International Journal of Engineering Science Invention (IJESI)
ISSN (Online): 2319 – 6734, ISSN (Print): 2319 – 6726
www.ijesi.org ||Volume 7 Issue 6 Ver V || June 2018 || PP 80-92

Dynamic Analysis of Laterally Loaded Piles in Group

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Abstract*:This present paper studied the behaviour of the piles in grouparrangedin series subjected to dynamic load due to earthquake. Various combinations of group piles in series like 2 piles, 3 piles and 4 piles are considered for various spacing 2D, 3D, 4D, 5D and 6D, where D is the diameter of the pile. The pile foundation is assumed to be enclosed within cohesion-less soil and soil properties are considered from a live soil report and similarly the load applied is also considered from the same live project report. The models are analysed in the finite element method based software naming STAAD Pro. to obtain the responses such as deflection, axial force, shear force and bending moment for piles in group. While pile cap is analysed for bending moment in 'x' and 'y' direction. It is seen that deflection increases till a certain length of pile and then reduces as the length increases for all cases and it is also noticed that deflection is more for the closely placed piles. Similarly it is noticed that axial force increases as the length increases for all cases. However, bending moment and shear force decreases as the length of piles increases for all cases and maximum value isobserved for closely placed piles.*

Keyword: *Piles, Pile Cap, Laterally Loaded Piles, STAAD Pro, Deflection, Axial Force, Shear Force, Bending Moment, Plate Stress.*

Date of Submission: 15-06-2018 Date of acceptance: 30-06-2018

I. Introduction

A pile is basically a long cylinder of a strong material such as concrete that is pushed into the ground to act as a steady support for structures built on top of it. Pile foundations are used in the situations when there is a layer of weak soil at the surface. Pile foundation is required when the soil bearing capacity is not sufficient for the structure to withstand. This layer cannot support the weight of the building, so the loads of the building have to bypass this layer and be transferred to the layer of stronger soil or rock that is below the weak layer. And also, when a building has very heavy, concentrated loads, such as in a high-rise structure, bridge, or water tank.

A pile cap is a thick concrete mat that rests on concrete or timber piles that have been driven into soft or unstable ground to provide a suitable stable foundation. It usually forms part of the foundation of a building, typically a multi-story building, structure or support base for heavy equipment. The cast concrete pile cap distributes the load of the building into the piles. The pile cap works as a load transferring member which distributes the load of superstructure evenly on all the piles.In the recent years, a variety of approaches for predicting lateral load behaviour of piles have been developed, including linear subgrade reaction analysis, nonlinear subgrade reaction analysis, elastic continuum analysis and finite element analysis. The subgrade reaction analysis is based on Winkler's hypothesis, according to which, soil is replaced by a series of infinitely closely spaced, independent and elastic springs. In the elastic continuum analysis, the pile is represented as an infinitely thin linearly elastic strip, embedded in elastic soil media. Shear stresses developed at the pile soil interface are not taken into account. The finite element method enables a more rigorous solution to be achieved comparatively, as the pile is modelled more accurately. Also, heterogeneous soil conditions are readily and correctly modelled.

Lateral loads on piles are developed both by the superstructure and by the wave propagation through the soil. The dynamic loads due to the horizontal movement of the superstructures are mainly generated by wind effects, machine vibrations, impact of vehicles or boats; the loads due to the wave propagation is primarily because of earthquakes. Therefore, the total forces are the result of two types of interaction: an inertial one from the movement of the superstructure and a kinematical one from the soil motion.

II. Methodology

The primary aim of the present study is to analyse the piles in group under dynamic condition.

2.1 Data considered

Fig 2.1 shows the animated top view of the pile cases considered for the research study. This pile foundations are considered to be placed below a pier bearing service load on it.

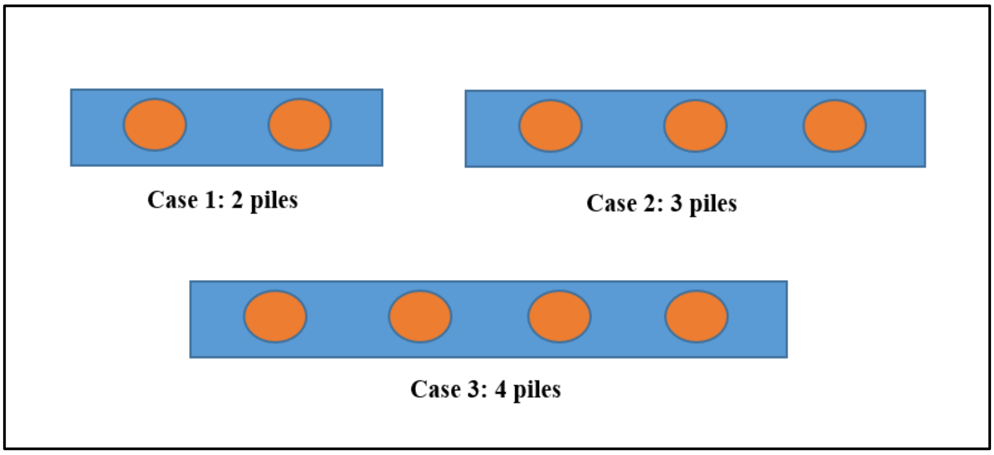


Fig 2.1 Animated top view of considered pile cases

The consideration for pile diameter with varying spacing between piles are explained below in Table 2.1. The length of pile is considered to be 10m in length from the pile – pile cap connection till the end of the pile.

Spacing	**2 Piles Diameter**	**3 Piles Diameter**	**4 Piles Diameter**
D	1m	0.8m	0.6m
2D	2 m	1.6 m	1.2 m
3D	3 m	2.4 m	1.8 m
4D	4 m	3.2 m	2.4 m
5D	5 m	4 m	3 m
6D	6 m	4.8 m	3.6 m

Table 2.1 Diameter variation as per spacing

The soil details considered for the analysis of the model is cohesion-less soil and properties considered are considered from the live project soil data which gives following details as
Spring coefficient – 3500 KN/m
Density – 20 KN/m^3

2.2 Modelling and analysis

The modelling is done in STAAD Pro. V8i software with the dimension taken under consideration. The model consists of 2 piles, 3 piles and 4 piles with pile spacing as 2D to 6D. Fig 2.2, Fig 2.3 and Fig 2.4 shows typical STAAD Pro. model for 2piles, 3piles and 4piles at spacing 2D. Similar models are been modelled for 2 piles, 3 piles and 4 piles for spacing 3D, 4D, 5D and 6D.

