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FIELD INVESTIGATION ON GROUND AND STRUCTURAL VIBRATIONS DURING PROTOTYPE PILE DRIVING

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ABSTRACT

As the land is very precious in urban areas and coastal regions, many structures are built in close proximity. When the soil is weak and heavy loads are to be carried, pile foundation is adopted for such structures. The impact caused by pile driving is a potential hazard to neighbourhood structures. Berthing structures are constructed using piles and the effect of pile driving on already installed adjacent piles is important. To predict the effect of pile driving on neighbourhood piles, measurement of ground and structural vibrations during prototype pile driving was carried out at a site in the city of Chennai, India. The soil at the site up to a depth of 19 m is mainly fine to medium sand. A driven cast in-situ pile of 600 mm diameter (D) was driven up to a depth of 15.8 m. The 25mm thick mild steel (M.S) tube casing is driven by 4.1t hammer with a drop height of 2.5m. During the pile driving, for every blow of hammer, the acceleration of the ground at various distances 5D, 8.33 D and 25 D from the pile are measured. Piezoelectric acceleration transducers, power amplifiers and taper recorder are used for measurement. The time history of vertical and horizontal ground accelerations as well as time history of vertical acceleration of an already installed pile at a distance of 6.25 m was analysed using PC based data acquisition systems. The time-histories and spectrum of ground and structural accelerations are presented.

INTRODUCTION

As the land is very precious in urban areas and coastal regions, many structures are built in close proximity. When the soil is weak and heavy loads are to be carried, pile foundation is adopted for such structures. The impact caused by pile driving is a potential hazard to neighbourhood structures. There is a need to have basic understanding of the response of structures due to ground vibration generated by prototype pile driving. The pile driving may cause damage to the adjacent structures by the vibration induced differential settlement as well as by vibrations transmitted directly to structures.

Berthing structures are constructed using piles and the effect of pile driving on already installed adjacent piles is important. Heckman and Hagerty (1978) developed equation relating to 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 could be reduced by various means such as precoring or selection of low-displacement piles. Mallard and Bastow (1979) reported the measurement of vibrations in the free-field and close to structures whilest driving precast concrete piles with a variety of impact hammer. 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 the vertical vibrations. Langley (1979) conducted experimental investigations on pile driving effects on structures and its noise levels. The noise levels due to conventional impact hammer pile driving and other hydraulic hammers have been reported. A formula to calculate the dynamic stresses due to induced vibration in structural member has been proposed. 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 modeling of various vibrations, the types of sources and their induced waves were characterized and the geometric co-efficients were determined.

The presents paper describes the details of measurement of ground and structural vibrations carried out during the prototype pile driving.

SITE DESCRIPTION

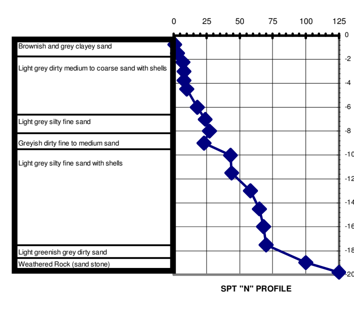


Fig.1 Description of soil strata available at the site

The measurement of ground and structural vibration during prototype pile driving in the city of Chennai were carried out. The soil investigation at the site was carried out by an agency specialized geotechnical investigation. A 150 mm dia bore hole was installed by the agency at the site.

Fig. 1 shows the description of the soil strata available at the site. The depth of the bore hole below the ground level was about 20 m at which the soil is essentially weathered rock. The soil upto the depth of 19 m is mainly fine to medium sand. Therefore, geotechnical expert has recommended friction pile foundation for this building. As the soil is essentially sand, a driven casing cast-in-situ pile of 600 mm diameter has been recommended.

METHOD OF PILE DRIVING

The two main methods of driving steel piles into the ground are impact or vibratory. An impact hammer operates by striking the top of the pile and thereby imparting energy to that pile, which drives the pile downwards into the soil. The amount by which the pile is driven per blow depends upon the efficiency of the blow, and the condition of the soil.
At the site, of this investigations driven casing cast-insitu concrete piles were installed.

