NUMERICAL ANALYSIS OF LATERALLY LOADED PILES IN FINE GRAINED SOIL

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Abstract- Pakistan is located at the intersection of two plates i.e. Indian and Eurasian plates, had faced various devastated earthquakes in the past. After the catastrophic earthquake of 2005, a group of researchers, academician and practice engineers proposed revision in seismic provision and published Building Code of Pakistan (BCP) in 2021. BCP 2021 provides generic guidelines related to soil dynamics, however, doesn't address the soil-pile dynamic interaction explicitly. In this study, an effort is made to examine the behavior of laterally loaded large diameter piles constructed in Islamabad using numerical method, a framework proposed in already published research studies. Two numerical methods were employed and dynamic characteristics of pile is examined. The result indicated higher displacement at the top and at natural frequency of the pile. Similar trends were noticed for bending moment and shear force variation.

Keywords- Bending Moment, Winkler Model, Finite Element Method, Shear Force, Stiffness

1 Introduction

Pile foundation is characterized as deep foundation is considered appropriate foundation type in the areas having problematic soil. Also in the presence of lateral load, the capacity of shallow foundation may became inadequate to provide resistance leading to adoption of piles as best choice of foundation. Although fundamental function of the pile is to provide resistance to axial loading in the form of skin resistance and end bearing, however, they withstand significant lateral loading coming from earthquakes, wind loading, wave action etc. during their design life. Therefore, a comprehensive understanding of the dynamic response of piles becomes vital for safe design. The design of piles subjected to lateral loading is challenging due to several factors including reliable estimation of soil dynamic properties, precision in numerical modeling, data analysis and interpretation. Ignoring underestimation or inaccuracy in the aforementioned factors may lead to catastrophic results.

Based on the published literature, numerical methods for lateral load analysis can be classified into three groups including (i) Winkler model; (ii) Closed form solutions and (iii) Finite element method. In Winkler model, spring are adopted to model the soil resistance whereas piles are modeled as elastic beam. The empirical relationship between dynamic soil stiffness by modeling soil as spring was first proposed in 1967 which opened the door for researchers to explore in this area [1]. The same idea was extended by considering harmonic loading and a set of equations were proposed to evaluate pile head displacement responses [2], [3], [4]. The first attempt to consider soil as nonlinear material was conducted by Nogami et al, in which formal introduction of p-y curves was presented [5]. With enhanced computational efficiency, the researchers also employed Finite Element Method (FEM) for lateral load analysis. Various finite elements such as 8 node brick element, triangular elements etc. were presented to model the soil [6-9]. Nominal experiment studies were performed in order to verify the accuracy of the aforementioned finite element methods [10-13]. Another disadvantage of the FEM is its high computational cost. The solution to this was proposed by introduction of reduced dimension FEM (RDFEM), in which soil and pile vertical displacement were ignored, as they don't contribute toward the lateral load analysis [14]. The experimental verification of RDFEM was also performed and the obtained results shows excellent matching, hence providing researcher a new framework to anticipate performance of laterally loaded piles [15].

In this study, a research framework proposed by Suhail S.A, and Thammarak, P [15], was employed to perform analysis of laterally loaded large diameter pile embedded in fine grained soil using two numerical methods i.e. Winkler model and finite element method. The dynamic characteristics such as natural frequency and dynamic pile displacement were first obtained, followed by determination of the bending moments and shear force by using theory of elasticity.

2 Research Methodology

2.1 Soil Data Collection

Data of 56 boreholes were collected from different areas of Islamabad and Rawalpindi region. The collected data includes SPT N field values along with soil classification. Based on the field values, corrected standard penetration test SPT N values were determined. Soil dynamic characteristics such as shear and compression wave velocity, dynamic modulus, poison ratio and density of the soil were then evaluated on the corrected SPT N values. The soil spring stiffness to be used for Winkler model was obtained by using the empirical equations proposed by Novak et. al. [3]. Since soil dynamic stiffness is frequency dependent, a code in MATLAB is written in order to obtain resistance at variable frequencies. The soil parameters employed in the present study is presented in Table 1

