International Journal of Applied Engineering and Technology ISSN: 2277-212X (Online)
An Online International Journal Available at http://www.cibtech.org/jet.htm
2012 Vol. 2 (3) July-September, pp.36-48/Sharma et al.
Research Article

BEHAVIOUR OF COMPOSITE PILED RAFT FOUNDATION WITH INTERMEDIATE CUSHION IN LAYERED SOIL UNDER SEISMIC FORCES

***V.J. Sharma, S.A. Vasanvala and C.H. Solanki**
Applied Mechanics Department, Sardar Vallabhai National Institute of Technology, Ichchhanath, Surat-395007, Gujarat, India
**Author for Correspondence*

ABSTRACT
In order to mobilize shallow soil to participate in the interaction of piled raft foundation sufficiently, the concept of piled raft has been modified to new type of foundation named composite piled raft. In the system of composite piled raft, the short piles made of flexible materials were used to strengthen the shallow soft soil, while the long piles made of relatively rigid materials were used to reduce the settlements and the cushion beneath the raft was used to redistribute and adjust the stress ratio of piles to subsoil. Finite element method was applied to study the behaviour of this new type of foundation subjected to seismic forces. This paper focuses on behaviour of various components of foundation system such as long pile, short piles and subsoil under seismic force (Koyna, 1967) in layered soil related to Surat city geological condition. A comparative study is done to understand the effect of cushion on axial stresses, shear stresses and shear forces along piles and soil beneath the raft.

Key Words: *Piles, Raft, Foundation, Analysis*

INTRODUCTION
In traditional foundation design, it is customary to consider first the use of shallow foundation such as a raft (possibly after some ground-improvement methodology performed). If it is not adequate, deep foundation such as a fully piled foundation is used instead. In the former, it is assumed that load of superstructure is transmitted to the underlying ground directly by the raft. In the latter, the entire design loads are assumed to be carried by the piles. In recent decades, another alternative intermediate between shallow and deep foundation, what is called piled raft foundation or settlement reducing piles foundation, has been recognized by civil engineers. The concept of piled raft foundation was firstly proposed by Davis and Poulos in 1972, since then it has been described by many authors, including Burland *et al.*, (1977), Cooke (1986), Chow (1987), Randolph (1994), Horikoshi and Randolph (1996), Ta and Small (1996), Kim *et al.*, (2001), Poulos (2001), and many others . Now the piled raft concept has been used extensively in Europe and Asia. In this concept, piles are provided to control settlement rather than carry the entire load. Piled raft foundation has been proved to be an economical way to improve the serviceability of foundation performance by reducing settlement to acceptable levels. The favorable application of piled raft occurs when the raft has adequate loading capacities, but the settlement or differential settlement exceed allowable values. Conversely, the unfavorable situations for piled raft include soil profiles containing soft clays near the surface, soft compressible layers at relatively shallow depths and some others. In the unfavorable cases, the raft might not be able to provide significant loading capacity, or long-term settlement of the compressible underlying layers might reduce the contribution of raft to the long-term stiffness of foundation. However, most of economically developed cities, especially in Shanghai Economic Circle of China, are located in coastal areas. In these areas, the piled raft concept is unfavourable as mentioned above because building construction often meets with deep deposit soft soil. In order to take advantage of piled raft foundation, civil engineers have developed many methods to practice it in China. Based on the engineering practices, the authors Liang *et al.*, (2003) developed the concept of piled raft foundation to long-short composite piled raft foundation with intermediate cushion (For short as ‘‘composite piled raft’’) as is shown schematically in Fig. 1 In this new type of foundation, short piles made of relatively flexible materials such as soil–cement columns or sand–gravel columns (also called sand–stone columns in China), etc. are applied to improve the bearing capacity of shallow natural subsoil; the long piles made of relatively rigid materials such as reinforced concrete are embedded in deep stiff

clay or other bearing stratum to reduce the settlement; and the cushion made of sand–gravel between the raft and piles plays an important role in mobilizing the bearing capacity of subsoil and modifying load transfer mechanism of piles. The advantages of different ground-improvement methodologies may be used fully.

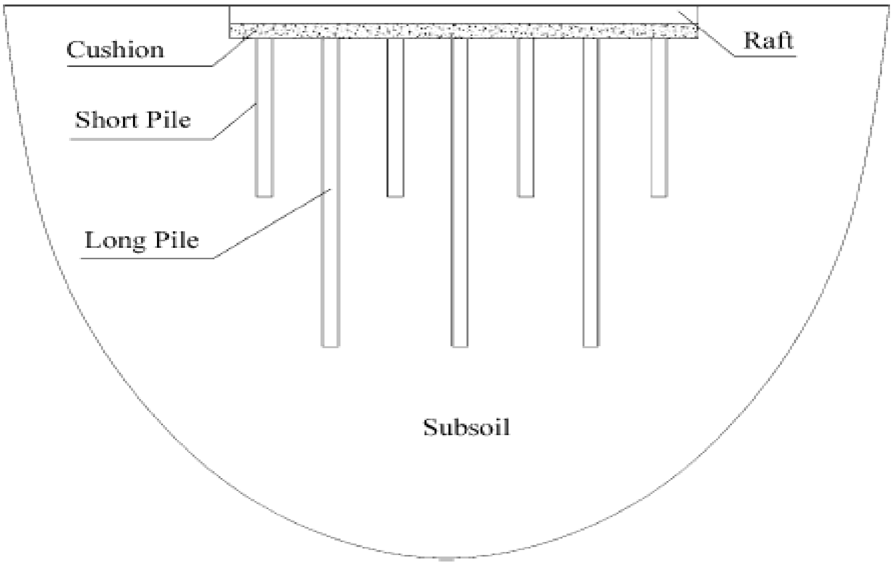


Figure 1: Sketch of composite piled raft foundation

This paper emphasizes on effect of horizontal force on piled raft foundation in seismically active zone . A comparison is done between composite pile raft foundation with cushion and without cushion under seismic force. The dynamic analysis was carried out for earthquake Koyna 1967 considering Surat city geological conditions .The parameters of study includes effect of horizontal shear forces , vertical stresses at head of piles and subsoil and displacement of raft and piles after inclusion of cushion.

MATERIALS AND METHODS

In this part of the paper model of composite piled raft foundation system which has been successfully validated and from which results for general effect of cushion on behavior of composite Piled raft foundation under axial load has been obtained is checked under seismic forces. The fig. 2 shown below gives clear idea of the model used for dynamic analysis. The model consists of 2.7m x 2.7m X 0.5m square raft resting on 15mX0.45mX0.45m long R.C.C pile at the centre surrounded by four 5.4m X0.45mX0.45m short piles (soil-cement columns).A cushion of sand gravel 0.3m thick is introduced between raft and piles.

