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Numerical Analysis of Ring Foundation Fixed with Geogrid

Rahul P. Shende[1], Dipendra C. Swarnkar[2] and A. K. Singh[3]

[1] M.Tech. Student, NIT Jamshedpur, India, rahul.shende1996@gmail.com
[2] Ph. D. Scholar, NIT Jamshedpur, India, dipendra.panda@gmail.com
[3] Associate Professor, NIT Jamshedpur, India, aksingh.civil@nitjsr.ac.in

Abstract. Ring foundation is normally used to support walls or columns of axi-symmetrical structures because it enables the economical use of bearing capacity and reduce the consumption of material and cost of construction. Ring foundations are often adopted for large and vertical cantilever tall structures to resist vertical load along with lateral load and to increase the stability against overturning. Numerical study has been carried out to determine the performance of ring foundation fixed laterally with geogrid resting on cohesion-less soil. The software ANSYS is used for 3D modeling of the problem. In this study, load carrying capacity of ring foundation fixed laterally with geogrid resting on cohesion-less soil medium, settlement behavior, and overturning stability has been studied. The soil domain is discretized with small grids for adopting FEM techniques. Particular emphasis has been given to fix the geogrid with the ring footing and spreading it on lateral directions at different angles. A model is created using ANSYS software. Study is being carried out for different sizes of ring foundation model (Ri, Ro, Rc and thickness) for varying vertical as well as lateral loads. Geo-grid is fixed at 90 degree and 45 degree and then maximum load carrying capacity is determined under vertical loading and lateral loading at top of structure. In addition, comparison of load carrying capacity and overturning moment of different size of ring foundation with or without geogrid has been also made. Behavior of ring foundation for different n value, sub-grade reaction, number of loaded column and central radius has been also studied. As a result of this study, analysis and design as well as optimization of ring foundation has been done. Results are highly encouraging for researchers.

Keywords: Numerical Analysis, Ring Foundation, Geogrid.

1 Introduction

Foundation of top heavy tower like structure and self supporting vertical cantilever structures like chimney, silos, overhead water tank, telecommunication tower, etc. are usually axi-symmetric. Foundation of these structures is frequently subjected to vertical load along with overturning moments caused due to lateral loads (wind). For such structures, ring foundation is used due to economic advantages. Ring footing varies from narrow circular beam to a circular footing. The central radius (R_c) is the radius that divides ring surface into two equal areas. The ring radii ratio is ratio of inner ring radius to outer ring radius i.e. $n = R_i/R_o$ and the performance of ring foundation depends on n value.

Geosynthetic material holds number of function like separation, filtration, reinforcement, stiffening, confinement sealing, lateral drainage and barrier. Geogrid is generally used with earth, soil, rock and different peripheral substance as reinforcement. Geogrid has openings ranges 10 mm to 100 mm in size and have relatively extended power, improved modulus and low rupture potential. Geogrid is the geosynthetic material which can be used as tensile reinforcement.

In this study, the three-dimensional finite element method is used to know the responses of ring foundation fixed with geogrid. Many researchers investigated ring foundation in the past and some of them utilized specific three dimensional finite element models. Textbooks and design manuals suggest different approaches to analyze and design the ring foundation. Compared to strip and circular footings, only limited studies are available that deal exclusively with ring footings. Bowels (1968) have given FEM model for ring foundation divided in 20 nodal elements. Winterkorn and Fang (1970) have given the solution of ring foundation resting on an elastic foundation using finite differences method. IS: 11089 (1984) has given empirical formula for determination of radial moment and tangential moment under different loading conditions. Timoshenko and Krieger (1959) have given the relation between different case of axi-symmetric loading on circular as well as ring plate with the vertical direction. Benmebarak et al. (2012) calculated values of bearing capacity factors N_γ of soil in case of rough and smooth ring footings, for values of high and low friction angle for associated as well as non-associated soils of Mohr–Coulomb type. Kumar and Chakrobarty (2015) analyzed bearing capacity factors by usage of finite element analysis. Effect of foundation embedment, rigidity, and soil non-homogeneity on the elastic vertical settlement of a ring foundation was evaluated by Naseri and Hosseininia (2015) using FDM technique. Hosseinimia (2016) investigated the bearing capacity of ring footings by numerical simulations applying the FDM. Sharma and Kumar (2018) studied behavior of ring footing resting on reinforced sand influenced to eccentric-inclined loading. Azzawi and Daud (2019) have done numerical analysis of ring foundation for different loading condition. In addition to the analytical and numerical solutions, some experimental investigation has been also carried out on ring foundations. M. Laman and A. Yildiz (2003) investigated behavior of ring foundation above sand bed with geogrid as reinforcement. El Sawwaf and Nazir (2012) investigated the behavior of ring footings loaded eccentrically which rests on geogrid reinforced compacted layered sand on a loose extended sand layer. Most of studies conducted on ring foundation focused on behavior of ring foundation on reinforced soil and bearing capacity factors. No one has tried to found out behavior of ring foundation by fixing geogrid with circumference of ring foundation.