Details of the piles
Drive-casing and cast insitu concrete piles
Diameter :600mm
Length :15.8m
Concrete grade :M25
Hammer weigth :4.1tonne
Hammer type : Electrically driven winch operated hammer
Heigth of fall: upto 2.5m

VIBRATION MEASUREMENT

The measurement of ground and structural vibration during prototype pile driving in the city of Chennai was carried out. During pile driving, the ground accelerations are measured from the centre of pile at a distance of 5D, 8.33D and 25D, where “D” is the diameter of pile. The vertical acceleration on an already installed pile head situated at a distance of 6.25 m from the driven pile is recorded. Ground vertical velocity at 25D from the piling is also measured. Fig. 2 shows the photograph of prototype pile driving.

Partly driven pile

Ground vibration=5D(D=diameter of pile)
Vertical vibration on a pile head =6.25m
Ground vertical velocity=25D

Fig.2 Prototype pile driving

After positioning the casing at appropriate location on the pile shoe and before commencement of piling, graduation mark at every 10 cm was made on the casing to monitor its penetration depth for each drop of the hammer. A cube mounted with two seismic accelerometers, one fixed vertically and other fixed horizontally, was positioned on the ground at a distance of 5D (D= diameter of the pile) from the driving location. Another cube mounted with accelerometer was positioned at 25D. An accelerometer was fixed vertically on the already installed pile head situated at a distance of 6.25 m from the centre of pile. 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.
The instrumentation systems consists of B& K make accelerometer type 8318, power amplifier and TEAC tape recorder. For each drop, the ground and structural vibration signals are recorded simultaneously using instrumentation tape recorder. For each drop, the depth of penetration of the casing was noted and recorded. During the pile driving, the acceleration of the ground at various distances from the pile as well as structural accelerations are recorded using tape recorder on 21 st May 2001.

ANALYSIS OF VIBRATION DATA

The recorded analog signals were converted into digital form with the help of PC – based Data Acquisition System. The data acquisition system transforms the analog signal from the tape recorder into digital data, which can be stored in the computer hard disk. The data was digitised with a sampling interval of 208 microseconds. The acquired data are in voltages and are converted into engineering units using a Fortran program.

Time History Of Acceleration

Typical time histories of horizontal and vertical ground acceleration are depicted in Figs.3 & 4 respectively. The peak value of horizontal and vertical acceleration of ground is 4.84 g and 8.09 g respectively. The peak value is preceded and followed by several other peaks of comparably smaller magnitudes indicating the effect of soil layering. The total duration of the horizontal vibration is about 400 ms, whereas duration of the vertical ground vibration of the soil is about 230 ms. Fig.3 show the typical time history of horizontal ground acceleration at a distance of 3m from the centre of pile. The total duration of horizontal vibration is 400ms. This signal corresponding to single drop. The spectrum of horizontal ground acceleraion is shown in Fig.10. The dominant frequencies are 16.43Hz, 42.26Hz, 58.69Hz and 133.8Hz. The natural frequency of structures matches with the excitation frequencies, the resonance occurs. At resonance condition, the structure may damage or crack may occur at beam-column joint. As in the case of earthquake the total duration is few seconds only. The total duration of horizontal vibration is 400ms. Independent of the duration of the signal, the frequency content of the signal is more important, because the excitation frequency only set the structures into vibrations and resonate in case both frequencies coincide.

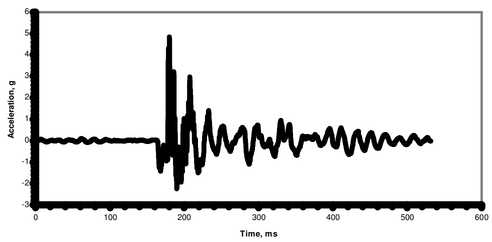


Fig.3. Typical time history of horizontal ground acceleration at a distance of 3m from the centre of pile.

