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ACCELEROGRAM FOR EARTHQUAKE RESISTANT DESIGN OF PILE SUPPORTED STRUCTURE

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ABSTRACT

The seismic motion at bedrock gets modified during upward travel through the overlying soil layers and piles to the base of a pile supported structure. Pile foundation helps modulate the frequency and acceleration level at the base of the super structure in the passive stage of the dynamic loading. In the active stage of dynamic loading Pile offers additional resistance to the lateral movement. The mode shapes and the period of vibration of the superstructure can be controlled significantly by proper selection of Pile parameters. The developed 3 tier numerical scheme, in time domain, offers acceleration response at the base of the pile supported structure considering soil pile structure interaction effect. Proper selection of Pile parameters help control the stresses, displacement and period of vibration of the super structure. Pile has been considered as a linear elastic material, nonlinearity of soil with geometric damping has been taken into account.

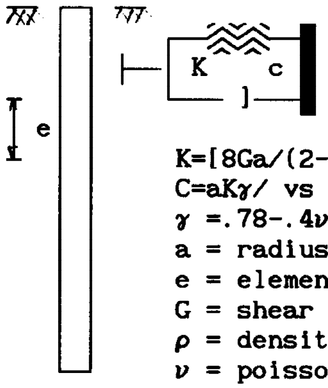
KEYWORDS

Earthquake Accelerogram; Soil Pile Structure interaction analysis; Pile bending; Earthquake resistant design of Building; Numerical scheme on wave propagation; Substructure Analysis; Non linear Soil.

INTRODUCTION

Frequent occurrence of Earthquake at different parts of the globe, in the recent past, has made the human society highly concerned about its devastation. This brings engineers, administrators and policy makers of countries together to mitigate the cruel effects. Present days, occurrence of Earthquake is not a mere matter of chance but needs proper preparedness to face the challenge of the nature. Design of economic and safe super structure which can withstand severe ground motion generated by Earthquake is a challenge demanding the best attention of structural engineers, foundation engineers, numerical analyst, seismologists and attention of other branches of science with an in depth knowledge of Earthquake generation, seismic wave propagation, rheological modeling of soil, structural response and material behavior.

For difficult subsoil condition structure on pile foundation is a common solution.
In the 'calm period' the role of Pile is to transfer the load of super structure to the supporting soil through skin friction and point bearing and supporting soil offers resistance to vertical and lateral movement of Pile.
During Earthquake, Pile plays two different roles:
(1) In the first phase, during the travel of seismic wave, the pile transfer seismic loading from soil to structure which sets the structure to motion.
(2) In the second phase, the pile offers resistance to the motion of the structure which was induced by the pile itself in the first phase.



$K=[8Ga/(2-\nu)](1+e/a)$
$C=aK\gamma/\ vs\ ;\ vs=\sqrt{(G/\rho)}$
$\gamma=.78-.4\nu$
a = radius of pile
e = elemental length
G = shear modulus
ρ = density
ν = poisson's ratio

Fig 1. Pile Soil Model

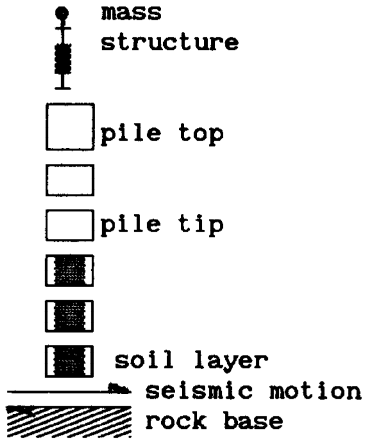
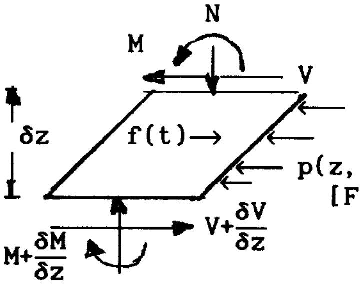


Fig2. Mathematical discretisation



u = lateral deformation
N = axial force
M = moment acting
V = transverse force

$$V = N\frac{\delta u}{\delta z} + \frac{\delta M}{\delta z}\ ;\ \frac{\delta V}{\delta z} = p - m\frac{\delta^2 u}{\delta t^2}$$

