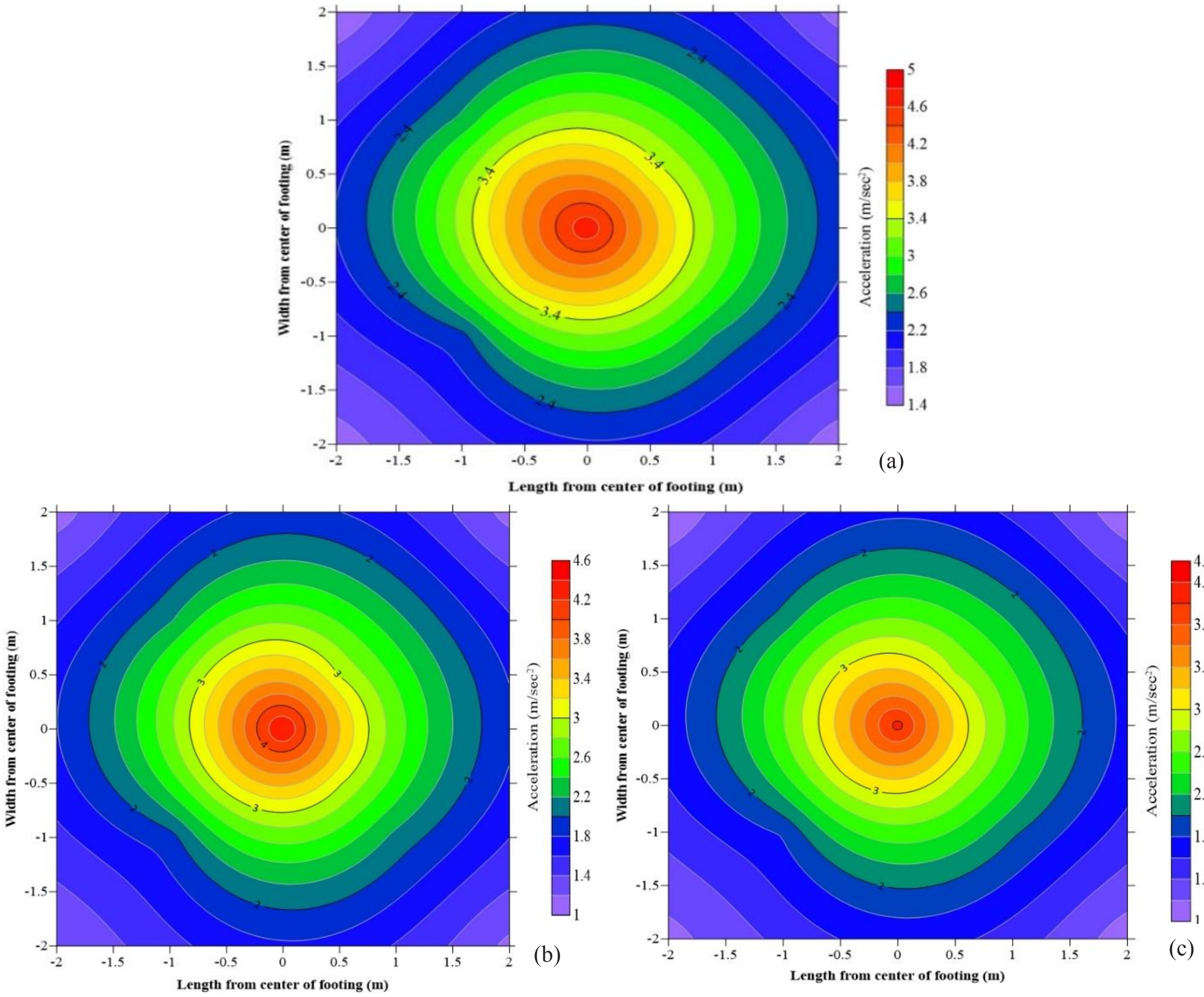

Figure 9. Effect of footing embedment on the acceleration response of geocell barrier system: (a) D_f=0*B*; (b) D_f=0.25*B*; and (c) D_f=0.5*B*

- The provision of footing embedment resulted in the attenuation in acceleration behavior of the geocell-reinforced system. From the test results, the insignificant attenuation of acceleration response was noticed beyond the embedment depth of 0.25*B*.

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