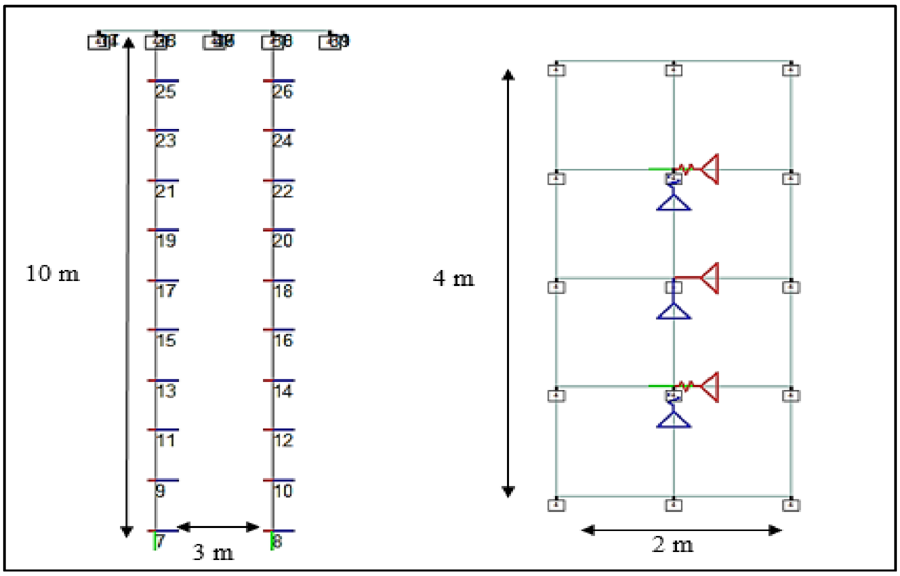


Fig 2.2 Details of 2 piles at spacing 2D

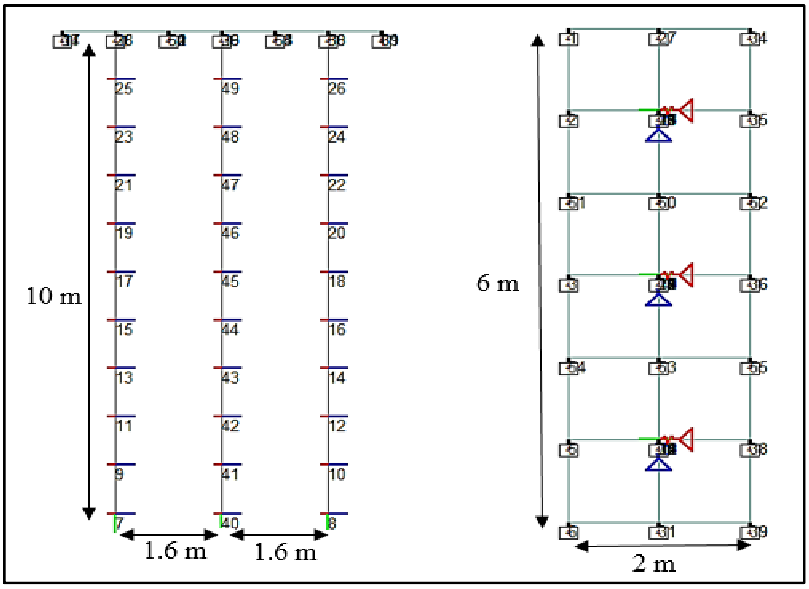


Fig 2.3 Details of 3 piles at spacing 2D

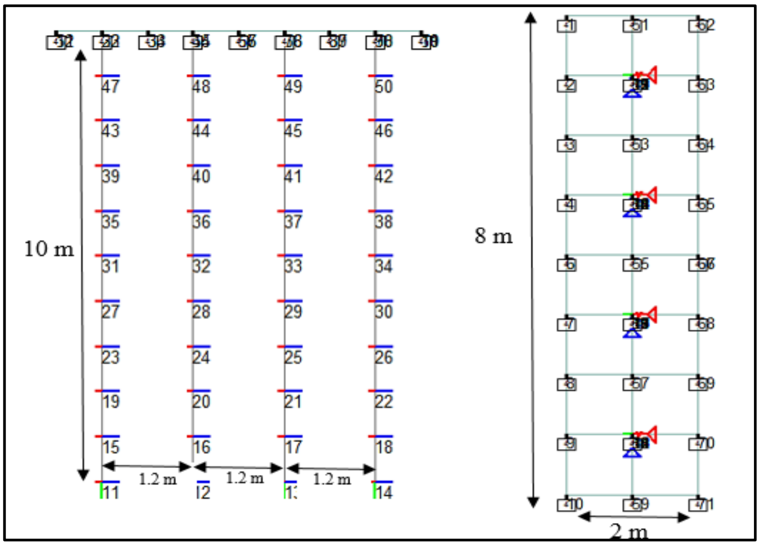


Fig 2.4 Details of 4 piles at spacing 2D

2.3 Load Application

The load applied on the STAAD Pro. model is been considered from the live project report. The following are the load applied on the models.

Seismic Load in x direction: Fx = 862 KN
Mz = 4811 KNm
Seismic Load in z direction: Fz = 79 KN
Mz = 1010 KNm
Self-weight + Dead Load: Fy = 2866 KN
Mz = 11447 KNm
Live Load: Fy = 480 KN
Mz = 620 KNm

2.4 Load Combination

The load combinations are considered as per IS 875(Part 5) - 1987 and IS 456 - 2000 and basic load combinations considered shown in Table 2.2.

LOAD COMBINATION
SELFWEIGHT+DEAD LOAD
LIVE LOAD
SEISMIC LOAD IN (+ X) DIRECTION
SEISMIC LOAD IN (+ Z) DIRECTION
SELFWEIGHT+DEADLOAD+LIVE LOAD
SELFWEIGHT+DEADLOAD+EARTHQUAKE LOAD(+X) DIRECTION
SELFWEIGHT+DEADLOAD+EARTHQUAKE LOAD(+X) DIRECTION
SELFWEIGHT+DEADLOAD+LIVELOAD+EARTHQUAKE LOAD(+X) DIRECTION
SELFWEIGHT+DEADLOAD+LIVELOAD+EARTHQUAKE LOAD(+Z) DIRECTION

Table 2.2 Load Combinations

III. Results And Discussion

Results obtained after analysis are mentioned below in graphs and tables format. The results for piles are considered for displacement, axial force, shear force and bending moment while for pile cap bending moment is considered for x and y direction. From the load cases in Table 2.2 the critical combination obtained that is Self-weight + Dead Load + Earthquake Load (+X) direction is been considered for all further result analysis.

3.1 Deflection details

3.1.1 For two 2, 3 and 4 piles

Table3.1 and Fig. 3.1 shows deflection values obtained by analysing 2 piles for 2D spacing. It can be seen that as the length of pile increases the deflection of pile also increases to certain length and then it again reduces for further length.