Table 1: Parameters of materials for seismic + gravity loading in layered soil

Material	Long piles	Short piles	Cushion	Raft
Elastic modulus/Mpa	$E_{p1} = 10^4$	$E_{p2} = 200$	E_m=25	E_c= 3x10^4
Poisson's ratio	μ_{p1}=0.2	μ_{p2}=0.3	μ_m=0.3	μ_c=0.2
Unit weight KN/m^3	25	18	17	25

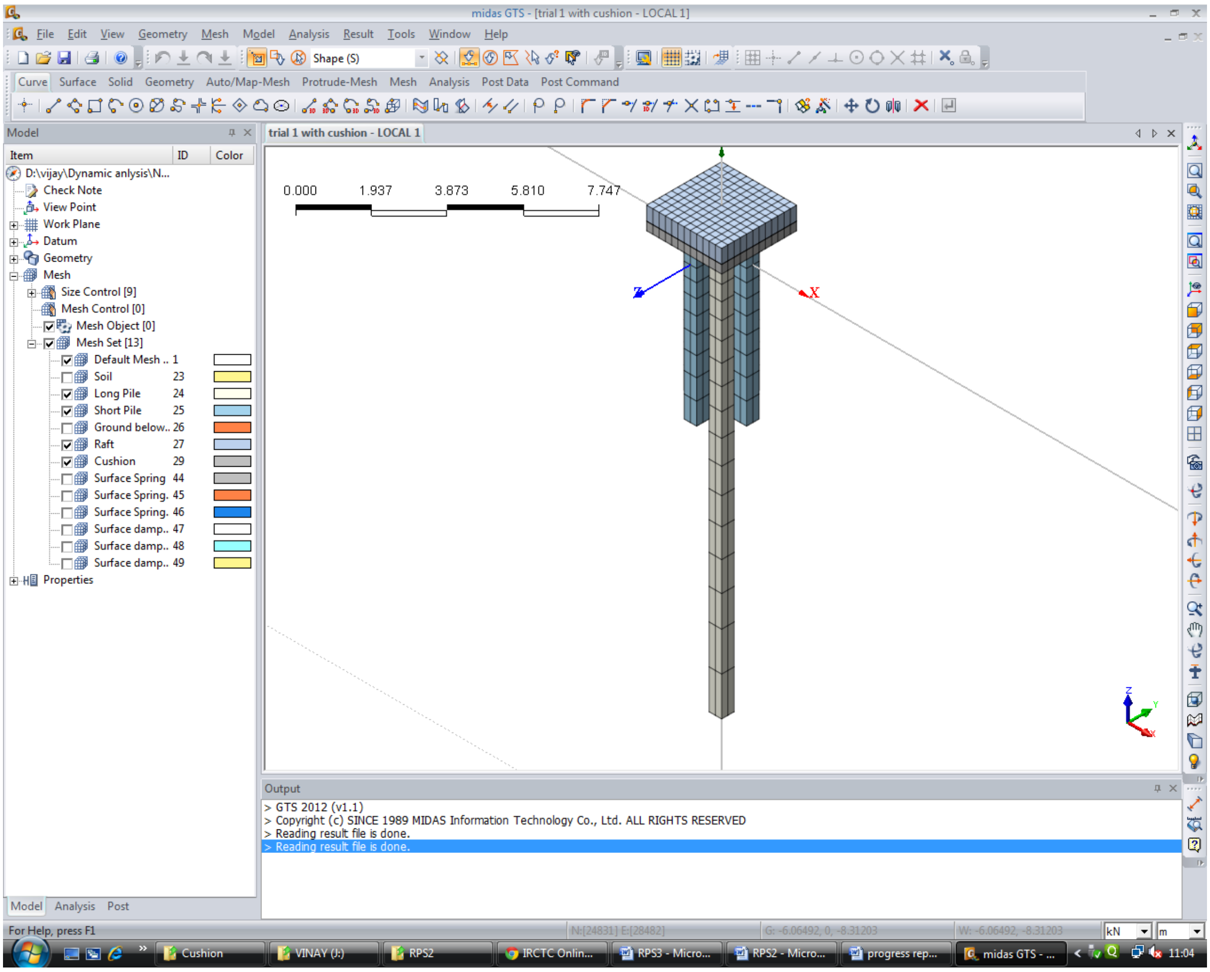


Figure 2: Three Dimensional models used for study under seismic forces.

The parameters used for analysis are enlisted below in tab.1 The values for subsoil is not presented in the table, as subsoil consists of four layers of different soil properties, and is represented in detail in tab .2.

Table 2 given below represent geological stratification of Surat city. The table presents generalized data based on soil investigation report on Urea Plant Kribhco unit-III Surat (1995) and forging shop at L & T limited. West Hazira complex, district Surat(2009).The water table exists at 8-10m below the ground level.

Table 2: Properties of stratified soil

Soil type	Depth (m)	Elastic modulus/Mpa	Poisson's ratio	Unit weight KN/m^3
Clayey Soil(CH or CI)	0-5	5	0.40	14.0
Silty Sand (SM)	5-10	40	0.35	15.5
Medium to fine well graded sand (SW)	10-17	50	0.35	17.0
Highly plastic clay(CH)	17-45	45	0.35	16.5

Before carrying out Time history analysis, Eigen value analysis was done. Sub grade reactions coefficients were calculated both in horizontal and vertical directions. Only horizontal sub grade reactions coefficients are calculated for upper three layers and applied along lateral boundary in both X and Y –direction. Both vertical reaction coefficients and horizontal reaction coefficients are

Research Article

obtained for bottommost layer and are applied along lateral and bottom boundary. The formulae used for the calculations of the horizontal and vertical reaction coefficients were as follow:

Vertical reaction coefficients: $K_v = K_{vo} *(B_v/30)^{-3/4}$ (kgf/cm^3) (3.1)

Horizontal reaction coefficients: $K_h = K_{ho} *(B_h/30)^{-3/4}$ (kgf/cm^3) (3.2)

Here, $K_{vo} = \alpha\ E_o/30 = K_{ho}$, $B_v = \sqrt{A_v}$, $B_h = \sqrt{A_h}$ (3.3)

Where α is scalar parameter depends on types of test conducted to find E_o.

A_v is area for which vertical reaction coefficient was calculated.

A_h is area for which horizontal reaction coefficient was calculated.

The values of K_h and k_v calculated from eqns. 3.1, 3.2 and 3.3 for different layers for no cushion case are tabulated below:

Table 3: K_v and K_h values for no cushion case

Soil layers	Horizontal reaction coeff.(K_h) KN/m^3	Vertical reaction coeff.(K_v) KN/m^3
Layer 1	1612.0	----------
Layer 2	12645.0	----------
Layer 3	14850.5	---------
Layer 4	7607.3	5885.3

The horizontal reaction coefficient was applied along the vertical boundary of the model whereas the vertical reaction coefficient was applied at the base of the model as surface springs and Eigen value analysis was carried out. There are no major changes in case of cushion except for K_h value in upper layer as cushion is introduced between piles and raft in upper subsoil layer. The value of K_h becomes 1578.1 KN/m^3 whereas rest remains the same.After Eigen value analysis dampers were applied to the model for which following damper calculation was done.

