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Comparative Study of Settlement Reduction of Rigid Raft through Granular Pile

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Abstract: ***Granular piles are a cost-effective technique of ground improvement which increases the load carrying capacity, reduces the settlement of foundations built on the reinforced ground and also a good alternative option of concrete pile. Reinforcement of ground becomes a necessity in many situations, where the soil is extremely weak or soft. The columns of granular material create a composite ground of reduces compressibility and increases shear strength than that of native soil.Piles under the raft are designed to decreases the settlements and differential settlement of the soil. Raft, piles and soil are three components of piled-raft system through which the loads transfer to the subsoil.The present analysis is done to the study the response of a floating granular piled raft based on the elastic continuum approach.***

Mathematical study is carried out for the comparative analysis of settlement of granular piled raft to rigid raft only and granular pile alone with variation of comparative stiffness of GP, comparative size of raft and relative length of floating granular pile. The overall response of a granular pile with the rigid raft on top is evaluated in terms ofsettlement influence factor for viz. granular piled raft, rigid raft only, and pile alone. On the basis of findings design charts are prepared to facilitate the design procedure.

Keywords: Granular piled raft, interfacial shear stress, comparative stiffness of granular pile, comparative size of raft, relative length of floating granular pile

I. INTRODUCTION

Use of granular piles (GP) /stone columns/sand compaction piles is considered as one of the most flexible and cost-effective alternatives compared to other methods such as preloading, removal and replacement, thermal stabilization, dynamic compaction, ground freezing, etc. Granular piles are made of compacted sand or gravel installed in soft ground by full displacement methods.Raft foundations are often preferred for high rise buildings constructed on soft soil for distribution of load on a larger area. Piles beneath raft are designed to reduce the settlements and unequaldisplacement of the ground. Raft, piles and soil are three components of piled-raft system through which the loads transfer to the subsoil.

Analysis of a rigid raft over an incompressible pile was presented by Poulos[10]. Butterfield and Banerjee[1] analyzed the pile group-pile cap interaction for the stiffness range of concrete and steel piles. Lee and Pande[6] presented an axi-symmetric model to study the performance of circular footing overlying stone column improved ground. Canetta and Nova[11] bring out a method of analysis of ground enhanced by columnar inclusions. The response of piled raft foundation on soft soil strengthened by short granular piles made of flexible materials was investigated by Liang et. al[7]. Madhav et al.[8] bring out the settlement analysis of a granular pile considering non-homogeneities in the deformation modulus as well as granular pile material.

Grover et. al[4] evaluated the vertical displacements of stiffened granular piles depends on the elastic continuum approach and find that with the rise in stiffness of GP, the displacement of a floating GP reduces. The effect of pile length and alignment on attained final load was investigated by Elwakil and Azzam[3]. El-garhy and Elsawy[2] presented a method to investigate strip footing founded on a granular layer over expensive soil stabilized by floating granular or piles resting on bearing stratum. Gupta and Sharma[5] conduct a study of a non-homogeneous GP with non-linear behaviour of modulus of elasticity for displacement analysis.

The analysis of a floating granular piled raft based on the elastic continuum approach, the vertical displacements of the GP are evaluated by integrating Mindlin's[9] equations for vertical displacements due to vertical point forces within the elastic continuum. Raft displacement is evaluated by integrating Boussinesq's equations for vertical displacement due to vertical point forces on the surface of elastic continuum. The response of the granular piled raft is evaluated in terms of influence factors for vertical displacements of granular piled raft system, rigid raft only, and granular pile alone. Present analysis deals with the numerical study of the sharing of load between the raft and granular pile with the Plot of the comparative stiffness of GP, the comparative size of raft and the comparative length of floating granular pile.