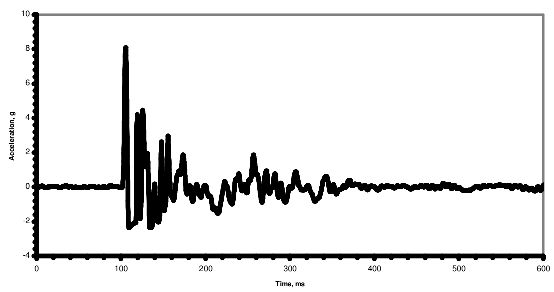


Fig.4. Typical time history of vertical ground acceleration at a distance of 3m from the centre of pile.

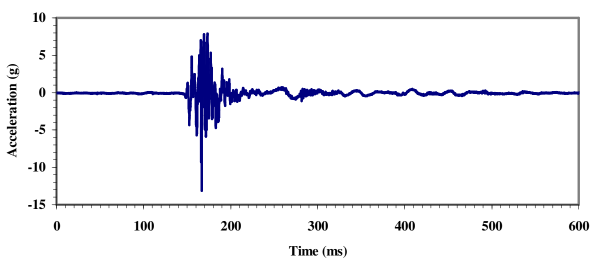


Fig.5. Typical time history of vertical acceleration on a already installed pile head.

Fig. 5 shows the vertical acceleration on already installed pile head. Fig. 6 shows time-history of vertical ground velocity. Fig. 7 illustrates the variation of ground accelerations with penetration depth of casing and the pile driven on 21st May 2001. The structural acceleration time history of compound wall at a distance of 18.8 m are shown in Fig.8.

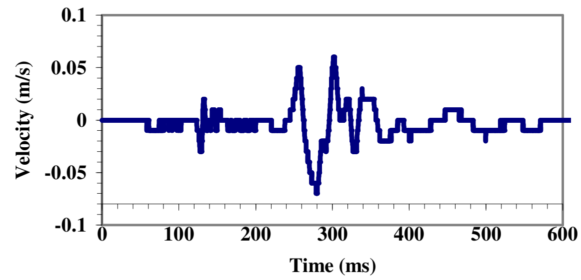


Fig.6. Typical time history of vertical ground velocity of at a distance of 15m from the centre of pile.

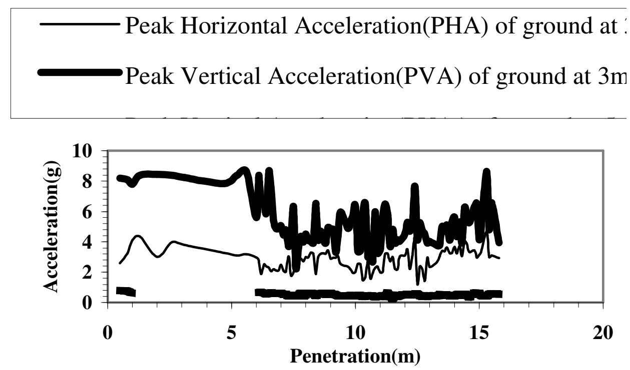


Fig.7. Variation of acceleration with penetratin depth of pile at various distances.

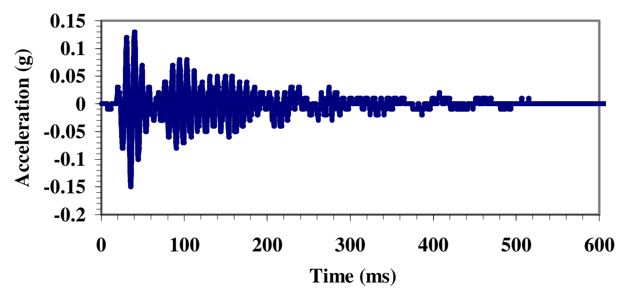
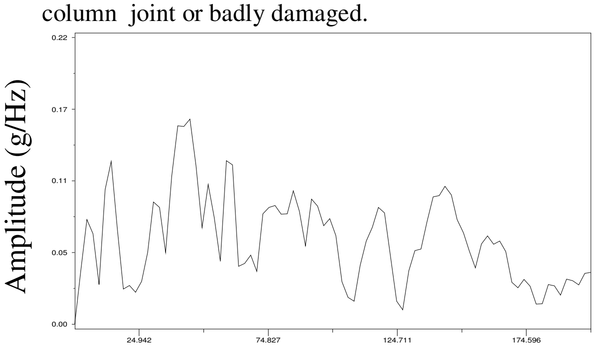


Fig.8. Structural acceleration time history of compound wall at a distance of 18.8m.