Table 3.1 Deflection value for 2 piles at 2D spacing

Length (m)	0	1	2	3	4	5	6	7	8	9	10
Deflection(mm)	0	4.50	7.57	9.49	10.52	10.89	10.80	10.41	9.85	9.19	8.51

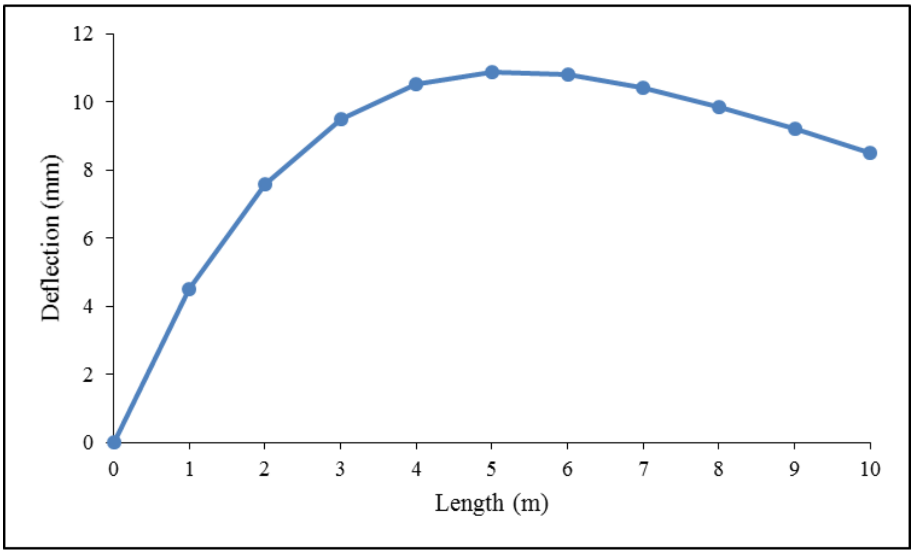


Figure 3.1 Deflection value for 2 piles at 2D spacing

Fig 3.2 and Fig 3.3 Shows the deflection value for 3 piles and 4 piles group arranged in series. It can be seen that central pile shows more deflection comparing to the corner piles for both 3 piles and 4 piles. For 3 piles at 2D spacing it is noticed that corner pile has 20% less deflection comparing to central pile; while for 4 piles spaced at 2D it is noticed that the corner piles deflects is 10% less than that of central piles.

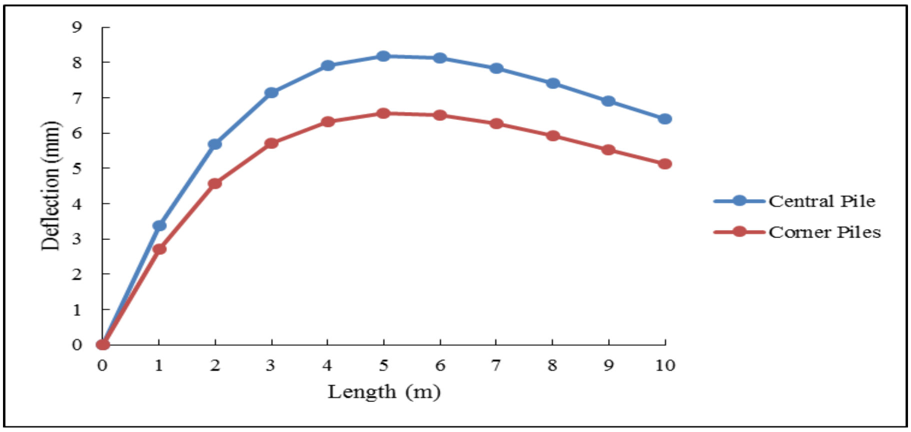


Fig 3.2 Deflection value for 3 piles at 2D spacing

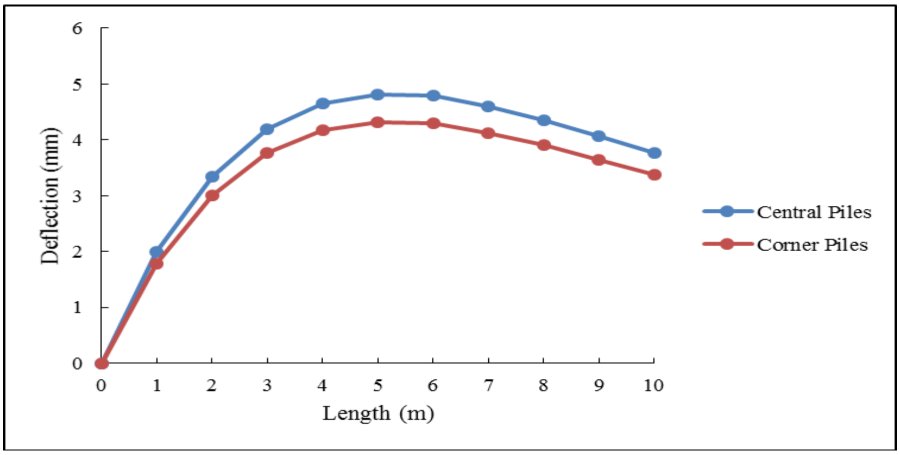


Fig 3.3 Deflection value for 4 piles at 2D spacing

Similar graphs and tables are studied for 2 piles, c piles and 4 piles at spacing 3D to 6D.

3.1.2 Deflection Comparison

All the values of 2 piles, 3 piles and 4 piles are compiled together to study the behaviour of deflection graph for all pile spacing from 2D to 6D as shown in Fig.3.4, Fig. 3.5 and Fig. 3.6 respectively. From Fig.3.4, the maximum deflection difference observed between 2D and 3D is about 18% and for 3D and 4D it is about 17%. It is observed that difference is same (16%) for both 4D and 5D and for 5D and 6D.It is seen that deflection increases significantly with increase in spacing. The increase in deflection is 19%, 37%, 57% and 82% respectively when compared the deflection at 2D spacing with 3D, 4D, 5D and 6D.

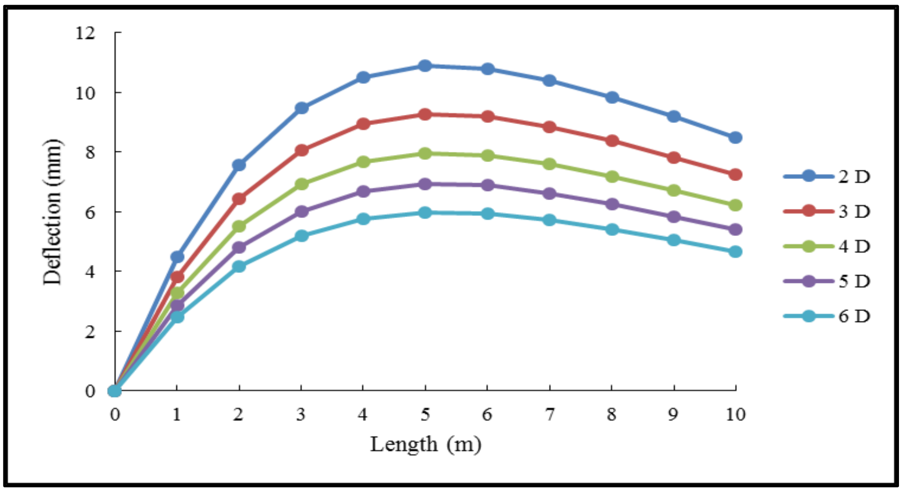
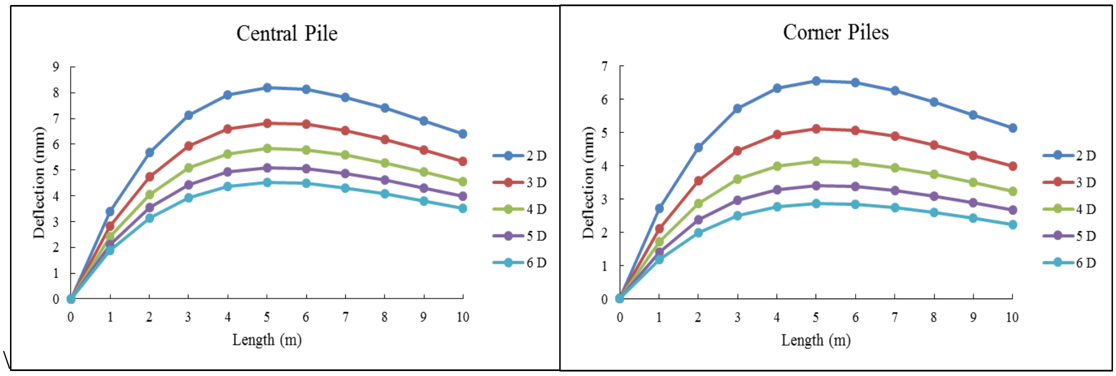