About P-wave, $C_P = \sqrt{(\lambda + 2G)\rho}$ (3.4)

S-Wave, $C_s = \sqrt{G * \rho}$ (3.5)

Here $\lambda = \nu * E / (1+\nu)(1-2\nu)$ (3.6)

$G = E/(1+2\nu)$ (3.7)

Where λ =Volumetric elastic Modulus (tonf/m^2)

G= Shear elastic Modulus (tonf/m^2)

E= Elastic Modulus

ν= Poisson's ratio

A= Section Area.

Using eqns 3.4, 3.5, 3.6, 3.7 dampers are calculated for different soil layers and applied along lateral boundaries for upper three layers. For bottommost layer the dampers are applied along lateral and bottom boundary as well. The values for damper calculation at different soil layers are tabulated below.

Table 4: C_p and C_s values from damper calculation

Soil layers	C_p KN*sec/m	C_s KN*sec/m
Layer 1	123.65	50.48
Layer 2	318.5	153.0
Layer 3	372.8	179.1
Layer 4	348.4	167.3

The values in above tab.4 are applied to both cushion and no cushion case.Time histories of two earthquakes were applied on the model with scale factor of 1 along X-axis and 0.33 along Y and Z-axis. The comparison was done with cushion and without cushion considering horizontal shear forces and axial stresses. Also displacement of raft, long pile, short piles and cushion was checked for cushion case.

RESULTS AND DISCUSSION

The behavior of composite piled raft foundation under seismic forces was studied by applying 1967 Koyna earthquake and results for horizontal shear force; vertical stresses on piles and subsoil were compared for cushion and no cushion case. Also displacement of raft, cushion and piles were analyzed for cushion case. The results are obtained at peak ground acceleration for all the cases. The results are extracted from contour daigrams at the centre of piles throughout its length and below the raft till bottom in case of subsoil.

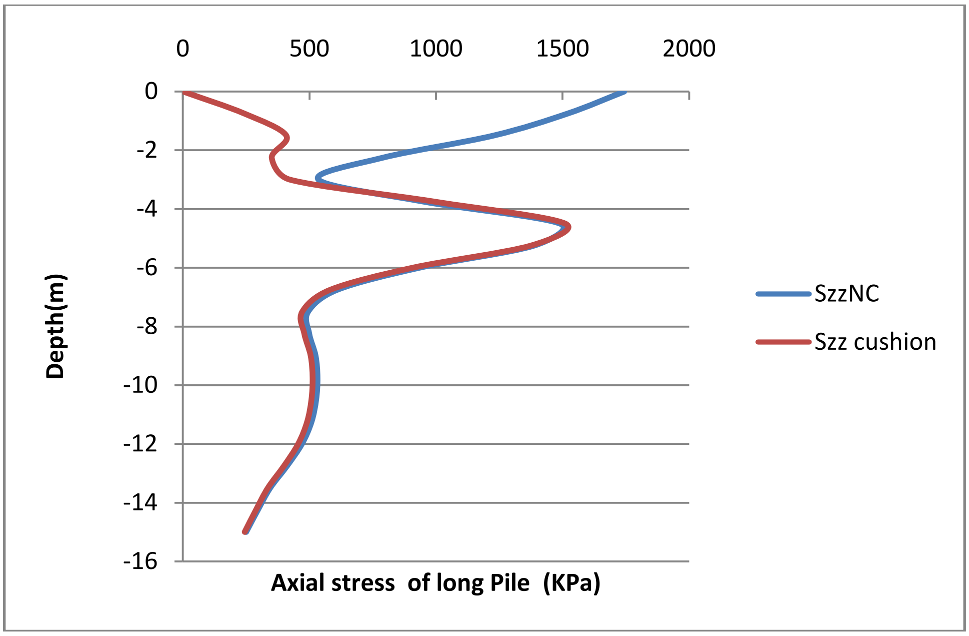


Figure 3: Effects of cushion on load transfer mechanism for long pile under Koyna 1967 (layered soil)

The graph above in fig. 3 is extracted from the contour of axial stresses for both cushion and no cushion case along long piles. The contour diagram shows that for no cushion case the tension is developed at the head and at the depth of 4.5m , however this tension totally diminished at the head by entering cushion between raft and piles. Also its visible from the graph in fig. 3 extracted from the contour diagrams that long pile is under tension due to lateral earthquake forces which reduces as depth of the pile increases for both cushion and no cushion case.

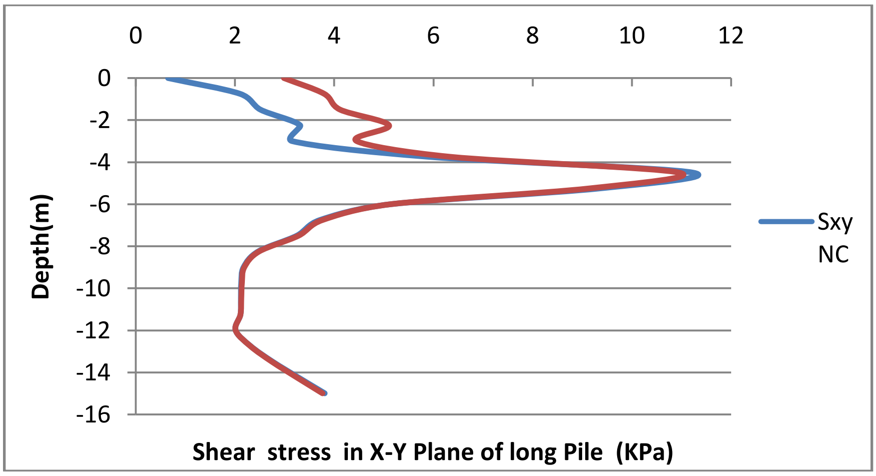


Figure 4: Effects of cushion on S_{xy} distribution along long pile under Koyna 1967 time history (layered soil)

Research Article

The contour diagrams obtained shows deformed + undeformed behaviour of long pile under seismic excitation. The graph plotted from contour diagram shows that for no cushion case the S_{xy} are maximum at the depth of 4.5m; however this shear stress reduces as the depth of long pile increases. The shear stress increases at the head for cushion case with maximum at 4.5m depth of long pile. However it is clear from the graph in fig .4 that S_{xy} beyond 4.5 m reduces along the depth of pile with slight Increase at the bottom.

