To Study Behavior of Piles in Liquefied Soil using ANSYS

Gaurao S. Patil[1], Swapnil R. Joshi[2], Pramod S. Sathe[3]
[1,2,3]Matoshri College of Engineering and Research Centre, Nasik, India
[1]gaurav.ptl@gmail.com,[2]swapnil.joshi1991@gmail.com

Abstract: Modern construction industry involves construction of a group of piles and raft foundation over loose soil. This type of composite construction handles eccentric loading and also minimizes settlement of soil. Analysis of a group of pile foundation is a problematic. Also, the design of raft foundation with piles along with soil structure interaction effect is somewhat difficult to process as the nature of the structure is affected by superstructure as well as the nature of foundation and soil. This paper includes analysis of raft foundation with a group of piles using ANSYS Workbench, a finite element software to study load-displacement response in loose sand with interaction effects. Liquefaction phenomenon develops when the structure of loose, saturated sand breaks down due to expeditiously applied load. Three different spacing of piles were considered for the study viz. 3D, 4D and 5D (where, D is the diameter of circular pile or side of the rectangular pile) with three different configurations viz. 2x2, 2x3 and 2x4 with a desire of finding an optimum number of piles and piles spacing for loose sand. Analysis of pile groups having 2x4 and 2x3 configuration has been done on ANSYS workbench and discussion and solution on results are presented in this research. Also, a comparison of various stress analysis results between 2x2 and 2x3 configuration of piles is discussed.

Keywords: Piled raft foundation, Liquefied soil, ANSYS Workbench, Static structural analysis, Vertical loading.

1. Introduction

Due to the earthquake, the convulsion of ground may cause loss of strength or stiffness resulting in landslides, settlement of buildings, failure of earthen dams or any other serious impacts. The phenomenon which leads to loss of such strength of soil is called soil liquefaction. Soil liquefaction is the process of mutation of soil from solid state to liquid state due to the application of stress. Liquefaction is a phenomenon which is associated with saturated cohesionless soil. This phenomenon has been observed in almost all huge earthquakes causing immense damages to the structure. The detrimental effects of liquefaction take many forms. Some catastrophic effects such as flow failure of slope or earth dams, settling of piers of bridges, total or partial failure of retaining walls are occurring with more hazardous effects. Other effects are less hazardous such as lateral spreading of slightly inclined ground, large deformations of the ground surface, settlement and consequent flooding of large areas. These harmful effects caused huge damage to railroad, highway, pipelines and buildings. The phenomenon of liquefaction exhibits when the structure of loose saturated sand fails down due to some rapidly applied loading. Since the structure of soil breaks down, the loosely packed individual soil particles attempt to move in a denser configuration. Liquefaction may be studied in the following ways:

- Flow liquefaction
- Cyclic mobility
- Liquefaction due to chemical process

Flow liquefaction exhibits when liquefied soil loses its shear strength due to static or dynamic loads with low residual strength. Residual strength is nothing but the strength of liquefied soil. The failure resulted from flow liquefaction is observed by rapid movements which suffered a remarkable bearing capacity failure.

Cyclic mobility occurred due to cyclic loading in deposits of soil with static shear stresses lower than soil strength. Cyclic mobility causes deformations because of static and dynamic stresses which are existing during the earthquake. Liquefaction occurring due to the chemical process is the result of the nature of cations in the pore water of soil mass in case of scattered soils. Figure no.3 shows the failure of the pile having a lateral ground displacement of 2m during Niigata Earthquake which was happened in 1964 [12]. During soil liquefaction, a large number of ground variations can take place on sloping ground or towards an open face such as bank of river. Three different spacing of piles were considered for the study viz. 3D, 4D and 5D (where, D is the diameter of circular pile or side of the rectangular pile) with three different configurations viz. 2x2, 2x3 and 2x4 with a purpose of finding an optimum number of piles and piles spacing for loose sand [2, 4, 6].