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II. ANALYSIS OF GRANULAR PILED RAFT

Fig. 1 shows a granular piled raft foundation carrying a load, P. The raft is rigid and of diameter, D. The granular pile shown in Fig. 2 is compressible with a constant of deformation or elasticity, E_{gp} , Poisson's ratio, ν_{gp} , diameter, d (=2a), and length, L . The surrounding soft soil is characterized by it's the modulus of deformation, E_s, and Poisson's ratio, ν_s. The present analysis uses the continuum approach to determine the stress systems, shear stresses along with the pile, τ and base pressure on the base of GP, pb, along with the soil-granular pile interface and raft stresses, p_r, at the raft – soil interface, which accomplish the similarity of displacements along the interfaces depicts in Fig. 3. For no slip at GP-soil interface, the GP and the raft displacements are equated to the soil settlement at the corresponding nodes. The stresses and the soil displacements for GP and raft are evaluated depends on the interactions of raft on raft, raft on GP, GP on GP and GP on raft. The essential steps of the analysis are the evaluation of (a) Soil displacements, (b) Granular pile displacement (c) raft displacements and (d) compatibility displacements.

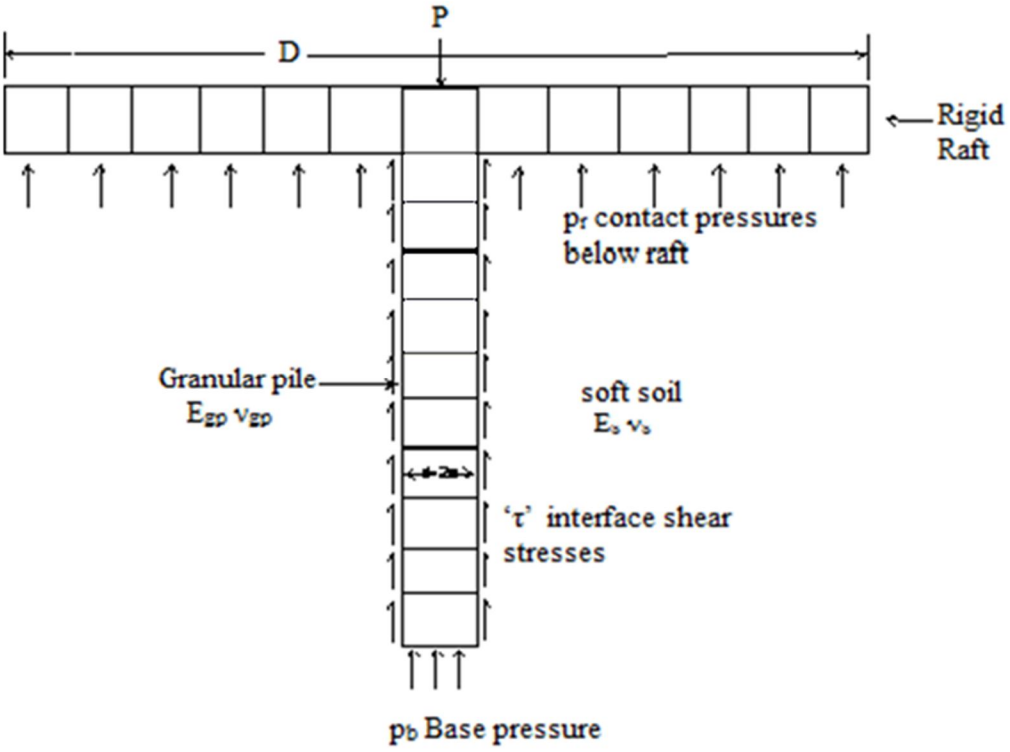

Fig. 1 Definition Sketch of Granular piled Raft

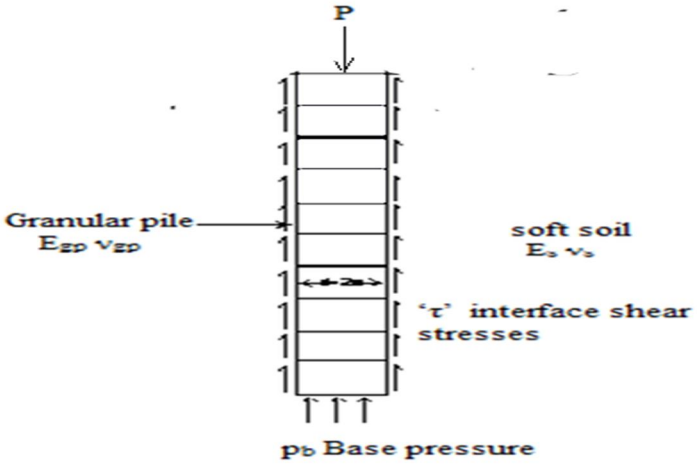

Fig. 2 Definition Sketch Granular Pile

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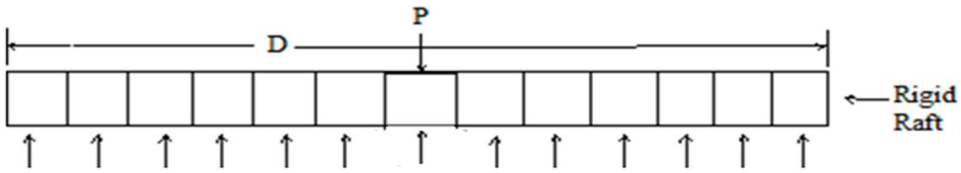

Fig. 3 Definition Sketch Rigid Raft

III. SOIL DISPLACEMENTS

Soil displacements along with GP-soil interface and along the raft-soft ground interface are evaluated at the mid-points on the side of each element by integrating Mindlin (1936) and Boussinesq's expressions correspondingly. The GP is divided in to 'n' elements of length, Δ L (= L / n). Displacements along GP-soil interface are evaluated at the mid-point on the side of each elements and at the centre of the base by the integration of Mindlin & Boussinesq's expressions depends on the effect of the elemental stresses of GP and the raft stresses correspondingly in matrix form following Sharma and Madhav (1999)

