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International Conference on Case Histories in Geotechnical Engineering
(2004) - Fifth International Conference on Case Histories in Geotechnical Engineering

16 Apr 2004, 4:30pm - 6:30pm

Prototype Piling in Soft Clay — A Case Study of Ground Vibrations: Field Measurement

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PROTOTYPE PILING IN SOFT CLAY-A CASE STUDY OF GROUND VIBRATIONS : FIELD MEASUREMENT

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ABSTRACT

Ground vibrations are generated either by natural phenomena or by human activities. Among the natural phenomena, earthquake is the principal source of ground vibrations of most interest. Ground vibrations generated by human activities are called man-made vibrations and these vary greatly in intensity depending on the particular source of vibration. The seismic waves associated with man-made vibrations propagate in the ground and inevitably interact with structures that are above-ground or underground. This interaction induces vibrations in the structure and, in extreme cases, affect its serviceability and integrity seriously. Still, there is no method to quantify the levels of piling vibration. Estimation of amplitudes and frequencies of vibration are based on experience and site testing. Therefore, in order to characterize the ground vibration due to piling, field measurement of ground vibration during prototype pile driving in soft clay was carried out. This paper presents the details of field measurement, instrumentation, collection of vibration data, acquisition and processing of data using PC-based data acquisition system made during the pile driving.

The measurement of ground and already installed pile vibrations during prototype pile driving at a construction site in Chennai was carried out. The soil at this site is loose soft clay. The pile was of the type driven casing cast-in-situ pile of 500mm (OD) diameter. The depth of penetration of the pile was 13.25m. A 4 tonne hammer with a drop height of 1m drove the 25mm thick Mild Steel (MS) tube casing. During driving, ground acceleration was measured at a distance of 5D and 25D, where D is the diameter of pile, from the centre of pile. The vertical acceleration of an already installed pile situated at a distance of 37D from the driven pile were recorded. Piezoelectric acceleration transducers, power amplifiers, and tape recorder were used for the measurement. Acceleration signals were recorded using TEAC recorder. The recorded signals were processed using PC-based Data Acquisition System with DASYLAB software. The response time-histories and spectra of ground vibrations are presented and discussed.

INTRODUCTION

Ground vibrations are generated either by natural phenomena or by human activities. Among the natural phenomena, earthquake is the principal source of ground vibrations of most interest. Ground vibrations generated by human activities are called man-made vibrations and these vary greatly in intensity depending on the particular source of vibration. The seismic waves associated with man-made vibrations propagate in the ground and inevitably interact with structures that are above-ground or underground. This interaction induces vibrations in the structure and, in extreme cases, affect its serviceability and integrity seriously. Still, there is no method to quantify the levels of piling vibration. Estimation of amplitudes and frequencies of vibration are based on experience and site testing.

The pile driving is achieved by impact or vibratory hammers and both processes generate ground vibrations. The mechanism of generation of seismic waves during pile driving is illustrated in Fig.1. Vertically polarized body shear waves are generated, as the pile is driven, along the skin of the pile and their wave front propagates outward having the shape of a cone, with, very shallow angle-practically along a cylindrical surface (Athanasopoulous and Pelekis, 2000). At the tip of pile, the displacement of an amount of volume, generates both compressional P-waves and shear S-Waves which propagate outward from the tip on spherical wave forms. When the P – and S-waves encounter the ground surface, part of their energy converted to surface Rayleigh (R-waves) and part is reflected into the ground. The R-waves have both vertical and horizontal components of motion and propagate along the surface of the ground decaying in amplitude in proportion to the square root of distance.