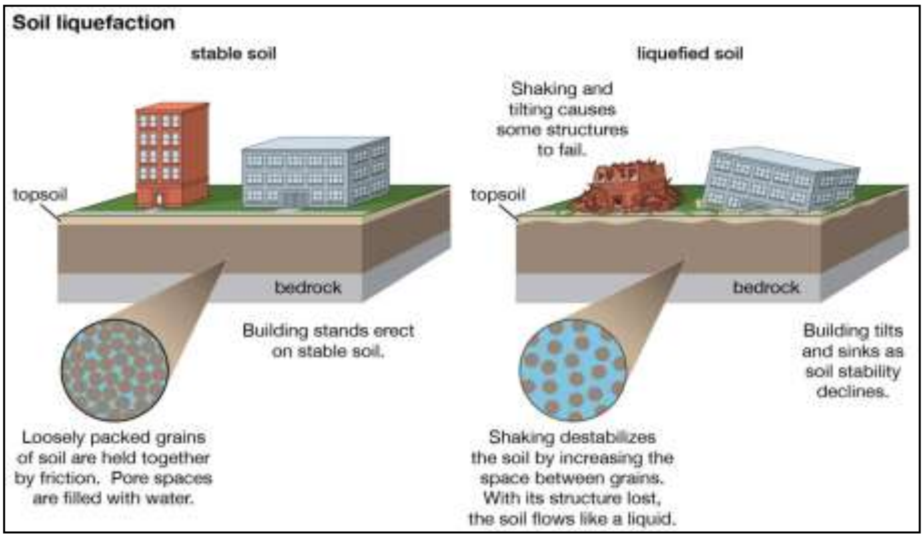

Fig. 1. Soil liquefaction for Non-liquefied soil (stable soil) and Liquefied soil (unstable soil) **(Source: Britannica encyclopaedia 2012)**

Fig. 2. Location map showing the 1964 Niigata Earthquake
(Source: GraphicMaps.com)

Fig.3. Failure of pile with 2m lateral ground displacement during the 1964 Niigata earthquake

1.1 Situations where liquefaction occurs:

- Loose to semi-dense silty sands
- Semi-dense sandy and loose soils
- A combination of loose to semi-dense gravelly sand, gravel and sand

1.2 Situations where liquefaction is not probable:

- Combinations of sand and cohesive fine materials with a moderate amount of fine-grained and fine materials.
- Compacted soils
- Cohesive soils containing more than 50% fine-grained materials which contains moderate amount of clay**.**

The basic aim of the research is to study and analyze deformation behavior of piles as well as stresses on piles in groups in liquefied soil using ANSYS workbench, a finite element software. The main objective of this research is to compare various stress results between a group of circular and a group of rectangular piles. Also to study static structural analysis modeling of piles with various configuration and analysis of this configuration. Another important objective is to model a group of piles for 3D, 4D, 5D spacing for loose sand and find out various relative stress results. Analysis of piled liquefied structure with soil-structure interaction is studied by finite element method.

For interpreting the finite element method, ANSYS workbench software is used for comparison of results.

2. Methodology

The basic intension of this research is to focus on current technology for effective analysis of pile foundations in liquefied soils. Analysis of a group of piles with soil structure interaction effect in liquefied soil is studied by using finite element analysis. The finite element method is a widely used method for numerical solutions of engineering problems. In this method, all the complexities of the problem like loads, boundary conditions, loads, etc. are maintained but the solution obtained is approximate. For solutions of finite element analysis, a wide variety of software is available. In comparison with all those software, ANSYS Workbench software is most helpful software. ANSYS is a finite element based software. Following are general steps involved in analysis using ANSYS software:

1. Engineering Data	2. Geometry
3. Modelling	4. Setup
5. Solution	6. Results

2.1 Details of data used for the study of a group of piles (IS 2911-2010):

The design and analysis of piles is taken as per norms of IS 2911-2010 [7].