Table 1 Soil Parameters Used in Numerical Modeling

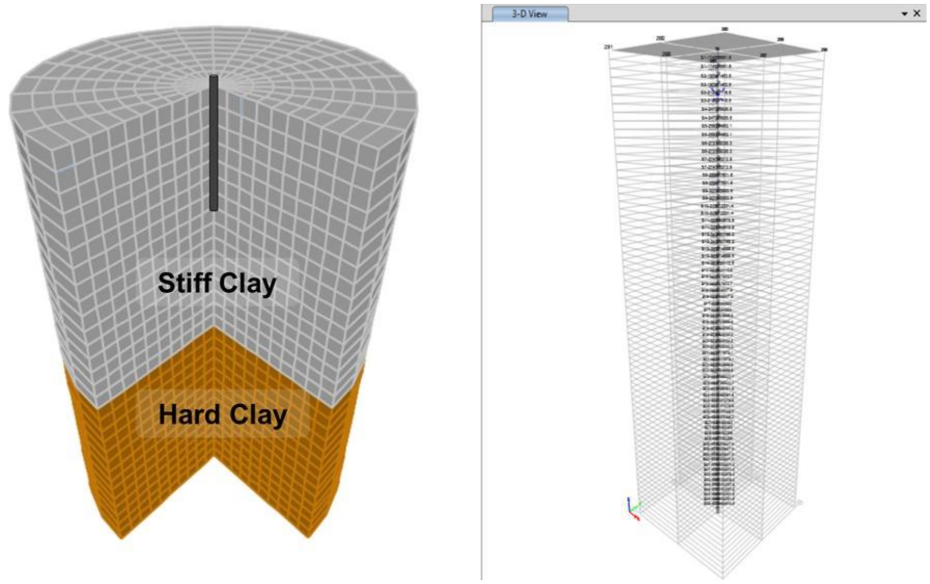
Depth	**V_s**	**UW**	**Elasticity**
(m)	**(m/s)**	**KN/m3**	**(MPA)**
0-3	139	11	3.67
3-11	224	18	8
11-45	249	20	14
45-60	300	21	25

2.2 Numerical Modelling

In Winkler Beam on Spring Foundation (WBSF) model beam elements are used to model pile whereas 1D discrete springs represent soil strength. Soil strength is obtained from the solution proposed by Novak et. al. [3]. WBSF analysis is performed on the commercially available software ETABS. RDFEM analysis was carried out using computer code written in FORTRAN. In RDFEM, Euler's beam element is used to model pile whereas 3D ring element represents soil. An appropriate mesh size and soil boundary were used that is obtained based on shear and compressional wave velocities. The pictorial view of numerical models is shown in Figure 1. A huge pile cap, having mass moments of inertia of 802,623 kg-m^2, is also modelled using area elements to represent superstructure. The input parameters for RDFEM models are given in Table 2.

Table 2: Input Parameters of RDFEM Model

Applied Frequency	1 - 10 Hz
Time Stepping Size	0.01 sec
No. of Time Steps	2000
Analysis Time	20 sec
$V_{s(min)}$	139 (m/sec)
V_p	141 (m/sec)
Smallest Wavelength	0.86 m
Element Size	0.5m
Calculated Outer Boundary Size	3440 m
Boundary Size Used	4000 m



(a) *(b)*

Figure 1: Numerical Models (a) RDFEM (b) WBSF Model

3 Results

The result of the present study indicates that natural frequency of pile is obtained from RDFEM is 2.5 Hz, whereas WBSF gives natural frequency of 2.0 Hz. The corresponding pile head displacements are 4.07E-5m and 5.37E-5m respectively. Based on the results of modal analysis, other dynamic characteristics including deformation, bending moment and shear force variation along the length of the piles were obtained using theory of elasticity for various frequencies including natural frequencies, pre-natural frequencies and post natural frequencies, and are presented in Figure 2, 3 and 4.

From figure 2, it can be observed that maximum deflection is observed at the pile top and at natural frequency of the pile. The amplitude of deflection at frequencies before and after natural frequency is less than what is recorded at natural frequency. The variation of bending moment and shear forces as shown in Figure 3 and 4 showed similar trends as that of pile deflection. This is generally because the dynamic pile responses are primarily governed by stiffness of the infrastructure. As the intersection of pile and superstructure represented by pile cap is modelled at the pile head therefore, the stiffness of the overall system becomes extremely high at the pile top level. As a result, deformation, bending moment and shear force amplitudes become maximum at the pile top. These results align with observations recorded by previous research studies [15].

The results of deflection, bending moment and shear force variation along the pile length also highlighted that these characteristics become zero at pile tip level. This clearly showed that the lower part of the pile (i.e. below the active length, doesn't contribute towards resistance lateral loads.

4 Conclusion

The following conclusions can be drawn from the conducted study:

1 Both numerical methods RDFEM and WBSF can simulate dynamic response of piles.

2 The dynamic head displacement, bending moment and shear will be higher at the pile top level, at the location of intersection of pile and superstructure.