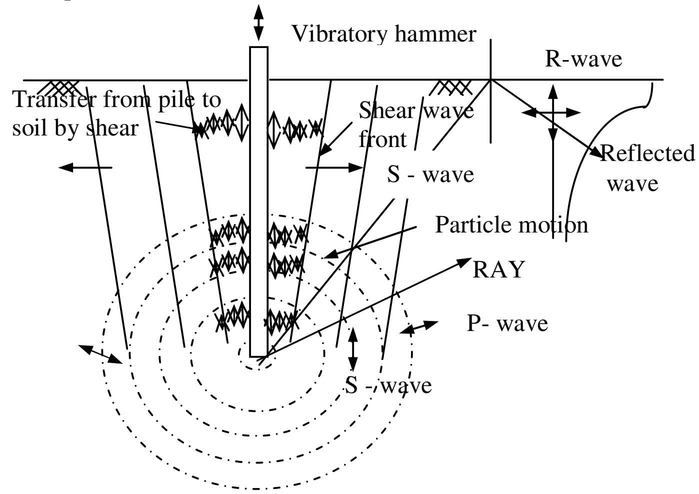

Fig.1 generation mechanism of seismic waves during vibratory or impact driving of piles in homogenous soil

Heckman and Hagerty (1978) developed a relationship between peak particle velocity and scaled energy that can be used to predict expected maximum levels of vibrations from pile driving. It was also reported that vibration levels can be reduced by precoring, (or) by selection of low-displacement piles. Mallard and Bastow (1979) reported measurement of vibrations in the free field and close to structures whilest driving precast concrete piles with a variety of impact hammers. Crockett (1979) has proposed a new method of assessing vibration limits for building structures. Near a pile driven by a vertically acting hammer, the soil vibration are mostly vertical, but often at a distance the change of the wave form results in the horizontal vibrations being larger than vertical vibrations. Langley (1979) conducted experimental investigations on pile driving effects on structures. He has reported the noise levels due to conventional impact hammer pile driving and other hydraulic hammers. He proposed a formula to calculate the dynamic stresses due to vibration induced into structural member. Series of structural damages to buildings by piling vibration was reported. Kim and Lee (2000) carried out field vibration measurement caused by train loading, blasting, friction pile driving and hydraulic hammer compaction using 3D geophones. For the geometrical modelling of various vibrations, the type of various sources and their induced waves were characterised and the geometric coefficients were determined.

Information on the characteristics of the ground vibration induced by pile driving are lacking. In order to have basic understanding of the pile driving induced ground vibration, field measurement during prototype piling was carried out. The present paper describes the details of measurement of ground and pile vibrations and presents results in the form of time histories and spectra.

FIELD MEASUREMENT

The measurement of ground vibration during prototype pile driving was carried out at a construction site in Chennai. The soil at this site was loose soft clay. The pile was driven casing cast-in-situ type of 500mm (OD) diameter. The depth of penetration of the piles was 13.25m. A 4 tonne hammer was dropped from a height of 1m on 25mm thick Mild Steel (MS) tube casing. During driving, ground vibrations and vibrations already installed pile were measured. Ground acceleration was measured from the centre of pile at a distance of 5D and 25D, where D is the diameter of pile using seismic accelerometer. The vertical acceleration on an already installed pile head situated at a distance of 37D from the driven pile was also measured using piezoelectric accelerometer. Right from the inception of piling, number of blows were counted continuously till the entire depth of the pile was reached and corresponding depth of penetration was also noted and recorded. For each drop, the depth of penetration of the casing was noted and recorded. For each drop, the ground and already installed pile vibration signals were recorded simultaneously using instrumentation tape recorder. The recorded signals were processed using PC-based Data Acquisition System with DASYLAB software.

RESULTS AND DISCUSSIONS

Depth of penetration of pile versus peak accelerations

Fig. 2 shows variations of PHA, PVA of ground with the depth of penetration of pile masured at 5D. In general, both vertical and horizontal acceleration oscillates with depth of penetration of casing. The vertical ground acceleration is higher than horizontal ground accelerations till the full depth of penetration of 9 m. The maximum vertical ground acceleration (5D) was 2.2 g at a penetration depth of 0.5 m. The PVA of ground at a distance of 2.5m from the centre, varies from 0.4g to 2.2g. The maximum horizontal ground acceleration (5D) was 1.2 g at a penetration depth of casing of 0.5m. The PHA of ground at 2.5m, varies from 0.26g to 1.21g. In all cases upto 6m depth of penetration, there is severe fluctuation in accelerations. Beyond 6m depth, accelerations remain constant. Fig.2 also shows that vertical vibration of the ground is more predominant than the horizontal. This is also quite clear from a comparison of time-histories shown in Fig.3 and Fig.4.Time-histories of ground vibrations