$$\left\{\rho^{sp}\right\} = \left\{\frac{S^{sp}}{d}\right\} = \left[I_{pp}\right]\left\{\frac{\tau}{E_s}\right\} + \left[I_{pr}\right]\left\{\frac{p_r}{E_s}\right\} \quad (1)$$

where {Ssp} and {rsp} are vertical and standardize vertical soil settlement vectors,
[Ipp]=(n+1)x(n+1) of the displacement factor calculated by integrating Mindlin's equation
[Ipr]= (n+1)xkr, of the displacement factor calculated by integrating Boussinesq's equation
{τ}and {pr} – column matrix , {n+1}and {kr} correspondingly.

$$\left\{\rho^{sr}\right\} = \left\{\frac{S^{sr}}{d}\right\} = \left[I_{rp}\right]\left\{\frac{\tau}{E_s}\right\} + \left[I_{rr}\right]\left\{\frac{p_r}{E_s}\right\} \quad (2)$$

where$\{S^{sr}\}$ and $\{\rho^{sr}\}$ are vertical and standardize vertical soil settlement vector,
$[I_{rp}]$= kr×(n+1), whose displacement factor are evaluated by integrating Mindlin's
$[I_{rr}]$ = (kr x kr) of the displacement factor evaluated by integrating Boussinesq's equation
{τ} and $\{p_r\}$ - column matrix of size {n+1} and {kr} correspondingly

A. Pile Settlement

Displacements of node of granular pile are calculated depends on a stress-strain relationship

$$\varepsilon_v = \frac{\sigma_v}{E_{gp}} \quad (3)$$

Where ε_v, are the direct/direct strains, and σ_v is the direct/direct stress on the element and E_{gp} is the elasticity modulus of the granular pile.

1) Direct & Shear Stresses Relationship

$$\{\sigma_v\} = [A]\{\tau\} \quad (4)$$

where {τ} and $\{\sigma_v\}$ are consecutively columns matrix of shear and direct stresses on the pile nodes, size of both vectors is (n+1). [*A*] is a matrix of (n+1) x(n+1) size is formulated.