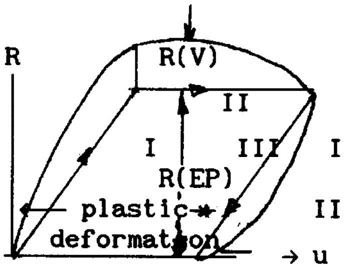
Equation of motion

$$\frac{\delta^2}{\delta z^2}\left[EI\,\frac{\delta^2 u}{\delta z^2}\right] + N\,\frac{\delta^2 u}{\delta z^2} + m\,\frac{\delta^2 u}{\delta t^2} = p \qquad (1)$$

Slope, $\theta = \partial u/\partial z$; Moment, $M = EI(\partial\theta/\partial z)$ (2,3)
Shear Force, $F = \partial M/\partial z$ (4)
Velocity, $v = \partial u/\partial t$ (5)
Shear Force Equilibrium Equation :

$$\frac{\partial F}{\partial z} + R + \frac{\partial}{\partial z}\left[N(z)\ .\ \theta\right] + m\,\frac{\partial v}{\partial t} \qquad (6)$$

Fig4. Influence of Axial Force (↓)



V=Viscous
I=Elastic loading
II=Plastic yield
III=Elastic rebound

R = Total soil resistance
= R(EP) + R(V)

R(EP) = Elasto plastic resistance
R(V) = Viscous resistance

During unloading or subsequent re loading R = 0 for lateral displacement less than plastic deformation forming the gap

Fig3. Lateral resistance of the soil showing the gap at pile soil interface after first unloading

Thus the excitation of Pile supported structure under Earthquake loading is the interaction of three phenomena: (1) impact of free field incoming wave (2)stress transfer from soil to pile and (3) vibration of pile because of the soil reaction and the inertial motion of the super structure. The soil surrounding the pile experiences a highly elasto plastic interaction which further modulate the motion transmitted to the base of the super structure. Methodologies used by the structural engineers for the Earthquake resistant design of buildings are (Dowrick, 1987):

(1) Step wise direct integration of the equation of motion
(2) Normal mode Analysis
(3) Response spectrum analysis.

To do proper justice to the complicated nature of this problem, it demands a complete three dimensional analysis of the system comprising structure, pile and the elastic halfspace. Because of the complexity, analysts prefer substructure procedure, where the total structure-pile-soil system is suitably idealized three connected sub systems (Shin ichiro Tokaro, 1992):
(1) Structure sub system, (2) pile embedded in soil subsystem and (3) Soil below pile and above base rock layer. Thus it is a 3 tier idealisation of the complete system. Several researchers have offered different methodologies for the analysis of Pile soil interaction problem. Makris(1994) has presented a comprehensive review on this subject. Laboratory controlled tests on clays[3] have clearly indicated that stress history is also another equally important parameter which influences the dynamic response of the pile. If the cyclic shear strain level is less than its endurance shear strength the soil will try to achieve a elastic non failure equilibrium condition. But if it exceeds the endurance strength, the soil stiffness deteriorates. The essential parameters, which represents these non linearities of soil at the pile soil interface, could be evaluated only from experimental data, either in laboratory or in field. All previous studies indicates that soil non linearity and the relative movement of the soil at pile soil interface strongly influences the pile behavior. Variation of soil property with depth, hysteritic damping, energy dissipation, loading rates are a few of the other parameters which govern the pile motion.

PROBLEM DEFINITION

The problem studied in this paper is that of a single vertical Pile embedded in soil. subjected to step function type impact loads. Earthquake load has been considered as summation of impact loads over suitable time intervals. Soil below Pile has been considered as a soil column, equal diameter of that of the Pile and surrounded by peripheral soil for geometric damping, which has been taken into account by Wolf's concept (Fig 1). This soil column extends upto base rock (Fig 2)

The tip of this soil column is considered as fixed with base rock, which has been excited by free field seismic motion. Many sophisticated numerical methods are already existing for the analysis of this type of problem. Three dimensional non linear dynamic analysis by finite element method is a very powerful numerical tool for this type of study but high computational cost of one run does not make it suitable during initial trial and error procedure of decision making between structural engineer, foundation engineer and architect. This scheme has been addressed for that purpose.