In this study, the behaviour of ring foundation fixed with geogrid at outer circumference and ring foundation without geogrid has been investigated. Behaviour of ring foundation is also investigated by changing parameters like n value, sub-grade reaction, central radius and number of loaded columns. Simulations are performed by ANSYS software for a ring foundation with and without geogrid.

2 Application of Numerical Method

2.1 Problem description

Wind acting on the body of tall structures creates overturning moment on ring foundation which tries to topple the structure. From design point of view, the overturning moment plays a vital role in design of ring foundation. In order to counter balance the effect of lateral load on ring foundation, the research has been carried out.

To reduce the effect of lateral forces, geogrid is fixed on the circumference of ring foundation and it is spread in lateral direction. Geogrid is fixed at the middle of the thickness of ring footing. One end of geogrid is fixed with ring footing and other end is taken as fixed in model to utilize tensile strength of geogrid. The concept behind this is that the geogrid will create an anchorage against the overturning force. The geogrid is attached at 90º and 45º and result is compared with ring foundation without geogrid. Behaviour of ring foundation is investigated by changing parameters such as sub-grade reaction, n value (Ri/Ro ratio), Number of loaded columns (N_C) and central radius of ring foundation. The analysis has been carried out using ANSYS software. In this study, static structural analysis is performed that works on Newton- Rapson approximation method.

2.2 Geometry and model creation

Ring foundation model
Ring foundation model is created in ANSYS design modular. The ring is divided into 20 segments/parts as in Winterkorn and Fang (1970) approach. 20 points are made on central radius spaced at equal distance. The values of deflections are considered on these 20 points. The load is applied on 4 columns on central radius equally spaced. In this study, three n values 0.2, 0.3 and 0.4 has been considered. Ring foundation of outer diameter 300 mm and 400 mm has been considered. Thickness of ring foundation is kept 70 mm.

Soil and geogrid model
Soil is modeled in a steel test box on which the ring foundation rest. The cross section of soil box is taken as 2 m x 2 m, keeping at least distance of five times the ring diameter. The depth of soil is taken as 1.0 m below ring foundation and 33 mm above base of ring foundation.

Geogrid is placed on the surface of soil model. The geogrid is fixed at 45º and 90º. The width of geogrid modelled is 100 mm and thickness is taken as 4.0 mm. The length of geogrid is kept 800 mm (greater than 2.5 times of ring diameter). The length is kept equal in all directions.

2.3 Finite element mesh, boundary condition and contacts

In numerical modelling, the selection of boundary conditions plays an important role. The bottom boundary of soil is considered to be fixed, and all side boundaries can only move vertically (vertical displacement). The Z-X plane's displacement is restricted in the y-axis in lateral direction. Likewise, in Z-Y plane's displacement is restricted in the x-axis in lateral direction. One end of geogrid is connected with ring foundation and other end is fixed and restricted from all displacements. The top surface of soil is assigned as elastic support with sub-grade reaction value as 86.4 kcf (13573 kN/m^3).

The contact is provided between interfaces of two surfaces in ANSYS software. By default ANSYS select bounded contact. The contact provided between ring foundation and soil is rough contact. The contact provided between ring foundation and geogrid is bounded contact with beam formulation. Frictionless contact is provided between geogrid and soil.