2) GP Displacements

The vertical displacements of granular pile is

$$\left\{\rho^{ppv}\right\} = \rho_t\{1\} + [B]\left\{\frac{\sigma_v}{E_s}\right\} \quad (5)$$

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where [B] is matrix of size (n+1)×(n+1)

By replacing the direct stresses by shear stresses using (Eq. 4), the settlement of granular pile nodes in form of shear stresses is

$$\left\{ \rho^{ppv} \right\} = \rho_t \{1\} + [C] \left\{ \frac{\tau}{E_s} \right\} \quad (6)$$

where [C] =(n+1)x (n+1) matrix.

B. Raft Displacements

Raft is considered as rigid and hence displacements of raft nodes are all equal. The settlement of the top of the GP (ρ_t) is equal to raft displacement and expressed as

$$\left\{ \rho^{r} \right\} = \rho_t \{1\} \quad (7)$$

where $\left\{ \rho^{r} \right\}$ is the raft displacement vector of size 'kr'.

C. Condition of Compatibility

1) Using compatibility of settlement of the granular pile and the soil,

$$\left\{ \rho^{sp} \right\} = \left\{ \rho^{ppv} \right\} \quad \text{or}$$

$$[AA] \left\{ \frac{\tau}{E_s} \right\} + [I_{pr}] \left\{ \frac{p_r}{E_s} \right\} = \rho_t \{1\} \quad (8)$$

where $[AA]=[I_{pp}] - [C]$, of size (n+1) x (n+1)

2) Using compatibility of settlement of the raft and the soil,

$$\left\{ \rho^{sr} \right\} = \left\{ \rho^{r} \right\} \quad \text{or}$$

$$[I_{rp}] \left\{ \frac{\tau}{E_s} \right\} + [I_{rr}] \left\{ \frac{p_r}{E_s} \right\} = \rho_t \{1\} \quad (9)$$

By solving the equations (8) & (9) standardize raft stresses and normalised interfacial shear stresses are evaluated. Further the settlement at the top granular piled Raft foundation, granular pile alone and rigid raft are evaluated as

$$S^{p} = \frac{P}{E_s d} I_p \quad (10)$$

where I_p, is settlement influence factor.

Present study deals with the analysis of granular pile with rigid raft based on the elastic continuum approach. The objectives of this study to include the comparative settlement study of granular piled raft to settlement of rigid raft only and granular pile alone. Response of granular piled raft is presented in terms of following factors

a) Settlement factor (SF), α = Settlement of granular piled raft/ settlement of pile alone.

b) Settlement ratio (SR), γ = Settlement of granular piled raft/ settlement of rigid raft.

IV. RESULTS AND DISCUSSION

Following variations of non-dimensional variable incorporated in the study are, comparative length of GP, L/d = 10-40, relative or comparative stiffness, K_{gp} of GP = 10-1000, comparative size of raft, D/d = 2-10, Poisson's ratio of soil, ν_s = 0.3-0.5, and Poisson's ratio of GP, ν_{gp}=0.3-0.5.

Fig. 4 represents the variation of SF, α, with the comparative stiffness of granular pile, K_{gp} along with influence of comparative size of raft, D/d for L/d = 10, υ_s =0.5. With the rise of comparative stiffness of GP, K_{gp}, the SF increases. Settlement of pile alone decreases more as compare to settlement of piled raft with the increase in the comparative stiffness of granular pile, $K_{gp.}$ It can be well seen that the SF reduces with the increase in the comparative size of raft, D/d. For L/d = 10, υ_s =0.5, K_{gp} = 10 and D/d= 3, 5, 7and 10 the values of SF are 0.59, 0.39, 0.28, and 0.20 correspondingly. The percentage decrease in SF is 66 for an increase in raft size, D/d, from 3 to10.