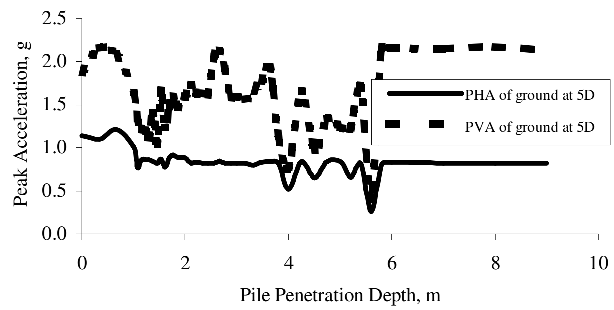

Fig.2 Variation of acceleration with pile penetration depth at various points

From the recorded analog signals, time history plots were obtained. Figure 3 shows typical time-history records of horizontal ground acceleration at 2.5m from the centre of pile. It shows a peak value of 1.2g for a duration of 0.025s. The first peak is P-wave and the second peak is the S-wave. Being horizontal vibration the magnitude of S-wave is greater than the P-wave.

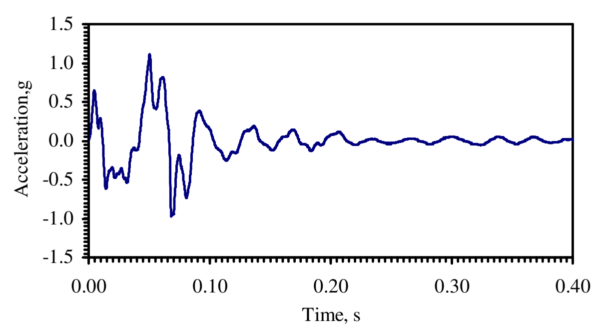

Fig. 3 Typical time-history of horizontal ground acceleration at a distance of 5D from the centre of piling

The typical time-history of vertical ground acceleration at a distance of 2.5m (5D) from the centre of pile is depicted in Fig.4. It shows the sharp peak values of 2.2g at 60ms and duration of peak about 10ms. The peak value of horizontal (PHA) and vertical acceleration (PVA) of ground is 1.2g (Fig.3) and 2.2g (Fig.4) respectively. The total duration of the horizontal vibration is about 300 ms, whereas duration of the vertical ground vibration of the soil is about 180 ms. A comparison of the horizontal and vertical ground vibrations of the soil indicates that vertical vibration is dominant over horizontal. Subsequently the vertical acceleration was higher than the horizontal till the full depth of penetration of 9m and it was the predominant vibration.

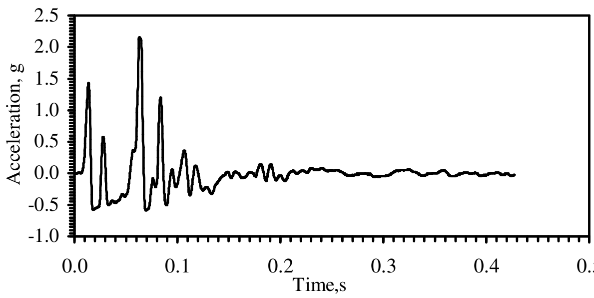

Fig.4Typical time-history of vertical ground acceleration at a distance of 5D from the centre of piling

The typical time-history of vertical ground acceleration at a distance of 12.5m (25D) from the centre of pile is depicted in Fig. 5. It shows the sharp peak value of 0.42g at 40ms and the duration of peak acceleration was about 10ms. There are several other peaks of far lesser magnitudes over a duration of about 180ms. The time-history signals of the ground acceleration indicates that the ground vibration is of impulsive dynamic in nature of short duration. This is quite different from the ground vibration generated by earthquake. A comparison of Fig.4 with Fig.5 discloses the attenuation of ground vibration with distance. Fig. 6 indicates the typical time-history of vertical acceleration on a pile top at a distance of 37D from the centre of pile. The measured peak value is 0.2g. The level of pile top vibration of an existing pile is low because it is very far away from the driving point where ground vibration has been attenuated considerably.