For instance, default meshes were specified for the model in numerical analysis. In cases where the stress and displacement is higher, refined mesh was used around the loaded points (i.e. finer meshes under loads).

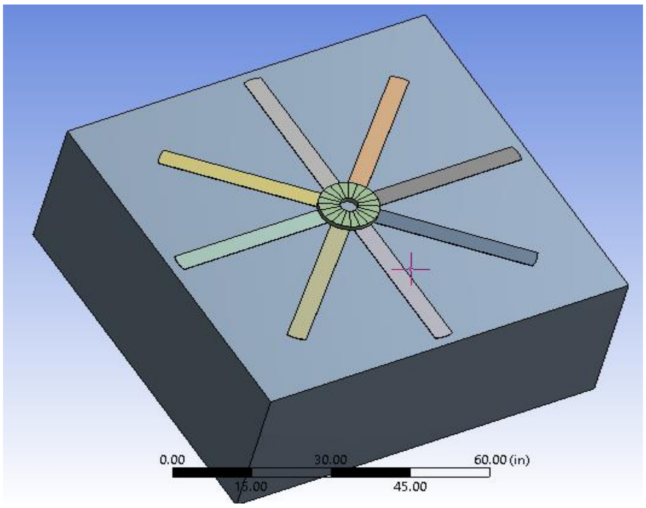

Fig. 1. Ring foundation resting on cohesion less soil fixed with geogrid at 45º

2.4 Properties of Material

Material used for ring foundation model is of concrete with modulus of elasticity 20684 MPa. Table 1 and Table 2 show properties of soil and geogrid used in the finite element models.

Table 1. Parameters used for soil

Sl. No.	Properties	Value
1	Type	Mohr-Coulomb
2	Modulus of elasticity (MPa)	43
3	Friction angle (degree)	40°
4	Density(Kg/m^3)	1600
5	Poisson's ratio	0.35
6	Dilatancy angle	10°
7	Cohesion	0

Table 2. Parameters used for geogrid

Sl. No.	Properties	Value
1	Density(Kg/m^3)	950
2	Modulus of elasticity (MPa)	2e5
3	Poisson's ratio	0.3
4	Tensile yield strength (MPa)	200
5	Tensile Ultimate strength (MPa)	230

2.5 Loading

The load is applied on 4 columns on central radius equally spaced. Stepwise incremental loading is provided to know load versus settlement characteristics. In case of overturning moment versus settlement, an overburden load of 10 kN is applied as load of structure and then overturning moment is increased stepwise.

To know effect of sub-grade reaction, number of columns and central radius, ring foundation of size 300 mm and ring radii ratio n = 0.3 is used and total load of 50 kN is applied on 4 columns at equal spacing on central radius. The settlement on 20 segments on central radius is found and maximum settlement among them is considered.

3 Results and Discussion

3.1 Numerical Analysis of Ring Foundation fixed with Geogrid

Effect of geogrid

The ring foundation with 300 mm outer diameter and n value 0.3 is used. The geogrid is attached at 45° and 90°. The comparison is carried out between ring foundations without geogrid and fixed with geogrid at 45° and 90°and shown in Fig. 2 and Fig. 3.

From the Fig. 2 and Fig. 3, it is observed that if geogrid is fixed with ring foundation, load carrying capacity and overturning moment resisting capacity increases and as the amount of geogrid (90° to 45°) is increased, it will further increases.