NUMERICAL MODELING

The stress deformation behavior of a laterally loaded beam has been well studied. Many classical solutions are available (Clough,R.W). In this paper the dictating governing differential equation of motion has been discretised into a set of few first order partial differential equations (Fig 4). Equations (2,3,4) are integrated over space and equations (5) and (6) are integrated over time in staggered fashion. The solution starts with initial at rest condition of all pile elements,with fixity at base and top free condition. The Soil resistance R at the middle of any time interval was found by iterative under relaxation scheme with under relaxation factor of 0.5. It offers good convergence within 6 cycles.

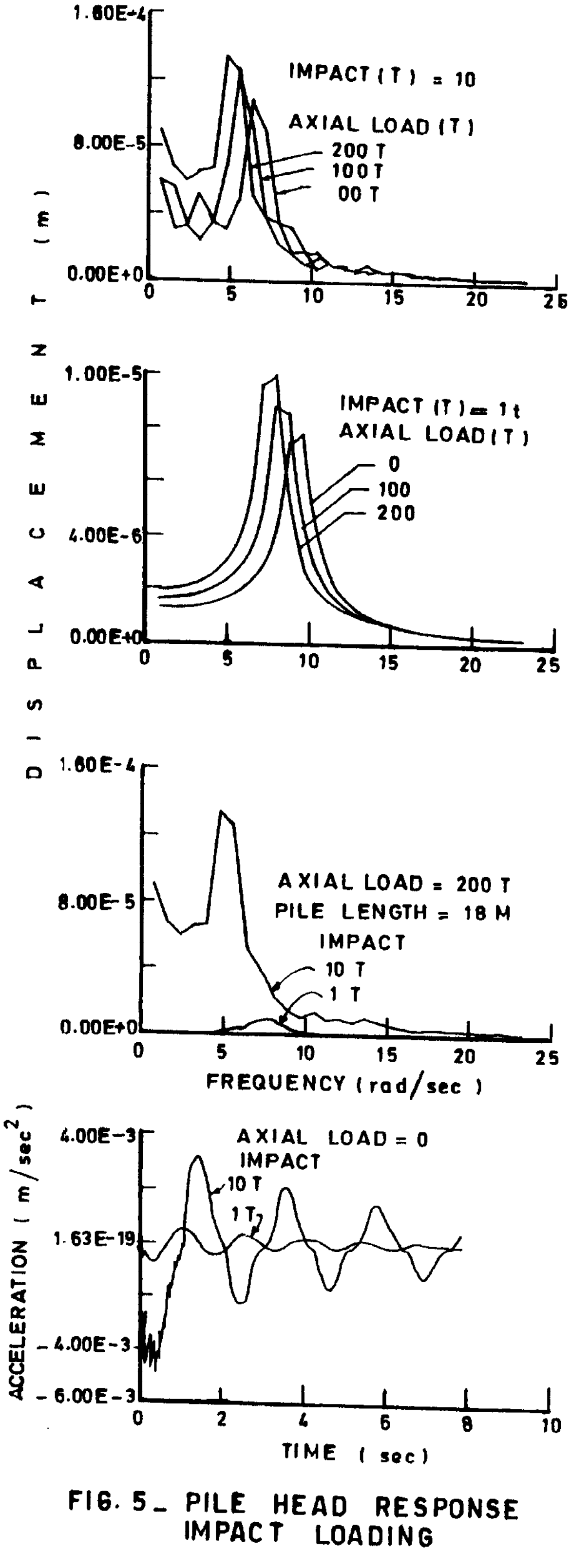


FIG. 5 _ PILE HEAD RESPONSE IMPACT LOADING

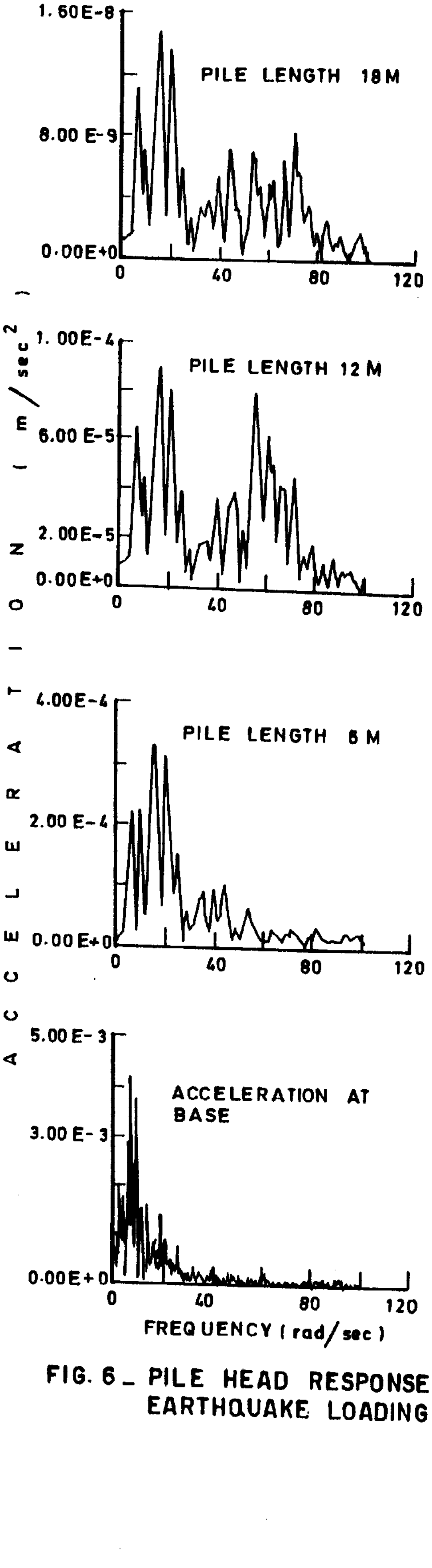


FIG. 6 _ PILE HEAD RESPONSE EARTHQUAKE LOADING

PARAMETRIC STUDIES

Example 1: Impact on free free Pile

The time history of impact load of 1t and 10t on free free pile shows (Fig 5) that response decays smoothly without any numerical noise (Authors, DFI, 1996, India). The resonant frequency decreases with increase in axial load or with increase in impact load, when soil enters into plastic deformation forming a separation of soil pile contact at top.

Example 2: Earthquake loading at Pile tip

A truncated Pasadena acceleration response at .08sec interval has been considered for this study and the intermediate values needed for the numerical scheme was linearly interpolated. Fig 6. presents that pile head response of shorter pile follows closely the tip response and as the pile length increases the dominant frequency spreads over a wider range with a reduction in pile head response. Thus longer pile distributes the energy over different mode shapes which helps reducing the possibility of overshooting of dynamic response of super structure near around the dominant frequency of the earthquake motion.

