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Response of Soft Soil Improved with Granular Piles Under Seismic Loading

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Abstract: This paper presents the results of numerical analysis by using 10-noded PLAXIS 3D software. A drained analysis was carried out using Mohr-Coulomb's model for soft soil and granular piles. 120m×4m×40m soft soil deposit is used to place a raft of size 16m×4m at 2m below the ground level. The soil was reinforced with a group of six granular piles arranged in square pattern, each having diameter 1m, at 2.5m c/c spacing and of length 10m. The ground response (in terms of amplification) is studied for the imposed 1990 Upland, USA earthquake of magnitude 5.4 data (acceleration versus time) under two situations namely the one without the granular piles below the raft and the other with the granular piles. Amplification is the ratio of value at surface to ground input motion in the form acceleration for this study. The peak amplification value corresponding to unimproved and improved soil is obtained as 41.12 and 4.36 respectively. Thus, significant reduction in peak amplification is exhibited by inclusion of granular piles in soft soils.

Keywords*: Soft Soil; Granular Piles; Seismic Loading, PLAXIS 3D, Mohr-Coulomb's Model*

1. Introduction

Major cities of India falling in soft soil region are Ahmadabad, Baroda, Bhopal, Bhusawal, Bilaspur, Coimbtur, Guntakal, Hugly, Hyderabad, Indore, Jabalpur, Madurai, Nagpur, Nasik, Puna, Raipur, Sholapur and Surat. According to Murty et al. (2006) that all soil other than poorly graded sand having standard penetration value less than 10 (N<10) are considered as soft soil. Soft soils have cohesion strength less than 100kPa, low undrained shear strength (0.3 to 25 kPa), higher plasticity index, highly compressible and having low load carrying capacity. Due to rapid infrastructural development and limited land resource especially in metro cities, there is a need to improve available soil and make suitable for construction. Out of several ground improvement techniques, granular piles are widely accepted all over the world. The use of granular piles in soft soil increases load carrying capacity, accelerate consolidation and reduces settlement. The length of granular pile may vary from 5m to 20m. Diameter may vary from 0.6m to 1.1m for stiff to very soft clay respectively. Aggregate Size may vary from 2mm to 75mm. Length to pile diameter ratio may vary from 4.5 to 20. By using either the vibro-replacement (wet, top feed) or vibro-displacement (dry, top and bottom feed) approach, the piles can be installed in a square or triangular configuration. Native soil is laterally displaced by a vibratory probe using compressed air in the displacement or dry method. Where the in-situ soil is firm and the ground water level is low, this installation technique is suitable. The holes are made with a vibratory probe and a water jet in the replacement or wet method, which replaces native soil with granular material in a regular manner. In general, the performance of granular piles depends on the spacing, length, diameter and the material property of the piles. Recent studies show that granular piles perform better in dynamic loading situation too. A foundation may experience dynamic loading due to blasting, heavy impact compaction, heavy machinery vibrations or earthquake. Kim et al. (2010) compared the amplification of acceleration, shear wave velocity and shear strain in unreinforced and stone column reinforced ground. They concluded that stone column is capable of preventing large shear strain and also amplification of composite ground is improved as compare to unimproved ground subjected to short period waves. Mahmood et al. (2012) performed test in 1g shaking table and concluded that the frequency content of earthquake motion affects the seismic response of the stone column enhanced ground. Because of the increased rigidity caused by the installation of stone columns in soft ground, the natural period of the improved ground is reduced.

When compared to unimproved ground, the test results suggest that the stone column improved ground can reduce earthquake-induced large shear deformation. Golding et. al. (1975) concluded that shear strength of stone column reinforced soil is better than in situ soil and resist horizontal forces due to seismic loading having acceleration of 0.25g. Wriggers (1995) used 3D Opensees PL finite element software to model the stone column and soil as they explored the behaviour of granular columns placed in a sloped layered deposit soil under seismic excitation. Peak ground acceleration, excess pore pressure, lateral displacement, and shear strain value were all reported to have been decreased by 0.7%, 2%, 6%, and 8%, respectively from their original values. Cengiz and Guler (2018) performed experimental study with granular piles encased with geosynthetic material with floating and end bearing piles and concluded that end bearing stone column having gravel as filler gives more reduction in settlement during seismic loading as compared to floating. They noted that partial encasement of stone column is not a good idea to mitigate seismic loading. The dynamic load influences in lower portion of the stone column.