The data clipping is not observed in signals, we have analysed more than 1149 drops data. There is no data clipping in the signals. In the case of shock load, the peak values are very important data for structural designer. The peak values of ground and structural acceleration are noted for various depth of penetration of steel casing(pile) are shown in Fig.7.
In general, both ground acceleration oscillates over the depth of penetration of pile . The oscillation of vertical acceleration is more severe than horizontal ground vibrations. The maximum peak vertical ground acceleration is (5D) is 8.6 g at a penetration depth of 5.6 m and 15.3 m. The maximum peak horizontal ground acceleration (5D), 3 m is 4.2g and 4.6 g at a penetration depth of casing of 1.3 m and 15.3 m respectively. The maximum vertical acceleration on an already installed pile head is 20 g at a penetration depth of 8m, which is very high value comparable to the permissible value is 0.5 g. The maximum peak particle velocity is oscillates from 60 mm / sec to 100 mm/.sec, even at a distance of 25D(15 m), even the permissible value is 25 mm/sec as per Published literature(Ref.9).

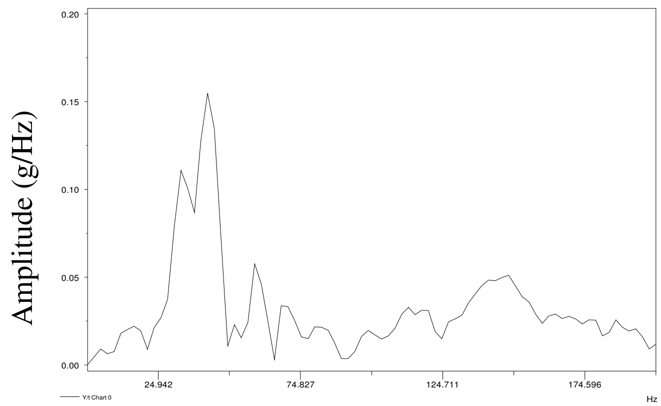
Spectrum Analysis

The PC-based DAS and associated software "DASYLAB" is used to analyse the time data and transform it into the corresponding spectral form. The acceleration amplitude versus frequency plot is obtained from the analysis and typical acceleration time histories and spectrum were plotted. The spectrum of vertical ground acceleration is shown in Fig.9. It has a frequency band of 4.7 Hz to 143 Hz. The spectrum has dominant frequencies are 4.7Hz, 14.09Hz, 39.9Hz, 58.69Hz, 84.51Hz, 117.3Hz and 143Hz. The spectrum of horizontal ground acceleration is shown in Fig.10. The spectrum has dominant frequencies are 16.43Hz, 42.2Hz, 58.69Hz, 112.6Hz and 133.8Hz. The spectrum has several large peaks at where the natural frequency of structures coincides with excitation frequencies, the resonance occurs. At resonance condition, the structure or structural components joints may crack or damage severely due to build up of amplitudes of vibration. The shock wave propagation through the structure or structural component like slab, beam or even column may induce differential settlement and either crack may occur at beam-column joint or badly damaged.



Frequency, Hz

Fig.9. Typical Spectrum of vertical ground acceleration at a distance of 3m from the centre of pile.



Frequency, Hz

Fig.10. Typical Spectrum of horizontal ground acceleration at a distance of 3m from the centre of pile

The Earthquake spectrum shows the frequency range of 1Hz to 10Hz. As earthquake occurs, the whole buildings and structures are cracked or damaged and this is due to fact that, the fundamental frequency of structure or component is matches with excitation frequency, the resonance occurs. At resonance condition, the structure, joint may crack or damage severely. As in the case of earthquake the total duration is few seconds only. Independent of the duration of the signal, the frequency content of the signal is more important, because the excitation frequency only set the structures into vibrations and resonate in case both frequencies coincide.