Example 3: Earthquake motion at the base of the Super structure only.

In the next phase of the study a very short duration (1.8sec=E) earthquake motion has been (Fig 7)considered and the resulting acceleration response of different cases has been normalized with its peak (P) value.
Fig 7b. presents the top response of a singe degree mass spring dashpot system when its base has been subjected to the above earthquake motion. It will be observed that with increase in axial load time period increases and decay rate increases with increase in structural damping.
In the next phase of the study Structure pile and soil combination was considered. Rock base was considered at 12 x 2.5 m from ground surface with 12 overlying soil layer of 2.5m (el=2.5m)thick with shear modulus 15,000 t/m3, yeilding at .0001m. Pile of Dia= 0.33m and E= 3.e+06 t/m2 (Pile= 5 el, Soil= 7 el). was slowly inserted into ground and normalized acceleration response under the action of short duration pulse at the rock base was observed. As mass of the structure head (Fig 7 c & e)) or as axial load (Fig 7 d & c)increases the Pile head response increases.
Fig 7 f to i presents the effect of Pile length on the transfer of rock base motion to the pile head. For a fixed base Pile the peak occurs almost simultaneously while the follow up motion at the active stage of loading increases as the pile length decreases. The location of peak acceleration (P) of structure head (Fig 7 c to e) and that of Pile head (Fig 7 f to i) changes depending upon the combination of mass, stiffness of super structure and the embedment length of Pile.

CONCLUSIONS

This paper emphasizes that the much needed accelerogram at the base of the superstructure for the Earthquake resistant design should consider the effect of mass, stiffness of superstructure, the parameters of pile soil combination and length of Pile and depth of soil and its properties above rock base.

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