- Diameter of Pile = 0.5m
- Length of Pile = 5m
- Spacing of Piles = 3D, 4D and 5D (Where, D is the diameter of circular pile and side of the rectangular pile)
- Number of piles in group = 4, 6, 8
- Configuration **:** Circular = 2x2, 2x3, 2x4
  Rectangular = 2x2, 2x3, 2x4
- Thickness of pile cap = 0.5 m
- Type of soil = Loose sand

2.2 Properties of materials:

- **Concrete:**
  - Density of concrete= 23.5 kN/m^3
  - Ultimate Compressive strength = 5x10^6 Pa
- **Soil:**
  - Density of soil = 14 kN/m^3
  - Ultimate Compressive strength = 8x10^6 Pa
- **Structural Steel:**
  - Density of steel = 78.5 kN/m^3
  - Yield tensile strength = 2.5x10^8 Pa
  - Ultimate tensile strength = 4.6x10^8 Pa

The geometrical sketch showing group of circular as well as rectangular piles is shown in following figure:

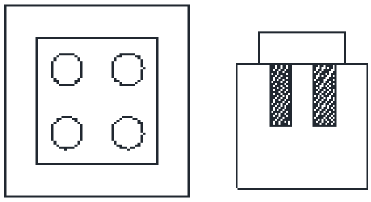

Fig. 4. Plan and elevation Circular piles

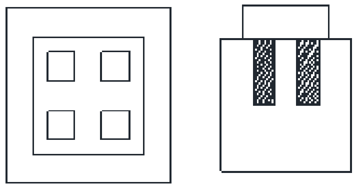

Fig. 5. Plan and elevation of Rectangular piles

The piles are cylindrical as well as rod-shaped in elevation. Piles are arranged in groups as 2x2, 2x3, 2x4 configuration with a spacing of 3D, 4D, 5D (where D is the diameter of circular pile and side of the rectangular pile) in liquefied soil. These various groups of piles are connected with a pile cap of thickness 0.5m. This whole structure is analyzed using ANSYS workbench software for comparison of various stresses. Results of total deformation, shear stress, strain energy, normal stress are compared between circular and rectangular piles.

3. Result and Discussion:

Analysis of group circular piles with 2x2 configuration is done using ANSYS software for total deformation, shear stress, normal stress and strain energy. These results are compared with the analysis of a group of rectangular piles with the same configuration. Final results of this comparison are shown by graphs for further conclusion of the research.

3.1 Analysis of a group of circular piles and a group of rectangular piles with 2x2 configuration (4 piles):

Draw sketch as per given dimensions along with pile cap having thickness 0.5m in a soil. Create a solid geometry of the structure for the analysis. Piles are arranged in a group having a spacing of 5D (where, D is the diameter or size of the pile) with 4 piles in a group. Structure is analyzed with rigid support. Vertically downward pressure is applied to the structure for loading analysis. Develop meshing to the structure. Generation of meshing will be used for analyzing the structure at each possible location. After completion of meshing, solve the problem in ANSYS software. Discuss the various results of the analysis with various parameters. Following are the most important results of analysis such as Total deformation, Strain energy, Shear stress, Normal stress. Compare these results with group of rectangular piles.