Fig 3.4 Deflection comparison for 2 piles for all spacing

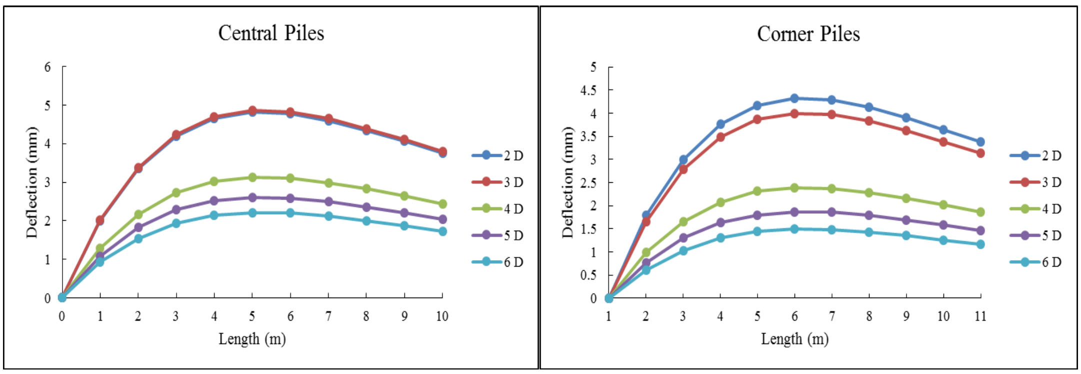
Fig 3.5 shows the comparative result for 3 piles for all spacing. For Fig 3.5(a) it can be noticed that the deflection difference between 2D and 3D is estimated approximately 20% while between 3D and 4D it is approximately 17% for 4D and 5D spacing it shows 14% and for 5D and 6D is 15. But while comparing 2D spacing with 3D, 4D, 5D and 6D it shows a percentage difference of 20%, 40%, 61% and 81% respectively. While Fig 3.5(b) explains that the deflection difference between 2D and 3D is estimated approximately 28% while between 3D and 4D it is approximately 24%. For 4D and 5D spacing it shows 21% and for 5D and 6D it is observed a difference of 19%. Deflection decreases with increase in spacing. If compare deflection at 2D spacing with 3D, 4D, 5D and 6D it is seen that percentage difference is 28%, 59%, 93% and 129% respectively for corner piles.Corner pile deflected more than the central piles.



(a) **(b)**

Fig 3.5 Deflection comparison for 3 piles for all spacing (a) Central pile and (b) Corner pile

Fig 3.6 shows the comparative study for 4 piles for all the spacing. The corner two piles shows similar deflection also the central two piles show same deflection but less than the corner piles. For central piles it can be seen that the 2D and 3D spacing overlap on each other showing marginal difference in deflection.Further, increase in spacing percentage difference between two consecutive spacing increases.



(a) **(b)**

Fig 3.6 Deflection comparison for 4 piles for all spacing (a) Central pile and (b) Corner pile

3.1.3 Maximum Deflection Comparison for all Pile cases

The maximum deflection for all spacingfor 2 piles and for3 piles and 4 piles at the centre is shown in the Fig.3.7. It can be seen that 2 piles shows more deflection than 3 piles and 4 piles for all the spacing. It shows that as the spacing increases the deflection value of piles reduces**.**The difference in maximum deflection for 2 piles and 3 piles is about 26% while for 3 piles and 4 piles are 48%. It can be observed that as spacing increases deflection decreases and also the percentage difference in deflectiondecreases.

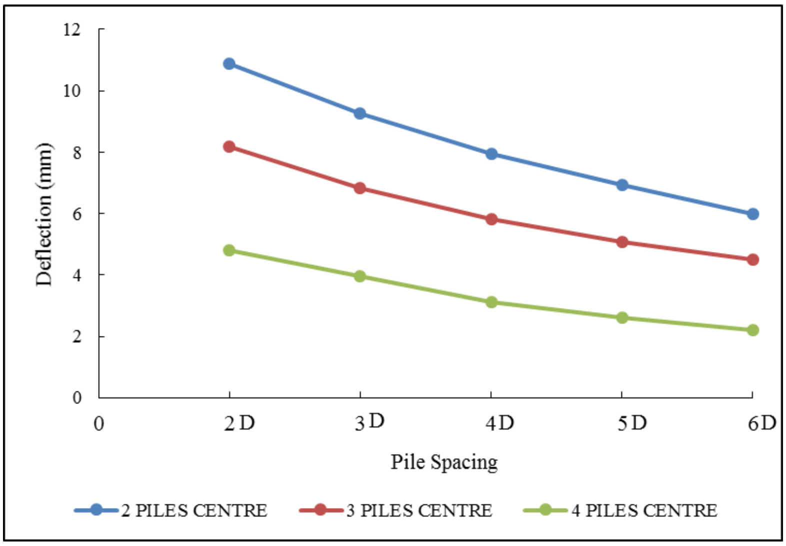


Fig 3.7 Maximum Deflection comparison for all piles

3.2 Axial force, Shear force and Bending moment

For the critical load case considered i.e. Self weight + Dead Load + Earthquake Load (+X) direction the axial force, shear force and bending moment are considered for all cases.

3.2.1 For 2 piles

The Fig 3.8 shows the variation of axial force throughout the pile length. It can be seen that for all the piles the axial force increases as the pile length increases from the pile-pile cap connection to the pile end. It is noticed that 2 piles with spacing 2D shows higher axial force comparing to that of 3D, 4D, 5D and 6D. Axial force difference between 2D and 3D is higher while the lowest difference is between 5D and 6D.