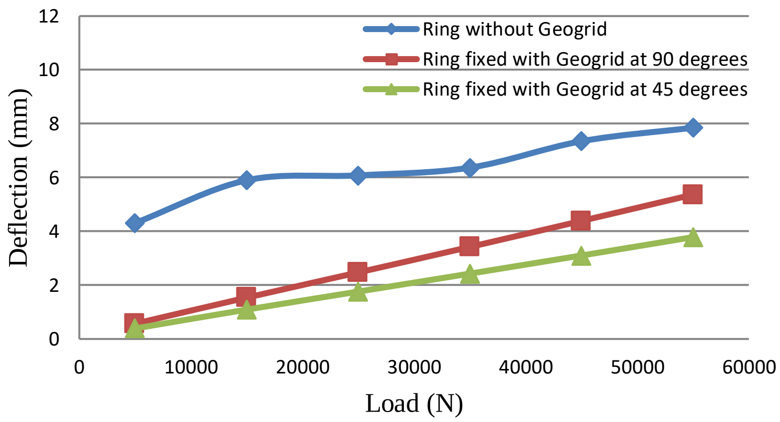

Fig. 2. Load v/s deflection for ring foundation

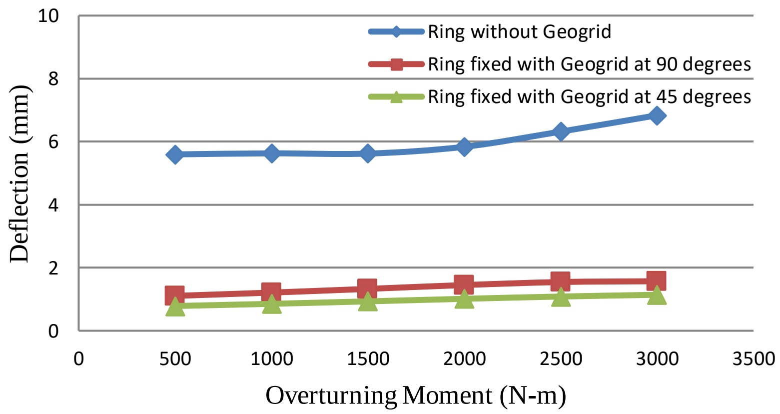

Fig. 3. Overturning moment v/s deflection for ring foundation

Optimization of ring foundation

The ring foundation of larger diameter without geogrid is compared with ring foundation fixed with geogrid of smaller diameter. For comparison, 400 mm size ring foundation and 300 mm size ring foundation of same ring radii ratio and thickness is considered. The 300 mm ring foundation is fixed with geogrid at 90^{o}.

For same loading, deflection in 400 mm ring foundation without geogrid is more than 300 mm ring foundation fixed with geogrid as shown in Fig. 4 and Fig. 5. The load carrying capacity and overturning moment resisting capacity in 300 mm ring foundation with geogrid is more than 400 mm ring foundation without geogrid. Hence, in this way the optimization of ring foundation is done.