During earthquake (dynamic loading), waves travel through the body of earth (known as P and S waves) reaches to the earth surface and causes destruction to life and property. So, the main aim of this study is to see the response of soft soil improved with granular piles under dynamic loading. For this amplification versus frequency curve is plotted and the results are compared between unimproved soft soil to that improved with floating granular piles. Amplification is the ratio of surface to ground input motion response. The analysis is performed with the help of PLAXIS 3D software

2. Material Properties and Input Parameters

Three basic materials used for this analysis are clay, gravel and sand.

Clay

The clay properties reported by M Khaja, Vilas (2015) is used for this analysis. The clay used in their work was from Bhalki Taluka, Karnataka and having in situ density 16.48 kN/m³, natural water content 33.80 %, specific gravity 2.62, medium fine graded type soil, liquid limit 60.83%, plastic limit 35.415%, plasticity index 25.415, maximum dry density 16.3 kN/m³ at optimum moisture content 23.5%, Cohesion 35.3 kN/m². This clay is of CH type. Other parameters like poison's ratio, volume compressibility for modulus of elasticity is taken from Bowles JE (1997).

Gravel

Crushed stones (aggregates) properties are used for granular piles reported by Ambily A.P., Gandhi S.R. (2007). It's maximum and minimum unit weight is 17.3 kN/m³ and 15 kN/m³. Angle of shearing resistance (φ) is 43° and dilatancy angle (Ψ) is 10°. Modulus of elasticity is reported 55000 kN/m². Poisson's ratio is taken from Bowles (1988).

Dimension of soft soil is taken as Xminimun = -60 metre, Xmaximum = 60 metre, Yminimum = -2 metre, Ymaximum = 2 metre and depth of soil strata 40m that is (120×4×40 m³). Boundary condition is very important parameter in PLAXIS 3D. Different types of boundary conditions are "None" (This results in full reflection of seismic waves), "Free Field" (simulate the propagation of waves into far field with minimum reflection at boundary and also adsorb secondary reflected waves), "Viscous" (given when wave source is inside the soil system), "Complaint base" (the continuation of waves into the deep soil with minimum reflection at the bottom boundary). If Considering X, Y, Z are perpendicular to each other. So, boundary condition taken for this study is Xminimun = Free Field, Xmaximum = Free Field, Yminimum = None, Ymaximum = None, Zminimum = Complaint base and Zmaximum = None. Raft foundation is provided having dimension of 16×4 m² and thickness input in PLAXIS 3D is 0.3m. Following table is given for parameters and input values for soft soil, Granular Piles (Gravel), very thin cushion for even surface (sand) and Raft foundation.

Table 2.1: Input Parameters data for PLAXIS 3D

PARAMETRS	SOFT SOIL	GRAVEL	RAFT
Material Model	Mohr- Coulomb (Soil and Interfaces)	Mohr- Coulomb (Soil and Interfaces)	Plate element
Drainage Type	Drained	Drained	-
Unit Weight γ (Unsaturated)	16.3 kN/m³	16.62 kN/m³	25 kN/m³
Unit Weight γ (Saturated)	20.4 kN/m³	17 kN/m³	-
Modules Of Elasticity	20000 kN/m²	55000 kN/m²	25000000 kN/m²
Poisson's Ratio (μ)	0.39	0.3	0.2
Cohesion	35.3 kN/m²	0.3 kN/m²	-
Angle Of Friction (φ)	1°	43°	-
Angle Of Dilatancy (ψ)	0°	10°	-
Soil Type	CH	Coarse	-
Rayleigh Constant (α)	-	-	0.2320
Rayleigh Constant (β)	-	-	0.008
Strength Reduction Factor	-	0.6	-
Interface Coarseness	-	0.01	-
Thickness	-	-	300mm

Note: Here minimum value of cohesion has to be taken greater than 0.2 kN/m² in Mohr-Coulomb's model to avoid singularity.

In this dynamic loading parameter used in the form of dynamic multiplier (acceleration versus time) data is taken from USGS website (United States Geological Survey), which is of 28/2/1990 Upland earthquake, United States of America, 6km from Northeast of Claremont having magnitude of 5.4 in Richter scale with Peak acceleration = -239.874 m/s² and epicentre is at 5 km and depth is of 3.3 km from Upland. In this earthquake some buildings get damaged and 30 peoples were injured.