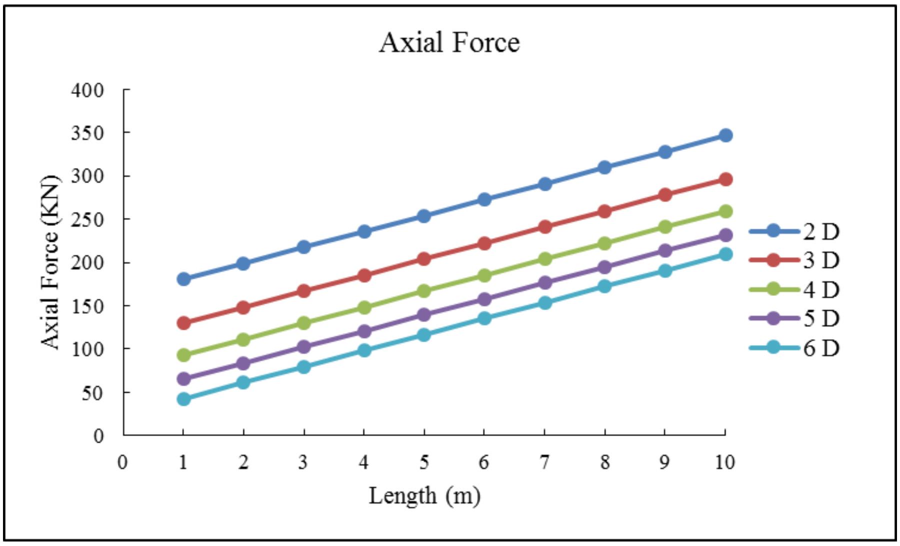


Fig 3.8 Axial force data for 2 piles for all cases

The Fig 3.9 shows the shear force over the length of pile from the pile – pile cap connection to the end of pile length. It is noticed that as the pile length increases the shear force decreases towards the end of the pile. Typical curve for shear force distribution can be seen for all the cases. The maximum shear force is observed for 2D spacing case while minimum for 6D spacing case.

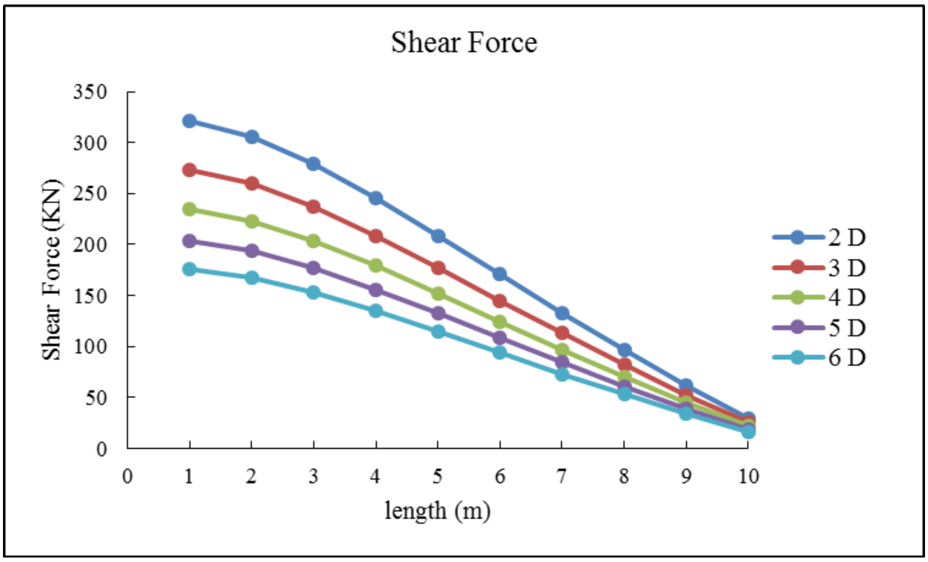


Fig 3.9 Shear force data for 2 piles for all cases

Fig 3.10 shows the bending moment over the length of the pile – pile cap connection to the end of pile length. It can be seen that the 2 piles at the pile – pile cap connection show more bending moment for spacing 2D and minimum value is observed for 6D. Bending moment decreases with increase in pile length.

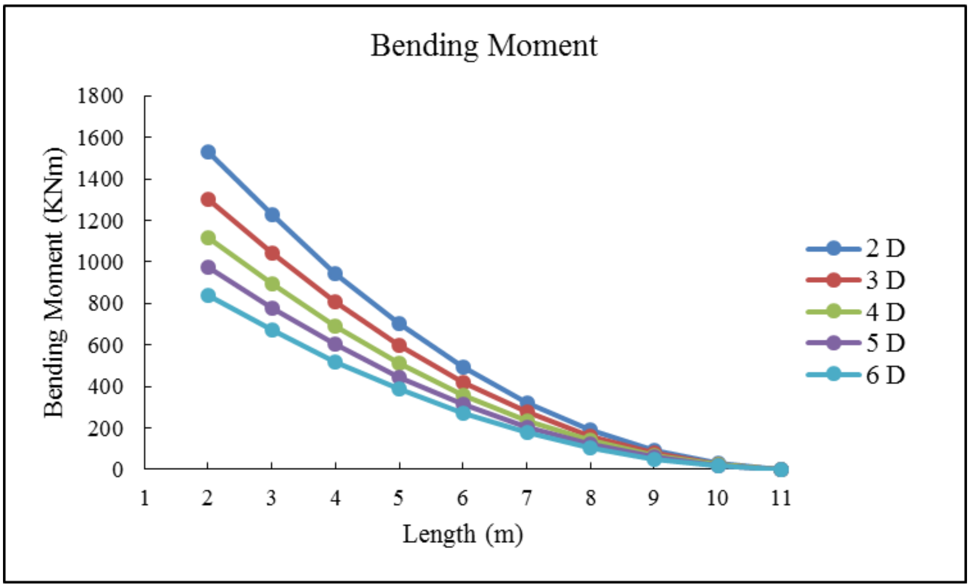
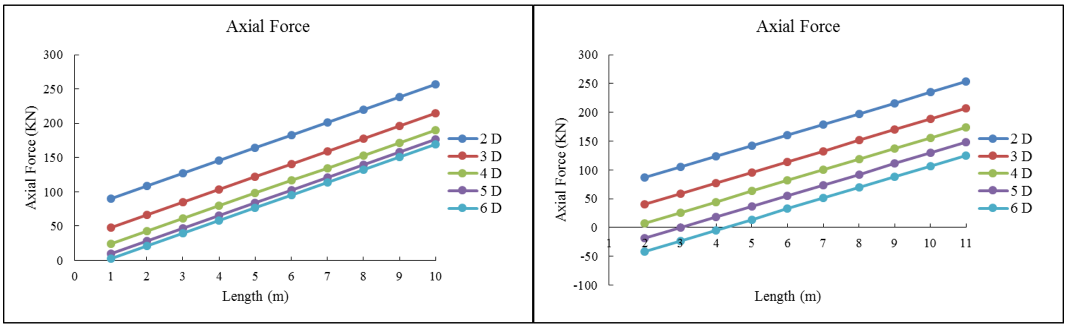