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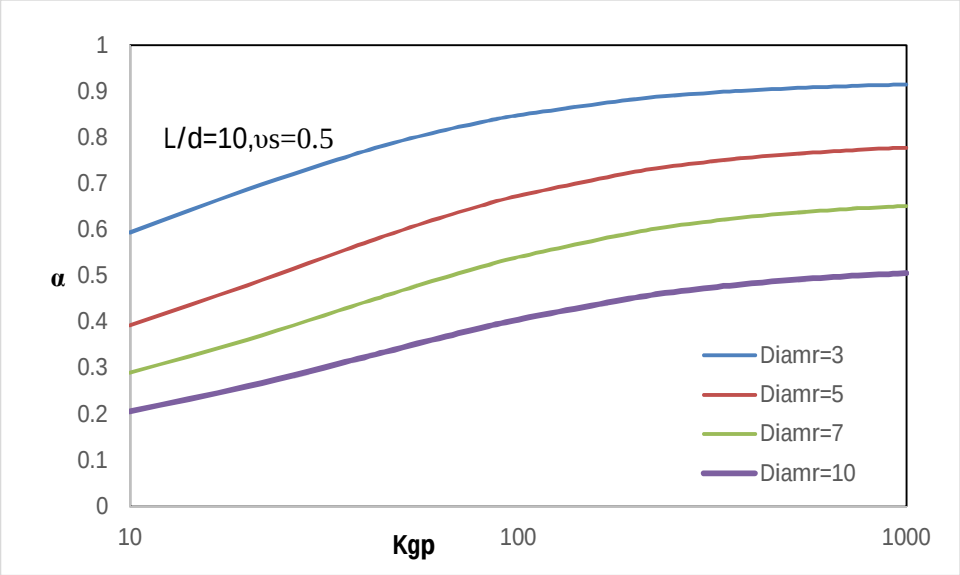

Fig. 4 Plot of settlement factor, α, with the comparative stiffness of GP, K_{gp} – effect of comparative size of raft, D/d on granular pile raft foundation (L/d=10, υ_s=0.5)

Fig. 5 depicts the variation of SF, α, with the comparative stiffness of granular pile, K_{gp} along with effect of comparative size of raft, D/d, for L/d = 20, υ_s =0.5. The SF increases with the rise of comparative stiffness of GP, K_{gp}. It may be noted that the SF reduces with the increase in the comparative size of raft, D/d this is because with the size of raft increases the settlement of pile raft reduces therefore SF is reduced. For L/d = 20, υ_s =0.5, K_{gp} = 100 and D/d= 3, 5, 7and 10 the values of SF are 0.85, 0.69, 0.54, and 0.44 correspondingly. The percentage decrease in SF is 48 for an increase in raft size, D/d, from 3 to10.

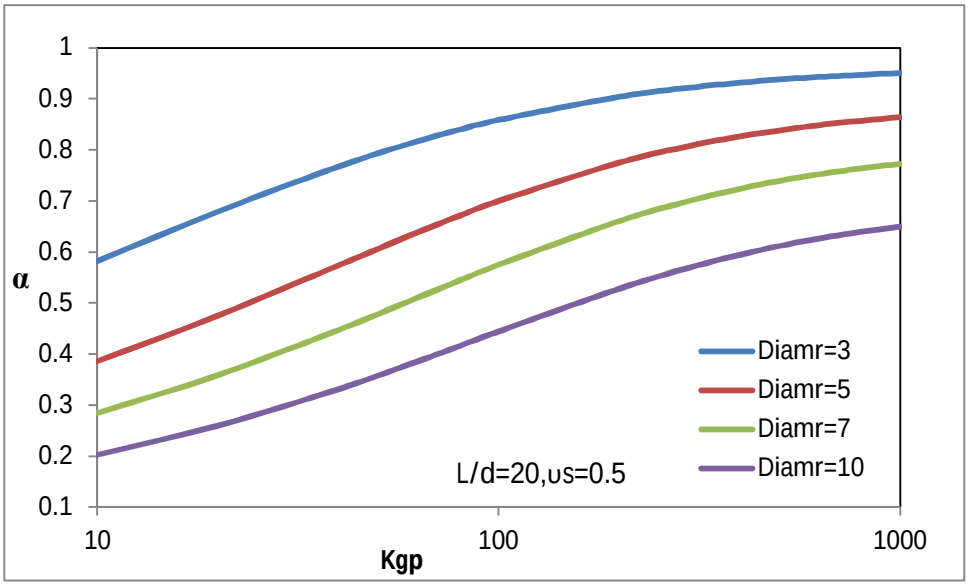

Fig. 4 Plot of settlement factor, α, with the comparative stiffness of GP, K_{gp} – effect of comparative size of raft, D/d on granular pile raft foundation (L/d=20, υ_s=0.5)