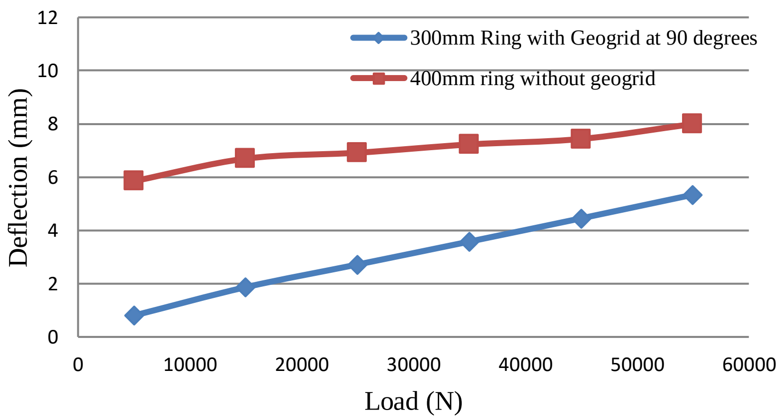

Fig. 4. Load v/s Deflection for optimization of ring foundation

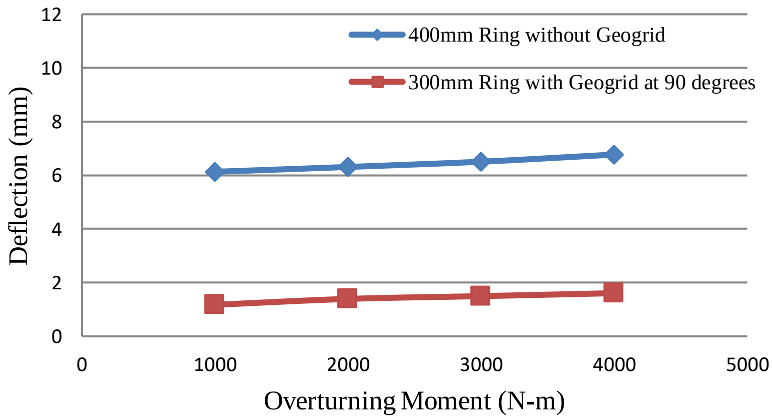

Fig. 5. Overturning moment v/s Deflection for optimization of ring foundation

3.2 Numerical Analysis Ring Foundation with Different Parameters

Effect of n value

The ring foundation of 300 mm outer diameter is used with changing n value of 0.2, 0.3 and 0.4 and presented in Fig. 6 and Fig. 7. From these figures, it is observed that with the increase in n value, the load carrying capacity and overturning moment resisting capacity decreases.

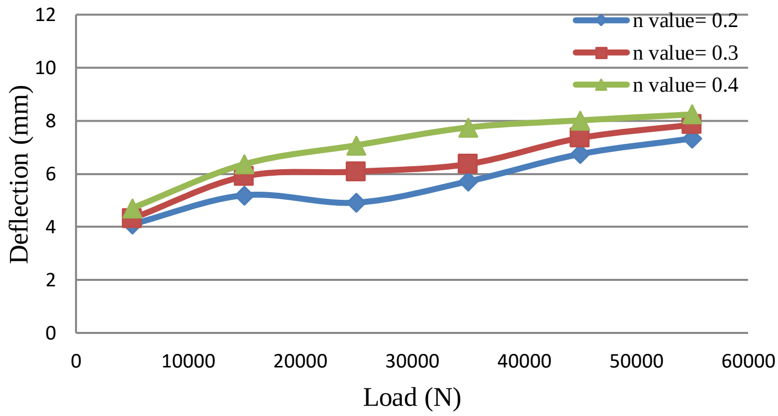

Fig. 6. Load v/s deflection for effect n value

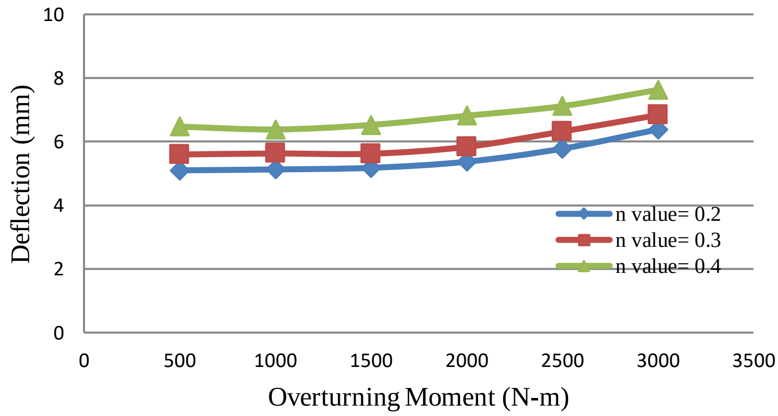

Fig. 7. Overturning moment v/s deflection for effect of n value

Effect of sub-grade reaction

Stepwise increment of sub-grade reaction is applied and maximum deflection is considered. From the Fig. 8, it can be concluded that when the sub-grade reaction increases the settlement of ring foundation decreases.