Fig 3.10 Bending Moment data for 2 piles for all cases

3.2.2For3 piles

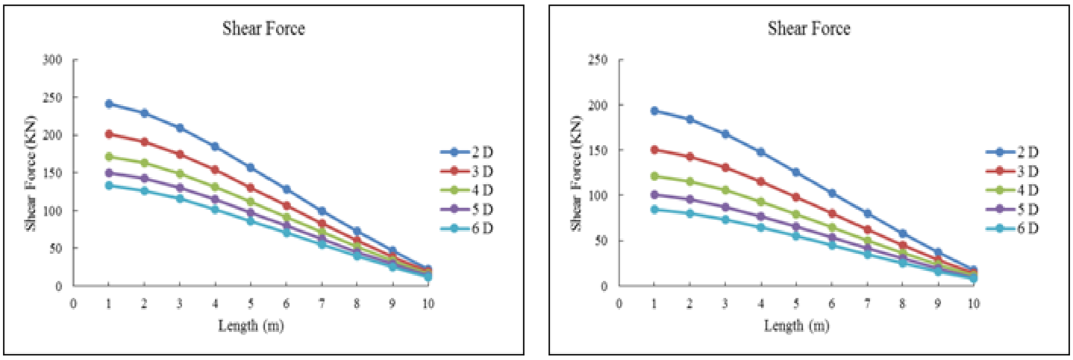
The Fig 3.11 (a) and (b) shows the axial force distribution over the pile length form pile – pile cap spacing to pile end for corner pile and central pile. . It can be seen that for all the piles the axial force increases as the pile length increases from the pile-pile cap connection to the pile end. It is noticed that 3 pileswith spacing 2D shows higher axial force comparing to that of 3D, 4D, 5D and 6D spacing. Axial force difference between 2D and 3D is higher while the lowest difference is observed between 5D and 6D.



(a) **(b)**

Fig 3.11 Axial force distribution over pile length for 3 piles (a) Central pile (b) Corner piles

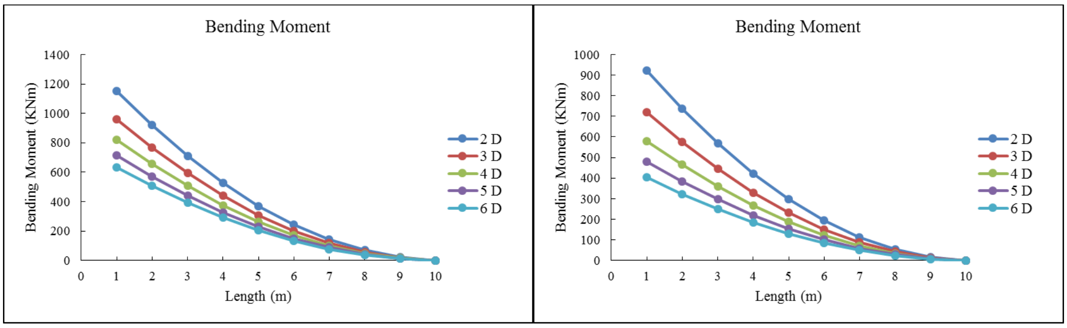
The Fig 3.12 (a) and (b) shows the shear force over the length of pile from the pile – pile cap connection to the end of pile for central piles as well as for corner piles. It is noticed that as the pile length increases the shear force decreases towards the end of the pile. Typical curve for shear force distribution can be seen for all the cases. The maximum curve is observed for 2D spacing case while minimum for 6D spacing.



(a) **(b)**

Fig 3.12 Shear force distribution over pile length for 3 piles (a) Central pile (b) Corner pile

Fig 3.13 (a) and (b) shows the bending moment distribution over the length of the pile form pile – pile cap connection to the pile end for both central pile and corner pile. It shows that as the length of pile increase bending moment decrease for both central and corner pile. The maximum bending moment is seen when the spacing between axes is 2D and minimum when spacing is 6D for both central and corner.

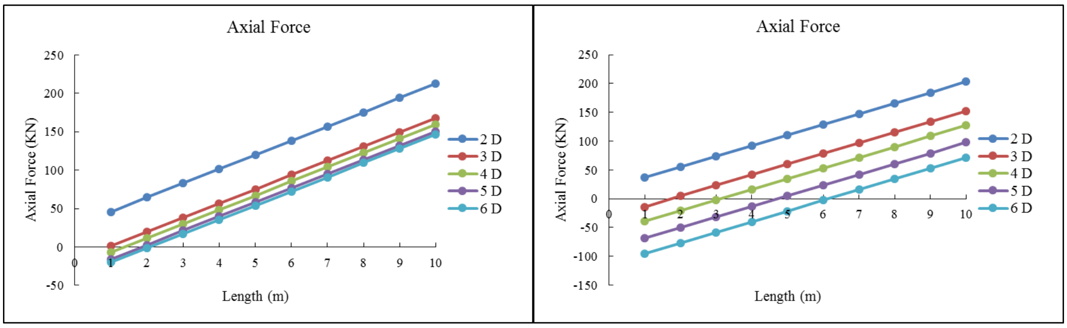


(a) **(b)**

Fig 3.13 Bending moment distribution over pile length for 3 piles (a) Central pile (b) Corner pile

3.2.3For4 piles

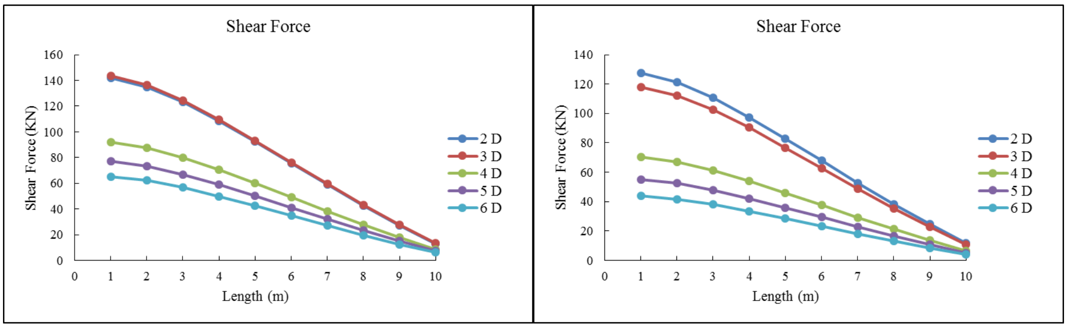
The Fig 3.14 (a) and (b) shows the axial force distribution for various spacing of corner pile and central pile. It can be seen that for all the piles the axial force increases as the pile length increases top to the pile end. It is noticed that 4 pileswith spacing 2D showshigher axial force comparing to that of 3D, 4D, 5D and 6D. Axial force difference between 2D and 3D is higher while the lowest difference is noticed for 5D and 6D.