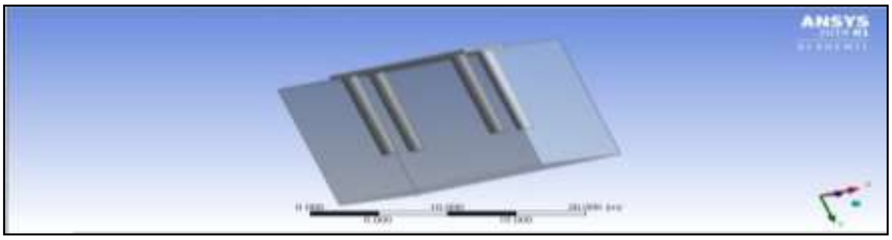

Fig. 6. Geometrical view of a group of 4 circular piles having 5D spacing

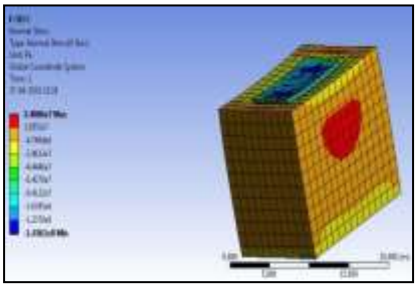

Fig. 7. Min. and Max. Normal Stress results

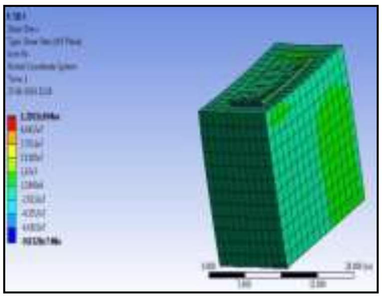

Fig. 8. Min. and Max. Shear Stress results

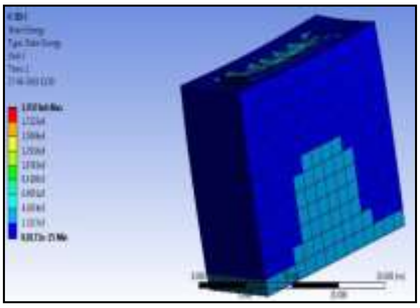

Fig. 9. Min. and Max. Strain Energy results

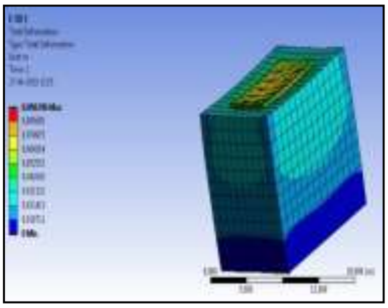

Fig. 10. Min. and Max.Total Deformation

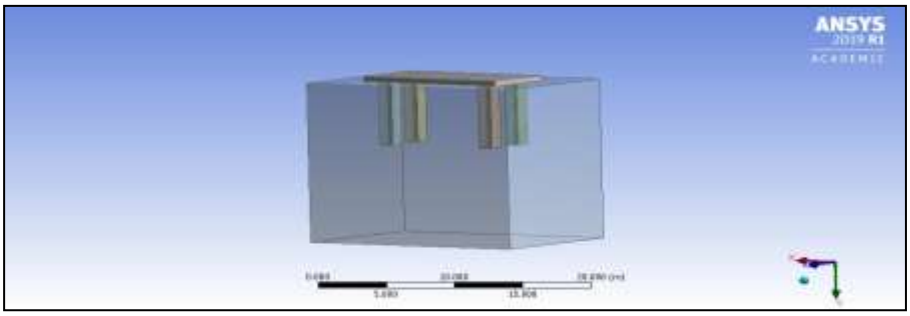

Fig. 11. Geometrical view of a group of 4 Rectangular Piles having 5D spacing

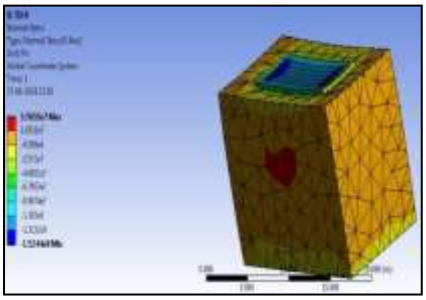

Fig. 12. Min. and Max. Normal Stress results

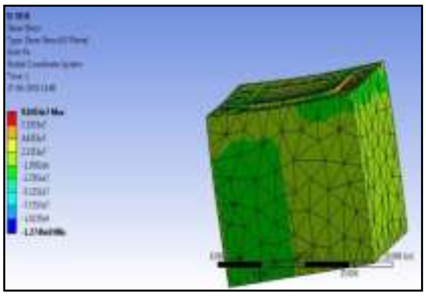

Fig. 13. Min. and Max. Shear Stress results

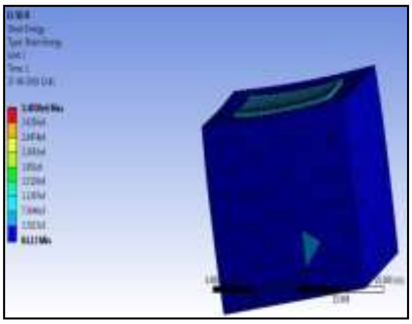

Fig. 14. Min. and Max. Strain Energy results

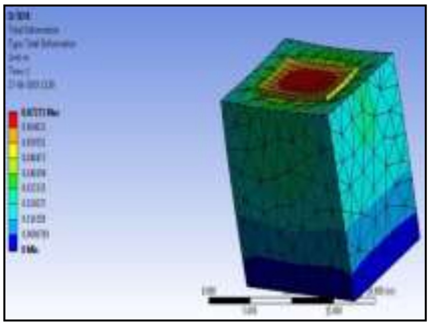

Fig. 15. Min. and Max. Total Deformation

Above result, figures show a comparison of stresses developed in a group of circular piles and a group of rectangular piles. Figure No. 10 and 15 shows a comparison of total deformation occurring between a group of circular and group of rectangular piles having a 2x2 configuration. From the above analysis, deformation occurring in a rectangular group of piles is minimum in comparison with the circular group of piles. Also, shear stress is much greater in a rectangular group of piles as compared to circular piles. Other results are also more in rectangular piles than circular piles.