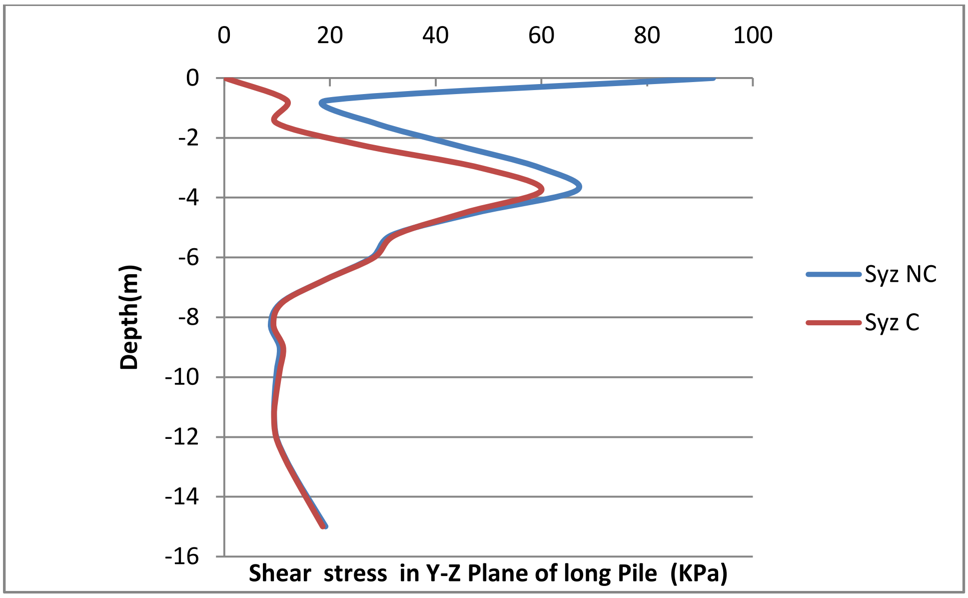


Figure 5: Effects of cushion on S_{yz} distribution along long pile under Koyna 1967 time history (layered soil)

The deformed + undeformed behavior of long pile under seismic excitation can be checked from contours of S_{yz} in Midas GTS. The contour diagram shows that for no cushion case the shear force S_{yz} is addressed maximum at the head and at the depth of 3.75m , however this shear stress is totally diminished at the head by entering cushion between raft and piles. Also its visible from the fig. 5 that S_{yz} has same behavior beyond 3.75m depth along the long pile which becomes constant for both cushion and no cushion case.

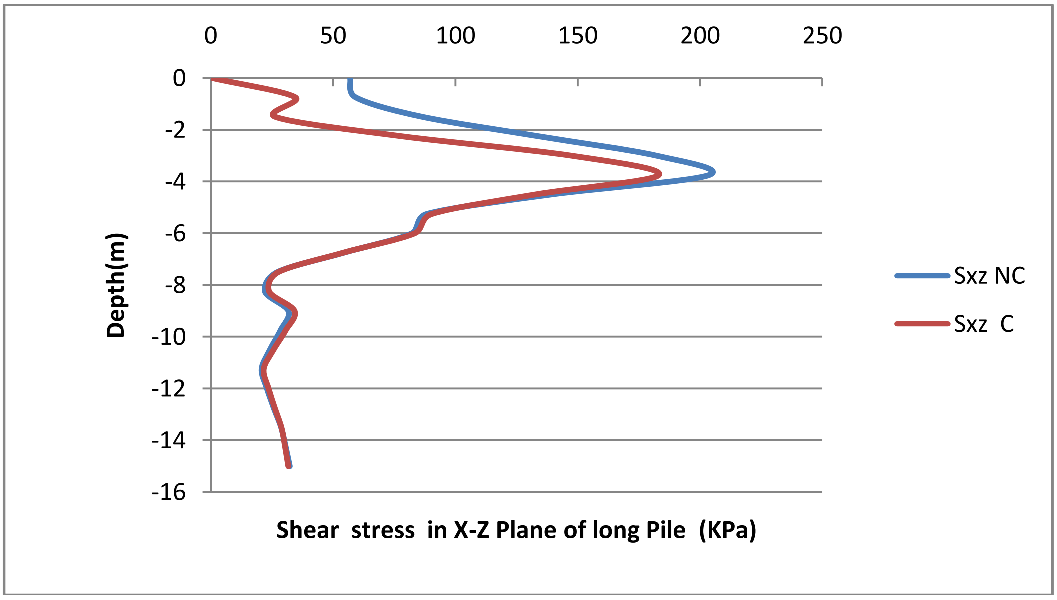
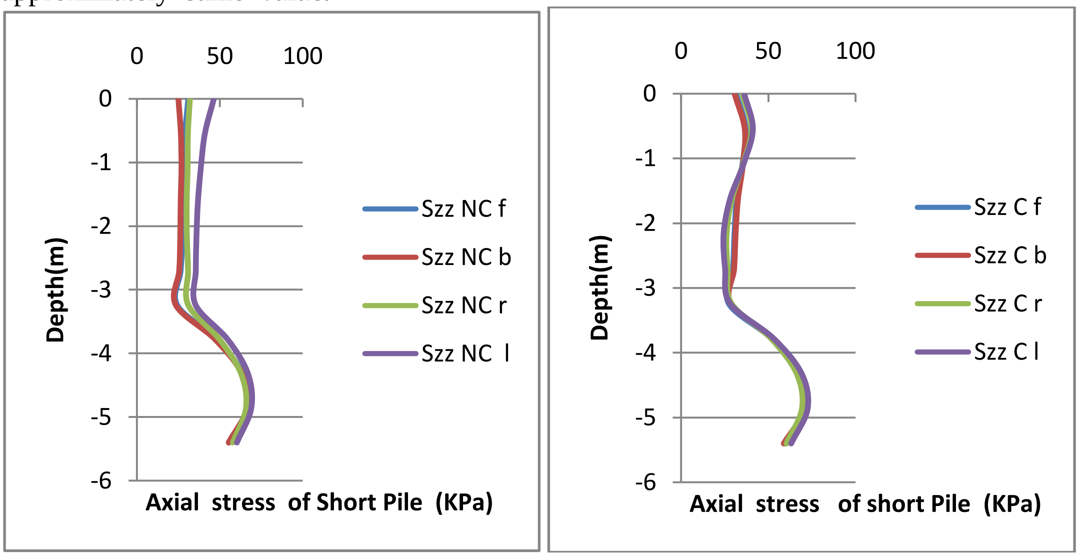


Figure 6: Effects of cushion on S_{xz} distribution along long pile under Koyna 1967 time history (layered soil)

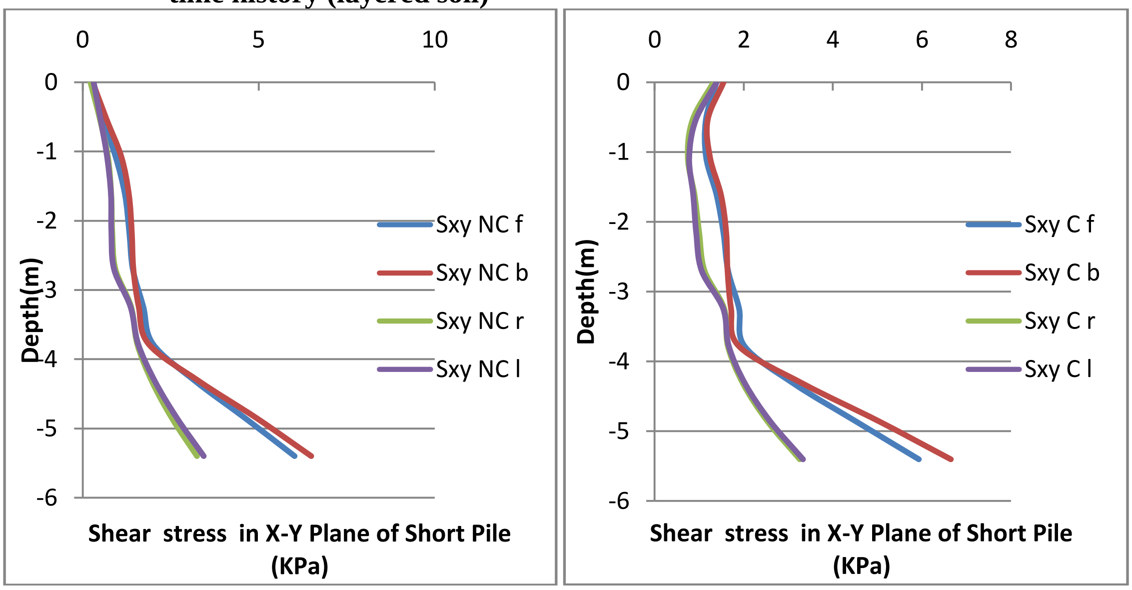
International Journal of Applied Engineering and Technology ISSN: 2277-212X (Online)
An Online International Journal Available at http://www.cibtech.org/jet.htm
2012 Vol. 2 (3) July-September, pp.36-48/Sharma et al.
Research Article