(a) (b)

Fig 3.14 Axial force distribution over pile length for 4 piles (a) Central pile (b) Corner pile

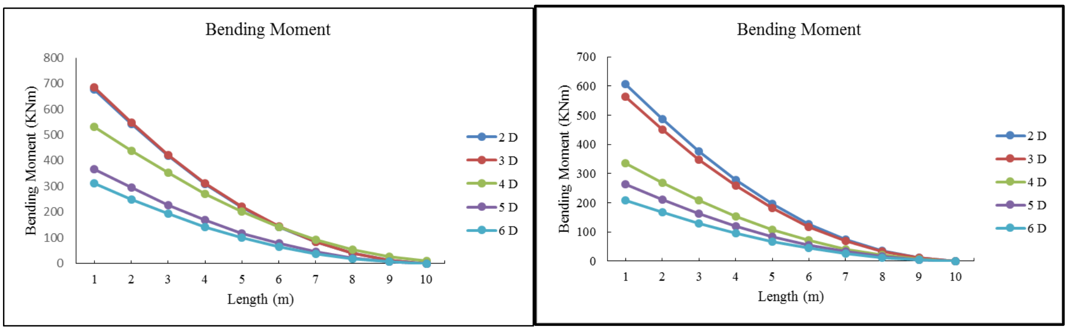
The Figure 3.15 (a) and (b) shows the shear force over the length of pilefor central piles as well as for corner piles. It is noticed that as the pile length increases the shear force decreases towards the end of the pile. Typical curve for shear force distribution can be seen for all the cases but for the central piles there is marginal difference in shear force for spacing 2D and 3D.



(a) (b)

Fig 3.15 Shear force distribution over pile length for 4 piles (a) Central pile (b) Corner pile

Fig 3.16 (a) and (b) shows the variations of bending moment for various spacing of 4 piles in group for central pile and corner piles both. It shows that as the length of pile increase bending moment decrease for both central and corner pile. There is not much variation in bending moment for both corner pile as well as for central between spacing 2D and 3D. The maximum bending moment is seen when the spacing is 2D and minimum when spacing is 6D for both central and corner.



(a) (b)

Fig 3.16 Bending Moment distribution over pile length for 4 piles (a) Central pile (b) Corner pile

3.3 Plate Stress

Fig 3.17 shows the distribution of plate stresses due to the load acting on the pile cap at load behaviour due to increasing spacing between the piles.

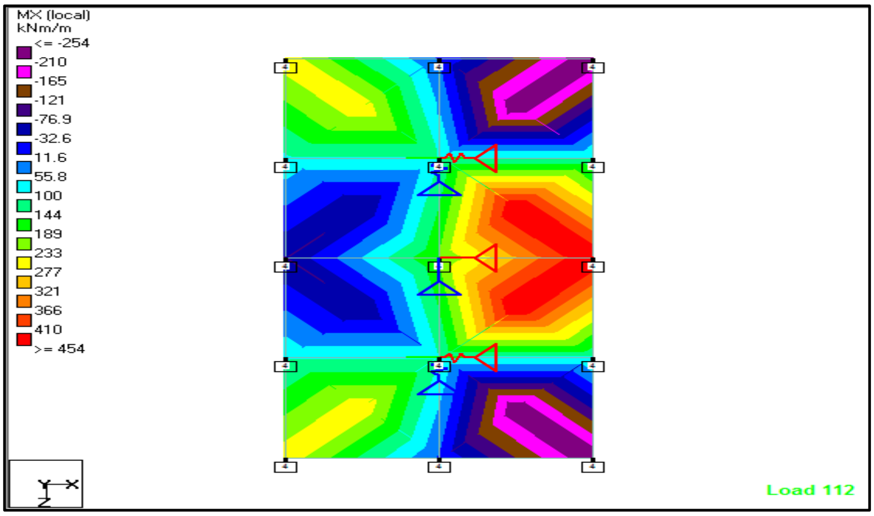
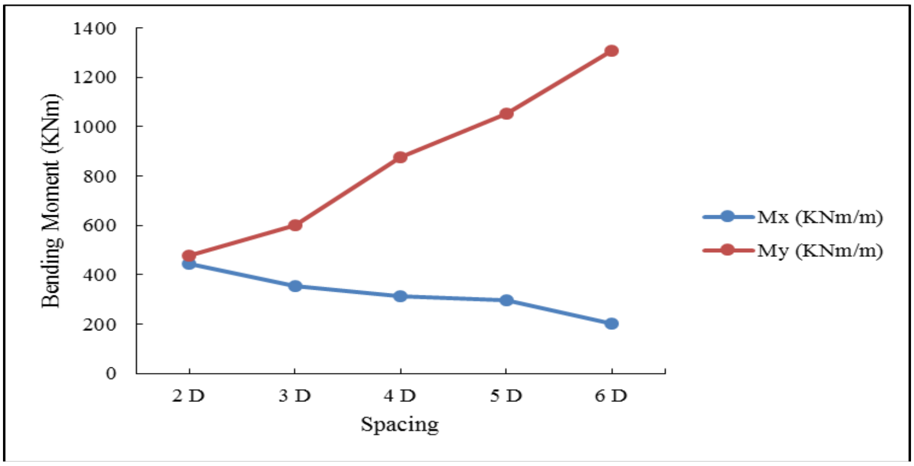
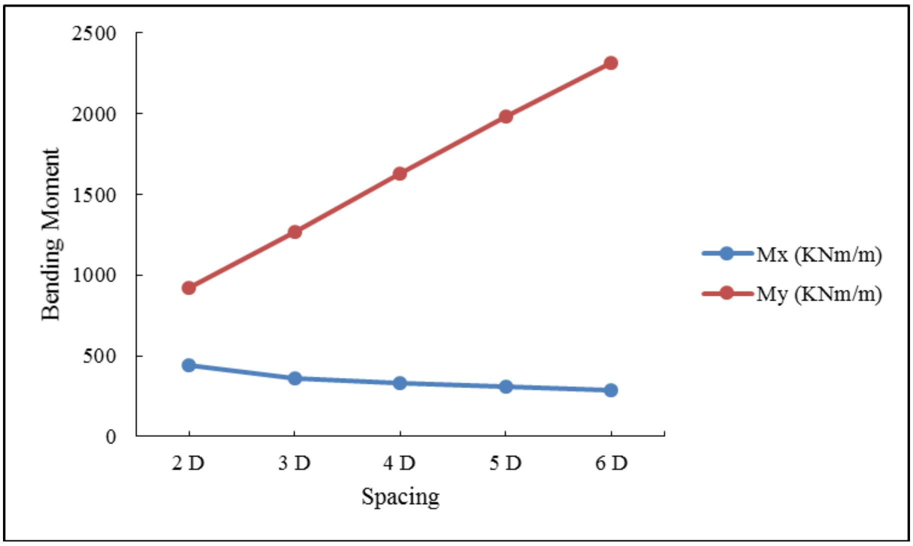