3. Methodology

This study is performed using PLAXIS 3D software which is based on Finite element method. PLAXIS 3D software is used to simulate complex problems of geotechnical engineering and analyse its performance before going to field. This study is done by considering two cases to compare the improvement due to reinforced granular Piles. (**Case 1**) Clay having raft foundation 2metre below the ground level without reinforcement. (**Case 2**) Clay having raft foundation 2metre below the ground level reinforced with group of 6 granular pile (GRAVEL) having circular diameter of 1m and length/diameter ratio 10 with centre to centre spacing spacing/diameter ratio 2.5, arranged in rectangular pattern having complaint base displacement in positive x direction 0.4m. First soil contour is defined having 120×4 m² and 40m depth of soil strata is taken by adopting borehole in **soil mode**. Material properties of gravel, sand, soft soil and raft foundation is assigned. In **structure mode** only raft is given for case1 and for case 2, group of six granular piles with interface element to mobilise shear followed by raft foundation just above granular piles which is 2 metres below the ground level is given. Interface element is provided for raft, base of soil strata and sides of soil strata for effectively propagation of waves. Earthquake load with option of dynamic multiplier is provided. In **mesh mode** mesh with coarse size is generated. After mesh generation in staged construction mode, calculation of all three phases followed by initial phase calculation is done. Phase 3 is for dynamic calculation having maximum steps 1000 with sub steps 4 and tolerated error of 1%. Boundary condition (as discussed above) also assigned separately for phase 3.