The graphs for S_{xz} behavior for long piles are obtained from contour diagrams which also show deformed + undeformed behavior of long pile under seismic excitation in Midas GTS. The contour diagram shows that for no cushion case the shear force S_{xz} is addressed maximum at the head and at the depth of 3.75m , however this shear stress is totally diminished at the head by entering cushion between raft and piles. Also its visible from the fig. 6 that S_{xz} has same behavior beyond 3.75m depth along the long pile which becomes constant for both cushion and no cushion case.
The contours for deformed+ undeformed shape of short piles under seismic force in Midas GTS give exact idea of short piles behavior under Koyna (1967) earth quake. The stress concentration is same at the bottom of short piles for both cushion and no cushion case. Also for both cases the short piles are in tension throughout its depth; however the tension has increased in lower portion. The graphs given below in fig.7 shows that the differences occur at the head where the values for Szz are on higher side for no cushion case and vary with each other (all short piles) , however the stress has been reduced by introduction of gravel cushion between raft and piles and all the axial stresses merge to approximately same value.



(a) No cushion case (b) Cushion case

Figure 7: Effects of cushion on load transfer mechanism for short piles under Koyna 1967 time history (layered soil)

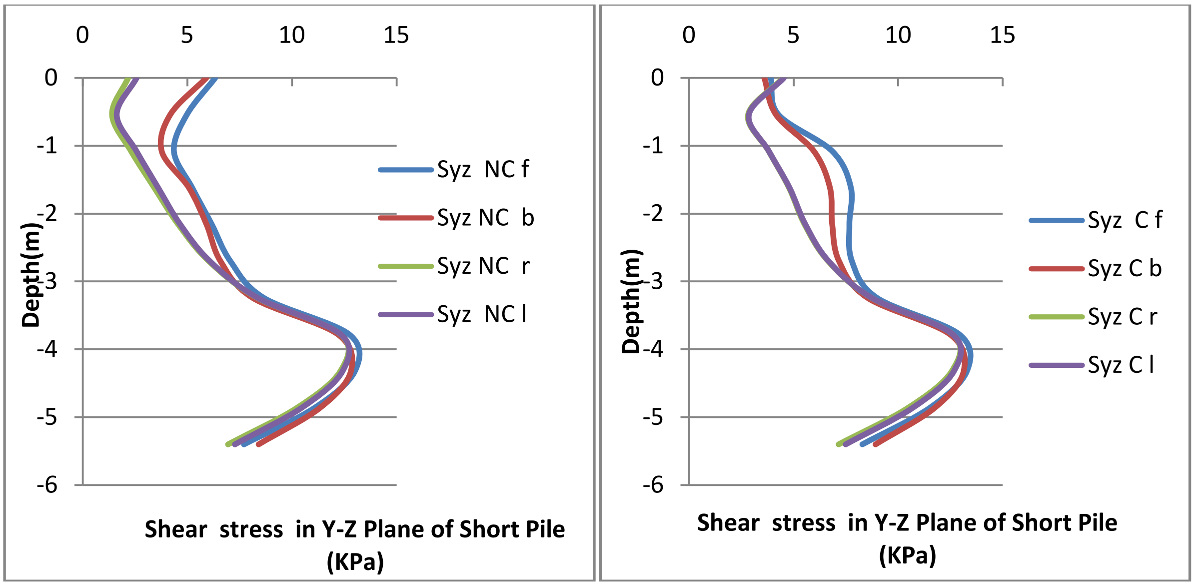


(a) No cushion case (b) Cushion case

Figure 8: Effects of cushion on S_{xy} distribution for short piles under Koyna 1967 time history (layered soil)

Research Article

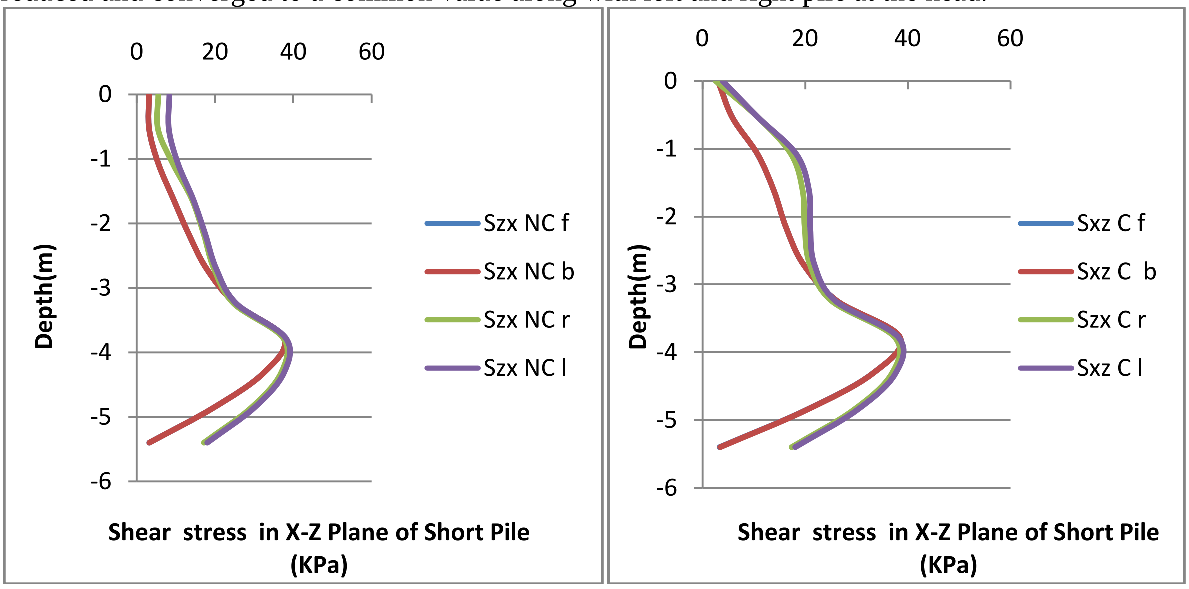
The graphs in fig. 8 obtained from contour diagram show that the shear force S_{xy} has increased at the head of short piles for cushion case and further follow same trend as that for no cushion case for all short piles.



