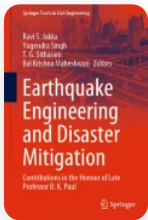


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Behaviour of Batter Piles Under Machine Induced Vibrations

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Abstract

The batter piles have several applications in infrastructure projects, such as offshore structures, transmission towers, bridges, and high-speed turbines involving machine-induced vibrations. This paper presents the details of a series of dynamic lateral and vertical loading tests as conducted on a vertical pile, B0 ($\beta = 0^\circ$) and batter (i.e., inclined) piles, B10 ($\beta = 10^\circ$) and B20 ($\beta = 20^\circ$) constructed in layered silty sandy soil, where β is the inclination of the pile to the vertical. All the piles had a length of 2.5 m and a diameter of 0.20 m. These piles were subjected to six force levels in lateral (X and Z) and vertical (Y)

directions. Accelerometers were placed on the pile cap to obtain the dynamic response of these piles. The results show that the resonant frequency of the soil–pile system decreases by 37–50% along the lateral direction and 43–50% along the vertical direction, with increasing force level. When the force level is increased, the maximum peak displacements in the X and Z directions increase by 11 and 4 times in the case of B0 and B20 piles, respectively. However, the peak displacement increases by 4–5 times in the Y direction with an increase in force level. The increase in lateral strains (in X and Z) in the piles with force level was more prominent in the case of B20 compared to B0 and B10. Further, the increase in axial strain (in Y) with force level was almost four times in all three piles. In both lateral directions, the rotational stiffness of the soil–pile system decreases nonlinearly, whereas the damping ratio increases nonlinearly with an increase in lateral strain.

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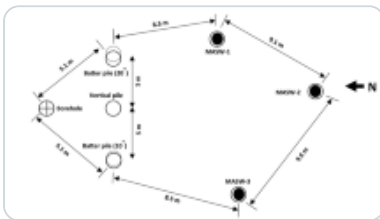
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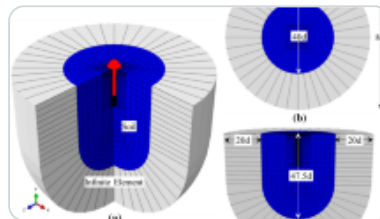
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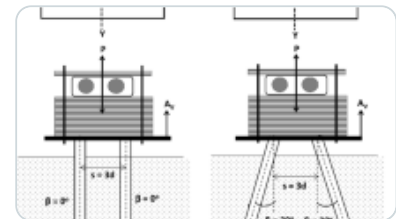
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References

1. Tomlinson M, Woodward J (2015) Pile design and construction practice. CRC Press

[Google Scholar](#)

2. Juneja A, Mohammed-Aslam AK (2018) Application of a cyclic degradation model for pore pressure accumulation in loose sands and silts subjected to dynamic loading. J Earthq Tsunami 12(05). <https://doi.org/10.1142/s1793431118500148>

3. Priestley N, Singh J, Youd T, Rollins K (1991) Costa Rica earthquake of April 22, 1991, reconnaissance report. vol 91-02. Earthquake Engineering Research Institute

[Google Scholar](#)

4. Mitchell D, Tinawi R, Sexsmith RG (1991) Performance of bridges in the 1989 Loma Prieta earthquake—lessons for Canadian designers. Can J Civ Eng 18(4):711–734.
<https://doi.org/10.1139/l91-085>

[Article](#) [Google Scholar](#)

5. Berrill JB, Christensen SA, Keenan RP, Okada W, Pettinga JR (2001) Case study of lateral spreading forces on a piled foundation. Géotechnique 51(6):501–517.
<https://doi.org/10.1680/geot.51.6.501.40462>

[Article](#) [Google Scholar](#)

6. Kastranta G, Gazetas G, Tazoh T (1998) Performance of three quay walls in Maya Wharf: Kobe 1995. In: 11th European conference on earthquake engineering, Paris, France

[Google Scholar](#)

7. Poulos HG (2006) Raked piles virtues and drawbacks. J Geotech Geoenviron Eng 132(6):795–803. [https://doi.org/10.1061/\(ASCE\)1090-0241\(2006\)132:6\(795\)](https://doi.org/10.1061/(ASCE)1090-0241(2006)132:6(795))

[Article](#) [Google Scholar](#)

8. AFPS (1990) Association française du génie parasismique, Presses des Ponts et et Chaussees [French Association for Earthquake Engineering, Presses of Bridges and Engineering]

[Google Scholar](#)

9. EC8 (2003) Eurocode 8 Part 5. Design provisions for earthquake resistance of structures: foundations, retaining structures, and geotechnical aspects. British Standards Institution, London

[Google Scholar](#)

10. Werner SD (1998) Seismic guidelines for ports. ASCE Publications, Reston, VA

[Google Scholar](#)

11. AASHTO (2014) LRFD bridge design specifications. Seventh edn. American Association of State Highway and Transportation Officials ©2014, Washington, D.C.

