Measurements and Predictions of Vibrations During Bored Cast In-situ Piling by Modified SPT

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ABSTRACT: During the chiselling operations for bored cast in situ piles, when the chisel hits the ground, energy is directly imparted to the soil and causes a stress wave to propagate in the surrounding ground. The present study deals with the vibration results obtained from model studies conducted in field to represent the chiselling action of bored cast in situ piles, by using the accessories of Standard Penetration Test (SPT) set up. A method is suggested to predict the probable ground vibrations that produced during piling by using accelerometers and auxiliary boreholes at the time of site investigation using SPT setup. A comprehensive dynamic three dimensional finite element model for the problem was developed in finite element program ABAQUS. The absorbing boundary conditions were modelled in a different method. The gained results proved the accuracy of the constructed model with the observations from the field study.

1 INTRODUCTION

1.1 *General*

The environment concerns about construction noise and vibration have increased significantly in the recent years, due to increase in number of construction activities, nearness of structures, excessive use of heavy machineries and lengthy periods of heavy construction. Energy from construction activities is transmitted into the ground and radiates out from the source of the energy in the form of stress waves. The potential effects from vibrations produced by the stress waves moving through the ground may include damage to structures, settlement of soils, interference with sensitive equipments and annoyance of people. The vibration complaints typically arise from interference with people's activities, especially when the adjacent community has no clear understanding of the extent or duration of the construction. Misunderstandings can lead to disputes, unnecessary delay and economic loss. The construction activities that often generate the greatest number of complaints on projects are construction of pile foundation and these activities occur regularly on projects. Therefore, it is important to accurately measure the ground vibrations produced during pile construction and to develop a vibration prediction model, which may help for a site-specific plan for minimizing the pile construction vibrations.

1.2 *Previous studies*

The stress waves produced during impact loading attenuate with distance. The attenuation is caused by two sources; the geometry of the propagating wave (geometric damping) and the material or materials through which the waves travel (material damping). Geometric damping reduces the amplitude of the vibrations as distance from the source increases, due to the fact that the same energy is spread over an increasingly larger surface or volume. Material damping is the loss of energy due to internal energy dissipation in the material as the soil particles are moved by the propagating waves. Amick and Gendreau, (2000) stated that the wave energy is transformed to heat due to friction, and the amplitude of the wave decreases. The big difference between material damping and geometric damping is that in material damping, elastic energy is actually dissipated by viscous, hysteretic, or other mechanisms.

Masoumi et al., (2006) states that vibration amplitudes attenuate monotonically in homogenous soil. However, in a layered soil model or in a model with increasing stiffness along depth, the attenuation is oscillatory. The oscillation is believed to be due to the interference of the reflected waves on the ground surface. Their results also showed that vibrations attenuate faster in a layered soil than in a homogeneous soil profile. Thandavamoorthy, (2004) conducted measurement of ground vibrations from piling by hammer impact in fine and medium sand. The measured time history of acceleration indicated that the ground vibration is of short duration in nature and of high frequency content. The vertical vibration values were greater than the horizontal vibrations.

Different empirical relations and theoretical models are used to predict the ground vibrations generated during pile driving. A series of curves for typical earth vibrations showing peak particle velocity in mm/s versus distance from source in meters, were available in literature. The curves developed by Wiss are a comparison of different vibration producing construction activities (Wiss, 1981) are widely used for predicting the vibration level. The wide range of vibrations measured for similar activities emphasizes the challenge and difficulty in comparing results from different sites. The over conservative predictions of vibrations will lead to the increasing costs and will limit the choice of construction method and this can make the total work delayed. But the under estimation of vibration can make damages in nearby structures and persons. More accurate predictions can only be made after a site specific study has been conducted.

The main objective of this study is to suggest a preliminary vibration measurement in the site to produce a database and by using these values develop a prediction model for vibration during pile construction with DMC method. The suggested model study can be conducted during the site investigation using SPT set up and accelerometers with data acquisition.

2 EXPERIMENTAL PROGRAM

2.1 *Field procedure*

A site with hard lateritic strata was selected for the study. The top layer was a lateritic stratum with high gravel content, followed by stiff lateritic clay with silt content. The stiff lateritic layer continued more than 5m depth where all the SPT N value goes above 50 after 1m depth.

In the field a main bore hole (MB) of diameter 10 cm is made using machine boring. Four auxiliary boreholes were also made at radially opposite directions. These boreholes are of 10 cm diameter and at distance of 2 m, 4 m, 8 m and 16 m from the main bore hole. Impact with varying energy was given at different depths up to 5m below ground level in the main bore hole. The ground vibrations at different distance from the source, due to impact loading are measured using accelerometers that mounted horizontally and vertically at auxiliary boreholes at the respective depth of impact.