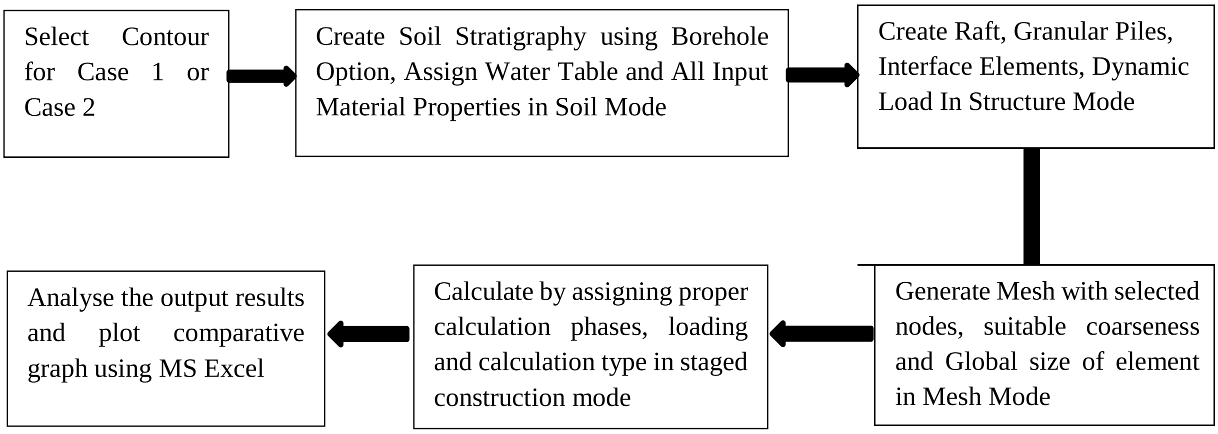

Fig. 3.1: Flow Chart for steps used in PLAXIS 3D

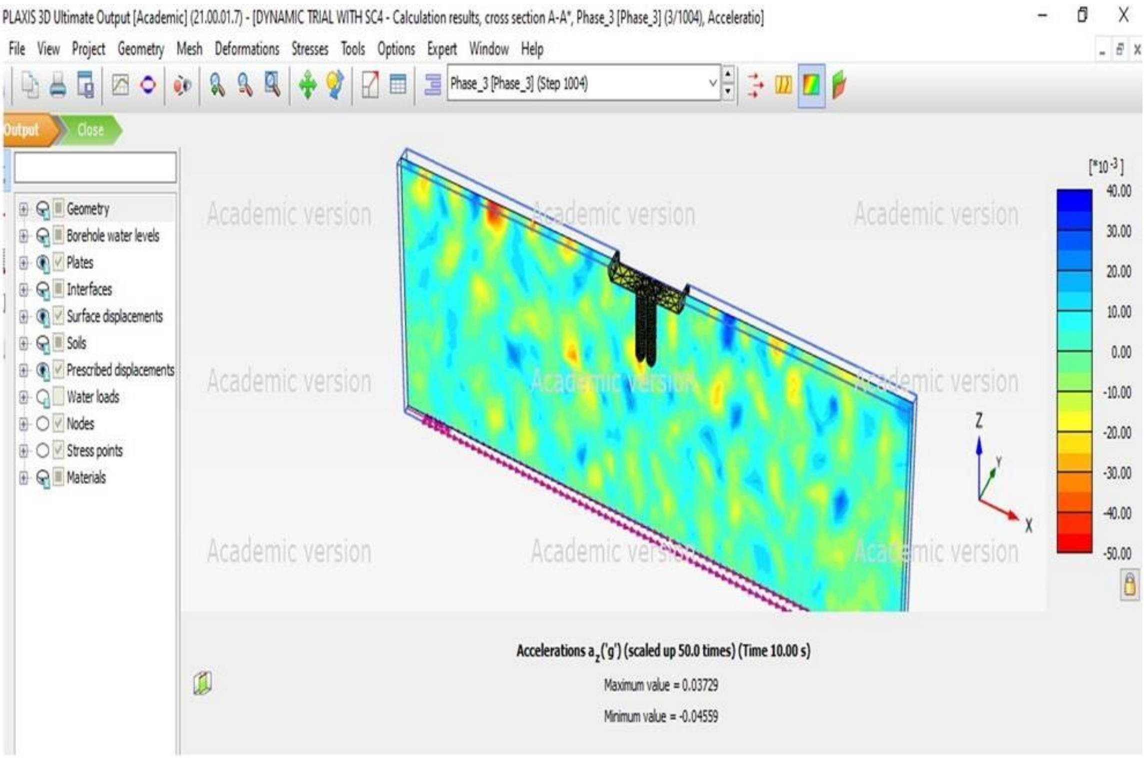

Fig. 3.2: Model view with group of six granular piles

3.1 Package Validation

This package of PLAXIS 3D is validated by using experimental results as material property in PLAXIS 3D for 90mm floating single granular pile assemble in cylindrical tank having diameter of 200mm and depth 630mm given by H. Murtaza, Samadhiya N.K. (2016). For this package validation cross section of tank is taken as square having area decided according to equivalent area concept.

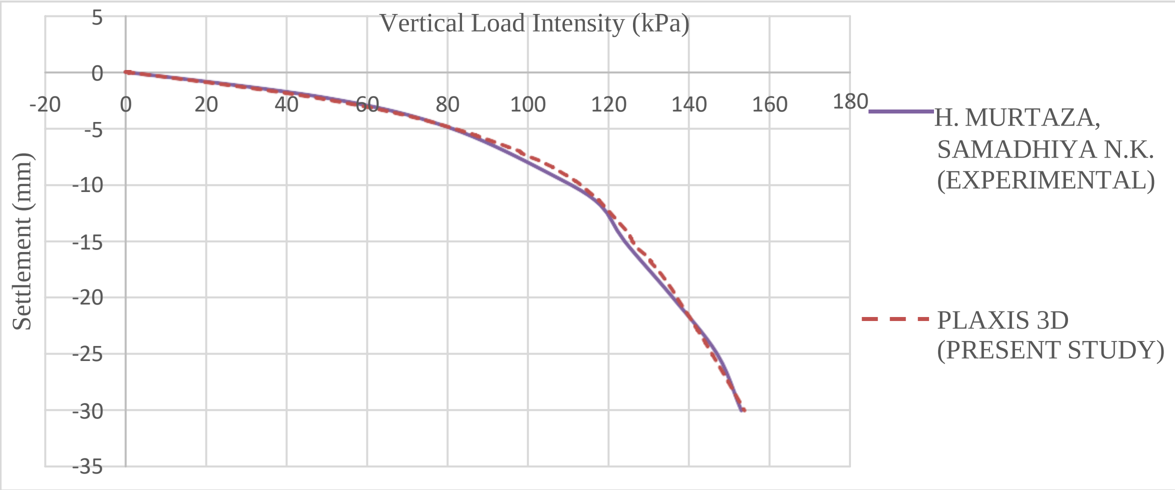

Fig. 3.1.1: Validation of PLAXIS 3D

4. RESULTS AND DISCUSSION

Results are shown with help of graph plotted between amplification v/s frequency as Fig. 4.1 for case 1, Fig. 4.2 for case 2 and Fig. 4.3 which gives comparison of reduction in peak amplification of acceleration in soft soil improved with granular piles. As in case 1 amplification variation is very high between frequency range 30Hz to 50Hz and achieve 41.12 but soil improved with granular piles gives significant reduction in peak amplification of acceleration from 7m below ground level top surface of raft foundation. As amplification is more means soil system is less capable to resist dynamic acceleration and then there may be more chances of damage to superstructure.