[Google Scholar](#)

12. Zhang L, McVay M, Lai P (1998) Centrifuge testing of vertically loaded battered pile groups in sand. Geotech Test J 21(4):281–288. <https://doi.org/10.1520/GTJ11367J>

[Article](#) [Google Scholar](#)

13. Gerolymos N, Giannakou A, Anastasopoulos I, Gazetas G (2008) Evidence of beneficial role of inclined piles: observations and summary of numerical analyses. Bull Earthq Eng 6(4):705–722. <https://doi.org/10.1007/s10518-008-9085-2>

[Article](#) [Google Scholar](#)

14. Escoffier S, Chazelas J-L, Garnier J (2008) Centrifuge modelling of raked piles. Bull Earthq Eng 6(4):689–704. <https://doi.org/10.1007/s10518-008-9094-1>

[Article](#) [Google Scholar](#)

15. Tazoh T, Sato J, Jang J, Taji Y, Gazetas G, Anastasopoulos I (2010) Kinematic response of batter pile foundation. In: Soil–Foundation–Structure Interaction. Taylor & Francis Group, London. <https://doi.org/10.1201/b10568-8>

16. Giannakou A, Gerolymos N, Gazetas G, Tazoh T, Anastasopoulos I (2010) Seismic behavior of batter piles: elastic response. J Geotech Geoenviron Eng 136(9):1187–1199. [https://doi.org/10.1061/\(ASCE\)GT.1943-5606.0000337](https://doi.org/10.1061/(ASCE)GT.1943-5606.0000337)

[Article](#) [Google Scholar](#)

17. Ghasemzadeh H, Alibeikloo M (2011) Pile–soil–pile interaction in pile groups with batter piles under dynamic loads. Soil Dyn Earthq Eng 31(8):1159–1170. <https://doi.org/10.1016/j.soildyn.2011.04.005>

[Article](#) [Google Scholar](#)

18. Ghazavi M, Ravanshenas P, El Naggar MH (2013) Interaction between inclined pile groups subjected to harmonic vibrations. Soils Found 53(6):789–803. <https://doi.org/10.1016/j.sandf.2013.08.009>

[Article](#) [Google Scholar](#)

19. Padrón LA, Aznárez JJ, Maeso O, Santana A (2010) Dynamic stiffness of deep foundations with inclined piles. Earthq Eng Struct Dyn 39(12):1343–1367. <https://doi.org/10.1002/eqe.1000>

[Article](#) [Google Scholar](#)

20. Padrón LA, Suárez A, Aznárez JJ, Maeso O (2015) Kinematic internal forces in deep foundations with inclined piles. Earthq Eng Struct Dyn 44(12):2129–2135. <https://doi.org/10.1002/eqe.2559>

[Article](#) [Google Scholar](#)

21. Medina C, Padrón LA, Aznárez JJ, Maeso O (2015) Influence of pile inclination angle on the dynamic properties and seismic response of piled structures. *Soil Dyn Earthq Eng* 69:196–206. <https://doi.org/10.1016/j.soildyn.2014.10.027>

[Article](#) [Google Scholar](#)

22. Medina C, Padrón LA, Aznárez JJ, Santana A, Maeso O (2014) Kinematic interaction factors of deep foundations with inclined piles. *Earthq Eng Struct Dyn* 43(13):2035–2050. <https://doi.org/10.1002/eqe.2435>

[Article](#) [Google Scholar](#)

23. Padrón LA, Aznárez JJ, Maeso O, Saitoh M (2012) Impedance functions of end-bearing inclined piles. *Soil Dyn Earthq Eng* 38:97–108. <https://doi.org/10.1016/j.soildyn.2012.01.010>

[Article](#) [Google Scholar](#)

24. Goit CS, Saitoh M (2013) Model tests and numerical analyses on horizontal impedance functions of inclined single piles embedded in cohesionless soil. *Earthq Eng Eng Vib* 12(1):143–154. <https://doi.org/10.1007/s11803-013-0158-0>

[Article](#) [Google Scholar](#)

25. Li Z, Escoffier S, Kotronis P (2016) Centrifuge modeling of batter pile foundations under earthquake excitation. *Soil Dyn Earthq Eng* 88:176–190. <https://doi.org/10.1016/j.soildyn.2016.05.013>

[Article](#) [Google Scholar](#)

26. Li Z, Escoffier S, Kotronis P (2016) Centrifuge modeling of batter pile foundations under sinusoidal dynamic excitation. *Bull Earthq Eng* 14(3):673–697. <https://doi.org/10.1007/s10518-015-9859-2>

[Article](#) [Google Scholar](#)

27. Subramanian RM, Boominathan A (2016) Dynamic experimental studies on lateral behaviour of batter piles in soft clay. *Int J Geotech Eng* 10(4):317–327.