(a) No cushion case (b) Cushion case

Figure 9: Effects of cushion on S_{yz} distribution for short piles under Koyna 1967 time history (layered soil)

The graphs in fig. 9 extracted from the contour diagram shows that Syz is maximum for front and back pile compared to right and left pile in no cushion case. Also there is difference in Syz values at head among front , back short piles and right , left short piles which is almost negligible below 3meter depth. From the graph of cushion, it can be drawn that the Syz for front and back pile has been reduced and converged to a common value along with left and right pile at the head.



(a) No cushion case (b) Cushion case

Figure 10: Effects of cushion on S_{xz} distribution for short piles under Koyna 1967 time history (layered soil)

The graphs above in fig. 10 show that shear stress S_{xz} are higher at the head of right and left short pile for no cushion case whereas the values of S_{xz} are almost same for front and left short pile. These values of shear stress for right and left pile are reduced and merged to a common value with

Research Article

front and left pile for cushion case. For the lower portion the behavior is almost same for both the cushion and no cushion case.

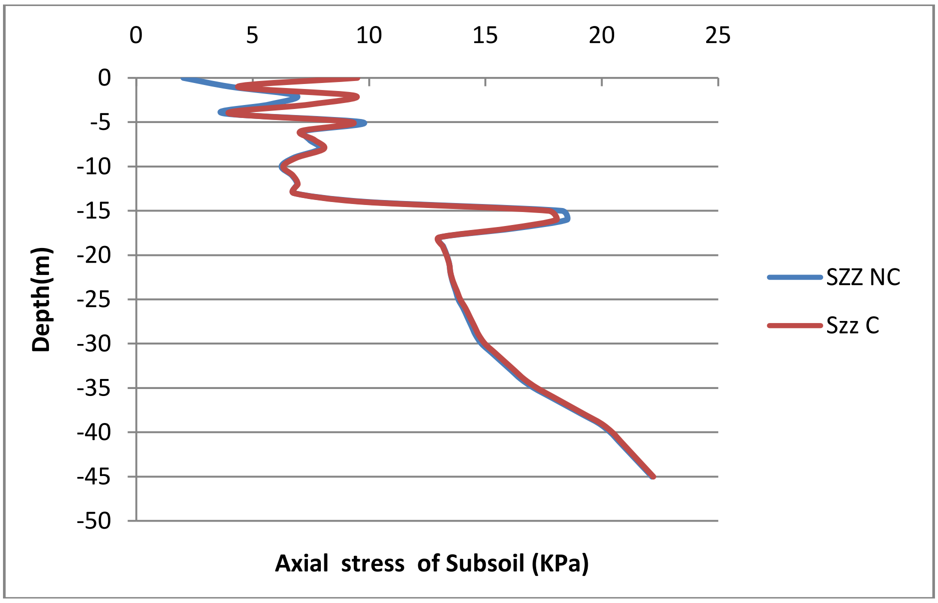


Figure 11: Effects of cushion on load transfer mechanism for subsoil under Koyna 1967 time history (layered soil)

The axial stresses (superimposed stresses) subsoil shown in fig. 11 that the soil mass below the raft for both cushion and no cushion case is under tension. For both the cases the tension has accumulated at the bottom of long piles which exponentially reduces and then gradually increases till the bottom of soil mass. With inclusion of cushion the tension in upper portion of soil mass increases significantly. Also at the transition zone that is where the layer 1 terminates and layer to starts; due to increase in E value of layer to slight stress concentration is noticed. The graph in fig. 12 obtained from contour diagrams of S_{xy} its clear that shear stress S_{xy} has increased at top portion of soil mass after inclusion of cushion. Also the shear stress has been accumulated at depth of 5m in both cases where the stratification of soil mass chances. Further the shear stress exponentially decreases with gradual increase at lower depth.

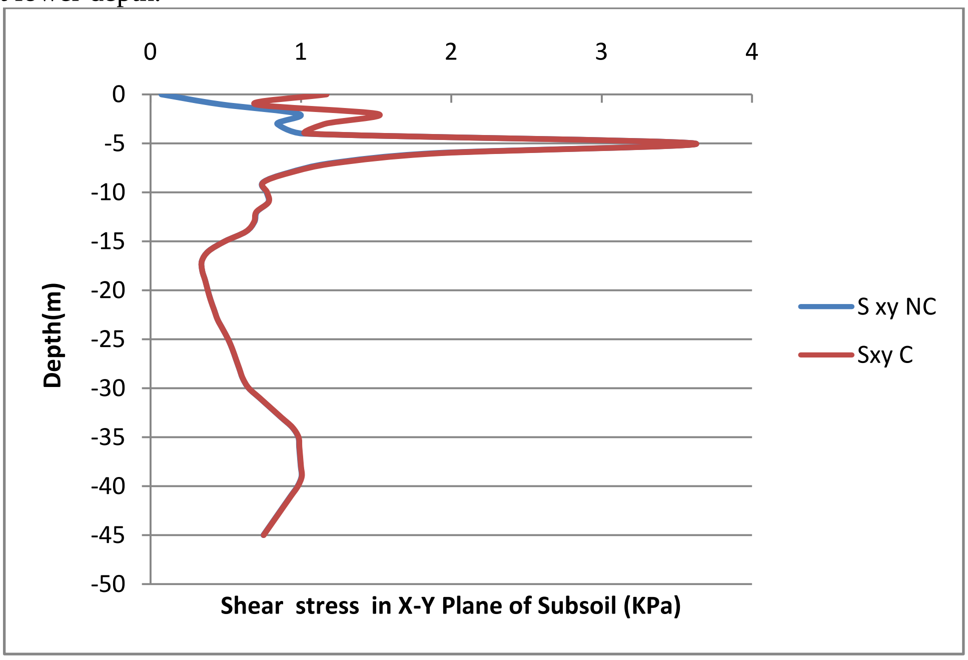


Figure 12: Effects of cushion on S_{xy} distribution along subsoil under koyna 1967 time history (layered soil)