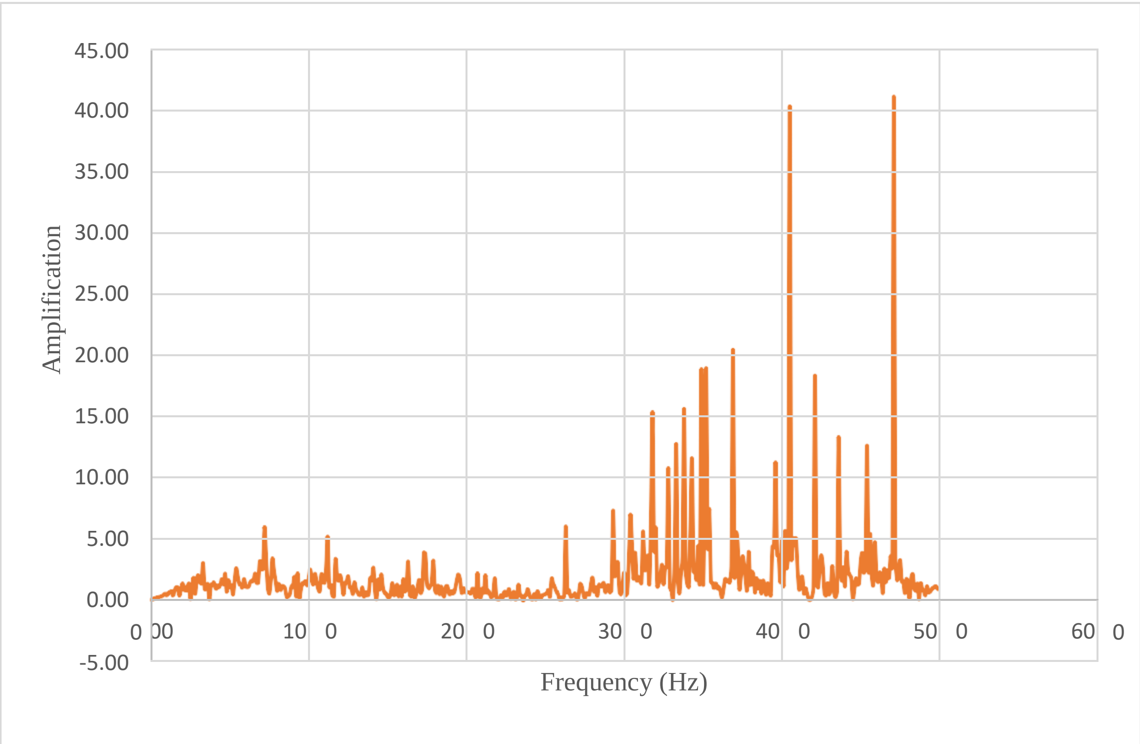

Fig. 4.1: Unimproved soft soil (Case 1)