Table 1. Results comparison of Circular and Rectangular Piles with 5D spacing (4 piles)

	5D Circular Piles		**5D Rectangular Piles**	
Range	Min	Max	Min	Max
Normal Stress (Pa)	-1.436e8	3.488e7	-1.524e8	3.765e7
Shear Stress (Pa)	-9.032e7	1.203e8	-1.274e8	9.845e7
Strain Energy (J)	8.817e-15	1.937e6	84.13	3.403e6
Total deformation (m)	0	0.0963	0	0.0727

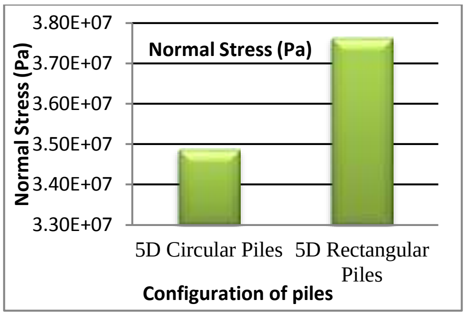

Fig. 16. Results of Normal Stress

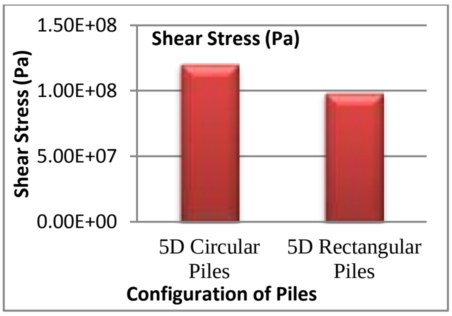

Fig. 17. Results of Shear Stress

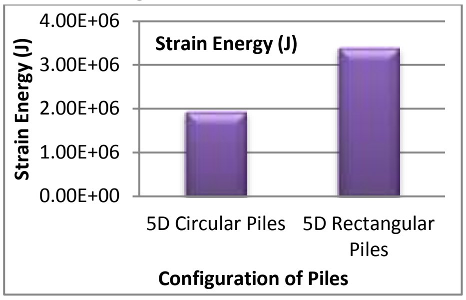

Fig. 18. Results of Strain Energy

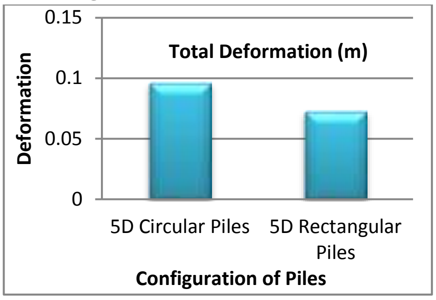

Fig. 19. Results of Total Deformation

Above graphical results interprets that shear stress in the rectangular pile is minimum as compared to circular pile with 5D spacing. Also, deformation in rectangular piles are less than circular piles**.** But normal stress and strain energy is increased in a rectangular configuration in comparison with circular group. The variation of these results may be due to properties of liquefied soil.

3.2 Analysis of the group of circular piles and a group of rectangular piles with 2x3 configuration (6 piles):

Draw sketch as per given dimensions along with pile cap having thickness 0.5m in a soil. Create a solid geometry of the structure for the analysis. Piles are arranged in a group having a spacing of 4D (where, D is the diameter or size of the pile) with 6 piles in a group. Structure is analyzed with rigid support. Vertically downward pressure is applied to the structure for loading analysis. Develop meshing to the structure. Generation of meshing will be used for analyzing the structure at each possible location. After completion of meshing, solve the problem in ANSYS software. Discuss the various results of the analysis with various parameters. Following are the most important results of analysis such as Total deformation, Strain energy, Shear stress, Normal stress. .