The variation of SF α, with the comparative stiffness of granular pile, K_{gp} along with effect of comparative size of raft, D/d, for L/d = 20, υ_s =0.5 shown in Fig. 6. It can be well seen that the SF reduces with the increase in the comparative size of raft, D/d. The SF, α rises with the rise of comparative stiffness of GP, K_{gp} and the difference between the curves is reduced with the increase of comparative stiffness of GP, K_{gp}. It implies that as the stiffness of pile increases the settlement is also reduces. For L/d = 40, υ_s =0.5, K_{gp} = 1000 and D/d= 3, 5, 7and 10 the values of SF are 0.96, 0.90, 0.83, and 0.73 correspondingly. The percentage decrease in SF is 21 for an increase in raft size, D/d, from 3 to10.

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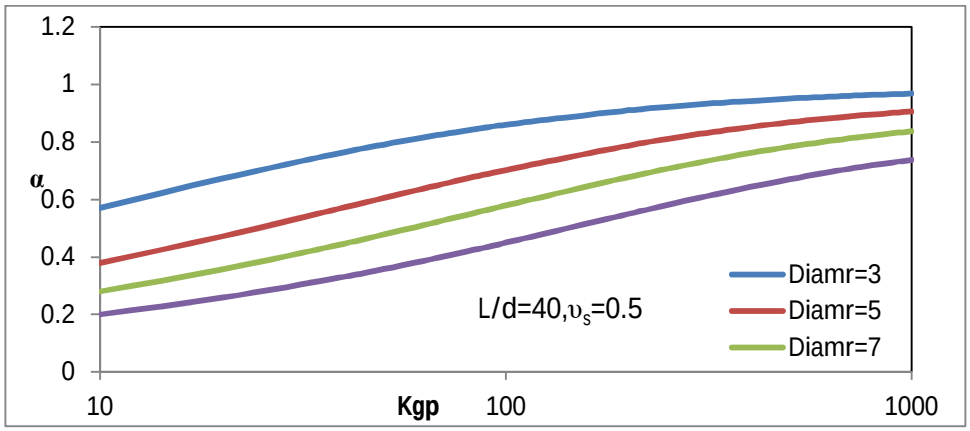

Fig. 6 Plot of settlement factor, α, with the comparative stiffness of GP, K_{gp} – effect of comparative size of raft, D/d on granular pile raft foundation (L/d=40, υ_s=0.5)

Variation of settlement ratio, γ with comparative stiffness of granular pile, K_{gp}, with the influence of comparative size of raft, D/d on a granular pile raft for L/d=10 and υ_s=0.5 depict in Fig.7. The settlement ratio decreases with increases in comparative stiffness of granular pile, K_{gp}. It can also be noted that settlement ratio increases with the increase in comparative size of raft, D/d. For L/d = 10, υ_s =0.5, K_{gp} = 10 and D/d= 3, 5, 7and 10 the values of SF are 0.84, 0.93, 0.96 and 0.98 correspondingly the percentage increase in settlement ratio are 10, 14 and 16 respectively with reference to D/d=3. As the size of raft (D/d=10) increases the settlement ratio is reaches towards 1for lesser comparative stiffness (Kgp=10) of granular pile.