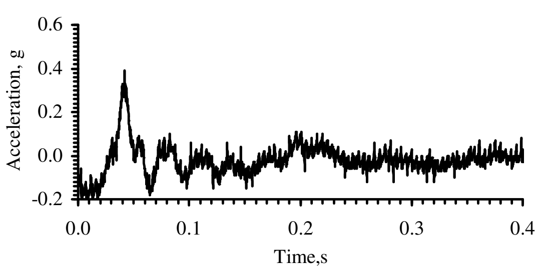

Fig.5 Typical time-history of vertical ground acceleration at a distance of 25D

Spectral analysis

The PC-based DAS and associated software 'DASYLAB' was used to analyse the time data and transform it into the corresponding spectral form. The spectrum of horizontal ground acceleration is illustrated in Fig. 7. It has a frequency band of 0 Hz to 200 Hz. The spectrum of horizontal ground acceleration indicated that it had a single largest peak at the frequency of 35.4Hz. Almost all the energy is concentrated in the frequency range of 9.3Hz to 100Hz. Structures having frequencies in this range may be resonated and damaged severely due to high amplitude of vibration.

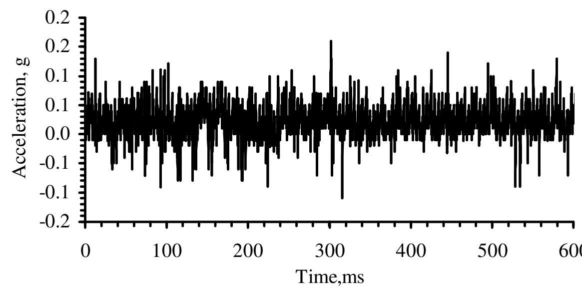

Fig.6 Typical time history of vertical acceleration on pile top at a distance of 18.5 cm

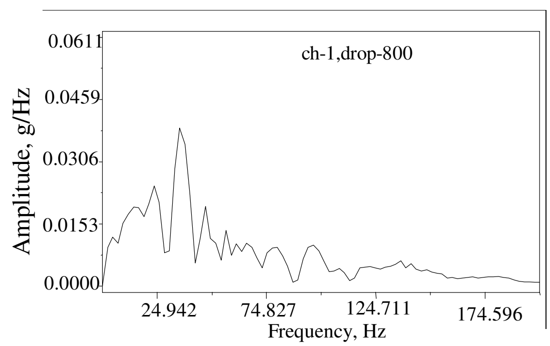

*Fig.7 Typical spectrum of horizontal ground acc*eleration at 5D

The spectrum of vertical ground acceleration at 2.5m from the centre of pile is depicted in Fig. 8. It has a frquency band of 0 Hz to 200 Hz. The dominant frequency is 85Hz. The spectrum

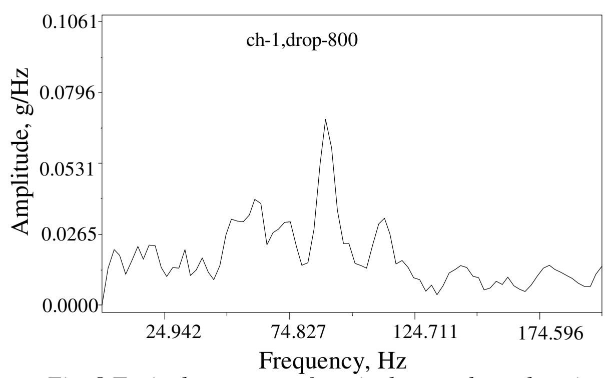

Fig. 8 Typical spectrum of vertical ground acceleration at 5D

has several larger peaks with concentration of energy over a range of 4.7 Hz to 125Hz. If the fundamental natural frequency of structure coincides with excitation frequency, then resonance occurs. At resonance, the structure undergoes large amplitudes and large strain. The structure may be damaged severely due to high amplitude of excitation. The spectrum of vertical ground acceleration at 12.5m from the centre of pile is depicted in Fig. 9. It has a frquency band of 0