Fig 3.17 Stress distribution on Pile cap

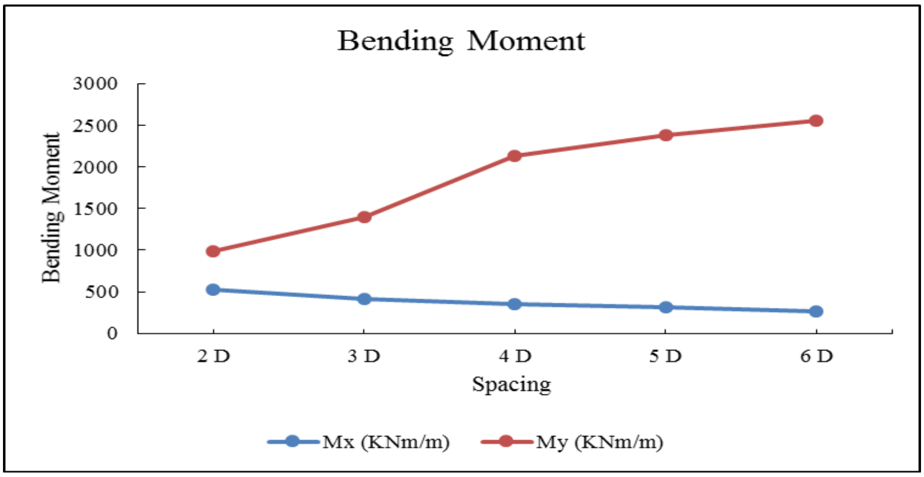
Fig 3.18 shows the variations of bending moment in x and y direction for different spacing. For bending moment in x-direction it is noticed that as the spacing between the pile increases the bending moment decreases while that for bending moment in y direction it is noticed that bending moment increases as the spacing between the piles increases for all 2 piles, 3 piles and 4 piles.



(a)



(b)



(c)

Fig 3.18 Maximum Bending Moment for Pile cap (a) 2 piles, (b) 3 piles and (c) 4 piles

IV. Conclusions

1. For 2 piles, 3 piles and 4 pilesin group arranged in series, it is observed that the deflection increases up to certain length and then it decreases for the remaining length.
2. It is seen that for 2 piles for spacing 2D the deflection is maximum compare to the other spacing and the value of deflection decreases as the spacing between the piles increases.
3. Similar observation is noticed for 3 piles and 4 piles. But for 3 piles and 4 piles the deflection is observed more for central pile than that of corner piles.
4. For 4 piles, it is observed that for spacing 2D and 3D the difference in deflection is marginal whereas for other spacing difference is notable.
5. The maximum deflection decreases as the spacing increases for 2 piles, 3 piles and 4 piles in group and the rate of decrease of deflection is more in case of 3 piles and 4 piles.
6. The axial force increases with increase in length of pile and maximum axial force occurs at spacing 2D and minimum at 6D for 2 piles. Similar observation is noticed for 3 piles and 4 piles.
7. Shear force decreases with increase in length of pile for all spacing. The percentage decreases in shear force is more at top and reduces significantly at bottom of pile.
8. Bending moment decreases with increase in length of the pile for all spacing. For spacing 2D and 3D the bending moment difference is marginal in case of 4 piles.
9. It is seen that the maximum bending moment in pile cap in x direction decreases and in y direction increases with increase in spacing for all the piles in group.

References

[1]. B. Brown and W. Michael (1987)," Cyclic Lateral Loading of a Large-Scale Pile Group", J.Geotech. Engrg.113:1326-1343.
[2]. D. Badoni and N. Makris (1996)," Nonlinear' response of single piles under lateral inertial and seismic loads", Soil Dynamics and Earthquake Engineering, 15:29-43.
[3]. F. Abdrabbo and K. Gaaver (2012), "Simplified analysis of laterally loaded pile groups", Alexandria Engineering Journal, 51: 121–127.
[4]. F. Dezi, S. Carbonari, A. Tombari and G. Leoni (2012)," Soil-structure interaction in the seismic response of an isolated three span motorway overcrossing founded on piles", Soil Dynamics and Earthquake Engineering, 41:151–163.
[5]. G. Anoyatis, R. Laora and A. Lemnitzer (2017)," Dynamic pile impedances for fixed-tip piles", Soil Dynamics and Earthquake Engineering. 97:454–467.
[6]. H. Poulos (1976)," Behaviour of Laterally Loaded Group Piles Near A Cut or A Slop", Australian Geomechanics Journal.
[7]. K. Gaaver (2006), "Behavior of laterally loaded piles in cohesionless soils", The Tenth EastAsia–Pacific Conference on Structural Engineering and Construction.
[8]. K. Thadapaneni, S. Venkata and R. Teja Gandhi (2017)," Analysis of pile foundation Simplified methods to analyse the pile foundation under lateral and vertical loads", International Journal of Engineering Development andResearch, 5(3).
[9]. K. Chatterjee, D. Choudhury and H. Poulos (2015)," Seismic analysis of laterally loaded pile under influence of vertical loading using finite element method", Computers and Geotechnics. 67:172–186.
[10]. L Hazzar, M. Hussien and M. Karray (2017), "Influence of vertical loads on lateral response of pile foundations in sands and clays", Journal of rock mechanics andgeotechnical engineering, 291-304.
[11]. M. Ashour and G. Norris (2002)," Lateral loaded pile/shaft response in liquefied soil and anticipated lateral soil spreading", D. Frechette, K. Walsh, W. Houston, Review ofdesign methods and parameters for laterally loaded groups of drilled shafts, Deep Found.1261–1274.
[12]. M. Naggar and M. Novak (1996)," Nonlinear analysis for dynamic lateral pile response", Soil Dynamics and Earthquake Engineering, 165(4): 233-244.
[13]. M. Khari, K. Kassim, and A. Adnan (2014)," Kinematic bending moment of piles under seismic motions", Asian Journal of Earth Science. 7(1) 1-9.

[14]. M. Khari, K. Kassim, and A. Adnan (2013), "An Experimental Study on Pile Spacing Effects under Lateral Loading in Sand", The scientific worldjournal.
[15]. M. Khari, K. Kassim, and A. Adnan (2014)," Development of p-y Curves of Laterally Loaded Piles in Cohesionless Soil", ScientificWorldJournal..
[16]. M. Sánche and J. Roesset (2012)," Evaluation of models for laterally loaded piles", Computers and Geotechnics.
[17]. M. Hajialilue-Bonab, D. Levacher, J. Chazelas and A. Kaynia (2014)," Experimental study on the dynamic behavior of laterally loaded single pile", SoilDynamic Sand Earthquake Engineering. 66:157–166.
[18]. M. Murugan, C. Natarajan and K. Muthukkumaran (2011)," Behavior of Laterally Loaded Piles in Cohesionless Soils", International Journal of Earth Sciences and Engineering, ISSN0974-5904, Volume 04, No 06 SPL, pp. 104-106.
[19]. P. Ooi, B. Chang; and S. Wang (2004)," Simplified Lateral Load Analyses of Fixed-Head Piles and Pile Groups", J. Geotech. Geoenviron. Eng.130:1140-1151.
[20]. R. Salgado, F. Tehrani and M. Prezzi (2014)," Analysis of laterally loaded pile groups in multi-layered elastic soil", Computers and Geotechnics. 62:136–153.
[21]. R. Wang, P. Fu, J. Zhang (2016)," Finite element model for piles in liquefiable ground", Computers and Geotechnics. 72:1–14.

Kushal M. Panchaland "Dynamic Analysis of Laterally Loaded Piles in Group "International Journal of Engineering Science Invention (IJESI), vol. 07, no. 06, 2018, pp 80-92