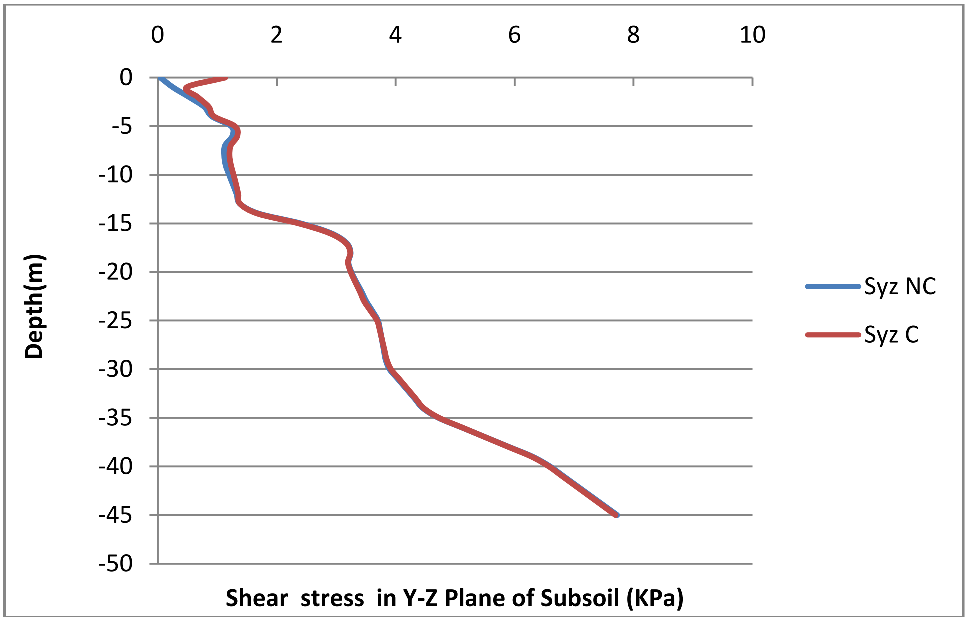


Figure 13: Effects of cushion on S_{yz} distribution along subsoil under koyna 1967 time history (layered soil)

The above graph in fig. 13 shows result for S_{yz} for cushion and no cushion case below the raft in soil mass till bottom. For both the case shear stress increases throughout the depth of soil mass. Thus when compared both the curve follow same trend. However for cushion case the Syz has increased compare to no cushion case. This increase is from top of subsoil mass up to shallow depth of 2.5 meters.

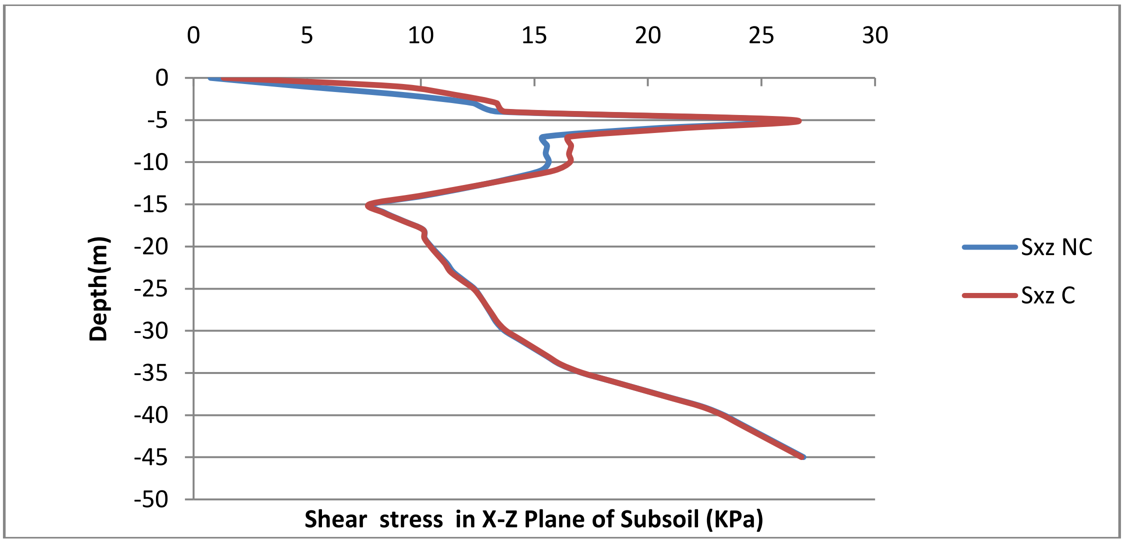


Figure 14: Effects of cushion on S_{xz} distribution along subsoil under koyna 1967 time history (layered soil)

The graph in fig. 14 for Sxz cushion show that there is no drastic change after application of cushion, however the values of S_{xz} for cushion are slightly on higher side when compared with no cushion case. for overall depth of soil mass below the raft and between th piles same trend i.e. there gradual increase upto depth of 3m and then sudden exponential increase at depth of 5m due to change in E of strata and then sudden fall followed with gradual decrease in S_{xz} and then finally gradual increase till the bottom of soil mass.

The results for shear force distribution along the length of long pile and short piles are discussed below. The distribution of F_x under influence of koyna (1967) is represented as graph below in fig. 15 and fig .16.

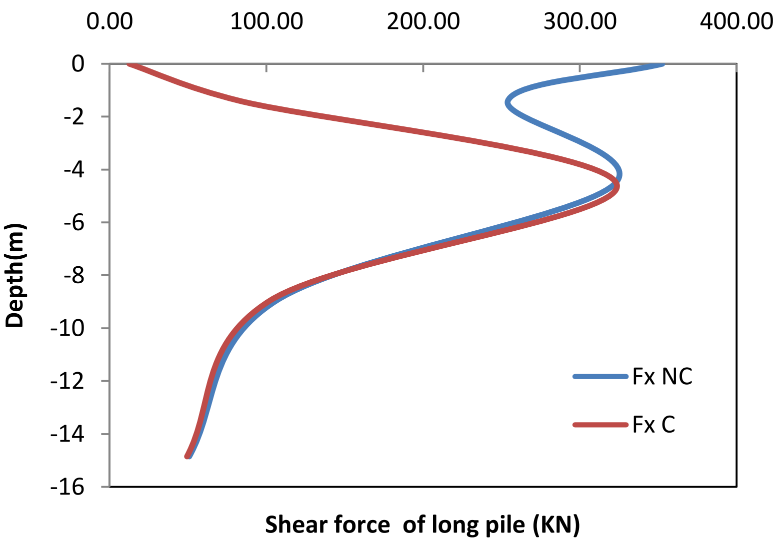
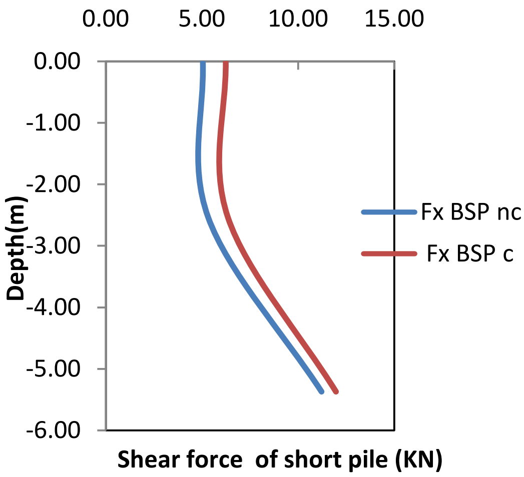
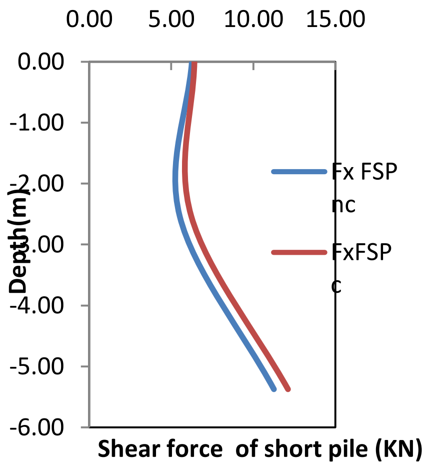