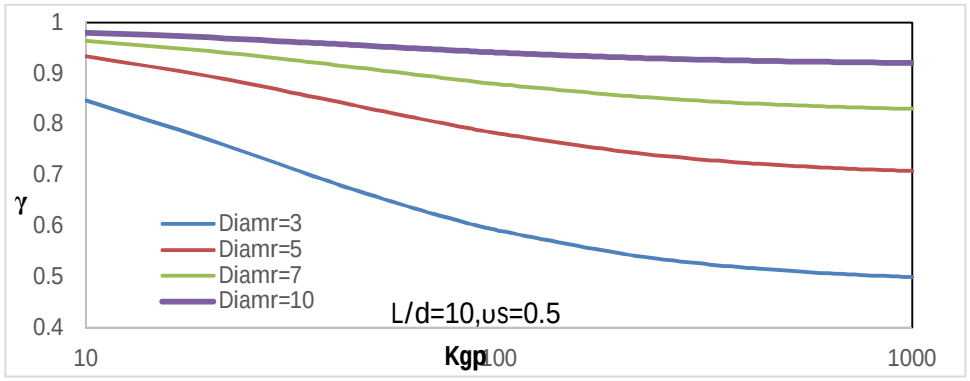

Fig. 7 Plot of settlement ratio, γ, with the comparative stiffness of GP, K_{gp} – effect of comparative size of raft, D/d, on granular piled raft foundation (L/d=10, υ_s=0.5)

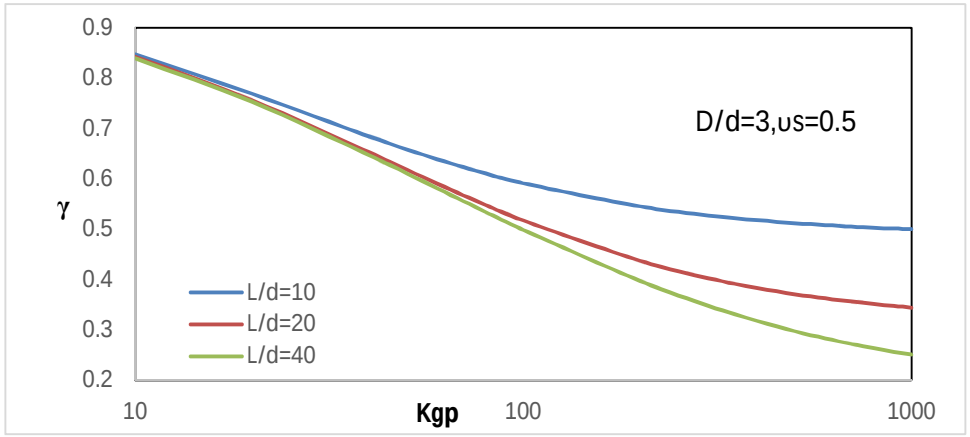

Fig. 8 Plot of settlement ratio, γ, with the comparative stiffness of GP, K_{gp} – effect of comparative length of granular pile, L/d, on granular piled raft foundation (D/d=3, υ_s=0.5)

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Fig.7 depicts variation of settlement ratio, γ with comparative stiffness of granular pile, K_{gp}, with the influence of comparative length of GP, L/d on a granular pile raft for L/d=10 and υ_s=0.5. The settlement ratio decreases with increases in comparative stiffness of granular pile, K_{gp}. It can also be noted that settlement ratio decreases with the increase in comparative length of pile, L/d as it is well noted with the increase in the length of pile the settlement of piled raft is reduces and the settlement of raft is un affected with the length of pile therefore the settlement ratio decrease. For D/d = 3, υ_s =0.5, K_{gp} = 100 and L/d= 10, 20 and 40 the values of settlement ratio are 0.59, 0.51 and 0.49 correspondingly the percentage decrease in settlement ratio are 13 and 16 percent respectively with reference to L/d=10.

V. CONCLUSION

Depends onelastic continuum approach a pile settlement matrix is formulated in the current study. Following are the outcome of this study.

A. Regarding the rise of relative or comparative stiffness of GP, K_{gp}, settlement factor, α increases.
B. The settlement factor, α reduces with the increase of comparative size of raft, D/d and comparative size of granular pile, L/d.
C. For L/d = 10, υ_s =0.5, K_{gp} = 10 the percentage decrease in settlement factor is 66 for an increase in comparative size of raft, D/d, from 3 to10.
D. The settlement ratio, γ reduces with the increase of comparative size of granular pile, L/d and settlement ratio, γ increases with comparative size of raft, D/d.
E. The settlement ratio, γ reduces with the increase of comparative length of granular pile, L/d. the percentage reduction in the settlement ratio is 16 with the increase in comparative length from L/d=10 to 40.