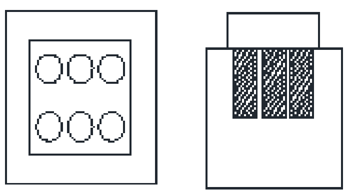

Fig. 20. plan and elevation of Circular piles

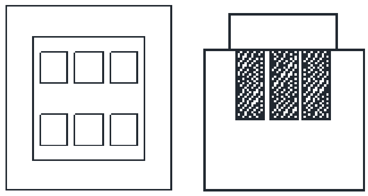

Fig. 21. Plan and elevation of Rectangular Piles

Fig. 22. Geometrical view of a group of 6 Circular Piles having 4D spacing

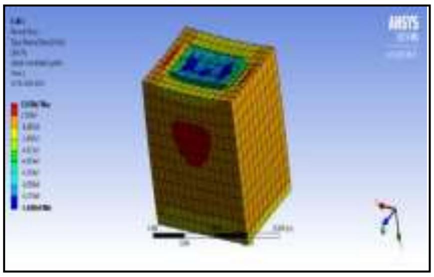

Fig. 23. Min. and Max. Normal Stress results

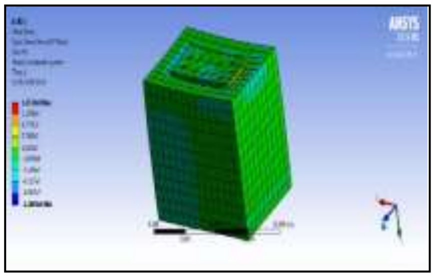

Fig. 24. Min. and Max. Shear stress results

Fig. 25. Min. and Max. Strain Energy results

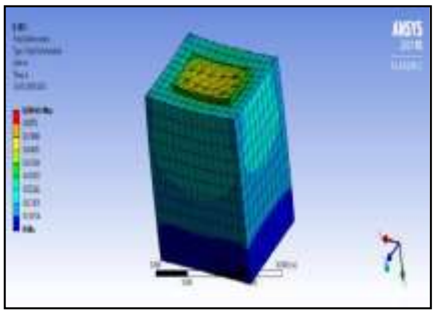

Fig. 26. Min. and Max. Total Deformation

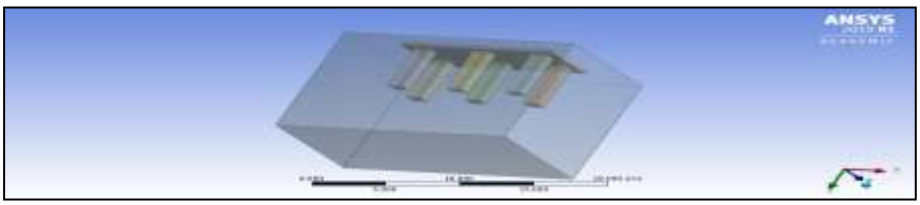

Fig. 27. Geometrical view of a group of 6 Rectangular piles having 4D spacing

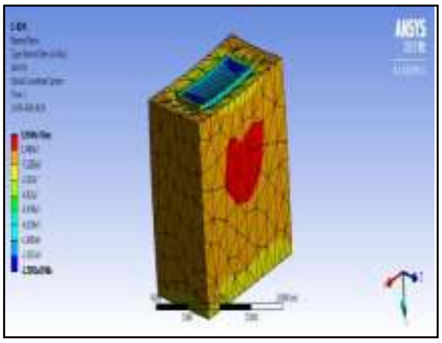

Fig. 28. Min. and Max. Normal Stress results

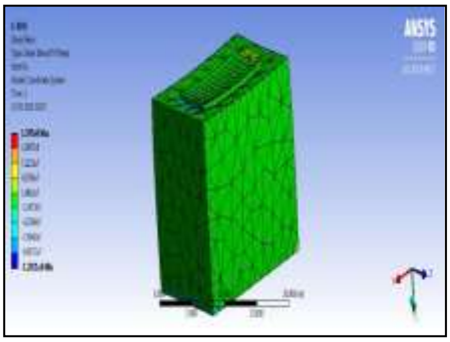

Fig. 29. Min. and Max. Shear Stress results

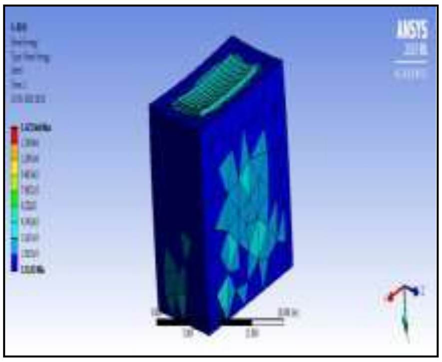

Fig. 30. Min. and Max. Strain Energy results

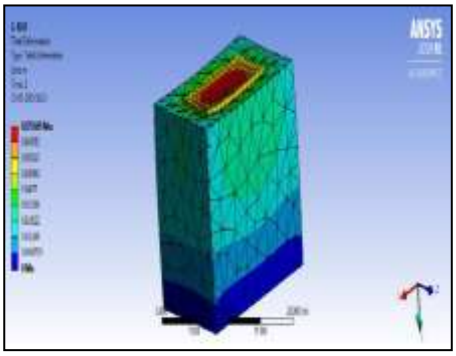

Fig. 31. Min. and Max. Total Deformation

Above figures show results of comparison of stresses developed in a group of circular piles and a group of rectangular piles. From the above analysis, deformation occurring in a rectangular group of piles is minimum in comparison with the circular group of piles. But shear stress, normal stress and strain energy are greater in a circular group of piles as compared to rectangular piles in 2x3 configuration of piles having 4D spacing.