The 63.5kg hammer is dropped at the MB from four different heights 0.5 m, 1.0 m, 1.5 m, and 2.0 m to get different energy levels E1, E2, E3 and E4 using modified SPT setup. The split spoon sampler is replaced by a 7.5cm diameter mild steel plate with perforations so that the impact energy can be uniformly distributed into the soil. The real time recording of accelerations and processing data were carried out using Dewesoft Software.

In the first step of model study, the impact loading was given at the surface where the MB is to be located and vibrations were measured at the surface of auxiliary borehole points. After given impact at the surface, boreholes were drilled at all the five points to a depth of 1m. Impact loading is given at main borehole at 1m depth and vibrations are measured at all auxiliary boreholes drilled at 1m depth. All the borehole depths were again increased to 2m and the same procedure is repeated.

3 RESULTS AND DISCUSSION

3.1 *Variation of peak ground acceleration*

Fig 1 shows the record of accelerations in auxiliary bore holes at a depth of 1m. From the figure it was noted that peak acceleration values decreases with distance from the main bore hole. Figs 2 and 3 show the variation of peak ground accelerations at a distance of 2 m from the source for different depth of impact. The variation of peak horizontal acceleration (PHA) and peak vertical acceleration (PVA) were plotted up to a depth of 5 m. The acceleration values decreased with depth of impact. Fig 2 and 3 also show the PHA and PVA values for different energy levels such as 312 Nm and 1246 Nm respectively. The acceleration values increased for higher energy level. The maximum accelerations were noted at the surface because body waves also convert to surface waves once it reaches the ground surface. The PVA values observed were higher compared to PHA values. The attenuation along the depth was oscillatory and this oscillation is believed to be due to interference of reflected waves.

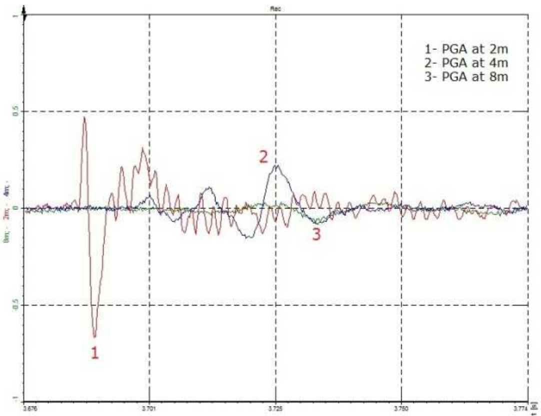

Fig. 1 Record of accelerations in auxiliary bore holes at a depth of 1m

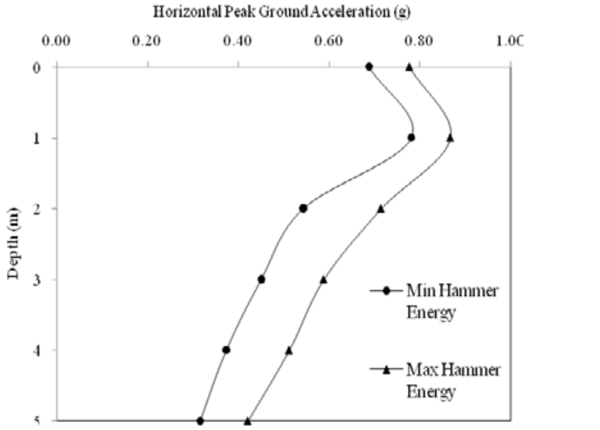

Fig. 2 Variation of PHA at a distance of 2m from source

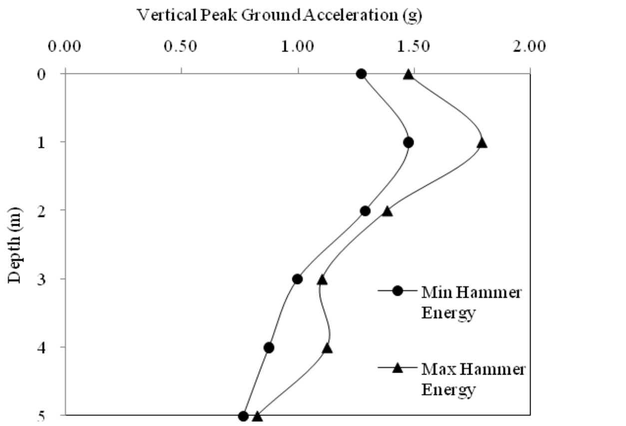

Fig. 3 Variation of PVA at a distance of 2m from source

3.2 *Prediction of vibration*

The peak particle velocities were measured from the acceleration values using software. The attenuation of waves depends on soil profile at the site and energy of impact. Hence the soil parameters *k* (Velocity at unit distance) and *n* (Slope of the attenuation rate) for different soil layers for the site were calculated by using the scaled distance for different hammer energies used in the model study. The average values of the soil parameters of the site obtained from the model study are given in Table 1.