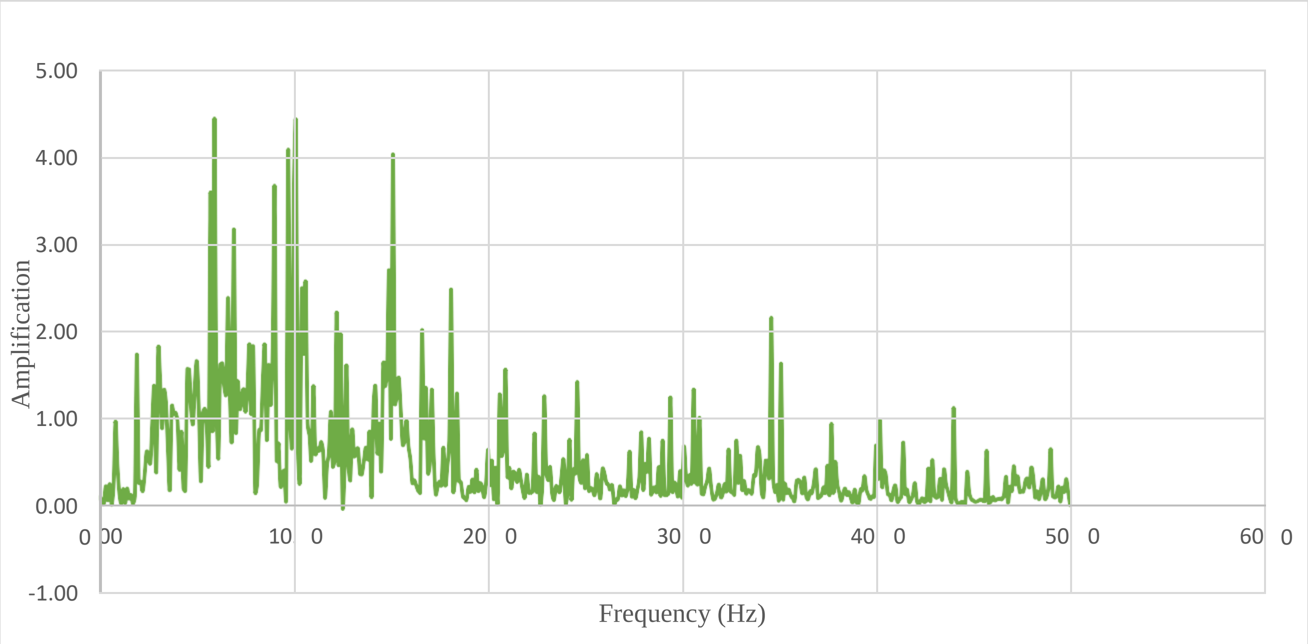

Fig.4.2: Soft soil improved with group of six granular piles with S/D 2.5 and L/D 10 (Case 2)