<https://doi.org/10.1080/19386362.2016.1150006>

[Article](#) [Google Scholar](#)

28. Wang J, Zhou D, Ji T, Wang S (2017) Horizontal dynamic stiffness and interaction factors of inclined piles. *Int J Geomech* 17(9):04017075.

[https://doi.org/10.1061/\(ASCE\)GM.1943-5622.0000966](https://doi.org/10.1061/(ASCE)GM.1943-5622.0000966)

[Article](#) [Google Scholar](#)

29. Bharathi M, Dubey RN (2018) Dynamic lateral response of under-reamed vertical and batter piles. *Constr Build Mater* 158(Supplement C): 910–920.

<https://doi.org/10.1016/j.conbuildmat.2017.10.042>

30. Bharathi M, Dubey RN, Shukla SK (2022) Dynamic response of underreamed batter piles subjected to vertical vibration. *Int J Geotech Eng* 16(8):991–999.

<https://doi.org/10.1080/19386362.2021.2025304>

[Article](#) [Google Scholar](#)

31. Bharathi M, Dubey RN, Shukla SK (2019) Experimental investigation of vertical and batter pile groups subjected to dynamic loads. *Soil Dyn Earthq Eng* 116:107–119.

<https://doi.org/10.1016/j.soildyn.2018.10.012>

[Article](#) [Google Scholar](#)

32. Bharathi M, Dubey RN, Shukla SK (2022) Numerical simulation of the dynamic response of batter piles and pile groups. *Bull Earthq Eng* 20(7):3239–3263.

<https://doi.org/10.1007/s10518-022-01362-7>

33. BIS (1973) IS2720 (Part2). Methods of test for soils: determination of water content. Bureau of Indian Standards, New Delhi, India

[Google Scholar](#)

34. BIS (1985b) IS2720 (Part5). Methods of test for soils: determination of liquid and plastic limit. Bureau of Indian Standards, New Delhi, India

[Google Scholar](#)

35. BIS (1985a) IS2720 (Part4). Methods of test for soils: grain size analysis. Bureau of Indian Standards, New Delhi, India

[Google Scholar](#)

36. BIS (1970) IS1498. Classification and identification of soils for general engineering purposes. Bureau of Indian Standards, New Delhi, India

[Google Scholar](#)

37. BIS (1981b) IS 6403. Code of practice for determination of bearing capacity of shallow foundations. Bureau of Indian Standards, New Delhi, India

[Google Scholar](#)

38. BIS (2010) IS 2911(Part1/Sec2). Design and construction of pile foundations, concrete piles, bored cast in-situ concrete piles. Bureau of Indian Standards, New Delhi, India

[Google Scholar](#)

39. LabVIEWSignalExpress (2009) Getting started with LabVIEW signal express. National Instruments Corporation Austin, Texas, USA

[Google Scholar](#)

40. BIS (1981a) IS9716. Guide for lateral dynamic load test on piles. Bureau of Indian Standards, New Delhi, India

[Google Scholar](#)

41. Boominathan A, Ayothiraman R (2005) Dynamic behaviour of laterally loaded model piles in clay. Proc Inst Civil Eng Geotech Eng 158(4):207–215.
<https://doi.org/10.1680/geng.2005.158.4.207>

[Article](#) [Google Scholar](#)

42. Boominathan A, Ayothiraman R (2007) An experimental study on static and dynamic bending behaviour of piles in soft clay. Geotech Geol Eng 25(2):177.
<https://doi.org/10.1007/s10706-006-9102-7>

[Article](#) [Google Scholar](#)

43. Manna B, Baidya DK (2010) Nonlinear dynamic response of piles under horizontal excitation. J Geotech Geoenviron Eng 136(12):1600–1609.
[https://doi.org/10.1061/\(ASCE\)GT.1943-5606.0000388](https://doi.org/10.1061/(ASCE)GT.1943-5606.0000388)

[Article](#) [Google Scholar](#)

44. Boominathan A, Krishna Kumar S, Subramanian R (2015) Lateral dynamic response and effect of weakzone on the stiffness of full scale single piles. Ind Geotech J 45(1):43–50. <https://doi.org/10.1007/s40098-014-0106-6>

[Article](#) [Google Scholar](#)

45. Manna B, Baidya DK (2009) Vertical vibration of full-scale pile—analytical and experimental study. *J Geotech Geoenviron Eng* 135(10):1452–1461.

[https://doi.org/10.1061/\(ASCE\)GT.1943-5606.0000110](https://doi.org/10.1061/(ASCE)GT.1943-5606.0000110)

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