Figure 15: Comparison of F_x for both cushion and no cushion case throughout long pile for Koyna 1967 time history (layered soil)

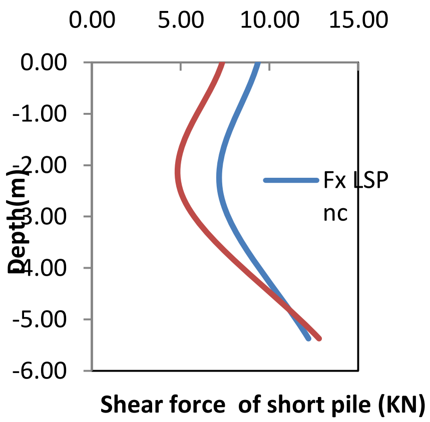
The shear force at the head of pile for connected condition is on higher side compared to detach condition. Thus by applying cushion technique the shear force accumulated at the head of long pile is released.



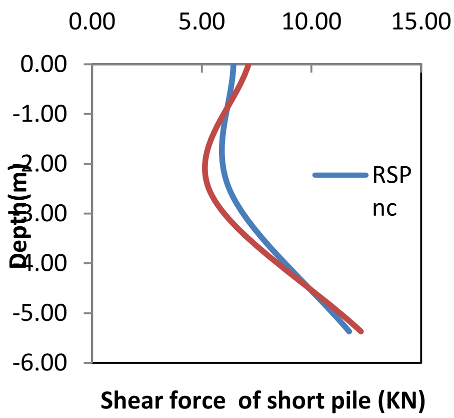
(a) Back Short pile



(b) Front short pile



(c) Left Short pile



(d) Right short pile

Figure 16: Comparison of F_x for both cushion and no cushion case throughout long pile for Koyna 1967 time history (layered soil)

From the above graphs in fig. 16 it's clear that the shear forces along the back short pile has slight increased after application of cushion, whereas the shear forces are almost same for front and right short piles. The graph for shear force for left short pile shows uniform decrease from top head to mid-height of pile, whereas almost same values at the bottom tip.

CONCLUSIONS

The effect of seismic forces along with axial load on composite piled raft foundation system in layered soil was studied considering parameters such as horizontal shear force, axial stresses and shear stresses. Koyna 1967 earthquake was considered for the study and following conclusions were drawn:

- The axial stress at the head of long pile has been reduced by 99 %. Also its visible from the graphs obtained for each earthquake, that long pile is under tension due to lateral earthquake forces which reduces as depth of the pile increases for both cushion and no cushion case.
- For no cushion case the S_{xy} addressed at head of long pile increases initially upto certain shallow depth , afterwards it starts decreasing throughout the depth of pile.For cushion case the values of S_{xy} is on higher side till certain shallow depth and finally reduces throughout the depth of pile and follow the same trend as for no cushion case. The increase of Sxy at the head of long pile is about 78.16 %.
- The upper portion of long piles shows S_{yz} and S_{xz} without cushion, which is on higher side initially and decreases beyond certain depth throughout the length of long pile. However with application of cushion the S_{yz} and S_{xz} shifts to lower value and increases up to certain shallow depth and beyond that follows the same trend as that in no cushion case. The decrease at the head of long pile in Syz and Sxz is 99.8 % and 99.1 % respectively.
- For no cushion case all the short piles are in tension throughout the depth; however the values are on higher side at the top of the piles. Similarly for cushion case the all the piles are in tension throughout the depth with S_{zz} on higher side at the top and decreases with the depth. However the values of S_{zz} at the top of short piles had increased by 18 % with inclusion of cushion.
- With application of cushion the S_{xy} has increased at the head of all the piles compared to no cushion case and decreases slowly till certain depth beyond which it becomes constant throughout the depth of piles. The increase of Sxy is by 81.6 %.
- The S_{yz} and S_{xz} values for all short piles reduce gradually till depth of 1 meter and also beyond this depth the differences remain the same as that for no cushion case. The reduction at the head is around 38.16%. and 52.8% respectively.
- The tension is maximum at the top portion of subsoil below the raft for cushion case compared to no cushion case. The tension has been increased to 78.6 % at the top with inclusion of cushion.
- The shear stresses S_{xy}, and S_{yz} has increased at the top portion of soil mass for cushion case by 93.7%. , 96.1% respectively compared to no cushion case S_{xz} has almost remain same following the same trend throughout with 44% increase at the top..
- The shear force F_x at the head of long pile has been reduced by 97 %, where as for short piles there is slight increase upto 6 to 5 % with inclusion of cushion in front and back piles whereas almost same in right and left short piles.

REFERENCES

A Eslami and S Salehi Malekshah, (2011). Analysis of non-connected piled raft foundations (NCPRF) with cushion by finite element method. *Computer Methods In Civil Engineering* **2**(2) 153-168.

A Eslami, M Veiskarami, MM Eslami (2008). Piled-Raft Foundation (PRF) optimization design with connected and disconnected piles, *Proceedings of the 33rd Annual and 11th Int'l Conference on Deep Foundations, Deep Foundations Institute (DFI), New York, NY, U.S.A., (October 15-17, 2008) 2*01-211.

A Eslami, M Veiskarami, MM Eslami (2011). Study on optimized Piled-Raft Foundation (PRF) performance with connected and disconnected piles-three case histories, Accepted and to be Published in International Journal of Civil Engineering, IJCE,.

Ahner C , Soukhov D and König G (1998). Reliability Aspects of design of Combined Piled-raft Foundations (CPRF**).** *2nd Int. PhD Symposium in Civil Engineering 1998 Budapest*.

Bowles JE (1988). Foundation Analysis and Design. McGraw-Hill, Inc.

Burland JB (1995). Piles as settlement reducers. Proceedings of the 19th *Italian National Geotechnology Congress* **2** 21–34

Burland JB and Broms BB *et al.* (1977). Behavior of foundations and structures. *Proceeding 13th International Conference on Soil Mechanics and Foundation Engineering, Tokyo* **2** 495– 546.

Chow YK, Thevendran V (1987). Optimisation of pile groups. *Computers and Geotechnics* **4** 43–58.

Cooke RW (1986). Piled raft foundation on stiff clays—a contribution to design philosophy. *Geotechnique* **36**(2)169–203.

Cui Chun-yi, Li Jun and Luan Mao-tian (2010). A Numerical Study on the Performance of Composite Foundation System with Piles and Cushion. *ASME 2010, 29th International Conference on Ocean, Offshore and Arctic Engineering* 731-736

Davis EH, Poulos HG (1972). The analysis of piled raft systems. *Australia Geotechnique Journal* **2** 21–7.

Eslami M.M, Aminikhah A,and Ahmadi M.M, (2011). A comparative study on pile group and piled raft foundations (PRF) behavior under seismic loading. *Computer Methods In Civil Engineering* **2(**2) 185-199.