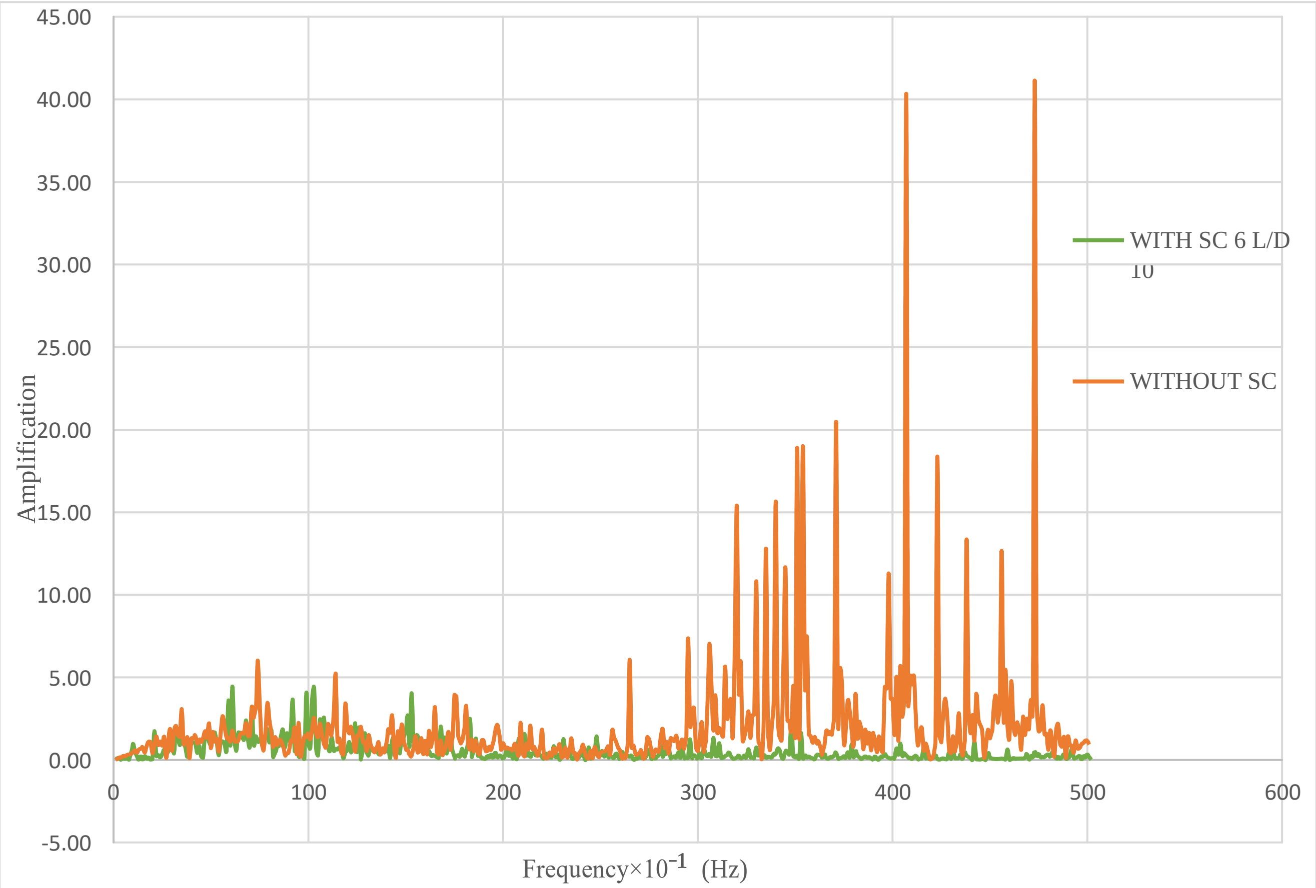

Fig.4.3: Comparison of Case 1 and Case 2

Apart from amplification maximum deformation for case 1 and case 2 is also observed. It is observed that soil without improvement can go large deformation under seismic loading. But soil reinforced with granular piles can reduce deformation significantly as in this study soil reinforced with granular piles reduces maximum value of deformation by 28.8% as compare to unimproved soil.

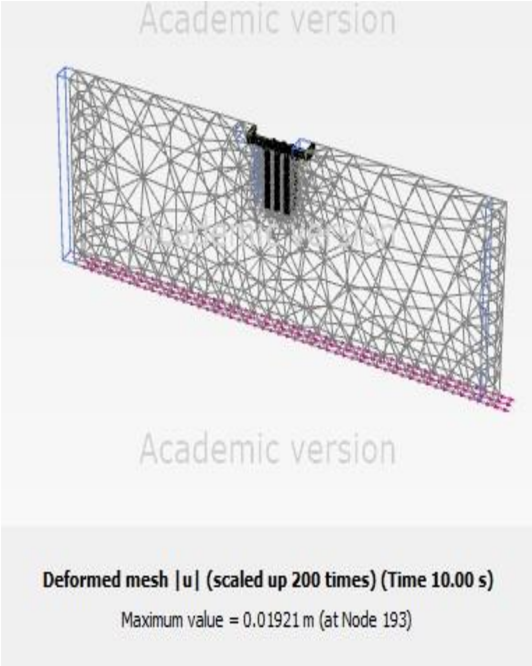

Fig. 4.4: Maximum deformed Value for Case 2

Fig. 4.5: Maximum Deformed Value for Case 1

5. Conclusions

The present study is performed to analyse the response of soft soil improved with granular piles under seismic loading. Model is prepared for numerical analysis using PLAXIS 3D software for unimproved soft soil and soft soil improved with granular piles and compare the results to obtain effect due to granular piles under seismic loading.

- Granular Pile in case of dynamic loading is good option to mitigate dynamic effect. Soft soil improved with group of 6 granular piles peak amplification value reduces from 41.12 corresponding to frequency 47.1 Hz for case 1 to 4.36 corresponding to 10.09 Hz for case 2. We can conclude from this that soft soil improved with granular piles can perform better against seismic vibration.
- Amplification is (response to acceleration) ratio of acceleration to selected point at top (-2m) to selected point at bottom (-7m in our case). As amplification decreases with the use of granular piles ensures that negative impact of earthquake(dynamic) loading on earth surface minimizes and causes less destruction.
- Frequency range of higher variation of amplification for unimproved soft soil (case 1) is 28Hz to 48Hz and for improved with group of six granular piles is 2 Hz to 18 Hz. One reason to get different frequency for peak acceleration may be due to reinforcement of granular pile, soil stiffness and mass changes which affect the natural frequency.
- Maximum deformed value for unimproved soft soil below foundation for Case 1 is 26.8mm and for improved soft soil with group of six granular piles Case 2 is 19.2mm. So can be concluded that use of granular piles as ground improvement technique can also reduce the deformation occurs due to seismic loading.

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