Hz to 200 Hz. The dominant frequency is 25Hz. The spectral energy is concentrated in the frequency range of 0 Hz to 30Hz. Fig.9 shows that with the increasing distance not only the vibration is attenuated but also the frequency content is also reduced. The spectrum of vertical acceleration on a pile top at 37D from the centre of pile is shown in Fig. 10. There are discrete peaks at 10Hz, 45Hz, 85Hz, 130 Hz and 180 Hz. The dominant spectral frequency is at 45Hz.

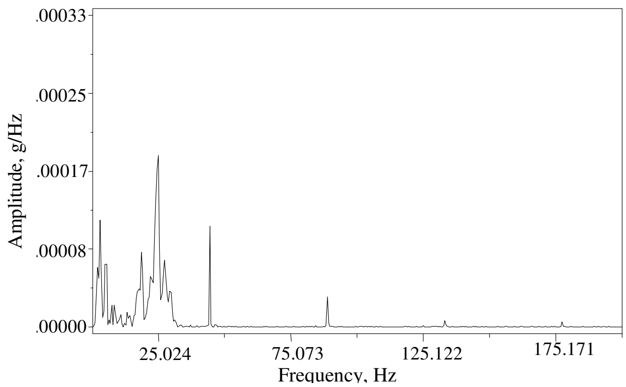

Fig.9 Typical vertical ground acceleration spectrum at 25 D

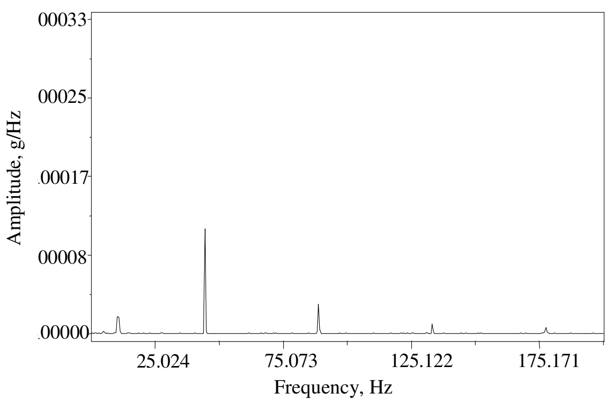

Fig. 10 Typical vertical acceleration spectrum on top of existing pile at 18.5 m from the driven pile

CONCLUSIONS

Field investigations of prototype pile driving were carried out at a construction site of school buildings. In general, both vertical and horizontal acceleration oscillates with depth of penetration of casing. The vertical ground acceleration is higher than horizontal ground accelerations till the full depth of penetration of 9 m. The maximum vertical ground acceleration (5D) was 2.2 g at a penetration depth of 0.5 m. The maximum horizontal ground acceleration (5D) was 1.2 g at a penetration depth of casing of 0.5m. Hence it can be concluded that the effect of vibration due to prototype pile driving is severe in the vicinity.

The spectrum of horizontal ground acceleration has a frequency band of 0 Hz to 200 Hz. It has largest peak at the frequency of 35.4Hz. It is wide band spectrum with energy concentration between 9Hz to 100 Hz. Structures having frequencies in this range may be resonated and damaged severely due to high amplitude of vibration.

The ground vibration induced by pile driving is of impulsive dynamic loading of short duration in contrast to that generated by earthquake. Therefore procedures adopted to evaluate response of structures due to earthquake are not applicable to such a short duration impulse induced by pile driving.

Acknowledgements

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