Table 2. Results of comparison of Circular and Rectangular Piles with 4D spacing

	4D Circular Piles		**4D Rectangular Piles**	
Range	Min	Max	Min	Max
Normal Stress (Pa)	-1.4368e8	3.5438e7	-1.509e8	3.394e7
Shear Stress (Pa)	-1.2069e8	1.473e8	-1.2821e8	1.295e8
Strain Energy (J)	2.766e-15	1.835e6	131.03	1.422e6
Total deformation (m)	0	0.09642	0	0.07266

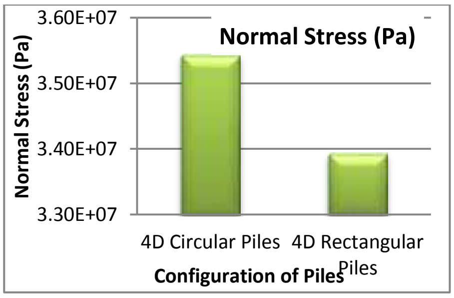

Fig. 32. Results of Normal stress

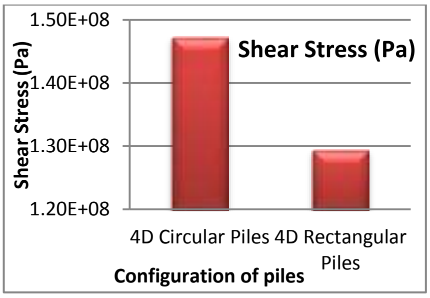

Fig. 33. Results of Shear stress

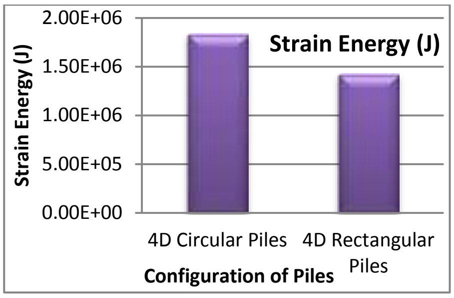

Fig. 34. Results of Strain energy

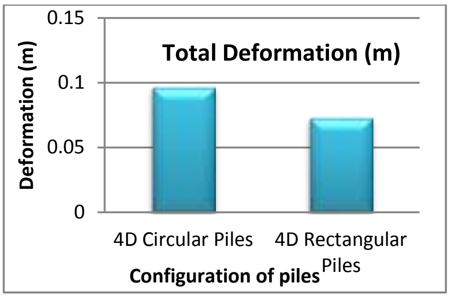

Fig. 35. Results of Total deformation

Above graphical results interprets that shear stress in the rectangular pile is much less as compared to circular pile with 4D spacing. Also, normal stress, strain energy and deformation in rectangular piles are less. Variation of these results among 4D and 5D group of piles interprets that rectangular piles can sustainably distribute the load coming on them with sufficient bearing capacity. On the other hand, circular piles may not able to sustain vertical load and surrounding pressure. Due to this, circular piles are showing large values of stresses as compared to rectangular piles.