Table 1. Average soil parameters

Depth(m)	k	n
1	0.798	1.024
2	0.774	1.123
3	0.780	0.978
4	0.776	1.033

By the soil parameters obtained, the vibration levels for higher hammer energy levels were predicted, using scaled distance equation. Vibration levels were measured during the chisel hammering in actual Direct Mud Circulation (DMC) method of piling for the same soil stratum to compare the predicted values from the model study. Accelerometers were mounted horizontally and vertically, on a 20 mm diameter steel bar, vertically placed at different depths and distances from the point of pile driving. The measurements were taken as explained in the previous section. By a machine operated pulley system and a three ton hammer, energy of 30kNm is applied on a single winch pull and the vibration levels were measured. The vibration levels from the actual piling were compared with the predicted values. Fig 4 shows the comparison of the predicted peak velocity values with the measured values during the boring for pile installation using DMC method.

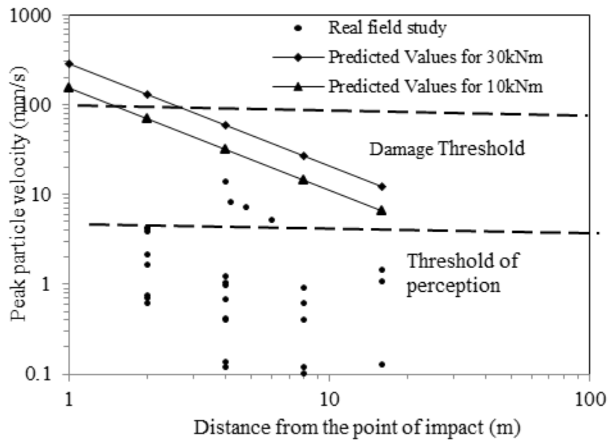

Fig. 4 Comparison of the predicted values with the real field data for hammer energies of 10kNm and 30kNm

Fig 4 shows that the peak particle velocities from real pile installation are well below the predicted values. The peak particle velocity predicted from the model study by considering the soil parameters at the site and energy of hammer impact can be used safely to avoid any causality at the site during construction.

3.3 *Numerical study*

A comprehensive three dimensional finite element model for the propagation of wave through soil due to chiselling during the installation of cast in situ piles was developed in ABAQUS. The absorbing boundary conditions were modelled using Lysmer's boundary conditions. The vibration levels at different depths and distances from the point of impact were evaluated. The accuracy of model was validated using the results of field model study. Fig 5 presents the parity plot for the numerical and the experimental studies for the PHA and PVA measured at different distances and depths from the point of impact. From the parity plot it can be observed that the experimental results are close to the numerical values.

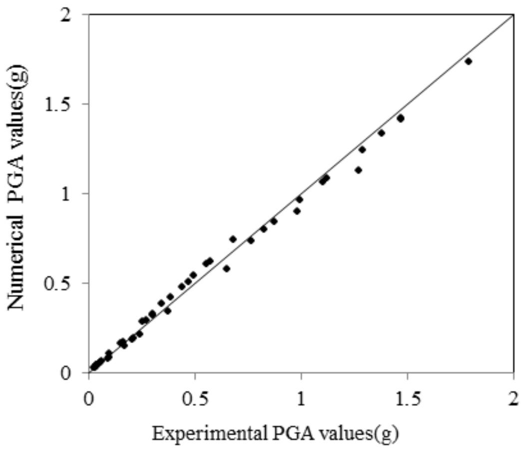

Fig. 5 Parity plot showing the values for numerical and experimental data

4 CONCLUSIONS

Field vibration measurements were conducted using modified SPT set up and accelerometers. From the study it can be concluded that the PHA and PVA decreases with distance from the source of impact. The wave attenuation at the site depends on soil profile and energy of impact. The vibration measurements from field model study were used to predict level of vibration during real pile installation using DMC method. The predicted vibration levels were compared with that from pile installation in the field. The evaluated vibration levels were higher compared to real pile installation. Hence the field model study can always predict a safe value of vibration to avoid damages during construction. A comprehensive three dimensional finite element model for the propagation of wave through soil due to chiselling during the installation of cast in situ piles was developed in ABAQUS. This numerical model can effectively predict the vibration levels during the pile driving if soil properties at the site are available.

ACKNOWLEDGMENTS

The authors would like to thank KSCSTE, Government of Kerala for giving financial support for the project titled “Dynamic Effects of Pile Driving on Adjacent Structures”.

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