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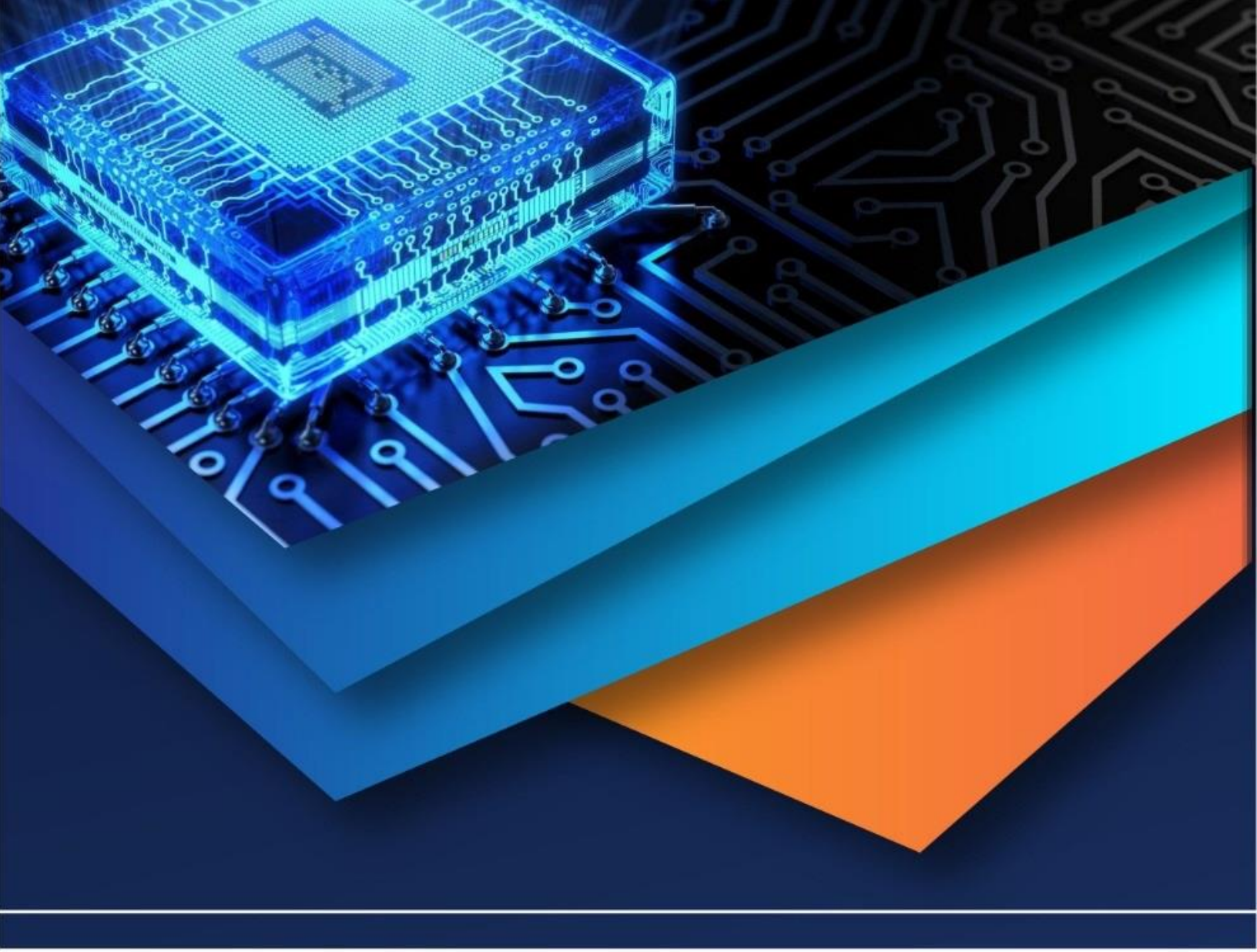

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