4. Conclusion

This study is based on analysis of the group of circular piles and a group of rectangular piles in a liquefied soil using ANSYS software. Group of circular piles is always preferred for any construction work. The research was going on possible option other than a circular cross-section. For that purpose, the square cross section of the pile has been taken for the analysis of the same effects as on circular piles in this study. The conclusion got from the comparison between circular and square cross-section shows positive results for square cross-section of the pile are given below.

- The spacing of piles affects various results of stresses and deformation analysis. Spacing between piles should be minimum so as to increase load carrying capacity.
- Group of piles with 5D spacing have some opposite results as compared with 3D and 4D spacing for rectangular and circular configuration of piles. Normal stress for rectangular pile group is more in 5D spaced piles than 4D and 3D spaced piles.

- Shear stress difference in 4D circular and 4D rectangular group is more as compared to 5D circular and 5D rectangular group of piles.
- A number of piles in one group also affect the impact of loading.
- Deformation in all cases is more in rectangular piles than in circular piles.
- Stresses in rectangular piles groups in less as compared to a circular group of piles.

References

1. Asskar Janalizadeh, Ali Zahmatkesh: Lateral response of pile foundations in liquefiable soil. Journal of Rock Mechanics and Geotechnical Engineering, Iran (2015).
2. Bhavik S. Parsiya, Dr. S. P. Dave: Analytical study of the laterally loaded pile group. E-ISSN2249–8974, International Journal of Advanced Engineering Research and Studies, Gujarat, India (April-June 2012).
3. Elarabi, Abbas: Piles for Structural Support. ISSN: 2277-9655,International Journal of Engineering Sciences & Research Technology (2014).
4. Elsamny M.K., Ibrahim M.A., Gad S.A., Abdel-Mageed M.F.: Experimental investigation on load sharing of soil around piles and underneath raft on pile groups. E-ISSN: 2319-1163 | P-ISSN: 2321-7308. International Journal of Research in Engineering and Technology (August 2017).
5. G. Srilakshmi, Yashwant M. P.: Analysis of Pile group using Finite Element Method. ISSN: 2319-5991, International Journal of Engineering Research and Science & Technology, Bangalore, India (2013).
6. G.L. Sivakumar Babu, B. R. Srinivasa Murthy, D.S.N.Murthy, and M.S. Nataraj: Bearing capacity improvement using micro piles. IISC Bangalore (2004).
7. IS 2911(Part 1/Sec 2):2010 Design and Construction of Pile Foundation - Code of practice. Bureau of Indian Standards 2010, Soil and Foundation Engineering Sectional Committee, New Delhi (May 2011).
8. Kenji Ishihara, Yasuyuki Koga: Case studies of liquefaction in the 1964 Niigata Earthquake. Japanese Society of SMFE, Tokyo, Japan (1982).
9. Patil Gaurao Suresh, Joshi Swapnil and Sathe Pramod: To Study Behavior of Pile in Liquefaction of Soil Using ANSYS. International Research Journal of Engineering and Technology, India. Volume: 06 Issue: 05 May 2019.
10. S.S. Chandrasekaran, A. Boominathan, G.R. Dodagoudar: Group Interaction Effects on Laterally Loaded Piles in Clay. Journal of Geotechnical and Geoenvironmental Engineering ASCE, Chennai (April 2010).
11. U.K. Nath, P.J. Hazarika, V. Giri, A. M. Tesfaye: Study of Lateral Resistance of Pile Cap using Finite Element Analysis. International Journal of Emerging Trends in Engineering and Development, Guwahati, Assam, India (August 2011).
12. W. D. L. Finn, N. Fujita: Behaviour of Piles in Liquefiable Soils during Earthquakes. Missouri University of Science and Technology, Anabuki Komuten and Kagawa University, Japan (April 2004).