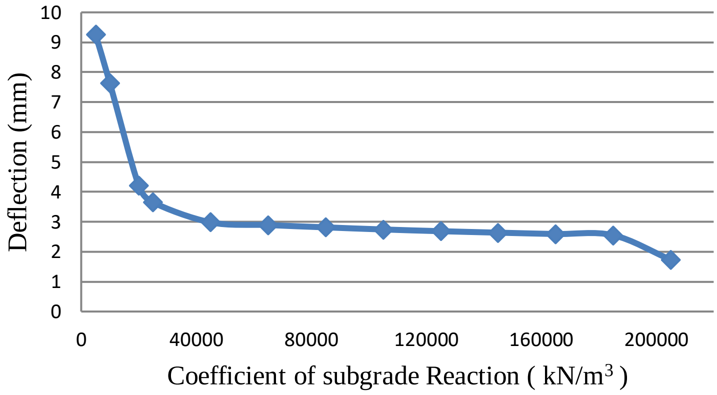

Fig. 8. Coefficient of sub-grade reaction v/s Deflection

Effect of number of column

The number of loaded column (Nc) has an effect on deflection behavior and also on tangential and radial moments. The load is applied on 4, 6, 8 and 10 numbers of columns respectively which are located on central radius equally spaced. Deflection versus Nc is shown in Fig. 9. From the Fig. 9, it is evident that when the N_C is increased, the deflection is decreased. Deflection is rapidly decreased when no. of columns increased from 4 to 6 and 8 and after that decreases slowly. It means, deflection decreases when concentrated load moves towards uniform load.

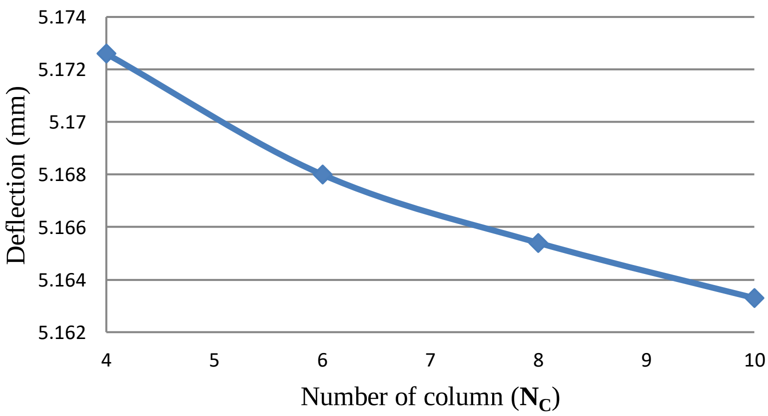

Fig. 9. Number of column v/s Deflection

Effect of central radius

The effect of central radius on ring foundation is studied in this case. Here the ring radii ratio is kept 0.3(constant). The inner radius is increased in stepped manner and accordingly outer radius is changed. For changed condition, the central radius is calculated.

From the Fig. 10, it can be recognized as the central radius increased keeping all other parameters constant the deflection is reducing.

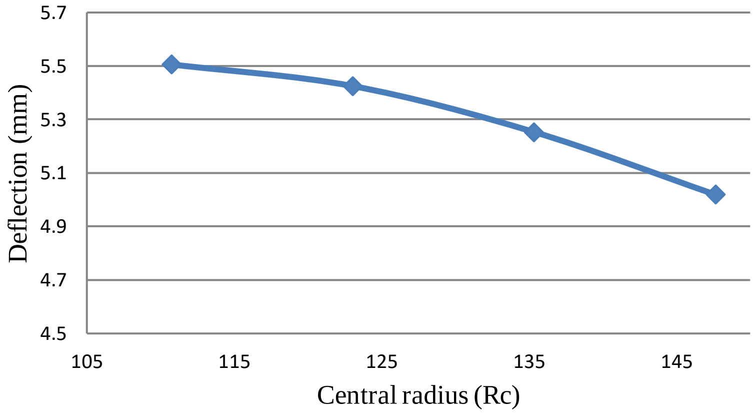

Fig. 10. Central radius v/s Deflection

4 Conclusions

1. It is found that settlement in ring foundation without geogrid is significantly more than settlement in ring foundation with geogrid fixed with ring foundation. Settlement is reduces if 8 nos. of geogrid strip is fixed at 45º as compared to the settlement when 4 nos. geogrid strip is fixed at 90º.
2. Overturning moment resisting capacity of ring foundation fixed with geogrid has high value than without geogrid. It is also concluded that the overturning resistance increases if no. of geogrid strip increases.
3. Size of ring foundation can be optimized and material can be saved if the ring foundation of small diameter (300 mm) fixed with geogrid at 90º or 45º as compared to large diameter (400 mm) without geogrid.
4. As n value increases, the load carrying capacity along with overturning moment resisting capacity decreases.
5. As value of sub-grade reaction of soil increases, the settlement of ring foundation decreases.
6. Settlement decreases if number of loaded column (N_C) increases.
7. Settlement of the ring foundation decreases as the central radius increases keeping constant load.

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