The WBSF method overestimates the pile lateral response in fine-grained soil

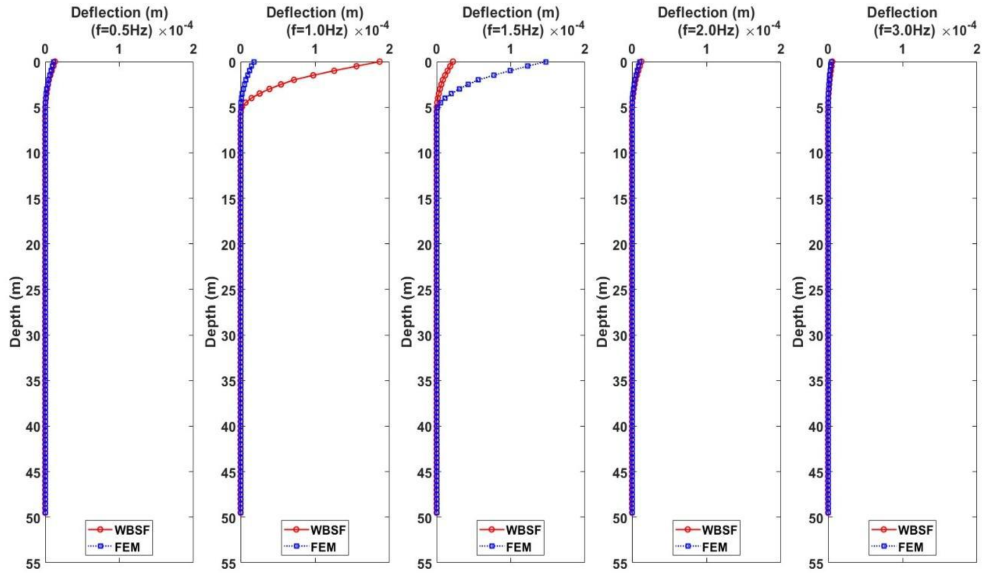


Figure 2: Deformation Pattern along Pile Length

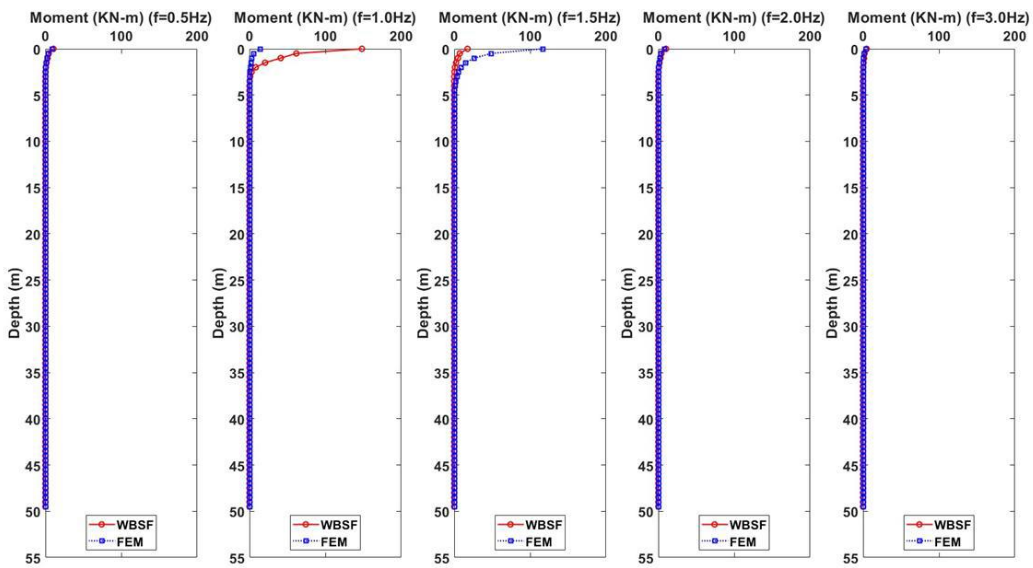


Figure 3: Bending Moment Pattern along Pile Length

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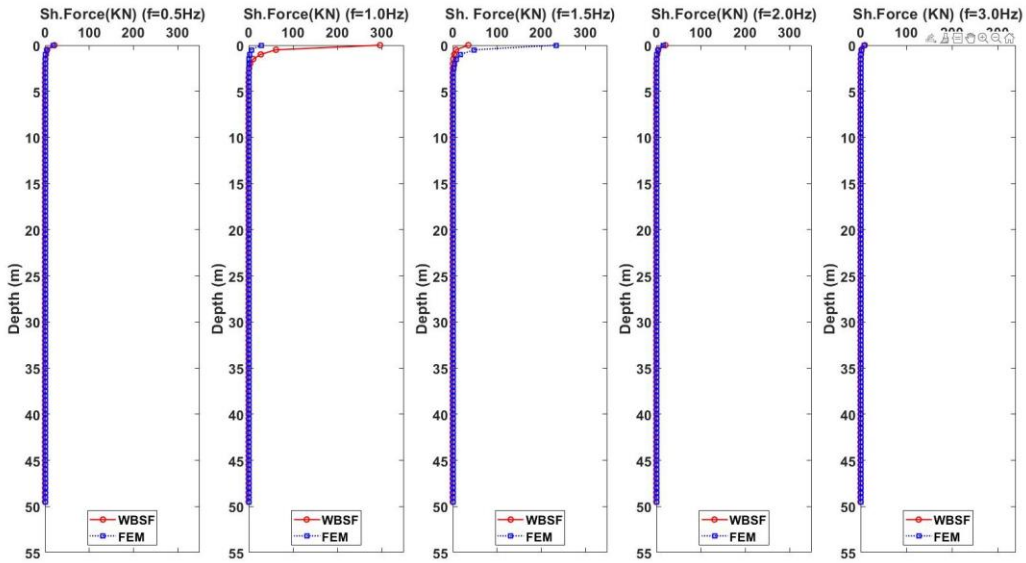

Figure 4: Shear Force Pattern along Pile Length

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