Vibration Level In Structures

Koch has compiled the amplitude of vibration for different frequencies and classified them under different categories that will indicate the intensity of possible damage figure and the corresponding effects are given in Fig.11. The movements of nearby buildings caused by pile driving, and a reference can be made to the coverage in a standard book by Poulos and Davis (1980) (Fig.12). From this figure, it can be seen that there were movements in the adjacent structures upto a distance of near by 100ft from pile.

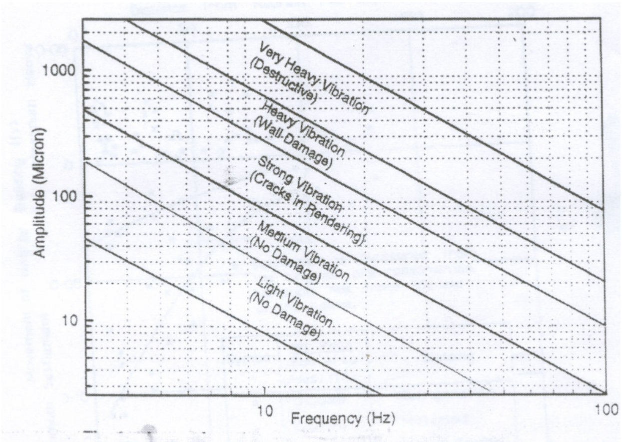


Fig.11 Intensity of possible Damage (After Koch)

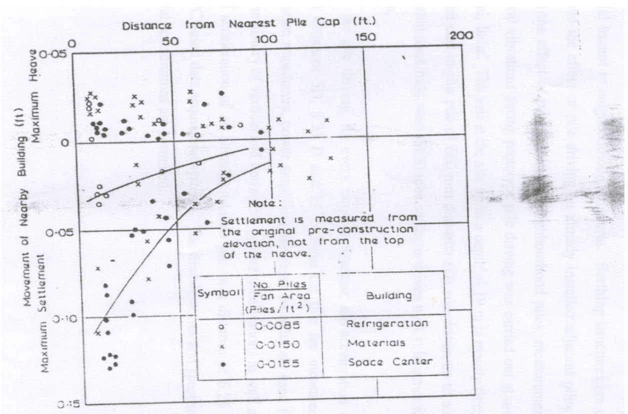


Fig.12 Movement of nearby buldings caused by pile driving operations.

An empirical equation for driven piling , published by Attewell and Farmer in 1973 (1)

$V = 1.33(W^{0.5/x})^{**}0.73$ (1)

Where "V" is the ground vibration velocity and "W" is the pile driver energy in units of joules(N-m).

Various researchers developed vibration criteria as function of natural frequency of structure in terms of Peak particle velocity (PPV). The allowable PPV for concrete foundations is 10 –25 mm/s for the frequency of 10 to 50 Hz and for building fabric is 5 – 12 mm/s. Based on the results , it is observed that for a distance of 25D (D = diameter of pile), the effect of vibration due to piling is very severe.

SUMMARY AND CONCLUSIONS

From the field measurement of vibration caused by piling , it can be concluded as follows

1. The maximum peak vertical ground acceleration is (5D) is 8.6 g at a penetration depth of 5.6 m and 15.3 m. The maximum peak horizontal ground acceleration (5D), 3 m is 4.2 and 4.6 g at a penetration depth of casing of 1.3 m and 15.3 m respectively. The maximum vertical acceleration on an already installed pile head is 20 g at a penetration depth of 8m, which is a very high value comparable to the permissible value of 0.5 g. The maximum peak particle velocity oscillates from 60 mm / sec to 100 mm/.sec, even at a distance of 25D (15 m).
2. The spectra of horizontal ground acceleration has a frequency band of 16.43 Hz to 133.8 Hz. The structure may fail or be damaged severely at resonance condition.
3. Based on the results, it is observed that effect of vibration caused by piling is very severe even up to a distance of 25D. The ground vibration caused by piling can disturb the neighbourhood building and cause damage to the sensitive equipments.

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